THE DIVERSITY OF LIFE IN AFRICAN FRESHWATERS: UNDERWATER, UNDER THREAT

An analysis of the status and distribution of freshwater species throughout mainland Africa

Edited by: William Darwall, Kevin Smith, David Allen, Robert Holland, Ian Harrison and Emma Brooks

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Foreword

For millions of people throughout Africa, wetlands are critical for livelihoods, providing vital supplies of water, food and materials as well as ecological services. Wetlands are, however, suffering from high levels of degradation, and this is likely to increase dramatically over the next few decades as Africa strives to provide food, water and electricity to an increasing population.

In the most comprehensive assessment of its kind, 4,989 African freshwater species were assessed by close to 200 scientists over a six-year period for the IUCN Red List of Threatened Species, including all described species of freshwater fish, molluscs, crabs, dragonflies and damselflies, and selected families of aquatic plants. The findings from this new study give us a unique opportunity to try to influence developers and governments when they are planning freshwater infrastructure projects, which are still in their early stages in most of Africa. Until now we have not had the information we need about species and the threats they face, but, armed with these IUCN Red List assessments, the extensive information upon which they are based, and the overall findings and recommendations, we hope that decision-makers in Africa will now make the right choices to develop their water resources in a sustainable manner whilst protecting and valuing biodiversity.

The Ramsar Convention on Wetlands covers all aspects of wetland conservation and wise use, recognising wetlands as ecosystems that are extremely important for biodiversity conservation and for the well-being of human communities. A key commitment of Contracting Parties, or Member States, is to designate suitable wetlands for the List of Wetlands of International Importance (‘Ramsar List‘) and ensure their effective management. This volume, and the data collated through the project, will greatly assist those parties to identify new Ramsar sites, to broaden their taxonomic coverage, and to help ensure the future wise use of wetlands in general. I therefore commend this report and the accompanying information to you, and I urge all those concerned with the management and conservation of wetland resources, to read it and to use this most extensive new data set in their future work to secure the future of Africa’s wetlands.

Anada Tiéga
Secretary General
The Convention on Wetlands
Ramsar Secretariat
Switzerland

Executive Summary

In this volume you will find the most up-to-date information on the distributions and conservation status of species in all inland water ecosystems across mainland continental Africa and the reasons behind their declining status. This represents the most comprehensive assessment yet of freshwater biodiversity at the species level for an entire continent. For managers, this information will assist in designing and delivering targeted action to mitigate and minimise these threats. From a policy perspective, this information is fundamental to meeting national obligations under the Convention on Biological Diversity (CBD), the Ramsar Convention, and the Millennium Development Goals (MDGs), and will input to national-level conservation priority setting. Information on species status is particularly important for Target 12 of the CBD: '…by 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.'

Biodiversity within Africa's inland waters is both highly diverse and of great importance to livelihoods and economies. Africa is, however, about to embark upon an unprecedented scale of development within its water and agriculture sectors. Such development is proposed by many as essential if Africa is to support and improve the livelihoods of a population that is projected to double by 2050 to almost two billion people. Development activities are, however, not always sustainable or compatible with species conservation in inland waters, the needs of which are poorly represented within the development planning process.

One commonly cited reason for the inadequate representation of biodiversity in development and environmental planning is a lack of readily available information on freshwater species. To close this information gap, the IUCN Species Programme, in collaboration with its partners, conducted an assessment of the status (according to the IUCN Red List of Threatened Species) and distribution of all described species of freshwater fishes, molluscs, odonates, crabs, and selected families of aquatic plants from across mainland continental Africa. A total of 4,989 species were assessed. With species information compiled for each of 7,079 river or lake sub-catchments, this represents a major advance in knowledge for informing development actions at a scale appropriate for conservation management. The full data set, including all species distribution files, is available on the DVD accompanying this report and through the IUCN Red List website (www.iucnredlist.org).

Twenty one percent of all species assessed are threatened within Africa. Ninety one percent of these species (4,539) are endemic to the continent and are, therefore, also globally threatened. This level of threat is relatively high in comparison to other taxonomic groups in Africa (12% of birds, 19% of mammals, and 26% of amphibians are threatened) and is predicted to increase dramatically unless the ecological requirements of freshwater species are given much greater consideration in future development planning, in particular for development of water resources. Major threats are identified as loss and degradation of habitat associated with deforestation, agriculture and infrastructure development, unsustainable levels of water extraction, water pollution from domestic industrial and agricultural sources, the introduction of alien invasive species, sedimentation, mining and subsistence use and trade. The majority of threatened species are found along the Mediterranean and Atlantic coasts of Morocco, Algeria and Tunisia, in Upper and Lower Guinea, southern and eastern South Africa, and in the Great Lakes in eastern Africa. This distribution largely reflects a combination of high levels of current development activity, and high pressure on water resources, relative to other parts of the continent.

Major centres of species richness include the Great Lakes of eastern Africa, rivers in coastal sub-catchments in western Africa, and sub-catchments that trace the course of major rivers through the centre of the continent, primarily in the Democratic Republic of Congo (D. R. Congo). A network of river and lake basins is identified as potential Key Biodiversity Areas (KBAs) most important for the protection of threatened and restricted range species. Forty eight sites are proposed as new Alliance for Zero Extinction (AZE) sites holding Critically Endangered or Endangered freshwater species in most urgent need of conservation action. These proposed AZE sites should form the focus of the most immediate conservation actions if species extinctions are to be prevented.

Africa's freshwater species are recognised to be as important today as they ever have been for supporting livelihoods. The most heavily used species are the fishes and plants, with 45% and 58% of species harvested, respectively. Justification for the conservation and sustainable use of these species should, therefore, be clear to all.

Inland waters throughout Africa are poorly represented within the existing protected areas network, which is largely designated for the protection of terrestrial ecosystems and species. Future conservation efforts must take greater account of the upstream and downstream connectivity in freshwater ecosystems. For example, it is recommended that conservation efforts focus on the protection of upper catchment areas, provision of adequate environmental flows, and the inclusion of rivers within protected areas rather than as the boundary markers. Integrated river basin management and systematic conservation planning approaches are recommended, along with the establishment of additional river and lake basin authorities.

Patterns of past and present species diversity suggest that Africa's freshwater species have been highly resilient to climate and geological change over time. The challenges facing African freshwater species are daunting, but the continent's climate history suggests that significant resilience exists. With informed development and management, African freshwaters may see a new century with different but not unhealthy qualities.

Following the six years of work required to complete this study, we recognise that the greatest challenge is to ensure the knowledge gained is transferred to the relevant decision makers and stakeholders, and that it is updated on a regular basis. This will enable freshwater systems across the continent to be managed in a way that ensures their long-term sustainability and maintains their ability to adapt to changing conditions that they may face in the future. With this in mind, a number of case studies have been conducted, as a key component of this project, to develop a series of 'Good Practice Guidelines' for the integration of biodiversity information within the environmental and development planning processes. The recommendations from these studies can be found at: www.iucn.org/species/freshwater/

The IUCN Red List is one of the most authoritative global standards supporting policy and action to conserve species. We hope this analysis, based in large part on an assessment of species Red List status, will provide new information and insights, which will motivate actions to help safeguard an essential and valued resource for millions of people – the diversity of life within Africa's inland waters.

Key messages

① **The inland waters of Africa support a high diversity of aquatic species with high levels of endemism.** Many of these species provide direct (e.g., fisheries) and indirect (e.g., water purification and flood control) benefits to people. The conservation and sustainable management of these species is essential to the livelihoods and economies of Africa's people.

② **Current levels of threat to freshwater species across Africa are high relative to other ecosystems, with 21% of species threatened.** Predicted future levels of threat, in particular due to development of water resources, are expected to be even higher. This is largely a result of: i) the high degree of connectivity within freshwater systems, such that threats like pollution and invasive alien species spread more rapidly and easily than in terrestrial ecosystems; and ii) the rapidly increasing use and development of water resources, with little regard to the requirements of the freshwater dependent species sharing the resource.

③ **Protected areas must be better designed to protect freshwater species.** The knowledge collected during this assessment can be integrated into conservation planning processes to ensure representation of the freshwater species. Currently, protected areas are rarely designed to protect freshwater species, meaning that taxonomic groups that represent a significant portion of the total species and genetic diversity on the planet are being overlooked.

④ **Protected areas and other conservation action for freshwater species must be designed to employ the principles of catchment management.** Even where species are identified by species-driven legislation, without catchment-based planning that extends the designated control areas to the edge of the river catchment, impacts such as water pollution and invasive alien species will inevitably lead to species decline.

⑤ **Management of water resources must take account of the requirements of freshwater biodiversity.** If we are to conserve and continue to benefit from the services provided by freshwater species we need to manage water as a resource for both people and freshwater biodiversity. This approach is encapsulated within the Environmental Flows concept, which aims to ensure that there is enough water to maintain environmental, economic and social benefits.

⑥ **Lack of available information should no longer be given as a reason for inadequate consideration for development impacts to freshwater species.** The data made available here must be integrated within the decision-making processes in planning for the conservation and development of inland water resources, ensuring all development projects have a 'Net Positive Impact'.

⑦ **Species information remains very limited for many parts of Africa.** The Congo, Angola, the Ethiopian Highlands, and Upper and Lower Guinea in particular, have been identified as priorities for future field survey. Information on the status and distribution of aquatic plants needs to be greatly improved.

⑧ **Environmental Impact Assessments should expressly require reference to the species data sets made available through the IUCN Red List.**

Chapter 1.

Background

Dudgeon, D.[1] (Section 1.1); Paugy, D. and Lévêque, C.[2] (Section 1.2); Rebelo, L.-M. and McCartney, M.P.[3] (Section 1.3)

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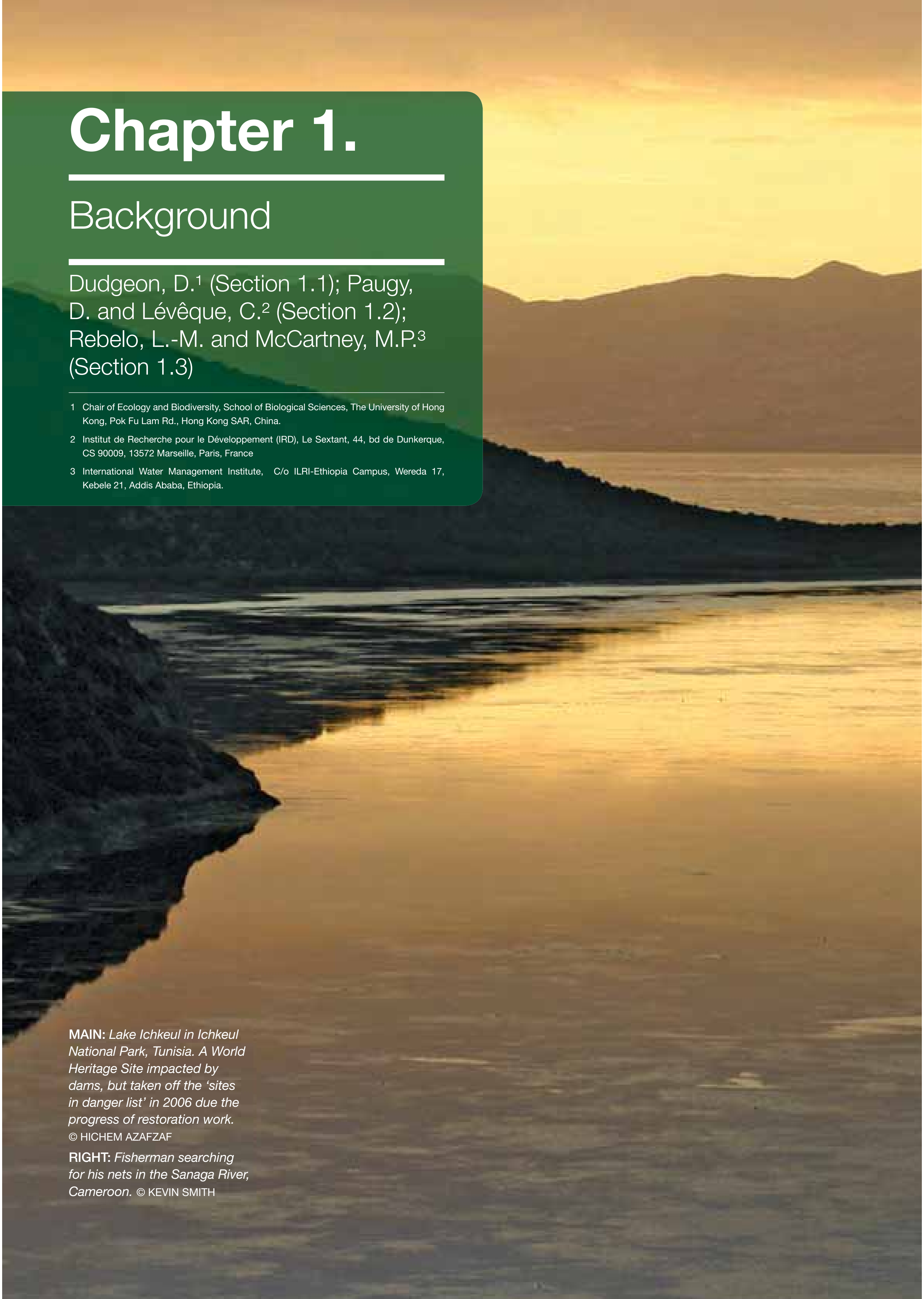
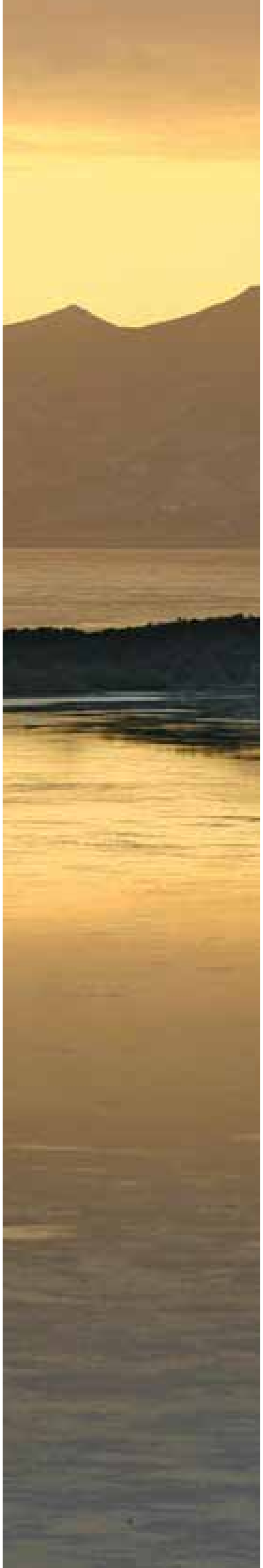


MAIN: *Lake Ichkeul in Ichkeul National Park, Tunisia. A World Heritage Site impacted by dams, but taken off the 'sites in danger list' in 2006 due the progress of restoration work.* © HICHEM AZAFZAF

RIGHT: *Fisherman searching for his nets in the Sanaga River, Cameroon.* © KEVIN SMITH



CONTENTS

Girls collecting water near Bukavu, D. R. Congo. According to the United Nations, access to clean water and sanitation is a fundamental right. © IUCN /INTU BOEDHIHARTONO

1.1 Global status of freshwater biodiversity

On 1 August 2010, 122 countries supported a United Nations (UN) General Assembly resolution declaring that access to clean water and sanitation is a fundamental human right. Some countries abstained, but there were no votes against the resolution. While implementing the recognition that access to clean water is a human right may be problematic, it is impossible to disagree with the imperative to ensure that all people should enjoy adequate water and sanitation. A significant proportion of the Earth's population (approximately 0.9 billion people) does not have ready access to drinking water, and perhaps 40% (more than 2.5 billion) of people lack adequate sanitation (WHO/ UNICEF 2008). The result is a parlous situation, where child deaths attributable to contaminated water number around 5,000 *daily* (approximately 1.5 million annually).

Concerns about water quality are paralleled by those relating to quantity. Humans already appropriate more than half of global surface runoff (Jackson *et al*. 2001), and rapid shifts in anthropogenic water use and withdrawal are causing dramatic changes in patterns of water stress (Alcamo *et al*. 2008). We may be close to overstepping planetary limits for 'blue water' runoff resources (Rockström *et al*. 2009a,b) so that, within current human lifetimes, demand is likely to exceed the supply from runoff. Thus, aside from legal concerns about the implications of a human water right, it is far from clear how the water needs of burgeoning human populations can be met in practical terms. It nevertheless seems obvious that meeting these needs will have major implications for the supply of water required by ecosystems; for example, the 'wasted' water remaining in rivers that sustains wetlands and estuaries as it flows to the sea. Furthermore – and self-evidently – the matter is urgent, not least because halving the number of people without access to clean water and sanitation is one of the Millennium Development Goals intended to stand as a major achievement of the UN-designated 'Water for Life' International Decade for Action (2005-2015).

Apart from the pronouncement that water is a human right, the midpoint of the 'Water for Life' decade is notable because 2010 was proclaimed as the UN International Year of Biodiversity. This served, in part, to highlight the fact that it is now more evident than ever that the biosphere is undergoing an epidemic of human-caused extinctions (e.g., Ehrlich and Pringle 2008; Butchart *et al*. 2010; Mace *et al*. 2010). These exceed background extinction rates to such an extent that we have 'overstepped planetary boundaries' for marine and terrestrial biodiversity loss (Rockström *et al*. 2009a,b). Moreover, a consensus has emerged that population declines and losses from inland waters are greater than their terrestrial or marine counterparts, so that freshwater ecosystems tend to have the highest portion of species threatened with extinction (e.g., Loh *et al*. 2005; Revenga *et al*. 2005; Dudgeon *et al*. 2006; Strayer and Dudgeon 2010). For instance, it has been estimated that

20% of the world's freshwater fish – almost 40% in Europe and the USA (Kottelat and Freyhof 2007; Jelks *et al*. 2008) – as well as many amphibians and freshwater reptiles, and 10,000-20,000 freshwater macroinvertebrate species (especially crayfish and unionid mussels) are threatened (Gibbons *et al*. 2000; Revenga *et al*. 2005, Strayer 2006; Taylor *et al*. 2007; Strayer and Dudgeon 2010). Freshwater cetaceans are among the most endangered mammals on Earth (Reeves *et al*. 2000), and the recently-declared functional extinction of the Yangtze River dolphin (Turvey *et al*. 2007) is emblematic of their imperilment. Evidently, fresh waters are hotspots of endangerment.

Degradation of fresh waters and their component species is a matter for grave concern, given the goods and services derived from them (Dudgeon *et al*. 2006). One estimate (Costanza *et al*. 1997) puts the value of ecosystem services provided by fresh waters at USD6.6 trillion annually, 20% of the value of all ecosystem combined, and in excess of the worth of all other non-marine ecosystems combined (USD5.7 trillion), despite the far smaller extent of inland waters. While valuation estimates are subject to controversy, the general message that fresh waters have immense economic importance seems self-evident. At least two billion people depend upon rivers directly for provision of ecosystem services that can be characterised most simply as 'food', such as the benefits to be derived from fisheries, flood-recession agriculture, and dry-season grazing (Richter *et al*. 2010)**.** Moreover, the value of fresh waters is bound to increase in the future, as ecosystems become more stressed and their goods and services scarcer.

It will be a colossal challenge to reconcile human needs for water without compromising provision of goods and services that result from functioning ecosystems and the biodiversity that sustains them (Naiman and Dudgeon 2010). Doubts have even been expressed that current conservation strategies will be sufficient to slow the rates of population decline and species loss from fresh waters (Strayer 2006). One thing is certain: planning, management, and decision-making processes must address the need to balance the trade-off between environmental and human needs for water, or risk further biodiversity declines, impairment of ecosystem functioning and consequential impacts on human livelihoods. In short, there is a need to 'legitimize' rivers, lakes and other freshwater habitats as users of water (Naiman *et al*. 2002). To achieve this, reliable information on the status and distribution of freshwater biodiversity, as well as the ecological conditions needed to sustain it, must become an essential component of environmental planning and water management. Provision of such information is a major objective of this report.

Stiassny (1999) co-opted Marshall McLuhan's phrase 'the medium is the message' in order to encapsulate the notion that freshwater biodiversity faces unparalleled threats due to dependence on a resource subject to unprecedented and ever-increasing human demands. Here, these threats are explained, with further discussion on why they are so severe, and what makes the biodiversity associated with fresh waters particularly vulnerable to human impacts. Beginning with the latter, there are two explanations for the relative vulnerability of biodiversity in fresh waters. Firstly, there is a great deal of biodiversity in the small area of the globe occupied by rivers, lakes and wetlands. This point is addressed in section 1.1.1. Secondly, the inherent features of freshwater environments make their inhabitants especially susceptible to changes wrought by humans. The consequences of this matter are considered in section 1.1.2, where the pandemic array of threats to freshwater biodiversity is described.

Wagenia fishing in the rapids of the Boyoma Falls, on the Lualaba River in D. R. Congo. © KLAAS-DOUWE DJIKSTRA

1.1.1 Species diversity

The biota of fresh waters has yet to be fully inventoried, especially in tropical latitudes, but a recent – albeit incomplete – global assessment (Balian *et al*. 2008) demonstrates that it is very much larger than would be expected from the area occupied by inland waters. Of the approximately 1.32 million species thus far described on Earth, around 126,000 live in fresh water (Balian *et al*. 2008) – almost 10% of the global total. Of these, more than 13,000 species are fish (Lévêque *et al*. 2008) – approximately 40% of global fish diversity, and one quarter of global vertebrate diversity. When amphibians, aquatic reptiles (crocodiles, turtles) and mammals (otters, river dolphins, platypus) are added to this freshwater-fish total, then as much as one-third of all vertebrate species are confined to fresh water. Yet surface freshwater habitats contain only around 0.01% of the Earth's water and cover only about 0.8% of the surface (Gleick 1996; Dudgeon *et al*. 2006). Fresh waters as a whole are therefore a 'hotspot' for global biodiversity, and this goes some way towards explaining why they are also hotspots of endangerment (see above). Given the large proportion of fresh waters situated in recently-glaciated regions that have relatively low biodiversity, it is evident that fresh waters in the remaining unglaciated regions must be 'ultra-hotspots' for global biodiversity (Strayer and Dudgeon 2010).

Although knowledge of freshwater biodiversity is improving, large gaps remain (Balian *et al*. 2008). They are particularly noticeable among invertebrates, and especially in tropical latitudes (Dudgeon *et al*. 2006; Balian *et al*. 2008). Accordingly, determination of conservation status of these animals is problematic. IUCN Red List assessments have been made for only three invertebrate groups globally: dragonflies (a sampled assessment) (Clausnitzer *et al*. 2009), freshwater crabs (Cumberlidge *et al*. 2009), and crayfish (IUCN 2010). While only 14% of dragonflies are threatened, the proportion rises to 40% if species classified as 'Data Deficient' (DD: essentially, those for which taxonomic status remains uncertain, or that are too poorly known to assess adequately) are considered to be at risk (IUCN 2010); the proportion of threatened freshwater crabs increases from 16% to 65% with the addition of the DD category, and for crayfish it rises from 16% to 38%.

This insufficiency of knowledge is not confined to invertebrates: 25% of amphibians are classified by IUCN as DD. When this figure is combined with the percentage known to be threatened, a total of 56% of amphibians are either threatened or too poorly known to assess. Even such well-studied freshwater taxa as fishes are incompletely known: between 1976 and 2000, more than 300 new fish species, approximately 1% of known fishes, were

Okavango Delta channel. Freshwater habitats cover only 0.8% of the Earth's surface but contain almost 10% of all described species, making them 'ultra-hotspots' for global biodiversity. © JENS KIPPING

A polluted canal in Chennai, India. Pollution of waterways from urban centres is a major threat to freshwater systems and their biodiversity. © MCKAY SAVAGE

formally described or resurrected from synonymy each year (Stiassny 1999; Lundberg *et al*. 2000). More strikingly, approximately 40% of the global total of 6,696 amphibian species has been described during the last two decades (AmphibiaWeb 2010). The equivalent proportions are likely to be more substantial for freshwater invertebrates, with tens of thousands of species awaiting description (Balian *et al*. 2008). Regional discovery rates of new freshwater species also vary widely. Investigations in the Mekong drainage, for example, suggest that it may support as many as 1,700 fish species (Sverdrup-Jensen 2002), more than three times the total of earlier estimates. Identification of areas that support particularly high freshwater richness has lagged behind efforts for the terrestrial realm, and the first attempt at mapping global freshwater ecoregions and hotspots was unveiled relatively recently (Abell *et al*. 2008). This is an important development, as previous global biodiversity assessments have largely ignored freshwater species (e.g., Myers *et al*. 2000; Brooks *et al*. 2006), despite the evidence that they are highly threatened and the lack of any confirmation that terrestrial and freshwater hotspots overlap (Strayer and Dudgeon 2010).

Why are fresh waters so rich in biodiversity? A few freshwater species have large geographic ranges, but the insular nature of freshwater habitats has led to the evolution of many species with small geographic ranges, often encompassing just a single lake or drainage basin (Strayer 2006; Strayer and Dudgeon 2010). High levels of local endemism and species richness seem typical of several major groups, including decapod crustaceans, molluscs and aquatic insects such as caddisflies and mayflies (Balian *et al*. 2008). The high endemism results in considerable species turnover (= β diversity) between basins or catchments. An outstanding example is cichlid diversity in African Rift Valley lakes, where hundreds of endemic species are found (Thieme *et al*. 2005; Chapter 3 in this report). The fundamental point is that because of high species turnover, water bodies tend not to be 'substitutable' with respect to their faunal assemblages (Revenga *et al*. 2005, Dudgeon *et al*. 2006), and this contributes to regional species richness.

Local endemism and high species turnover reflect the limited ability of most freshwater species to disperse through terrestrial landscapes or to migrate from river to river along the coast. Moreover, the hierarchical arrangement of riverine habitats means that the populations and communities they harbour are differentially connected to – or isolated from – each other (Fagan *et al*. 2002; Benda *et al*. 2004), with abilities to disperse through networks that depend on the vagaries of confluence patterns, stream gradients, or the presence of barriers such as waterfalls. Geographic distance may appropriately reflect the degree of isolation among terrestrial habitats, whereas stream distance, which is often much larger than straight-line distance, reflects the degree of isolation among stream habitats. Thus, headwater streams tend to be isolated habitats for fully aquatic species, even if they are geographically proximate (Gomi *et al*. 2002), because there can be large 'stream

Algal blooms in Lake Dianchi, China. Industrial and domestic pollution has led to the eutrophication of the lake, threatening biodiversity and impacting the water supplies to Kunming City. © GREENPEACE CHINA

distances' between them. Geographic distance is a more appropriate measure of the degree of isolation among lakes or other standing-water bodies, but the problem of overland dispersal remains. The hierarchical architecture and/or isolation of fresh waters can contribute to richness (through evolution of endemism), but also influences rates of recolonization or recovery following perturbations or local extinction events (Cook *et al*. 2007; Lake *et al*. 2007). Thus, the features generating freshwater biodiversity also contribute to its vulnerability to the many threats generated by human activities, as described below.

1.1.2 Major threats to freshwater species

'The medium is the message' effectively conveys the notion that the vulnerability of freshwater biodiversity arises from the fact that fresh water is a resource that may be extracted, diverted, contained or contaminated by humans in ways that compromise its value as a habitat for organisms (reviewed by Dudgeon *et al*. 2006). In addition, overexploitation of fishes and other animals is a global problem (reviewed by Allan *et al*. 2005; Dudgeon *et al*. 2006; Wong *et al*. 2007), while introductions of exotic non-native or alien species (reviewed by Strayer 2010) present an additional threat to freshwater biodiversity – the impacts of Nile Perch in Lake Victoria being an egregious example (Hecky *et al*. 2010). There will be complicated interactions between these threats or stressors, and their consequences will be further compounded by global climate change leading to rising temperatures and shifts in runoff and precipitation patterns. This makes it difficult to predict likely outcomes (Moss 2010; Ormerod *et al*. 2010) and consequential extinction risks. For example, both the largest and smallest species of freshwater fish appear to be at greatest risk of extinction globally, but the former are at-risk due to overfishing, while threats to the smallest species are particular to local circumstances and the species concerned (Olden *et al*. 2007).

The multiplicity of human impacts on freshwater biodiversity is a result of the tendency for the integrity and diversity of lakes, streams and rivers to be determined to a very significant extent by the condition of their catchment areas. Land transformation for agriculture or urbanization can lead to sedimentation, pollution by nutrients, changed runoff patterns and so on, leading to direct mortality of biota by poisoning and habitat degradation, and sub-lethal effects and physiological impairment that may cause extinction over longer time scales. Pollutants may result in eutrophication, toxic algal blooms, fish kills and so on that are associated with biodiversity losses. In short, lakes and rivers are landscape 'receivers' (Dudgeon *et al*. 2006) and catchment condition impacts biodiversity via multiple complex direct and indirect pathways. Furthermore, downstream assemblages in streams and rivers are affected by upstream processes, including perturbation, so that flowing-water habitats are 'transmitters' as well as 'receivers' (Ward 1989). For example, pollution from upstream is transmitted downstream, thereby spreading potential impacts to otherwise intact reaches. Disturbances that threaten riverine biodiversity can also be transmitted upstream against the flow of water. Examples include downstream dams that impede upstream migration of fishes or shrimps that breed in estuaries, thereby resulting in extirpation of whole assemblages in headwaters (Pringle 2001). Dams and overfishing have caused declines or complete losses of salmon runs in rivers along the west coast of North America, leading to reductions in 'uphill' transfer of marine-derived nutrients with major consequences for in-stream and riparian production in headwaters (e.g., Gende *et al*. 2002). Migratory fishes (alewives, eels, salmon and shad) have likewise declined by as much as 98% from historic levels of abundance in rivers along the Atlantic seaboard (Limburg and Waldman 2009).

Further complexity arises from the linkage between rivers and their floodplains via seasonal inundation during high-flow periods (Ward 1989). Many riverine or wetland species are adapted to and dependent on such flooding (Lytle and Poff 2004). Levee construction, channelization and flow regulation degrades floodplains by limiting or severing their connection with the river channel which, in turn, impacts migration and reproduction of aquatic species (Lytle and Poff 2004). Changes to riparian zones or river banks disrupt food webs and the reciprocal transfers of energy and nutrients between terrestrial and aquatic habitats (Nakano and Murakami 2001; Fausch *et al*. 2010). Further susceptibility to anthropogenic impact can be attributed to the fact that exchanges between surface and ground waters are fundamental for maintaining the integrity of freshwater ecosystems although, typically, surface and ground waters are managed as separate resources (Ward 1989). In summary, the inherent connectivity between freshwater bodies and their surrounding catchments ensures that threats to biodiversity can originate well beyond lake or river banks, and within-river hydrologic connectivity allows impacts to be transmitted both downstream and upstream (Pringle 2001). This is markedly different from the relatively localized effects of most human impacts in terrestrial landscapes.

One category of human impacts that is peculiar to inland waters is the threat to species endemism at the basin scale posed by transfer of alien species among river systems (e.g., deliberate stocking with non-indigenous fish or hatchery-reared fry with limited genetic variability – see review by Strayer 2010), and the particular threat arising from 'introduction' and mixing of formerly isolated species brought about through large-scale interbasin water transfers and interconnection of rivers planned or ongoing in China, India, southern Africa and the Neotropics. For instance, the La Plata River System is listed as one of the ten rivers most at risk globally, on account of plans to connect the Paraguay, Orinoco and Amazon Rivers for fluvial navigation as industrial waterways or *hidrovias* (Wong *et al*. 2007). Even species that occur in multiple lake or river systems may be represented by endemic, locally-adapted genetic lineages within individual water bodies or drainages. These represent unique taxonomic units that will be lost due to interbreeding and mixing of genetic lineages that can accompany interbasin water transfers (Moritz 2002).

It is a paradox that impacts can be transferred with efficiency throughout drainage networks (especially downstream), yet – as mentioned above – the complex architecture of such networks and the isolation of water bodies tends to constrain resilience and recovery from impacts (Lake *et al*. 2007). The consequences of the fragmented and insular nature of fresh waters are greatly magnified by the construction of dams (e.g., Nilsson *et al*. 2005), and the interaction of this anthropogenic fragmentation and the geometry of the drainage network can strongly affect the persistence of threatened aquatic species (e.g., Fagan *et al*. 2002; Matthews and Marsh-Matthews 2007). The extent of such dam-related impacts is very substantial: a global overview of dam-based impacts on large rivers revealed that over half (172 out of 292) were affected by fragmentation, with the greatest flow regulation in the Volta River (Nilsson *et al*. 2005). Another indication of the extent of human alteration of global flow regimes is that dams retain over 10,000km3 of water, the equivalent of five times the volume of all the world's rivers (Nilsson and Berggren 2000), while reservoirs trap 25% of the total sediment load before it reaches the oceans (Vörösmarty and Sahagian 2000).

A fundamental reason why alteration and regulation of flow is problematic is that all fresh waters are spatially and temporally dynamic systems, exhibiting variability in discharge, inundation or other aspects of water regime, as well as light and temperature, on diurnal, seasonal and inter-annual timescales. Temporal variability in sediment and nutrient fluxes are also typical of biologically-diverse freshwater ecosystems, and interact with flow regime (including disturbances such as floods and droughts) to maintain habitat diversity and ecosystem processes, and thereby enhance persistence and richness of native species (Bunn and Arthington 2002; Poff *et al*. 2007). Some of these species are adapted to ephemeral or intermittent systems, where water is present for part of the year only, whereas others require perennial inundation or flows. Seasonal peaks in the hydrograph and/or associated changes in temperature or turbidity may represent reproductive cues for fish and other organisms, whereas some species may recruit only during low-flow conditions (Bunn and Arthington 2002; Lytle and Poff 2004).

Humans tend to treat flow variability as undesirable or – in extreme cases – disastrous (for example, floods and drought), and therefore modify or engineer freshwater

Riano Dam, Spain. An indication of the extent of human alteration of global flow regimes is that dams retain over 10,000km³ of water, the equivalent of five times the volume of all the world's rivers. © FELIPE GABALDON

bodies to increase predictability and control variability. As well as leading to a loss of hydrographic cues for reproduction (Lytle and Poff 2004), a 'flattening' of peak flows limits the fluvial disturbance needed to rejuvenate habitat (Bunn and Arthington 2002; Poff *et al*. 2007). Maintaining the dynamic and variable nature of streams and rivers is a prerequisite for protecting freshwater biodiversity (Poff *et al*. 1997), but presents a formidable challenge given the context of a resource management paradigm aimed at controlling hydrological variability. While new and innovative strategies to develop regionally-specific environmental water allocations (or e-flows) are being developed (Arthington *et al*. 2006, 2010; Poff *et al*. 2010), including holistic methods used in

Asia and Africa that attempt to strike a balance between development and resource protection (King and Brown 2006, 2010), their implementation at appropriate scales will be challenging. Nonetheless, some successes with modification of dam operations to mitigate their impacts have been reported (Richter and Thomas 2007; Olden and Naiman 2010).

Research on e-flows is evidence of growing awareness of threats to freshwater biodiversity and, more importantly, represents an attempt to address them. However, it must be emphasized that declines in freshwater biodiversity are not a recent phenomenon. Impacts on fresh waters have been sustained over centuries in some places and, in the case of many major rivers in China, have persisted for over 4,000 years (Dudgeon 2000). Declines in European freshwater fish from around 1000AD have been attributed to a combination of siltation from intensive agriculture, increased nutrient loads and pollution, proliferation of mill dams, introduction of exotic species, and overfishing leading to reductions in mean size and abundance (Hoffmann 1996, 2005; Barrett *et al*. 2004). Allowing for some differences in scale or intensity of action, these are much the same factors that threaten freshwater biodiversity today. Historical losses of salmon, beaver and unionid mussels from North American rivers are certain to have influenced nutrient transfer, food webs and organic-matter dynamics (Humphries and Winemiller 2009; Limburg and Waldman 2009). Such impacts occurred well before any formal stock assessments, giving rise to the false impression that conditions in the immediate past reflect conditions in the intermediate and distant past: i.e., deception, and thus a tendency to underestimate the extent of human impacts, due to a ‘shifting baseline’ (Humphries and Winemiller 2009). The shifting baseline is not just a matter of historic interest: large and charismatic species exploited by fishers can be affected by baseline shift within the span of a human generation; when these species are not encountered on a fairly regular basis, they are rapidly forgotten (Turvey *et al*. 2010). The term ‘ecosocial anomie’ has been used to describe this breakdown in expectations of what species should be present in fresh waters, and societal loss of interest in their preservation (Limburg and Waldman 2009).

Human-caused climate change is certain to present a profound threat to freshwater biodiversity, and now dominates discussions about the fate of ecosystems and conservation planning in the terrestrial, marine, and freshwater realms (Heino *et al*. 2009) (see also Chapter 8, section 8.6.1, this volume). Evidence for impacts on fresh waters already has appeared in the form of warmer temperatures, shorter periods of ice cover, and changes in the geographic ranges or phenology of freshwater animals (reviewed by Allan *et al*. 2005b; Parmesan 2006; Heino *et al*. 2009). Warmer temperatures will have direct metabolic effects on ectothermic organisms and could impact species with narrow thermal tolerances (e.g., Poff *et al*. 2001; Allan *et al*. 2005). Hydrological changes, caused by changes in the amount and timing of precipitation, evapotranspiration, and glacial melting, may also be associated with an increase in the frequency and severity of floods and droughts (IPCC 2007), and will have profound implications for freshwater biodiversity. Temperature increases in the tropics may be smaller than those further from the equator (IPCC 2007), but this does not mean

Flooding across vast tracts of land in Pakistan's Sindh province, six months on from the extreme monsoon rainfall in 2010 that forced more than 20 million people from their homes. © DFID – UK DEPARTMENT FOR INTERNATIONAL DEVELOPMENT

that tropical ectotherms ('cold-blooded' animals such as fish and amphibians as well as invertebrates) will be less affected by rising temperatures, since they may already be close to their upper tolerance limits (Deutsch *et al*. 2008). The inverse relationship between temperature during growth and body size in amphibians (and many aquatic invertebrates) has the important implication that warmer temperatures will lead to smaller size at metamorphosis and reduced adult fitness (e.g., Semlitsch *et al*. 1988).

Given the insular nature of freshwater habitats, adaptations to climate change by way of compensatory movements into cooler habitats further from the equator or to higher altitudes are often not possible, especially for the many fully aquatic species that cannot move through the terrestrial landscape (Dudgeon 2007). Even flying insects and amphibians might find their dispersal opportunities limited in human-dominated environments. Moreover, compensatory movements north or south are not possible where drainage basins are oriented east–west. One conservation initiative that could help address this problem would be translocation or aided migration of threatened species from warming water bodies to habitats within their thermal range (Dudgeon 2007; Hoegh-Guldberg *et al*. 2008). Such actions would be controversial and costly, requiring detailed information about the species (which is available for only a tiny fraction of freshwater species threatened by climate change), and pose the risk of transferring diseases or leading to the ecological impacts of the type associated with alien species (Strayer and Dudgeon 2010).

Climate change will have strong direct effects on freshwater biodiversity over the coming century, but human responses to this climate change could give rise to impacts that will be as strong or even greater. Climate change will create or exacerbate water-supply shortages and threaten human life and property, effects that will encourage engineering solutions to mitigate these problems (Dudgeon 2007; Palmer *et al*. 2008), including new dams, dredging, levees, and water diversions to enhance water security for people

and agriculture and provide protection from floods. In addition, there is increasing impetus to install new hydropower facilities along rivers to reduce dependence on fossil fuels and meet growing global energy needs. The ecological impacts of such engineering responses will magnify the direct impacts of climate change, especially if they are initiated in response to disasters (such as severe floods associated with rainfall extremes) when there may be a temptation to circumvent environmental reviews and regulations because of the urgent need for project implementation (Dudgeon 2007; Palmer *et al*. 2008; Strayer and Dudgeon 2010).

If we have already transgressed planetary boundaries for terrestrial and marine biodiversity loss, as Rockström *et al*. (2009) assert, it is evident that we must also have far exceeded whatever margins would have been sustainable for freshwater biodiversity. Indeed, the extent of the declines and losses of freshwater biodiversity that have been documented is probably a reliable indicator of the extent to which current practices are unsustainable (Dudgeon *et al*. 2006), and demonstrate how human exploitation and impairment of inland waters have outpaced our best attempts at management (Ormerod *et al*. 2010). Extinctions are likely to continue over the next few decades, regardless of actions taken now, resulting from a large unredeemed – and unquantified – extinction ‘debt’. This could, for instance, be incurred by habitat fragmentation reducing the viability of populations that are now in the process of dwindling to extinction (Matthews and Marsh-Matthews 2007; Strayer and Dudgeon 2010).

The outlook is bleak, but not entirely so. In June 2010, 85 nations agreed to establish an Intergovernmental Science policy platform on Biodiversity and Ecosystem Services (IPBES) in Busan, South Korea. The IPBES is intended to mirror the Intergovernmental Panel on Climate Change (IPCC), and will work to integrate data on declines in biodiversity and degradation of ecosystems with the government action required to reverse them (Larigauderie and Mooney 2010). The IPBES will co-ordinate global-scale peer reviews of research on the status and trends of biodiversity and ecosystem services and provide ‘gold standard’ reports and policy recommendations to governments. Formal establishment of the IPBES will require agreement by the UN General Assembly, but the initial agreement was an important initiative for the International Year of Biodiversity. The IPBES will also provide a conduit by which reports such as this can achieve wider currency and thereby inform conservation action.

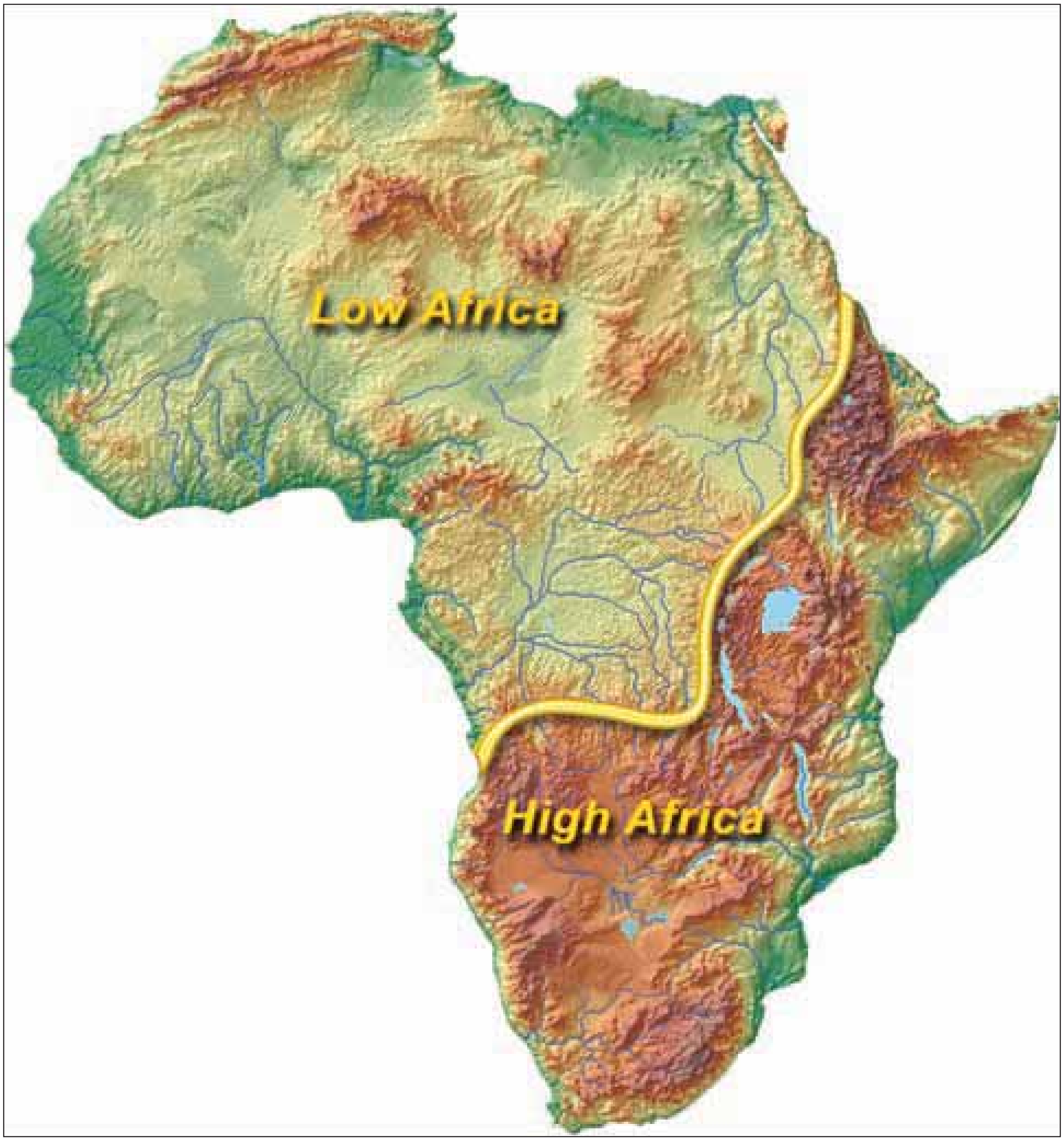
1.2 Situation analysis for Africa

1.2.1 General overview

From the muddy waters of the Congo River spilling into equatorial swamp forests to the vast floodplains of the Inner Niger Delta or Okavango Delta, from the deep and shallow lakes of the Rift lakes in eastern Africa to ephemeral streams of the Namib or Sahara deserts, from the equatorial and perennial basins to the mountain and coastal rivers of the Maghreb or South Africa, the inland waters of Africa are incredibly diverse.

For a long time, the African environment has been relatively preserved from serious anthropogenic threats. This is no longer the case, and several threats presently affect both the hydrological and biological resources, with the rate of loss of freshwater biodiversity in some areas already suspected to be high. For example, Begg (1988) showed that in the Mfolozi catchment of Natal, South Africa, 58% of the original wetland area had been lost by the mid-1980s. Another well-known example is from Lake Victoria, where, at the beginning of the 1980s, some 70% of the endemic cichlid species were reported to have disappeared (Worthington and Lowe-McConnell 1994).

Figure 1.1. The general topography of Africa, showing the approximate division between High and Low Africa (redrawn from Beadle 1981).



Except for a few groups of economically important species (for example, fishes and shrimps) or species associated with human health (e.g., disease vectors), the African aquatic fauna is still rather poorly known. Moreover, our knowledge of freshwater systems is quite heterogeneous. Some areas, such as southern and western Africa, have been reasonably well investigated, while others, such as the Congo Basin and eastern Africa, are still poorly known. As a result, updated inventories are necessary to improve the baseline data on wetland area, distribution, seasonality, characteristics, biodiversity and values.

Geology and geography

Africa is an ancient continent, where freshwater systems have a long evolutionary history compared to temperate zones. They offer a high number and variety of habitats that have resulted from land transformation, by tectonic activity, mainly during the past 20 million years. The present distribution of freshwater species across the continent has been determined largely by these geologic events, combined with the impacts of climate changes.

Taking into account the current relief, the African continent can broadly be divided into Low and High Africa (Beadle 1981) (Figure 1.1). Low Africa is largely composed of sedimentary basins and upland plains below 600m above sea level. In contrast, High Africa to the south and east is mainly over 1,000m above sea level. The famous Rift Valley, a result of tectonic events, includes some of the most ancient lakes in the world, such as Lake Tanganyika

(12 million years old (Fryer 1991)) and Lakes Malawi and Victoria, where evolution has given rise to unique species flocks of fish and invertebrates (Worthington and Lowe-McConnell 1994) (also see Species in the Spotlight – **A unique species flock of freshwater crabs in Lake Tanganyika: a model for studies in evolution and extinction**, this volume).

Climate and hydrology

The climate is of utmost importance in determining the distribution of aquatic systems. Within tropical Africa, three major climatic types prevail: (i) equatorial: hot and humid with two rainy seasons; (ii) tropical: hot with summer rain; and (iii) subtropical: hot and arid. In the north and south, Mediterranean climate types also occur, with arid summers and winter rains. The amount of rain and its distribution throughout the year varies greatly within Africa. Both within and between year variations in rainfall determine river flows and lake levels. Evidently, these large spatial and temporal patterns in rainfall and temperature greatly influence the ecology of the continent and its aquatic organisms.

Rainforest covered central Africa almost entirely 30 million years ago, but savannas expanded between 16 and 8 million years ago. The last million years remained changeable and dry, with less rainforest than now for 80-90% of the time. Just 12,000 years ago, the continents rainforest covered only 10% of the current area. While the Sahara was dotted with swamps and lakes 8,000 years ago, the most recent arid phase culminated only 2,500-2,000 years before present. Africa still receives less rainfall than other tropics, and what does fall is more seasonal and irregular, with frequent droughts and floods. Little is known about the long-term consequences of such constant shifts for freshwater fauna. Increasing aridity and seasonal variability within and between years, for instance, could lead to increasing extinction rates in more affected areas.

Freshwater biodiversity

Altogether, the combined effects of geographic, climatic and topographic factors have given rise to a high diversity of freshwater species and assemblages. Africa's freshwater fish diversity, reported to include more than 3,000 species, rivals that of Asia (more than 3,600 species known) and South America (more than 4,200 species known) (Lévêque *et al*. 2008). In addition, the existence of diverse species flocks and relict 'living fossils' provides a special additional value to the African fish fauna (Lévêque and Paugy 2006), and there are an unusually high number of primary division fish families in Africa as compared to other continents. One reason for this exceptional phylogenetic diversity may be that the African continent has not been totally submerged, at least for the last 600 million years (Lévêque 2001). Information on the diversity of other taxonomic groups is compiled through the Freshwater Animal Diversity Assessment (FADA) project (Balian *et al.* 2008).

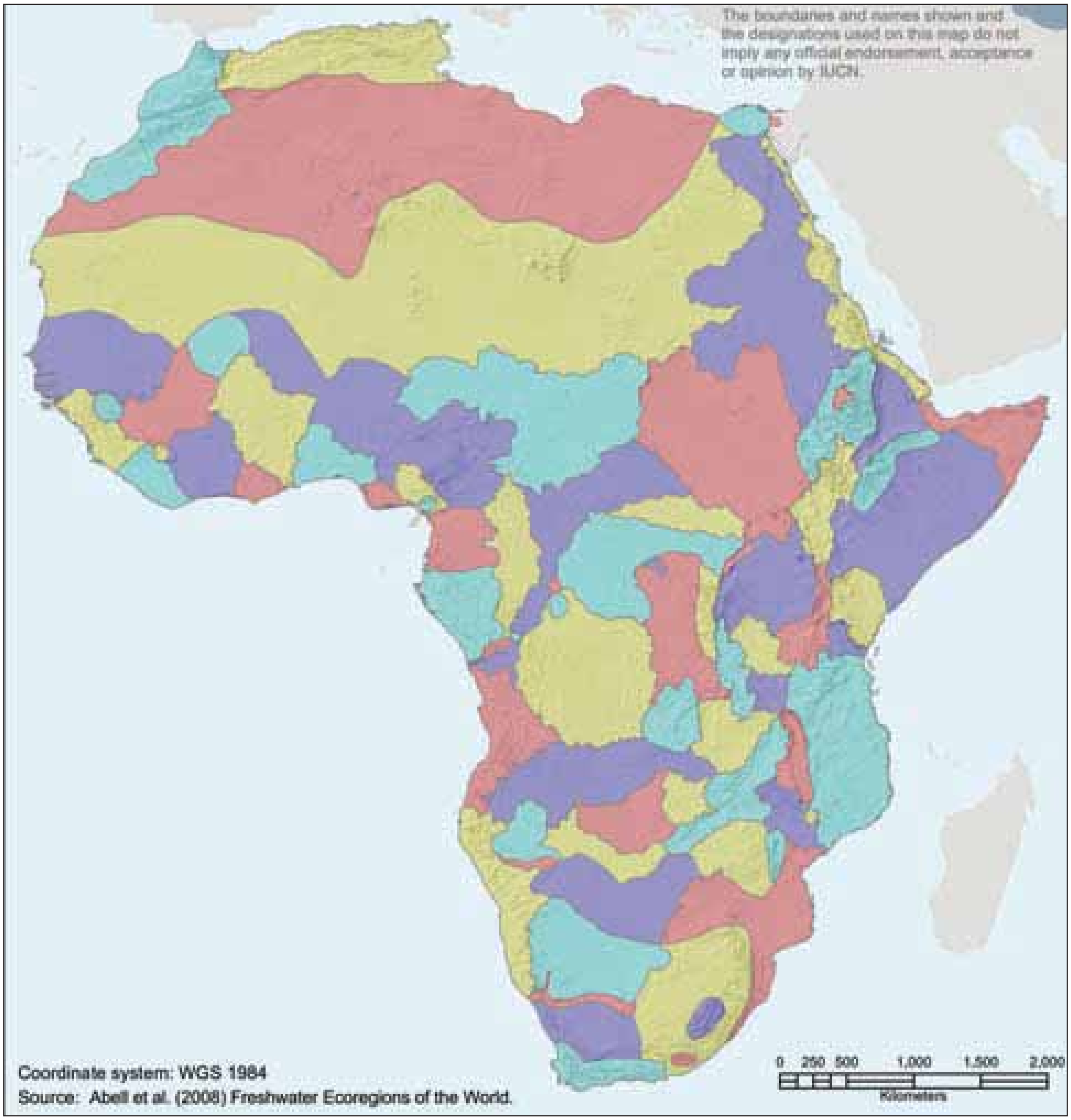
Fish catch in a bucket, caught in the Lower Itimbiri River in D. R. Congo. Fish diversity in Africa rivals that of Asia and South America. © KLAAS-DOUWE DJIKSTRA

FADA provides a global overview of genus and species-level diversity of animals and plants in the inland waters at the continental level. Within continental Africa, information has been compiled across two large biogeographical areas; south of the Sahara and Madagascar belong to the Afrotropical region, while the Maghreb to the north belongs to the Palearctic region. Through combining the information for these two regions, it is possible to obtain an estimate for the diversity of the aquatic African freshwater fauna (58 groups studied) and flora. A preliminary estimate proposes that at least 16,789 freshwater species occur in the Afrotropical region alone (including Madagascar and other offshore islands) (Balian *et al*. 2008).

Main ecological zones in Africa

There have been several attempts to delineate geographic areas across Africa based on the origins and similarities of the aquatic fauna. The most recent of these is based on the ecoregion concept (Olson and Dinerstein 1998), which has been refined for application to Africa's freshwater ecosystems as a large area of land or water containing a distinct assemblage of natural communities and species, whose boundaries approximate the original extent of natural communities before major land use change (Thieme *et al*. 2005). Furthermore, they defined a biogeographic province, or bioregion, as a complex of ecoregions that share a similar biogeographic history and so often have strong affinities at higher taxonomic levels. Based on existing knowledge of fish, freshwater conservation biology and aquatic entomology, a final set of 11 bioregions and 79 freshwater ecoregions for Africa was delineated (Figure

Figure 1.2. Freshwater ecoregions of continental Africa.



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

Coordinate system: WGS 1984

Source: Abell et al. (2008) Freshwater Ecoregions of the World.

1.2). Twelve provinces and several 'hotspot provinces' corresponding to the Great Lakes endemic fauna (species flocks) were delineated for fish (Skelton 1994; Lévêque and Paugy 2006; Paugy 2010).

1.2.2 Threats to freshwater ecosystems

A number of anthropogenic threats to freshwater ecosystems are recognised to operate at the continental scale, including: habitat loss or transformation; water extraction and hydrological disruption; invasive alien species; pollution; and overexploitation.

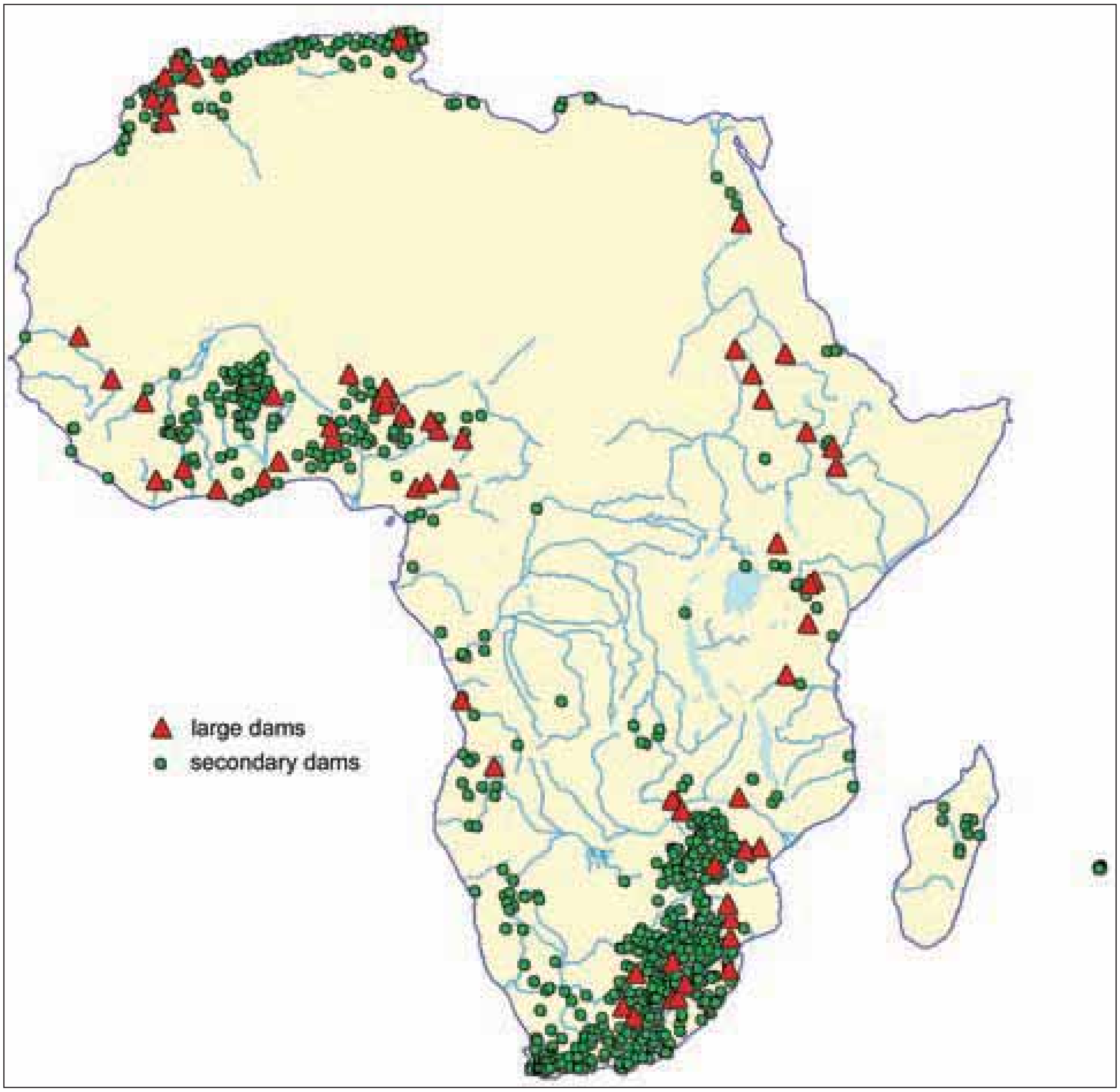
Given the unpredictable rainfall, very high evaporation rate (around 65% of rainfall), and low conversion of rainfall to runoff, it is clear that large areas of Africa face water management difficulties in satisfying the growing demands for reliable and safe water supplies. In an effort to meet the increasing demand for water and power, many large wetlands have been affected by developments, such as dams, flood control measures, or direct abstraction, resulting in impairment of their ecological function (Postel and Richter 2003; Richter *et al*. 2003; Dudgeon *et al*. 2006). Groundwater reserves are being used, most often to provide irrigation for agriculture, at a faster rate than they can be replenished, resulting in the water table being lowered and wetland areas disappearing; this is particularly true for areas of northern and southern Africa (Darwall *et al*. 2009; Garcia *et al*. 2010). Abstraction for agriculture or industry accounts for a large part of the total water consumption from rivers, lakes and aquifers, with an estimated 85% of Africa's total water withdrawals

Polluted water from a leather tannery in Addis Ababa mixing with the Akaki river. Industrial water pollution is major threat to freshwater biodiversity in many parts of Africa. © MANGUS FRANKLIN

directed toward agriculture (FAO 2010a), and about one-third of its surface area estimated to be under agricultural land use in 2000 (FAO 2010b). To compound existing pressures on water resources, Africa is poised to embark on an unprecedented scale of development within its water sector, targeting a 100% increase in irrigated land area, and an increase from 7% to 25% of total hydropower potential captured by 2025 (Economic Commission for Africa 2003). Water runoff from these agricultural lands brings sediments, nutrients and pesticides that can destroy or reduce the effective functioning of wetlands and their floodplains, with a consequent impact on associated biodiversity. Pollution from domestic sewage and industrial facilities is already a major problem in many parts of Africa where the infrastructure required for water purification is often inadequate or non-existent (Saad *et al*. 1994; Lévêque 1997; UNEP 2004).

The impacts from each of these threats are treated in more detail below, through a discussion of impacts on fishes in particular. Specific impacts to other taxonomic groups are also covered in Chapters 3 to 7.

Figure 1.3. Location of 135 large dams (≥ 500,000m³) and 1,072 secondary dams (< 500,000m³) in Africa (data from FAO, Aquastat 2010a).



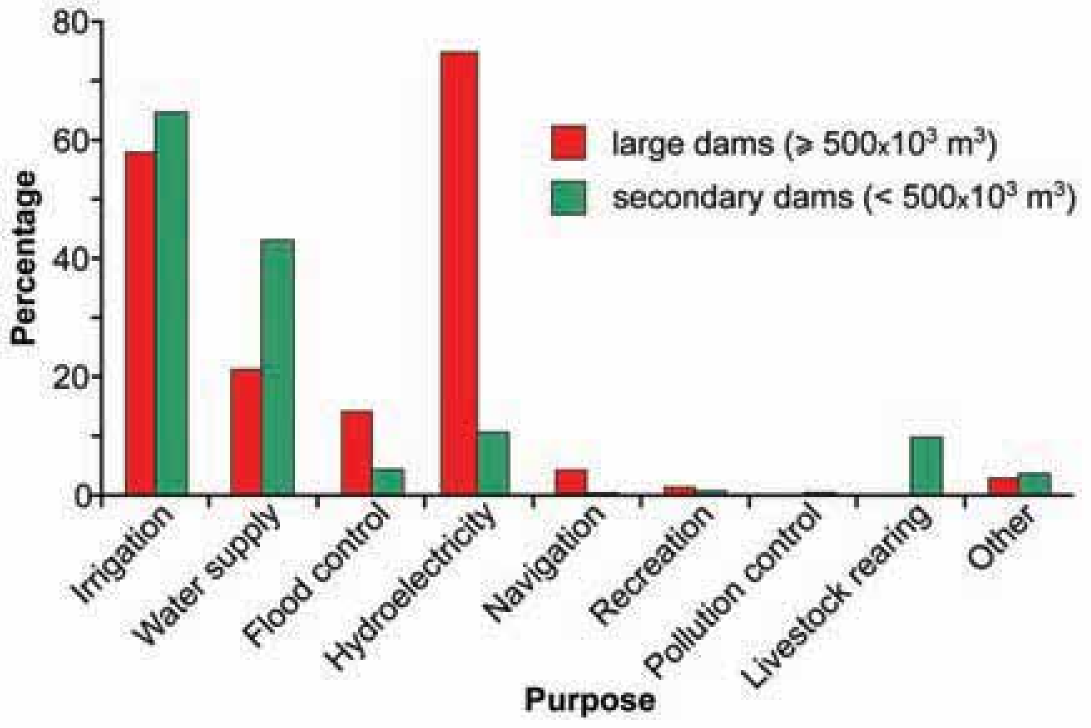
1.2.2.1 Habitat transformation

Dams (water fragmentation)

Africa has a large number of dams, particularly in the Maghreb, southern and western Africa (Figure 1.3), and many more are either under construction or have been proposed. Large dams or secondary dams have been built for a range of purposes, including for domestic, industrial and mining water supply, crop irrigation and hydroelectricity. Most of the largest dams were built after the mid 1950s, on large rivers and for electricity supply. More recently, probably thousands of smaller reservoirs have been established to meet other water demands including, irrigation, water supply (domestic use) or fish production (Figure 1.4).

The impacts of large dams on ecosystem functions and biodiversity are well documented (e.g., Nilsson *et al* 2005; McAllister *et al.* 2001; McCartney *et al*. 2001). They constitute obstacles to longitudinal exchange of nutrients and sediments along rivers, permanently destroy upstream submerged habitats, and block the migration pathways for some aquatic species. Downstream impacts include changes to the flow regime, water temperature and water quality. Such changes in ecosystem functions can be felt many hundreds of kilometres from the site of the dam. The ecosystem impacts from dams should, therefore, be treated as costs to society and be factored into decisions taken before building a dam, and in the subsequent design of its construction. The nature of these impacts is summed up through one of the main conclusions of the Report of the World Commission on Dams (World Commission on Dams 2000): 'On balance, the ecosystem impacts are more negative than positive and they have led, in many cases, to significant and irreversible loss of species and ecosystems. In some cases, however, enhancement of ecosystem values does occur, through the creation

Figure 1.4. Main purposes of dams in Africa (data from FAO, Aquastat 2010a).



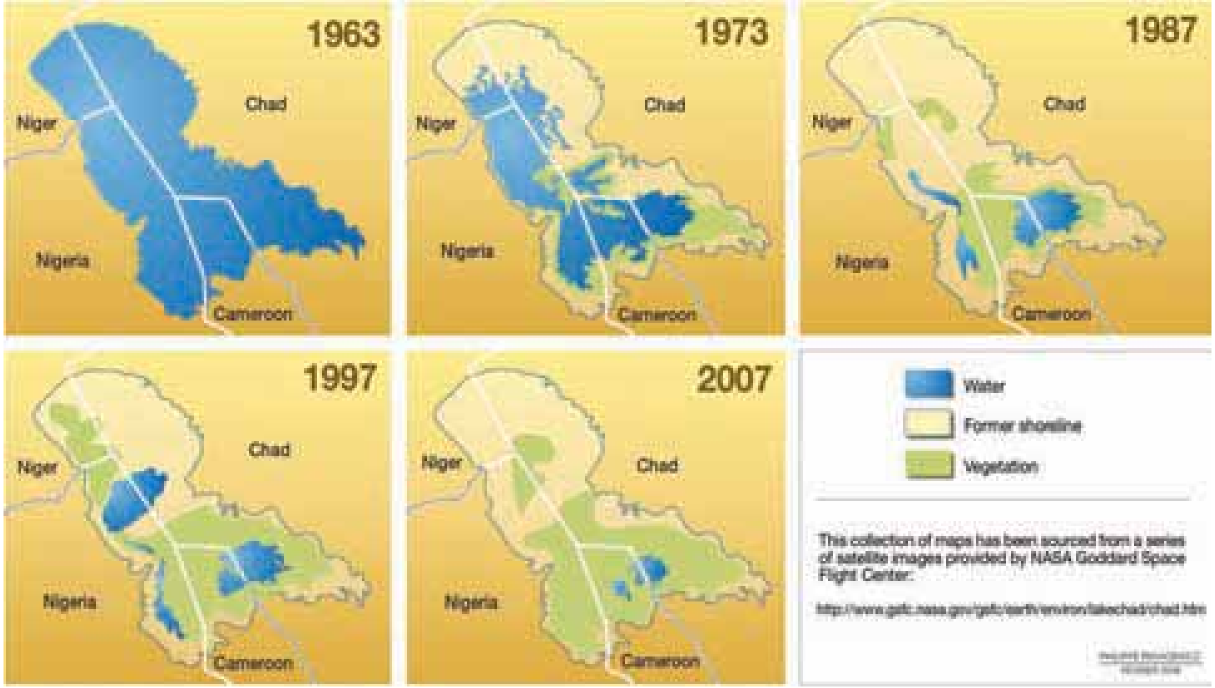
of new wetland habitat and the fishing and recreational opportunities provided by new reservoirs… Efforts to date to counter the ecosystem impacts of large dams have met with limited success due to the lack of attention to anticipating and avoiding such impacts, the poor quality and uncertainty of predictions, the difficulty of coping with all impacts, and the only partial implementation and success of mitigation measures.'

One of the largest projects is the Grand Inga on the Congo River (Showers 2009). The idea of diverting the waters of the Congo through electricity generators was first proposed in the 1920s and has been revived periodically since that time. The Congo has the world's second largest flow (after the Amazon), but it is the only major river with significant falls or rapids close to its mouth. Furthermore, as the river drops its final 96m to sea level, the channel narrows and its course makes a 180 degrees bend – this is Inga Falls. The Grand Inga scheme would divert the lower Congo River through a channel cutting across this bend, to flow through a bank of electricity generators before returning the river to its natural course. Grand Inga has been calculated to produce twice as much power as China's Three Gorges Dam, with the potential for export to Europe. As a precursor to Grand Inga, Inga I and II were constructed in 1972 and 1982, respectively, to constitute Africa's second largest hydroelectric generating capacity. As is the fate of many of the world's large dams, lack of maintenance meant that by 2006 both were operating at an estimated 20% of total capacity. Plans for the massive Grand Inga Dam were replaced in 2009 with proposals for a Grand Inga Cascades, once the potentially catastrophic environmental impacts of Grand Inga were recognised. It was realised that Grand Inga Dam would create a lake so large that it would submerge both Kinshasa and Congo Brazzaville and would cause 'irreversible environmental harm to all living matter and organisms at the river mouth'. The potentially catastrophic disruptions to the Congo River and the Atlantic Ocean interaction, in terms of threats to global carbon and water cycles, were also realised. The Amazon, Orinoco and Congo rivers, which empty into the Atlantic, combined contribute 15-18% of the world ocean's total organic carbon inputs (Coynel *et al*. 2005). Inga III and IV were proposed in 2009 as 'run of the river' structures that do not disrupt the river flow.

For a few major impoundments in Africa, the sequence after damming has been studied (e.g., Jackson *et al*.

An aerial view of the Inga Dam on the Congo River which, due to lack of maintenance, was running at an estimated 20% capacity in 2006. © INTERNATIONAL RIVERS

Figure 1.5. Reduction in the size of Lake Chad over the period 1963 to 2007. Source: Musa *et al.* 2008.



This collection of maps has been sourced from a series of satellite images provided by NASA Goddard Space Flight Center.

http://www.gsfc.nasa.gov/gsfc/earth/environ/lakechad/chad.htm

1988) and, in general, the impacts are different from those observed in north temperate man-made lakes. Soon after the closure of a dam, there is a substantial increase in the populations of those fish species favouring lacustrine conditions. For example, the high proliferation of larvae and nymphs of *Povilla adusta* (Ephemeroptera), which are favoured by drowned trees, becomes a basic food for most of the generalist feeders that do well in the new conditions, and supports an increase in numbers. In the same way, algal grazers do well, as phytoplanktonic and epiphytic algae increase. However, this expansion of fish populations does not last long and the fish biomass ultimately decreases sharply. It is difficult to predict the ultimate state adopted by the fish community, but it is clear that the transformation of the ecosystem from fluviatile to lacustrine results in the disappearance of fish populations adapted to running waters, and replacement by other species favouring lacustrine conditions, such as small clupeids.

In tropical regions, problems of public health associated with dam construction arise, in particular, as the upstream reservoir provides more extensive habitats for the aquatic vectors of certain important diseases. The most common of these is schistosomiasis, a parasitic disease considered to be the second most damaging economically after malaria. Snails, which represent the intermediate host for the disease, breed in slow-flowing or stagnant water, with artificial lakes associated with dam construction providing favourable conditions for transmission of the disease (see also Chapter 4, this volume). Examples from Nigeria indicate that amongst communities resettled along the shores of reservoirs, infection can reach epidemic proportions, with up to 80% of the community infected (e.g., Ofoezie 2002; Ogbeide and Uyigue 2004).

Finally, a peculiarity of the artificial tropical lakes resulting from impoundment is the annual drop in level (draw-down) resulting from the opening of the sluice-gates to make room for incoming flood waters during the rainy season. This drop can amount to several metres, and can result in large areas of land fluctuating between periods where they are inundated and then exposed. The ecological and societal impacts of all these effects are very important, and differ substantially from impacts of impoundments observed in temperate regions.

Larger water-diversion projects in Africa have also led to reductions in estuarine and freshwater fish population, as a reduction of freshwater inflow reduces the amount of nutrients flowing into downstream areas and increases salinity (Jackson *et al*. 1988). The response to such actions has been observed, for example, as a drastic decline in fish populations in the lower Nile (Aswan Dam, Egypt) (Ryder 1978), and a decline in oyster populations in the lower Volta (Akosombo Dam, Ghana) (Petr 1986).

Water abstraction

Northern and southern Africa are both heavily impacted by the over-abstraction of water for urban, industrial and agricultural uses, although the problem is also present in other parts of Africa. The scale of the problem is most vividly illustrated by Lake Chad, which has shrunk to around 5% of its volume since the 1960s, due to both drought and desertification caused by shortage of rainfall and the over-abstraction and diversion of water for agriculture, in

Deforestation of the Upper Guinean rainforest in western Ghana. Population growth across many parts of Africa has led to increased levels of deforestation and increased sediment loads in catchments. © JOHANNES FÖRSTER

particular for rice production (Musa *et al*. 2008) (Figure 1.5). Virtually all wetlands in the region around Lake Chad are either dried up or on the verge of drying up, and the planned irrigation development of 213,400ha has been stopped at 33,824ha (Musa *et al*. 2008). With more than 20 million people, most of whom are farmers, fishermen and livestock breeders dependent upon the lake and its surrounding wetlands for their subsistence and livelihoods, the problem is so serious that plans are being tabled to transfer water from other rivers in the region. Water transfers, such as proposed here, present additional problems in relation to threats to species diversity (see section 'Water transfers', below).

Water transfers

The uneven distribution of rainfall across Africa has left some regions rich in water resources while others have insufficient supplies. The obvious solution from a manager or user's point of view is to transfer water from water-rich catchments to those where water is limited. At present, this action is largely limited to southern Africa; however, In the 1960s, a plan was proposed to divert the Ubangi River into the Chari to revitalize the drying and dying Lake Chad. Such inter-basin water transfer schemes were proposed at different periods in the 1980s, 1990s and finally in 2008 (Musa *et al*. 2008). The 'Transaqua' project envisions the construction of a 'broad navigable canal which, running along the eastern and northern crest of the Congo catchment, could intercept the waters of the extreme north eastern edges of the basin and, after a course of about 2,400km would reach the Congo-Chad watershed in Central African territory and discharge its entire flow at the head of the River Chari, a tributary of Lake Chad'. The feasibility studies have been completed, and bids for the project were opened in 2008.

Generally speaking, the risks associated with water transfers can be summarized as follows:

- Flow reduction in the donor river and increased flow in the recipient river, with major implications for channel integrity and ecological functioning leading to a frequent loss of biodiversity;
- Changes in the physical and chemical status of the river water, such as through the transfer of clear water to a normally muddy river, which is likely to increase algal growth;
- Introduction of fine sediments from one river to another, leading to a loss of habitats, such as gravel spawning beds for fishes; and
- The spread of alien fish species, floating aquatic plants, and animal diseases and their vectors.

Deforestation and sedimentation

Since the 1950s, Africa's population has grown rapidly with an average growth rate of around 2.5% for the period 1950-2005 (UN 2010). This demographic pressure has accelerated rates of deforestation, such as around the Great Lakes of eastern Africa. The case of Lake Tanganyika is well known, where increased sedimentation following deforestation has resulted in changed species composition and disruption of community interactions in some areas (Cohen *et al*. 1993). Increasingly, sedimentation from watershed deforestation, road building and other anthropogenic activities is impacting lacustrine habitats, particularly those of rock-dwelling communities.

1.2.2.2 Pollution

Few detailed studies of water pollution impacts have been carried out in Africa, despite the fact that sources of all types of pollution are rapidly increasing on the continent and their impact on freshwater communities is clearly apparent (Dejoux 1988). The major forms of water pollution impacting Africa's inland waters are discussed below.

Eutrophication

Eutrophication occurs when nutrients (mainly nitrogen and phosphorus) are released into freshwaters in excess of quantities normally required by the ecosystem. In Africa, it is estimated that 28% of all lakes and reservoirs are eutrophic (Water Research Commission, South Africa; issue September/October 2008), and many examples of eutrophication across inland sub-Saharan Africa are reviewed by Nyenje *et al*. (2010). A well known example is the eutrophication of Lake Victoria (e.g., Witte *et al*. 2008) (see Box 1.1 Is Nile perch a scapegoat?). Most of the nutrients causing eutrophication originate from agricultural and urban areas. In developing countries, such as those in sub-Saharan Africa, waste waters from sewage and industries in urban areas, which are often discharged untreated in the environment, are increasingly becoming a major source of nutrients, leading to eutrophication of many surface waters.

The environmental effects of eutrophication include increases in phytoplankton, replacement of diatoms with cyanobacteria, large-scale blooms of macrophytes, and ultimately the eradication of species such as fish, following deoxygenation of the water column. Blooms of cyanobacteria can disrupt virtually all interactions between organisms within the aquatic community, and may produce harmful secondary metabolites that are toxic to humans and animals. In extreme cases, a total depletion of oxygen may result as dead organic matter, such as the die-off of macrophytes, decompose, consuming oxygen and generating harmful gases, such as methane and hydrogen sulphide.

Domestic and industrial organic loads

Population growth over the last few decades has led to a steep increase in urban, industrial and agricultural land use. Sewage and other effluents, rich in organic material, cause primary organic pollution, which is highly oxygen-demanding and causes, in turn, anoxia. Less than 30% of waste water is treated in sewage treatment plants in sub-Saharan Africa (Nyenje *et al*. 2009). Such forms of pollution are, for example, well known in the Bujumbura area of Lake Tanganyika and around much of Lake Victoria (see box 1.1 Is Nile perch a scapegoat?).

Heavy metals

Heavy metals are taken up by both plants and animals, with a few, such as mercury, shown to accumulate up

Nile perch fish heads being smoked at a fish landing site on Lake Victoria, Kampala, Uganda. © SARAHEMCC

Box 1.1 Is Nile perch a scapegoat?

The introduction of Nile perch (*Lates niloticus*) to Lake Victoria is usually quoted as an example of the disastrous consequences on indigenous fauna of the introduction of an alien species. This large predatory fish, introduced into the lake in the 1960s, started to proliferate at the beginning of the 1980s. At the same time, populations of endemic cichlid species strongly receded (Witte *et al*. 1992). The conclusion appeared obvious: the introduced Nile perch was to blame for this 'ecological catastrophe', because the indigenous fish fauna was not prepared to deal with the highly intensive predation pressure from this new species. Such a phenomenon is referred to as the 'Frankenstein effect'. More recent studies have, however, shown that the reality is more complex, involving not only the impacts of species introductions but also major environmental changes to the whole lake ecosystem (Balirwa *et al*. 2003).

Why did the Nile perch, which occurs all over the Sahelo-Sudan area, start to proliferate in Lake Victoria? Such a phenomenon was not observed in those other aquatic environments where the Nile perch cohabits the food chain. Mercury discharge in freshwater systems is generally linked to gold mining, a particular problem in the Congo River system. Nevertheless, in Africa, the occurrence of trace or heavy metals is still relatively low when compared to some other parts of the world, such as South America (Biney *et al*. 1992).

Oil pollution

Chronic discharges of oil, mainly in estuaries and lagoons, are considered a major threat to aquatic systems. An unfortunate example demonstrating the serious impacts oil pollution can have in inland waters was reported in July 2010, when an oil spillage may have destroyed about 6,000 fish ponds in Delta State (Nigeria), affecting an estimated USD100 million worth of fish (Amaize 2010). Considering the massive loss of fish, environmental contamination, and damage to the fishing settlement where over 2,000 families from different parts of the country make a living, the cost is undoubtedly high.

Pesticides

An important source of contamination in African lakes and rivers is the increasing use of pesticides to curb diseases of people and livestock, and for agricultural purposes. In Africa, however, the impact of pesticides on the functioning of aquatic ecosystems and communities is still poorly documented. One long-term study in western Africa has, however, looked at the impact of a weekly application of insecticide against blackflies over a period of more than twenty years, and concluded that the effect of the larvicides on fish and invertebrates populations was low (Lévêque 1997). In another study in the Okavango Delta, spraying the insecticide deltamethrin for control of the Tsetse fly was found to have a significant impact on non-target aquatic invertebrates, although subsequent monitoring has found indications of likely recovery for most species (Perkins and Ramberg 2004).

1.2.2.3 Impact of fisheries

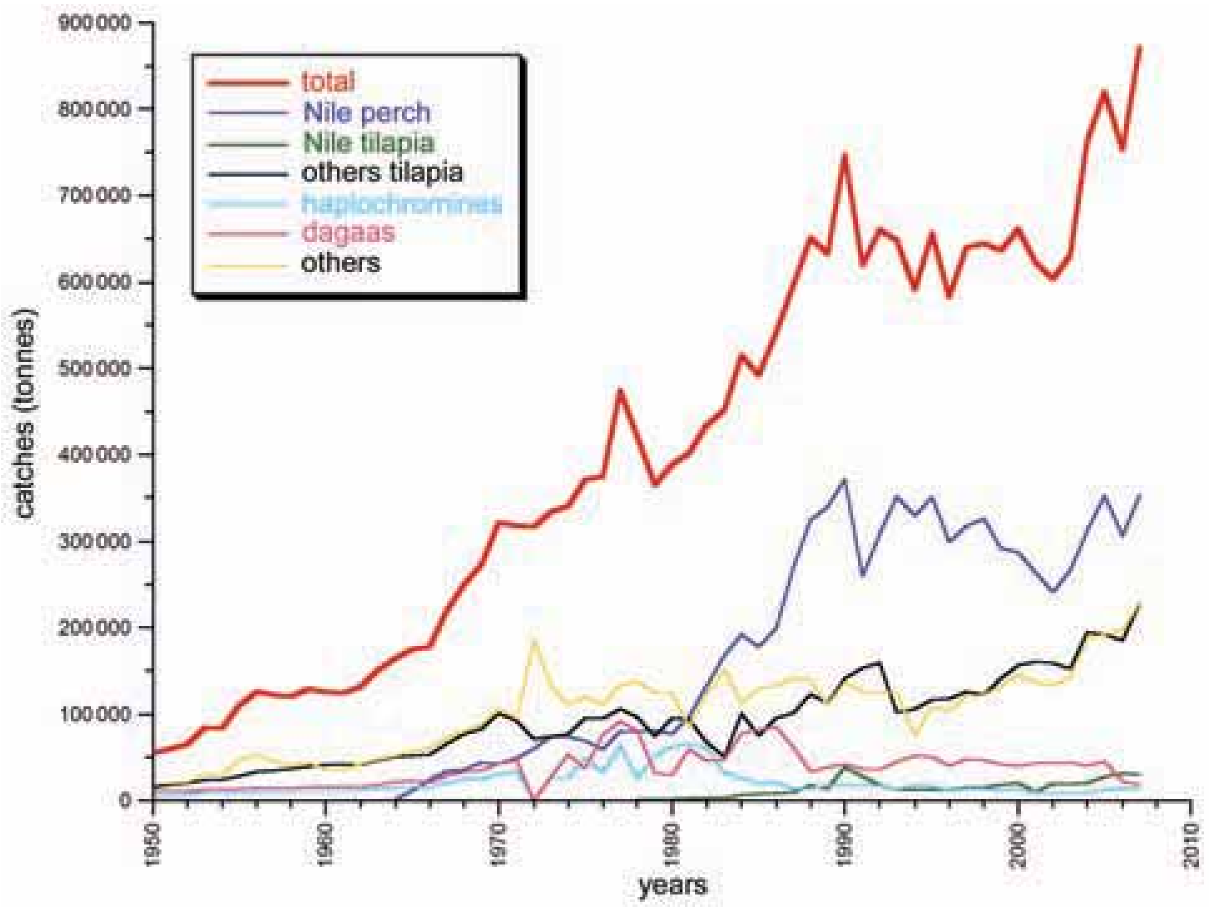
The impacts of fishing in African lakes are reviewed by a number of contributions in Pitcher and Hart (1995). Overfishing is often recognised as an important form of perturbation, but there are few documented examples of species completely disappearing following overexploitation. Impacts on species composition in lake fish communities are, however, more commonly documented (e.g., Craig 1992). For example, demersal trawling is reported to have played a significant role in the local selective decline of large cichlid species in Lake Victoria (Goudswaard and Ligtvoet 1988) (see below) and Malawi (Tweddle *et al*. 1995). In Lake Tanganyika, where the main fishery has been for pelagic species, the initial impact was a reported steady reduction in all *Lates* species and an increase in clupeids (Coulter 1991). Ultimately, the community was reduced to a single predator-prey pairing between *Stolothrissa tanganicae* and *Lates stappersi.* The overall effect was summarised as a change from a stable fish community based on a predator and prey system to an unstable community structured

with other fish species without any significant impact on their populations. For example, the same ecological imbalance was not observed in Lake Tanganyika, where four autochtonous *Lates* species occupy similar niches to the Nile perch.

Lake Victoria has undergone a number of major changes since the beginning of the 20th century (Balirwa *et al.* 2003). Firstly, the indigenous fish fauna was overfished (see Section 1.2.1.3). Secondly, there was a high increase in the local human population in the lake basin, where large cotton and tea plantations were established. Development of the lake basin in this manner has led to increases in a number of pollutants, including fertilisers and insecticides as used in the plantations, and increased loading of domestic and urban pollutants. A lack of water purification plants has resulted in an accumulation of pollutions throughout the lake, leading to widespread eutrophication. The main consequences of eutrophication include a reduction in water transparency, and increased anoxia (lack of oxygen) in deeper water. These two phenomena have had particularly significant impacts on the endemic cichlid fauna. Increased water turbidity, especially near the lake shore has interfered with the visual sexual recognition system of many cichlids, leading to hybridisation and likely loss of genetic diversity (Spinney 2010). Water anoxia limits the potential reproduction grounds where cichlids build nests, and has forced some species to move from deep water into the shallows where the risk of predation from the Nile perch is increased.

The proliferation of Nile perch in Lake Victoria would thus result from a deep and progressive change in the ecological status of the lake, related to pollution. Transformation of the ecosystem led to the increase of predator communities by providing an abundant food source (for example, the shrimp biomass exploded as a result of increased plankton populations). Even without introduction of the predatory Nile perch, indigenous endemic populations of cichlid fishes would probably have declined as a result of the significant environmental changes within the lake. Although the Nile perch has most likely had a significant impact on the endemic fish fauna of the lake, the situation is not as clear cut as originally thought. This case study demonstrates why we need to be cautious when developing our conclusions about the effects of introduced species on native biodiversity.

Figure 1.6. Evolution of fish catches in Lake Victoria (Kenya, Uganda, Tanzania). Source: FishStat Plus, FAO and Lake Victoria Fisheries Organization.



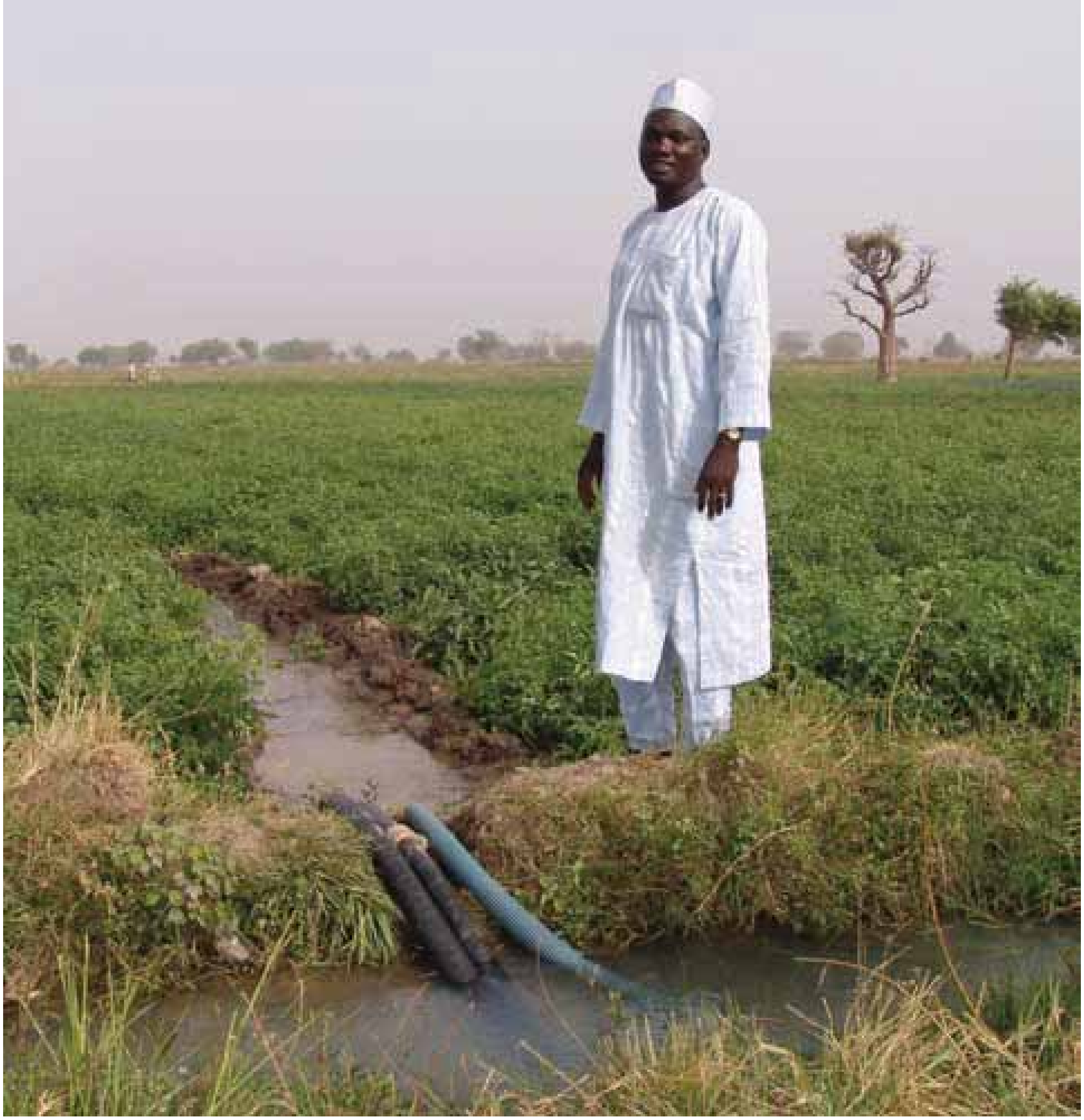
through a balance of competitive interactions (Coulter 1991). In summary, the impacts of fishing on community structure are apparent but are hard to separate from the impacts of natural environmental change.

In the case of Lake Victoria, improved fishing technology (nylon gillnets and outboard motors), combined with increased fishing effort, resulted in a severe drop in catches of the endemic tilapia species by the beginning of the 1970s, well before the Nile perch was established in the lake (Fryer and Iles 1972) (Figure 1.6). In this case, as the native species declined, new fisheries were established, targeting newly introduced species (particularly *Lates niloticus* and *Oreochromis niloticus*). The total catch reached 0.9 million tonnes by 2007. However, such dramatic changes in catch composition pose the question of how stable the new fishery, based on non-native species, will be over the longer term (Witte *et al*. 2007).

1.2.2.4 Invasive alien species

The spread of alien invasive plants and animals is recognised to be a major threat to freshwater biodiversity (Dudgeon *et al*. 2005; Leprieur *et al*. 2009; Samways and Taylor 2004). Only a few species have been deliberately introduced into African freshwaters until now, with the exception of Madagascar (Benstead *et al*. 2000). More often, there have been species translocations within Africa from one water-body to another. For example, Nile tilapia, *Oreochromis niloticus*, has been introduced both for aquaculture and fisheries throughout most of inter-tropical Africa, where they are reported to have negative impacts on the indigenous fish fauna (Canonico *et al*. 2005). However, on the other side of the argument, those involved in aquaculture encourage the introduction of tilapia species as an important species group for improving fish production in many African water bodies. For instance, in newly built reservoirs, stocking by tilapias and *Heterotis niloticus* has enabled development of sustainable fisheries (Moreau *et al*. 1988).

The main goal of deliberate introductions has often been to replenish overexploited wild stocks or to boost fisheries in newly created water-bodies such as Lake Kariba (Marshall 1995). In the past, however, fishery officers also introduced alien species to improve sport fisheries, such as in South Africa, where bass and trout were introduced in the Western Cape province. In South Africa (see Darwall *et al*. 2009), alien fishes introduced for angling are a particularly serious threat. Smallmouth bass (*Micropterus dolomieu*), together



Irrigated tomato field fed by Tiga Dam outside Kanoon, north-east Nigeria. Increased agricultural production through an African Green Revolution will lead to unprecedented development within the water sector. Such efforts will be greatly aided by the provision of information on the distribution, ecology and conservation needs of freshwater species. © IUCN/DANIÈLE PERROT MAÎTRE

with largemouth and spotted bass (*M. salmoides* and *M. punctulatus*) and bluegill sunfish (*Lepomis macrochirus*), all from North America, and banded tilapia (*Tilapia sparmanii*), from further north in Africa, now dominate the fish fauna throughout more than 80% of the Olifants River system, with indigenous fish often surviving in refuges of less than 1km in headwater streams. Rainbow trout, *Oncorhynchus mykiss,* and brown trout, *Salmo trutta*, have had major impacts in cooler headwater streams.

The impacts of invasive alien species are treated in more detail in Chapter 8, Section 8.2.3.

1.2.2.5 Climate change

Anthropogenic climate change and increasing human water use are widely expected to place great stress on available water resources across Africa (Thieme *et al*. 2005), but the effects of these changes on freshwater biodiversity have only just begun to be considered (see www.freshwaterbiodiversity.eu). The impacts of climate change are treated in more detail in Chapter 8, Section 8.6.1

1.2.3 The African Green Revolution and wetlands

Tens of millions of African farmers, with hundreds of millions of dependents, are living in subsistence conditions. Until recently, donors sent only food aid in response to Africa's deepening agricultural crisis. Now they are proposing a new plan: increased agricultural production through a homegrown African Green Revolution. It will require four kinds of assistance: financing for better farming inputs; extension services to advise farmers on the new technologies; community nurseries to diversify production; and investments in infrastructure. As previously laid out in the Africa Water Vision for 2025 (UN-Water/Africa 2003), this will translate into an unprecedented scale of development within its water sector. Every effort must, therefore, be made to safeguard the services of freshwater ecosystems and to mitigate potential damage. Such efforts will be greatly aided by provision of reliable and accessible information on the distribution, ecology and conservation needs of freshwater species throughout Africans inland waters, as provided by this study. Development plans for Africa's water sector are covered in more detail in Chapter 10, Section 10.1.

1.3 Functions and values of freshwater ecosystems in Africa

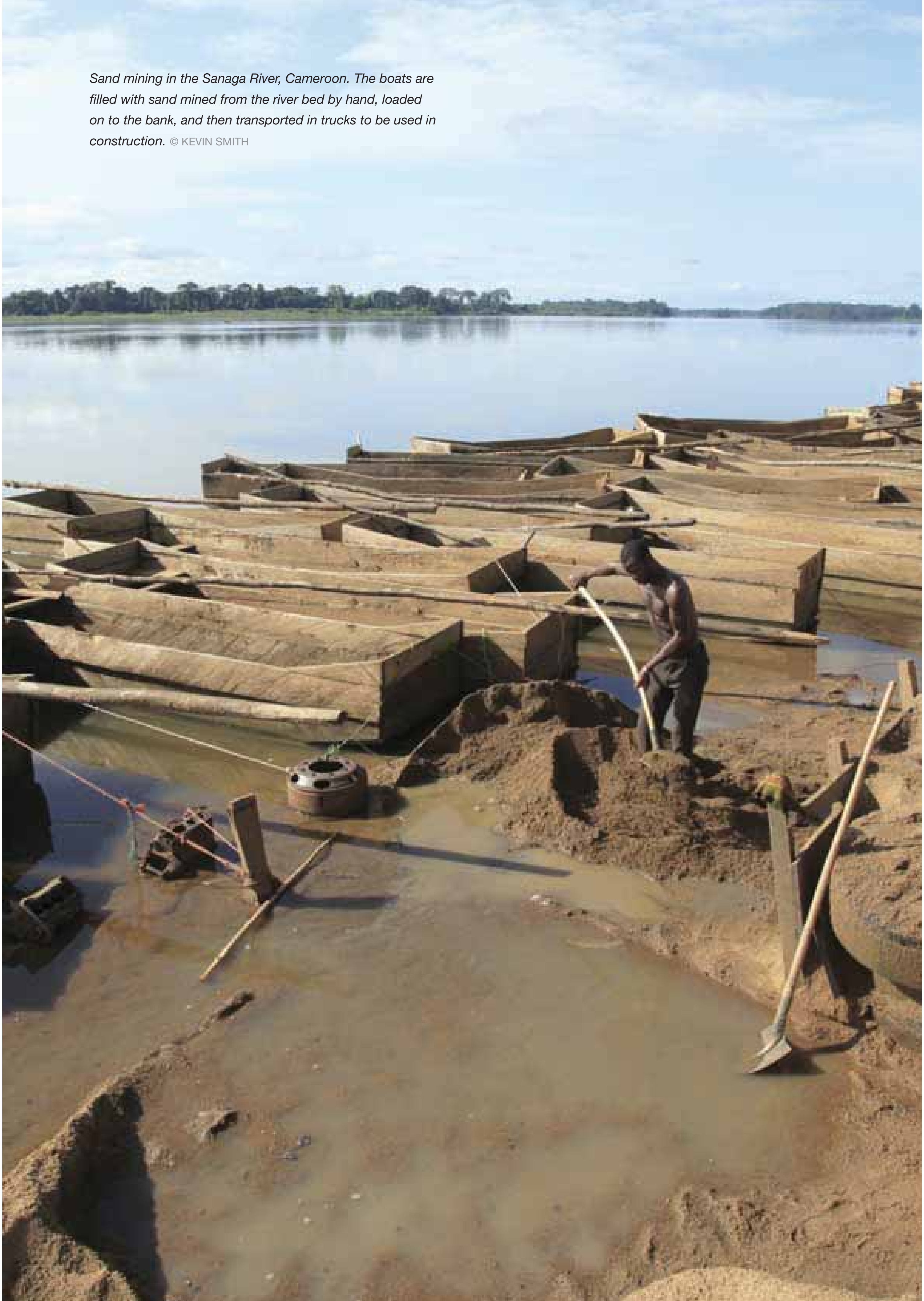
It is becoming increasingly accepted that inland wetlands are valuable ecosystems (Millennium Ecosystem Assessment 2005; UNEP 2010). Wetlands maintain environmental quality, sustain livelihoods, support immense biodiversity and have important recreational and aesthetic qualities. These ecosystems play an important role in sustaining the livelihoods of many millions of people in Africa through the provision of numerous ecosystem services, including food. In many places they are inextricably linked to cropping and livestock management systems. For example, many valley bottom wetlands are of major importance in agricultural systems; saturated during the wet season, the ground retains water into the dry season, allowing the cultivation of crops for extended periods. As a result, these wetlands act as a key resource for cultivators and pastoralists, by providing a source of arable land or grazing throughout the dry season and during droughts.

The value of wetlands for people arises from the interaction of the ecological functions they perform with human society. In Africa, wetlands play a particularly vital role in directly supporting and sustaining livelihoods. They do this through the provision of a range of 'ecosystem services', which bring both physical and non-physical benefits to people. Different wetlands perform different functions and hence provide different ecosystem services, depending on the interactions between their physical, biological and chemical components, and their surrounding catchment.

1.3.1 Wetland functions

Wetlands are amongst the most productive ecosystems in the world, characterized by high primary productivity and a multiplicity of habitats that enable them to support a large diversity of life (Silverton *et al.* 1999). It is the wide range of natural resources that occur within wetlands that makes them valuable in socio-economic as well as

Boys holding a fish catch (Mormyrops spp.) in Bomane, Lower Aruwimi, D. R. Congo. Fish caught for food are a vital service provided by wetlands, directly supporting local livelihoods. © KLAAS-DOUWE DJIKSTRA



Sand mining in the Sanaga River, Cameroon. The boats are filled with sand mined from the river bed by hand, loaded on to the bank, and then transported in trucks to be used in construction. © KEVIN SMITH ecological terms (Millennium Ecosystem Assessment 2005). Although wetlands are generally of great benefit to people, they do also harbour disease vectors such as mosquitoes and some species of mollusc – this is one reason why so many wetlands have been drained. It should be noted, however, that populations of disease carrying species most often increase when wetlands are disturbed, whereas the preservation of intact ecosystems and associated biodiversity will generally reduce the prevalence of infectious diseases (Chipps *et al.* 2006; Keesing *et al.* 2010). Many wetland functions do enhance human wellbeing, and it is widely accepted that overall the advantages of wetlands outweigh any disadvantages.

Ecological functions are the result of the physical, chemical and biological processes that occur through the interaction of the biotic (i.e., flora and fauna) and abiotic (i.e., soil and water) components that comprise an ecosystem. The exact nature of the functions is unique to any particular wetland and dependent on site-specific factors, including climate, geology, topography and the wetland's location within a catchment. However, it is now recognized that biodiversity *per se*, plays an important role in maintaining wetland processes (for example, nutrient cycling, condensation and evapotranspiration) across a range of temporal and spatial scales (Lawton 1999).

The physical benefits derived from wetlands include 'provisioning services', such as: domestic water supply; fisheries; livestock grazing; cultivation; construction materials; and wild plants for food and medicinal use. Other ecosystem services are often not explicitly recognized by communities, but include a wide diversity of benefits such as flood reduction, maintenance of dry season river flows, groundwater recharge, water purification, climate regulation and sediment retention. Wetlands in this way provide a wide variety of tangible and intangible benefits to large numbers of people. The way in which they do so is complex and multifunctional, and is directly related to the specific ecological functions and, hence, the condition of the wetland. A summary of some of the physical benefits human societies gain from wetland functions is presented in Table 1.

Some wetlands play an important role in maintaining or improving water quality. The large number of chemical and biological processes that take place within wetlands (including nitrification, denitrification, ammonification and volatilisation) may convert heavy metals to insoluble forms and remove nutrients from the water. In Uganda, the Nakivubo papyrus swamp receives semi-treated effluent from the sewage works of the capital city Kampala. During the passage of the effluent through the wetland, the papyrus vegetation absorbs nutrients, and the concentration of pollutants is reduced before the water enters Lake Victoria, the principal water source for the city (Kansiime and Nalubega 1999).

People also gain *non-physical* benefits from wetland functions. These are associated with spiritual enrichment, cognitive development and aesthetic experience. For example, the culture of the Lozi people in western Zambia has developed as a consequence of the hydrological dynamics of the Barotse floodplain. Each year, important cultural ceremonies are conducted when the people move out of the floodplain during periods of high water and back again when the water levels fall. Such ceremonies are important in enhancing the social cohesiveness of communities. Elsewhere, wetlands such as the Okavango Delta in Botswana are major tourist attractions, not only enriching the lives of visitors, but also generating income for local people.

Wetlands support a rich diversity of flora and fauna. Some animals live permanently in wetlands (for example, the swamp tortoise and lechwe antelope), whilst others use them as refuges, migrating to them when conditions of drought or food scarcity exist elsewhere or at particular stages of their life-cycle. Wetlands are especially important for migratory birds. Of the 300 species of bird that migrate between Europe and Africa each year, a large number depend on wetland habitats to support them *en route*. The Okavango Delta and Kafue Flats in Africa each support over 400 species, and it is estimated that the Inner Delta of the Niger Delta hosts up to 1.5 million birds each year (Roggeri 1995).

Many groups of people benefit from the presence of wetlands and very often the benefits are experienced far beyond the boundaries of the wetland itself. Many wetland contributions to human welfare accrue without people being aware of them. As a consequence, wetland functions have in the past often gone unrecognised in development and resource planning and management.

1.3.2 Wetland values

The values attributed to wetlands are largely dependent on social perceptions of the use and benefits to be gained from them. In Africa, many millions of people are directly dependent on wetland functions that provide critical contributions to their livelihoods and welfare through provision of food supplies, medicines, income, employment and cultural integrity. Such communities often have limited alternative livelihood options, and this makes them particularly vulnerable to changes in the condition of the natural environment on which they depend.

Many ecosystem services are forms of 'public good', accruing outside monetary systems. Consequently, they very often go unrecognised and are often under-valued.

Table 1.1. Examples of wetland functions that benefit human populations.

Wetland function	Use by society	Examples
Storage of precipitation and runoff	• Water supply • Agriculture • Fisheries	• Based on the inclusive Ramsar definition of wetlands, over half the world's population (i.e., more than 3 billion people) obtain their basic water needs from inland freshwater wetlands. The remaining 3 billion people depend on groundwater, which in some cases is recharged via wetlands. • In the Kilombero floodplain wetland in Tanzania, 80% of 'poor' households and 35% of 'better-off' households rely on the wetland for drinking water (McCartney and van Koppen 2004). • In western Africa, the shallow groundwater and elevated soil moisture of about 5 million hectares of inland valley wetlands are used extensively in crop cultivation. • Non-irrigated rice grown on the floodplains of the Inner Niger Delta fluctuates between 40,000 and 200,000 tonnes per year, with yields of the order of 380-1,500 Format: Kg ha^{-1} (Zwarts *et al*. 2005). • The total catch from inland waters (i.e., lakes, rivers and wetlands) was 8.7 million tonnes in 2002 (FAO 2004). This compares to 85 million tonnes from marine capture fisheries and 48.4 million tonnes from aquaculture. However, in Africa, where many people cannot afford to practice aquaculture, the contribution of inland wild fisheries (2 million tonnes) to the livelihoods of people is much greater than that of cultured fisheries (283,409 tonnes) (UNEP 2010). Catches from inland fisheries are very often unreported, in particular those from subsistence fisheries, which are of great important to the rural poor in particular.
Groundwater recharge	• Water supply	• The Hadejia-Nguru wetlands in Nigeria contribute to the recharge of an aquifer used for water supply by approximately 1 million people that live in the region (Hollis *et al.* 1993).
Nutrient transformation	• Waste water treatment	• Sewage from 40% of the residents of the city of Kampala (around 500,000 people) is discharged into the 5.3km² Nakivubo wetland. The presence of the wetland significantly improves the quality of water entering Lake Victoria, approximately 3km from the city's main supply intake (Kansiime and Nalubega 1999).
Biomass production (e.g., wood, grass, fish etc.)	• Food and medicine • Biodiversity	• Local people use the fruits, seeds, tubers, roots and leaves of around 200 plants from the wetlands surrounding Lake Chilwa in Malawi (International Water Management Institute 2006). • The wetlands of the Kafue floodplain in Zambia support fisheries averaging 6,500 tonnes per year (McCartney 2005). • Local people collect eight plant species from the Bumbwisidi freshwater wetland in Tanzania to treat ailments ranging from fever and stomach disorders to chest pains and coughs (Rebelo *et al.* 2009). • Globally, wetlands are highly productive and, because heterogeneity in hydrology and soil conditions results in a wide variety of ecological niches, they support immense biodiversity (Junk *et al.* 2006). • Kafue and Luena Flats, wetlands in Zambia, support an outstanding diversity of organisms, including over 4,500 species of plants, more than 400 species of birds, and 120 species of fish (Howard 1993).
Chemical cycling	• Gas regulation	• Wetlands are important in the biogeochemical cycling of carbon-dioxide, methane and hydrogen sulphide (Kayrnali *et al.* 2010). • Globally, wetland peat deposits occupy just 3% of the world's land area but store 16-24% of the planet's soil carbon pool (Lloyd in prep.).

The Okavango Delta in Botswana is a major global tourist attraction, generating income for local communities. © WILLIAM DARWALL

Attempts to value some wetland ecosystem services have been made at both the micro and macro scales (Barbier *et al.* 1997; Mitsch and Gosselink 2000; Terer 2004; Emerton 2005; Schuyt 2005; Adekola *et al.* 2008). These have demonstrated that the replacement costs for wetland ecosystems are generally far greater than the opportunity costs of maintaining them intact.

The site-specific nature and diversity of wetland functions, however, makes quantification of wetland values extremely difficult. For some wetlands, monetary values have been assigned to the ecosystem services they provide. For example, the total use value of Zambia's wetlands (with fish production and floodplain recession agriculture accounting for the main share) have been estimated to be the equivalent of approximately 5% of Zambia's GDP in 1990 (Seyam *et al.* 2001). The economic value of wetlands in the Zambezi River basin is also considerable, with estimates suggesting the economic value in terms of crops alone is close to USD50 million a year (UNEP 2006). In addition, the value of wetland fisheries in the basin is estimated to be USD80 million a year, while the floodplain grasslands support livestock production valued at over USD70 million annually. Table 2 provides some additional examples of monetary values that have been derived for particular ecosystem services provided by African wetlands.

It is impossible to assess all of the functions and services provided by wetlands with money as the sole determinant of their value. Beyond the purely financial, the social values of wetlands are also considerable. In many places there is a great deal of local knowledge about wetland resources and the environment as a whole, which often informs traditional practices and customs. Traditional resource management strategies are often in harmony with hydrological regimes, and in many cases fishing cycles, and peoples' socio-political arrangements and settlement patterns have been established to safeguard resources and ensure sustainable use of wetlands (Terer *et al.* 2004). However, such traditional systems are increasingly under pressure

Table 1.2. Examples of values of African wetlands.

Ecosystem Service	Value
Provisioning:	
Agriculture	• On the Barotse floodplain, Zambia, 28,000ha of cultivation (including maize, rice, sweet potatoes, sugar cane, fruit and vegetables) supports approximately 27,500 households and is estimated to be worth USD2.34 million. In the same area 265,000 cattle that graze on the floodplain are valued at approximately USD3 million (Emerton 2005). • The estimated total grazing value of the 311ha Mfuleni peri-urban wetland in Cape Town, South Africa, is USD540,286 (Lannas and Turpie 2009). • Agricultural activities in the Hadejia-Nguru wetlands in Nigeria are valued at USD11 million per year (Schuyt 2005).
Fisheries	• In contrast to the global figures, in Africa, where many people cannot afford to practice aquaculture, the contribution of inland wild fisheries (2 million tonnes) to the livelihoods of people is much greater than that of cultured fisheries (283,409 tonnes). • The livelihoods of approximately 300,000 people are dependent on the fisheries of the Inner Niger Delta (a floodplain wetland). Depending on flood extent they catch between 40,000 to 80,000 tonnes per year (Zwarts *et al.* 2005). • Fisheries in the Lake Chilwa wetland, Malawi, are valued at USD18.7 million per year (Schuyt 2005).
Fibre and fuel	• The total area of wetlands in Tanzania (1,828,000ha) is estimated to generate a gross income from wild resources of USD120 million per year (SARDC *et al*. 1994). • Reeds and papyrus collected from the Barotse floodplain wetland in Zambia are estimated to have a value to local communities of USD373,000 per year (Emerton 2005).
Regulating:	
Groundwater recharge	• The economic value of groundwater recharge in the Hadejia-Nguru wetlands in Nigeria is estimate to be USD17,391 per year (Acharya and Barbier 2000).
Pollution control and detoxification	• The annual water treatment value of wetlands in the Fynbos Biome of the Western Cape, South Africa, is estimated to be USD43.7 million (Turpie *et al.* 2010)
Supporting:	
Biodiversity	• The economic value of the wetland biodiversity of the Barotse ecosystem in Zambia has been estimated to be USD4,229,309 (Schuyt 2005).
Cultural:	
Recreational	• Approximately 120,000 tourists visit the Okavango Delta in Botswana each year, generating an annual income of USD13 million. This makes it one of the primary tourist attractions in southern Africa. • There are 450,000 line fishing permits sold annually in South Africa, with a total value of USD2.7 million. Although many of these are for marine fishing, an unknown number are for inland fishing. Although there are no data, recreational exploitation of freshwater fish on inland rivers and wetlands is known to be extensive (FAO 2008).

as population rises, people's need for cash income increases and contemporary management institutions (for example, formal government) replace ones based on custom.

The high productivity of wetland ecosystems is reflected in the high human populations that they can support. The freshwater and estuarine wetlands of the Nile, Congo, Rifiji, Tana, Niger and Zambezi river catchments each sustain the livelihoods of many hundreds of thousands of people through provision of fisheries, dry season grazing for cattle, water for domestic use and agriculture and plants for traditional medicines, building materials and firewood. It has been shown, however, that the use of wetland resources differs markedly from location to location, as well as across socio-economic groups (Rebelo *et al*. 2009). This diversity and complexity of wetland utilization greatly complicates the development of appropriate wetland management policies. If the benefits wetlands bring are to be used more wisely in the future, there is need for much greater insight into the dynamics of wetland functions and the links between wetlands and human society. Only through such understanding will the true value of wetlands be determined.

Chapter 2.

Assessment methodology

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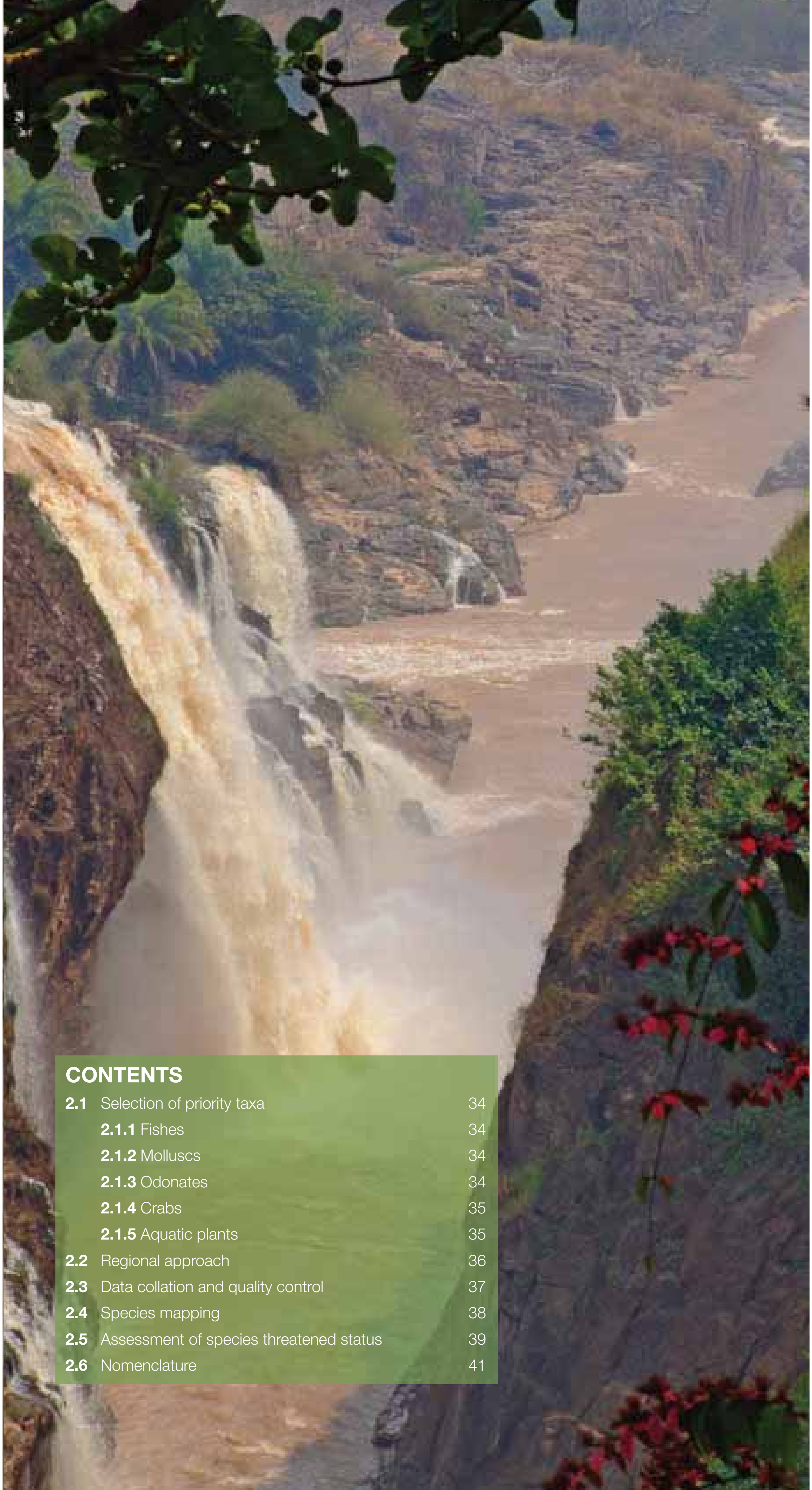
MAIN: *Chutes Guillaume on the Kwango River, a tributary of the Kasai which forms the Angola and D.R.C. border*
© DENIS TWEDDLE

RIGHT: Ledermanniella *spp. are habitat specialists found in waterfalls, rapids and riffles. They require well oxygenated and clean water and are therefore very sensitive to changes in river flows*
© J.-P. GHOGUE



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2.1 Selection of priority taxa

In the majority of cases, large-scale biodiversity assessments have focused on a limited range of taxonomic groups, most often including those groups that provide obvious benefits to humans through direct consumption, or the more charismatic groups, such as mammals and birds. In the case of aquatic systems, it is the wetland birds and fishes that have received most attention. It is, however, important that we take a more holistic approach by collating information to conserve those other components of the food web essential to the maintenance of healthy functioning wetland ecosystems, even if they are neither charismatic nor often noticed. Clearly, it is not practical to assess all species. Therefore, a number of priority taxonomic groups were selected to represent a range of trophic levels within the food webs that underlie and support wetland ecosystems. Priority groups were selected to include those taxa for which there was thought to be a reasonable level of pre-existing information. The taxonomic groups selected were: fishes; molluscs; odonates (dragonflies and damselflies); crabs; and aquatic plants.

Although fish provide a clear benefit to the livelihoods of many people throughout the region, either as a source of income or as a valuable food supply, benefits provided by the other taxa may be indirect and poorly appreciated but nonetheless important. Given the wide range of trophic levels and ecological roles encompassed within these five taxonomic groups, information on their distributions and conservation status, when combined, will provide a useful indication of the overall status of the associated wetland ecosystems.

2.1.1 Fishes

Arguably, fishes form the most important wetland product at a global scale, and are often referred to as a “rich food for poor people” (WorldFish Center 2005). They provide the primary source of protein for nearly 1 billion people worldwide (FAO 2002) and food security and employment for many more (Coates 1995; Dugan *et al.* 2010). It is estimated that in Africa, inland fisheries land nearly 2.5 million tonnes per year (FAO 2006). This accounts for nearly 25% of the world’s inland capture fishery (FAO 2006), providing essential nutrition for the poorest of communities and employment and income for many more (for example, 165,000 people earn a living as fishermen on the major rivers of western Africa (WorldFish Center 2008)). Africa is, however, the only continent where the per-capita consumption of fish is projected to decline (Delgado *et al.* 2003). As a consequence, while populations increase, access to food, income and livelihoods from small scale fisheries are likely to decline (WorldFish Center 2005).

For the purposes of this assessment, freshwater fishes are defined as those species that spend all or a critical part of their life cycle in fresh waters. Those species entirely confined to brackish waters are also assessed. There are almost 13,000 freshwater fish species in the world, or about 15,000 species if brackish water species are included (Lévêque *et al.* 2008). Prior to the start of this project in 2005, the risk of global extinction had only been assessed for 7% (918 species) of freshwater fish species using the IUCN Red List Categories and Criteria.

Hemichromis serasogaster *(EN), only known from the type locality in Lake Mai-N'dombe (Leopold II), D.R. Congo. The use of small mesh nets (mosquito nets) poses a threat to the population.* © ANTON LAMBOJ

2.1.2 Molluscs

Freshwater molluscs are one of the most diverse and threatened groups of animals (Lydeard *et al.* 2004; Vaughan *et al.* 2004). They are mostly unobtrusive, and are not normally considered as being charismatic creatures, rarely attracting the attention of the popular media, unless in a negative light, as some species play a significant role (as a vector) in the transmission of human and livestock parasites and diseases. This is unfortunate, as they play a key role in the provision of ecosystem services and are essential to the maintenance of wetlands, primarily due to their contribution to water quality and nutrient cycling through filter-feeding, algal-grazing and as a food source to other animals (see Strayer *et al.* 1999; Vaughan *et al.* 2004; Howard and Cuffey 2006; Vaughan *et al.* 2008). Some species are of high commercial importance to humans as food or ornaments (e.g., clams and some mussels and snails). There are just fewer than 5,000 freshwater mollusc species (Bogan 2008; Strong *et al.* 2008) for which valid descriptions exist, in addition to a possible 4,000 undescribed gastropod species (Strong *et al.* 2008). Of these, only a small number had their conservation status assessed before this assessment, with just 14% of known species (679 species) on the IUCN Red List at that time.

2.1.3 Odonates

Larvae of almost all species of dragonflies and damselflies (order Odonata) are dependent on freshwater habitats. The habitat selection of adult dragonflies strongly depends on

Acisoma panorpoides *(LC), widespread in Africa (except in dense rain forest), southern Europe, the Middle East, southern Asia, and the Indian Ocean islands.* © KEVIN SMITH

the terrestrial vegetation type, and their larvae develop in water where they play a critical role with regards to water quality, nutrient cycling, and aquatic habitat structure. The larvae are voracious predators, often regarded as important in the control of insect pest species. A full array of ecological niches is represented within the group and, as they are susceptible to changes in water flow, turbidity or loss of aquatic vegetation (Trueman and Rowe 2009), they have been widely used as an indicator for wetland quality. There are 5,680 extant described species. However, even though the group is well studied, it is believed that the actual number is close to 7,000 species (Kalkman *et al.* 2008). Fewer than 1% (31 species) of odonates had had their risk of extinction assessed using the IUCN Red List Categories and Criteria by the time this project started.

2.1.4 Crabs

There are 1,280 species of freshwater crabs (Cumberlidge *et al*. 2009), of which 120 species are recognised from Africa. The detritus shredding guild was thought to be almost completely absent from most tropical African systems. However, it is now thought that this important nutrient cycling role may be taken up by freshwater crabs, as the overwhelming importance of detritus in the diet of most species and their abundance and high biomass indicates that they are key shredders in African rivers (Dobson *et al*. 2002; Abdallah *et al.* 2004; Cumberlidge *et al.* 2009). Freshwater crabs are vectors of the parasite that causes onchocerciasis (river blindness) in Africa (Cumberlidge *et al*. 2009), and an intermediate host of paragonimiasis (lung fluke) in Asia, Africa, and the Neotropics. The fact that paragonimiasis is a food-borne zoonosis indicates that freshwater crabs are widely consumed by humans. Freshwater crabs are good indicators of water quality, as they are found in wide variety of aquatic habitats and require relatively pristine water conditions (Yeo *et al.* 2008). Only a small number, slightly more than 9% (174 species) of freshwater crabs, had their conservation status assessed for the IUCN Red List before this assessment began.

2.1.5 Aquatic plants

Aquatic plants are the building blocks of wetland ecosystems, providing food, oxygen and habitats for many other species. They are also a hugely important natural resource, providing direct benefits to human communities across the world. Numerous aquatic plants are highly valued for their nutritious, medicinal, cultural, structural or biological properties. They are also key species in the provision of wetland ecosystem services, such as water filtration and nutrient recycling. An aquatic plant is defined here as a plant that is physiologically bound to water (a hydrophyte) or as a terrestrial plant whose photosynthetically active parts tolerate long periods submerged or floating (a helophyte) (Cook 1996). According to Cook (1996) aquatic plants represent between 1 and 2% of the approximately 300,000 species of vascular plants, equivalent to between 2,900 and 5,800 species (Chambers *et al*. 2008; Vié *et al.* 2008). Only 20 species of aquatic plants had been assessed for the IUCN Red List before this assessment began.

Sudanonautes aubryi *(LC), a widespread species throughout western Africa.* © DENIS TWEDDLE

For this project, the conservation status of all aquatic plant species from 21 selected plant families was assessed (see Chapter 7), with species from other families also assessed, although not comprehensively (i.e., not all aquatic species within these family were assessed). The selection of families was based on the following criteria: i) the family contains a relatively large proportion of aquatic species; ii) there is a reasonable level of available information on the relevant species; iii) the taxonomy is relatively stable; iv) the selected families would, when combined, cover a wide range of ecological niches and contain a substantial number of species; and v) the family is widely represented at the global scale.

2.2 Regional approach

To collate information on the freshwater species of Africa, a regional approach was taken for the following reasons: i) to allow regional conservation priorities to be identified (as might be lost at the global scale); ii) to facilitate better engagement with regional scientists and decision makers; and iii) to ensure only a manageable number of species would need to be assessed at one time. Africa was divided into six regions, delineated by major river catchments (see Figure 2.1). Once each regional assessment was completed, a report was published (with the exception of north-eastern Africa) highlighting the status and

Figure 2.1. Regional assessment boundaries based on major river basins.

distribution of each taxonomic group and the conservation priorities within the region (see Darwall *et al*. 2005; Darwall *et al.* 2009; Smith *et al.* 2009; García *et al.* 2010; Brooks *et al.* 2011) and the data made freely available through the IUCN Red List website. All regional data sets were then combined, resulting in the pan-Africa data set that is presented and analysed here.

The assessments began in 2003, with the eastern Africa regional assessment acting as a pilot project funded separately by The Netherlands' Ministry of Foreign Affairs (DGIS). Following the successful completion of the eastern Africa assessment, the remaining regions were assessed through a staggered approach, culminating in the continental assessment presented here. Given the six-year time period over which the assessments have been completed, it is unavoidable that some earlier assessments may now be out of date, especially for those species subject to ongoing threats. Efforts were made, however, to update information from earlier assessments during the final pan-Africa workshop in 2009, at which point data from all regions were merged and updated to provide species assessments at the continental scale. For the most current information, please visit www.iucnredlist.org.

2.3 Data collation and quality control

Information was sourced and collated for all known species within the priority taxonomic groups (see Section 2.1). Experts from across Africa and beyond (as necessary) were identified by IUCN, the project partners, and through consultation with the relevant IUCN SSC Specialist Groups. These experts were trained in use of the project database, the Species Information Service (SIS), application of the IUCN Red List Categories and Criteria (IUCN 2001), and Geographic Information Systems (GIS) for digitally mapping species distributions.

The western Africa regional review workshop (fish working group) held in Accra, Ghana in 2006. © KEVIN SMITH

Following the training workshop, in each region a number of participating experts were contracted to collate, and input within the SIS, all available information on each species from the priority taxonomic groups. The required data fields within SIS are summarized in Table 2.1; some are free text fields allowing the assessors to add general information, such as for species distributions, habitat preferences and ecology, whereas other fields are based on classification schemes using pre-defined lists to record against. Standard classification schemes allow for consistency in analysis across other groups or geographic regions. For more information on the classification schemes employed visit the IUCN Red List website www.iucnredlist.org/technical-documents/classification-schemes.

Spatial data were sourced for the production of species distribution maps (see Section 2.4). All species from the selected taxonomic groups were then assessed at the regional scale, using the IUCN Red List Categories and Criteria version 3.1 (IUCN 2001) and the Guidelines for

Table 2.1. Compulsory data fields within the Species Information Service (SIS) database for the compilation of a species assessment. Text = text field; CS = Classification Scheme

	Fields			
Taxonomy	Higher taxonomy	Synonyms	Common names	
Geographic range	General information (text)	Countries of occurrence (CS)	Biogeographic realm (CS)	
Population	General information (text)	Population trend (CS)		
Habitat and ecology	General information (text)	Habitats (CS)	System (CS)	Movement patterns (CS)
Use and trade	General information (text)	Utilisation (CS)	Harvest trends (CS)	
Threats	General information (text)	Threats (CS)		
Conservation measures	General information (text)	Conservation measures (CS)		
Red List assessment	Red List Category and Criteria (CS)	Red List assessment rationale (text)	Assessor & evaluator names	Assessment date
Bibliography	References			

Figure 2.2. Level 6 river basins as delineated by the edited HYDRO1K Elevation Derivative Database (USGS EROS), as used to map and analyse species distributions.

Application of IUCN Red List Criteria at Regional Levels: Version 3.0 (IUCN 2003) (see Section 2.5). All information was then reviewed at a second workshop, where each species assessment was evaluated by at least two independent experts to ensure that: i) the information presented was both complete and correct; and ii) the Red List Categories and Criteria had been applied correctly.

All regional assessment data, including species distribution maps, were then combined to produce the pan-Africa data set. All species (apart from those endemic to a region) were then re-evaluated at a final review workshop held in Cairo in March 2009.

2.4 Species mapping

Species distributions were, with the exception of some plants that could only be mapped to country boundaries, mapped to individual river/lake sub-basins, as delineated by the HYDRO1K Elevation Derivative Database (USGS EROS) at level 6 (the highest resolution available) using GIS software. At the time of the data collation phase, this represented the only pan-Africa GIS river basin layer available. The HYDRO1K database was first edited to eliminate many small errors before submission for subsequent analysis. The resulting data set identified 7,079 individual sub-basins in mainland continental Africa (see Figure 2.2). River sub-basins were selected as the spatial units for mapping species distributions as, even though it is recognised that species ranges may not always extend throughout a river sub-basin, it is generally accepted that the river/lake basin or catchment is the most appropriate management unit for inland waters.

Point localities (the latitude and longitude where the species has been recorded), expert opinion, and published data were used in most cases to identify which sub-basins are known to currently contain each species of fish, odonate or crab. For many species it has also been possible to identify sub-basins where a species is inferred/expected to occur although its presence has not yet been confirmed. These "inferred" sub-basins are often connected to those with confirmed species locality records. Inferred distributions were determined through a combination of expert knowledge, course scale distribution records, and unpublished information. For many of the plant and mollusc species, distribution maps are entirely based on inferred basins, as digitized point localities or detailed distribution information were not available. Finally, many of the widespread plant species were mapped to country boundaries in the absence of any more detailed distribution information.

All analysis presented here is based on species spatial data mapped to the sub-basins delineated by HYDRO1K (edited by IUCN), as described above. However, the individual species maps that will be available for download from the IUCN Red List website (www.iucnredlist.org) have since been transferred to a new global hydrographic data standard called HydroSHEDS (Lehner *et al.* 2008). This new data layer, which delineates 18,689 individual sub-basins for continental Africa, is more accurate and contains fewer errors than HYDRO1K, being derived from elevation data of a higher resolution.

2.5 Assessment of species threatened status

The Red List Categories and Criteria are widely accepted as the most objective and authoritative system available for assessing the risk of a species becoming extinct (Lamoreux *et al.* 2003; De Grammont and Cuarón 2006; Rodrigues *et al.* 2006, Mace *et al.* 2008). The IUCN Red List of Threatened Species™ is the world's most comprehensive information source on the global conservation status of plant and animal species, and is widely use to help inform conservation priority setting.

The risk of extinction for each species was assessed according to the IUCN Red List Categories and Criteria: Version 3.1 (IUCN 2001). Red List assessments completed for any species endemic to continental Africa represent the species' global extinction risk, but for those species with distributions extending beyond Africa the Red List status assigned only relates to that part of the population within Africa; these are termed "Regional Assessments". To ensure that this regional approach was consistent and comparable to other IUCN regional assessments, the Guidelines for Application of IUCN Red List Criteria at Regional Levels: Version 3.0 (IUCN 2003) were followed. Red List Categories at the regional level are shown in Figure 2.3.

A species assessed as "Critically Endangered" is considered to be facing an extremely high risk of extinction in the wild. A species assessed as "Endangered" is considered to be facing a very high risk of extinction in the wild. A species assessed as "Vulnerable" is considered to be facing a high risk of extinction in the wild. All taxa listed as Critically Endangered, Endangered or Vulnerable are described as "threatened". To distinguish between the three threatened categories, there are five criteria with quantitative thresholds (Table 2.3), reflecting biological indicators of populations threatened with extinction.

To identify which assessments are "Regional" as opposed to "Global", the regional assessments have *RG* appended in superscript to their Red List Category; for example, an Endangered species would be written EN^{RG}.

For an explanation of the full range of categories, and the criteria that must be met for a species to qualify under each Category, please refer to the following documentation: The IUCN Red List Categories and Criteria: Version 3.1, which can be downloaded from http://www.iucnredlist.org/technical-documents/categories-and-criteria.

Part of the regional assessment process is the application of "filters" to exclude certain species from the assessment where appropriate. The following filters were applied in this case:

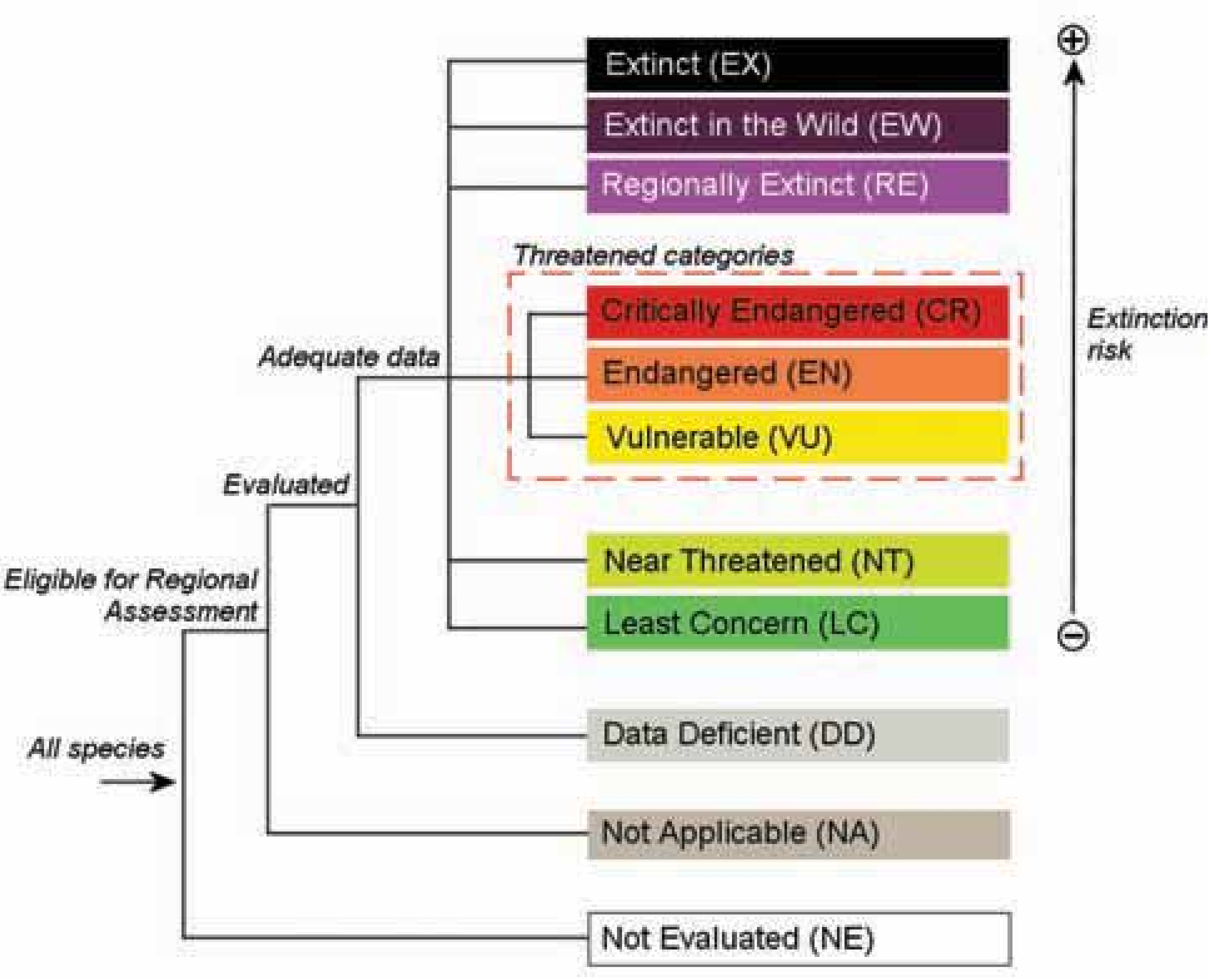
1) Species having less than 5% of their global distribution within Africa were not assessed, and;

Participants from the final pan-Africa review workshop, held in Cairo, Egypt March 2009. © KEVIN SMITH

Table 2.3. Summary of the five Criteria (A–E) used to determine the Category of threat for a species.

Use any of the Criteria A–E	Critically Endangered	Endangered	Vulnerable
A. Population reduction	Declines measured over the longer of 10 years or 3 generations		
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%
A1. Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible **AND** understood **AND** have ceased, based on and specifying any of the following: **(a)** direct observation **(b)** an index of abundance appropriate to the taxon **(c)** a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality **(d)** actual or potential levels of exploitation **(e)** effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.			
A2. Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased **OR** may not be understood **OR** may not be reversible, based on (a) to (e) under AI.			
A3. Population reduction projected or suspected to be met in the future (up to a maximum of 100 years) based on (b) to (e) under AI.			
A4. An observed, estimated, inferred, projected or suspected population reduction (up to a maximum of 100 years) where the time period must include both the past and the future, and where the causes of reduction may not have ceased **OR** may not be understood **OR** may not be reversible, based on (a) to (e) under AI.			
B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)			
B1. Extent of occurrence (EOO)	< 100 km^2	< 5,000 km^2	< 20,000 km^2
B2. Area of occupancy (AOO)	< 10 km^2	< 500 km^2	< 2,000 km^2
AND at least 2 of the following:			
(a) Severely fragmented, **OR** Number of locations	= 1	< 5	< 10
(b) Continuing decline in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** area, extent and/or quality of habitat; **(iv)** number of locations or subpopulations; **(v)** number of mature individuals.			
(c) Extreme fluctuations in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** number of locations or subpopulations; **(iv)** number of mature individuals.			
C. Small population size and decline			
Number of mature individuals	< 250	< 2,500	< 10,000
AND either C1 or C2:			
C1. An estimated continuing decline of at least:	25% in 3 years or 1 generation	20% in 5 years or 2 generations	10% in 10 years or 3 generations
(up to a max. of 100 years in future)			
C2. A continuing decline **AND** (a) and/or (b):			
(ai) Number of mature individuals in each subpopulation:	< 50	< 250	< 1,000
OR	**OR**		
(aii) % individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals.			
D. Very small or restricted population			
Either:			
Number of mature individuals	< 50	< 250	**D1.** < 1,000
			AND / OR
Restricted area of occupancy			**D2.** Typically: AOO < 20 km^2 or number of locations <5
E. Quantitative Analysis			
Indicating the probability of extinction in the wild to be:	> 50% in 10 years or 3 generations (100 years max.)	> 20% in 20 years or 5 generations (100 years max.)	> 10% in 100 years

Figure 2.3. IUCN Red List Categories at the regional level.



2) Species arriving in Africa post 1500 were treated as being "non-native" and were not assessed, but their distributions were mapped where possible.

Species summaries and distribution maps are presented for all species assessed on the DVD that accompanies the paper copy of this report. An example output is given in the Appendix.

2.6 Nomenclature

Taxonomic schemes are constantly changing as results from ongoing studies, in particular with the introduction of molecular techniques, are made available. Taxonomy is also a somewhat controversial field, and in many cases it is difficult to find a universally agreed taxonomic hierarchy. In this case, the taxonomy followed is that adopted by the IUCN Red List which, where possible, employs existing published world checklists. Fish classification generally follows the online Catalog of Fishes maintained at the California Academy of Sciences (Eschmeyer 2010). Odonate classification generally follows the World Odonata List maintained at the University of Puget Sound (Schorr and Paulson 2010). There is currently no widely accepted single taxonomy for molluscs and crabs, and we therefore follow the standards recommended by the IUCN SSC Mollusc Specialist Group and the Freshwater Crab and Crayfish Specialist Group, respectively. For plants, where appropriate, we follow the World Checklist of Selected Plant Families hosted by the Royal Botanic Gardens, Kew (WCSP 2010), but other more specialist lists are also followed, such as the Checklist of World Ferns (Hassler and Swale 2010). For more information on the taxonomic standards of the IUCN Red List, visit www.iucnredlist.org/technical-documents/information-sources-and-quality#standards.

A taxonomist at work at the South African Institute for Aquatic Biodiversity (SAIAB). © KEVIN SMITH

Chapter 3.

The status and distribution of freshwater fishes

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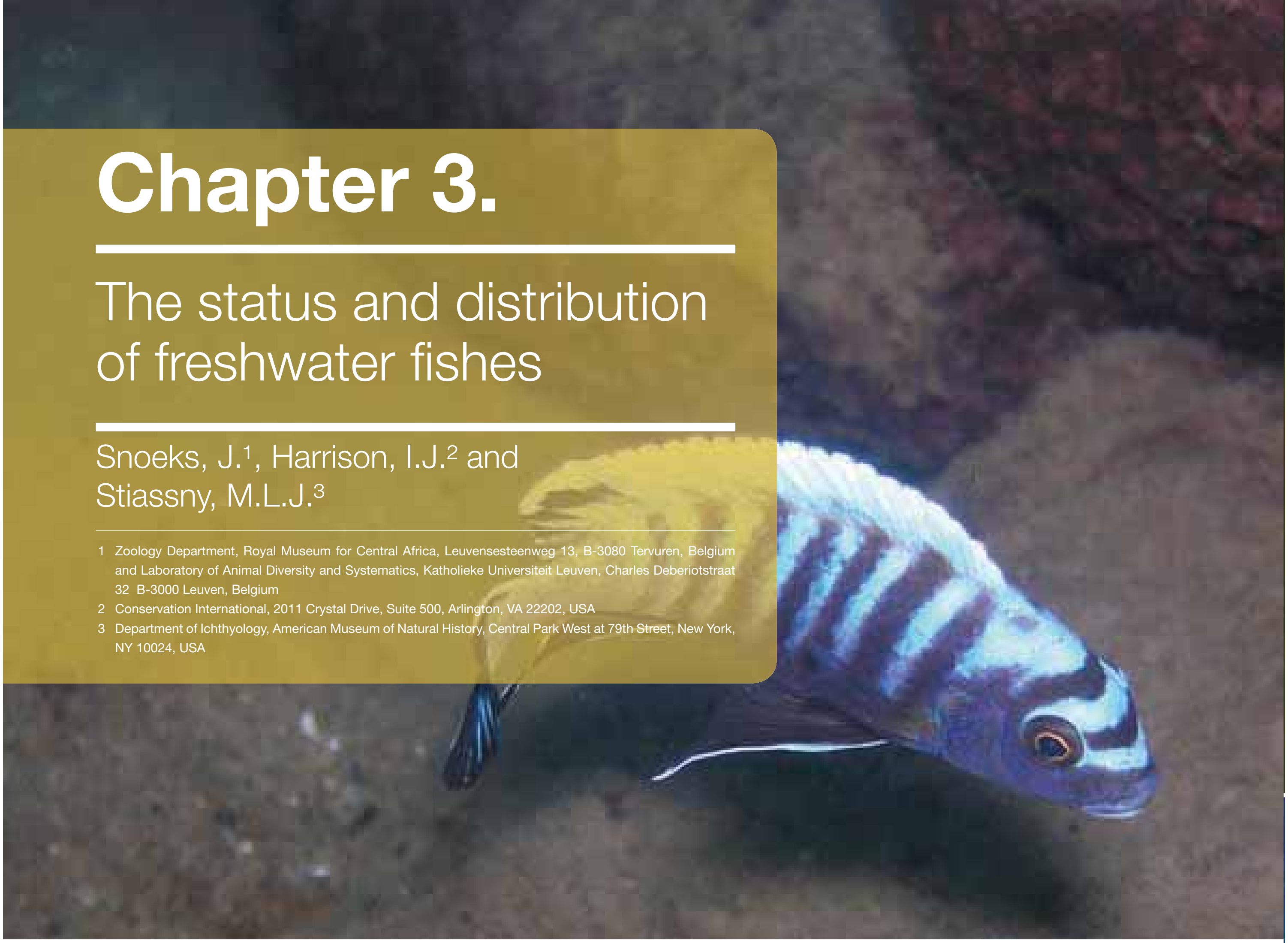


3.1 Overview of the ichthyofauna of Africa

Africa harbours a well-diversified fish fauna, resulting from a long history of complex climatic and geological events that resulted in geographic isolation followed by speciation for some populations, or extinction for others (Roberts 1975; Lévêque 1997). While the African ichthyofauna shows many unique features compared to other continents, it shares affinities with both South America and Asia, as a result of its connection to these landmasses as part of Gondwana.

Africa has several archaic and phylogenetically isolated taxa (e.g., the bichirs, Polypteridae; lungfishes, Protopteridae) (Lundberg *et al*. 2000). Lungfishes, which include four African species in the genus *Protopterus*, are members of the most ancient group of bony fishes that still have living representatives. Fossil lungfishes date back some 410 million years (Le Cointre and Le Guyader 2001), although members of the extant genera are younger, originating in the Eocene, 35-54 million years ago. Africa also has representative species groups that have undergone extensive recent adaptive radiation, if not even ‘explosive speciation’. The best-known case is the 500 or more species of cichlids (Cichlidae) in Lake Victoria that went through a major lineage diversification about 100,000 years ago (Verheyen *et al*. 2003). While it is clear that the desiccation of Lake Victoria about 14,700 years ago had a large influence on this fauna, the evolutionary impact of a possibly completely dry Lake Victoria has been heavily debated (Stager *et al*. 2004; Verheyen *et al*. 2004). Lundberg *et al*. (2000) also provide other examples, such as the species flock of *Labeobarbus* in Lake Tana (see also Species in the spotlight – **A unique species flock in Lake Tana – the *Labeobarbus* complex**) and the diversity of sympatric mormyrids found in small rivers of the rainforests of western and central Africa. The levels of endemism are high for many parts of Africa, with some notable examples in the East African Great Lakes, the crater lakes (see Species in the Spotlight– **Cauldrons for fish biodiversity: western Africa’s crater lakes**) and the rivers of central Africa.

The scientific study of African fresh and brackish water fishes is more than a century old. A first major step in compiling the existing information was set by George Boulenger, a Belgian ichthyologist, then working in the Natural History Museum in London. His important four volumes Catalogue of the African fishes (Boulenger 1909-1916) provided the most authoritative account of 1,425 species. Even now, this catalogue is a major source of information for poorly known areas and poorly defined taxa. In a more recent effort to inventory all the fishes occurring in African continental waters, the *Check-List of Freshwater Fishes of Africa* [CLOFFA] (Daget *et al*. 1984-1991) listed 2,908 species (Boden *et al*. 2004). CLOFFA represented a considerable increase in knowledge, and this knowledge has expanded further over the last two decades, as a result of several regional accounts. Lévêque *et al*. (1990, 1992) and Paugy *et al*. (2003a,b) published accounts for western Africa; Skelton (1993) published for southern Africa; and Stiassny *et al*. (2007a,b) published for the Lower Guinean region (see below). Many of these and other studies, as well as data from museum collections from around the world, are synthesized in FishBase (Froese and Pauly, 2010), highlighting that the total number of scientifically known African freshwater fishes has risen dramatically since CLOFFA was compiled. For example, currently in FishBase, the number of fishes in the Ethiopian or Afrotropical Zoological realm (that is, Africa excluding northern Africa, but including Madagascar and the southern part of the Arabian Peninsula) is about 3,200, almost all of them endemic to the realm. This endemism is not restricted to the species level; the majority of genera are endemic, as are about half of the families. In addition, it is likely that several hundred species are still to be described from the African continent, especially from the Great Lakes region, and the Congolian and Angolan river systems.

Polypterus endlicherii congicus *(LC), a subspecies of bichir widespread throughout the Congo catchment and Lake Tanganyika. Bichirs are within the Polypteridae family, an archaic and phylogenetically isolated group of fishes.* © ULI SCHLIEWEN

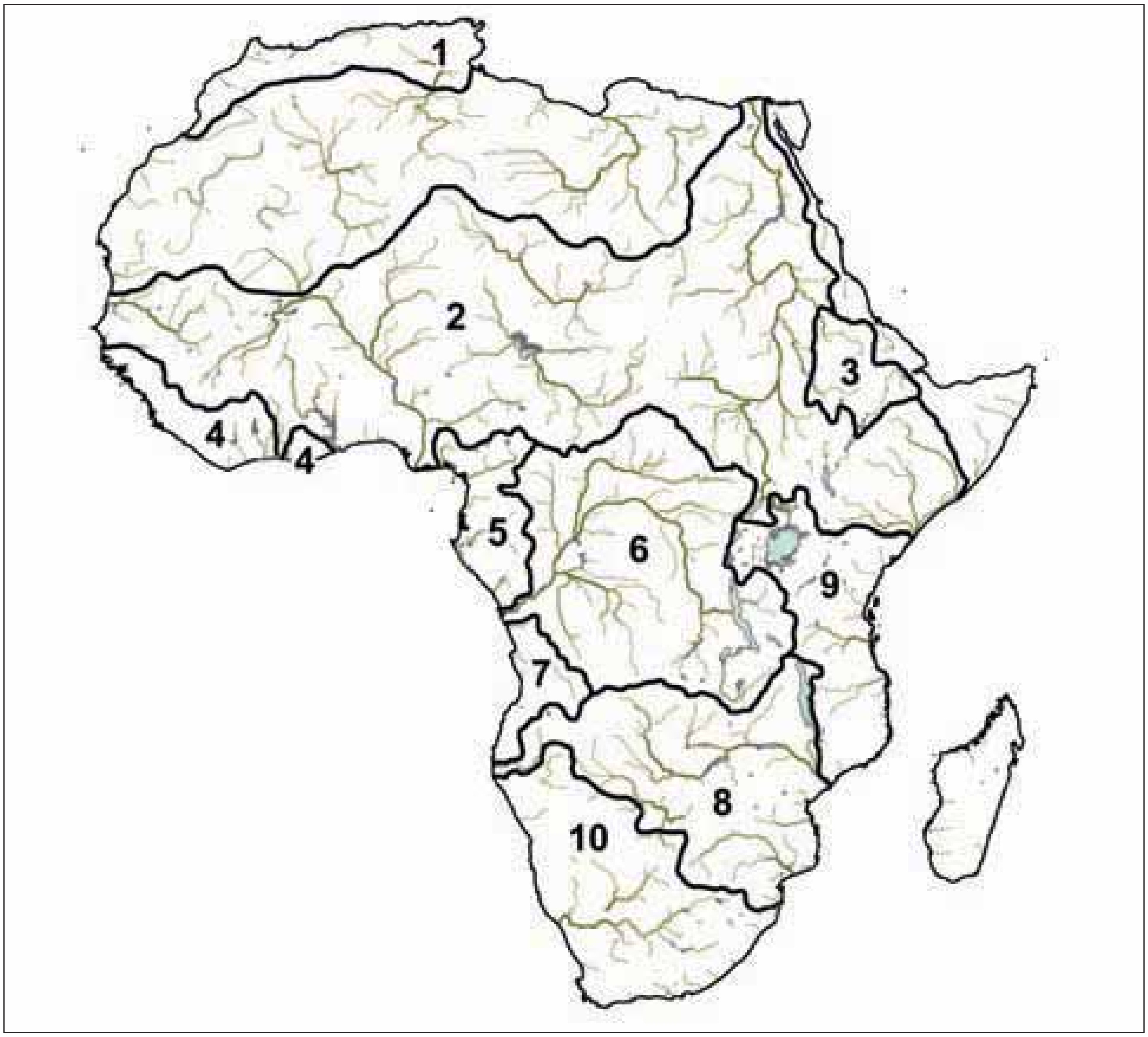
3.1.1 A short introduction to the ichthyofaunal regions

Attempts to subdivide Africa into ichthyofaunal provinces dates back more than a century. However, the basis for a modern synthesis was formulated by Roberts (1975), who based his work on Boulenger (1905); Pellegrin (1911, 1921, 1933); Nichols, (1928); Blanc (1954); Poll (1957, 1974); and Matthes (1964). Roberts (1975) recognised ten ichthyofaunal provinces (Figure 3.1):

- Maghreb
- Abyssinian (Ethiopian) Highlands
- Nilo-Sudan
- Upper Guinea
- Lower Guinea
- Zaire (Congo) (including lakes Kivu and Tanganyika)
- East Coast
- Zambezi
- Quanza
- Southern (including Cape of Good Hope)

The Maghreb province in the north of Africa is quite distinct from other regions of continental Africa. It is relatively poor in species numbers, with dominance of Cyprinidae (Doadrio 1994). In biogeographic terms, this part of the continent has a closer affinity with the Mediterranean part of the Palaearctic realm than with the remaining part of Africa (Balian *et al*. 2008b; Lévêque *et al*. 2008).

Figure 3.1. The major ichthyofaunal provinces of continental Africa, modified from Stiassny *et al.* (2007a). (1) Maghreb, (2) Nilo-Sudan, (3) Abyssinian Highlands, (4) Upper Guinea, (5) Lower Guinea, (6) Congo (Zaire), (7) Quanza, (8) Zambezi, (9) East Coast, (10) Southern (including Cape of Good Hope).



The Nilo-Sudan province is the largest, spanning the total width of the continent from Senegal to Mozambique. It includes two major river systems, the Nile (but excluding lakes Victoria and Edward and their affluents) and the Niger, many West African coastal basins, and the endorheic Lake Chad system. It excludes a region spanning the coastal basins of the so-called Guinean ridge, from Guinea to the western part of Ivory Coast. This is the Upper Guinea province (see below), for which the exact boundaries are not well defined (Lévêque 1997). In a recent review of the fishes of western Africa (Paugy *et al.* 2003a,b), including the Upper Guinea and the Nilo-Sudan provinces, but excluding the Nile system, 584 fresh and brackish water species were listed. A review of the Nile Basin fauna is long overdue, but counts of the River Nile (excluding the region of Lakes Victoria and Edward) include 128 species (Witte *et al*. 2009). However, several additional species that are endemic to Lakes Tana (*Labeobarbus*; see Species in the spotlight– **A unique species flock in Lake Tana – the *Labeobarbus* complex**), Albert and Turkana (haplochromines) should be added to this figure. The existing inventory of the Nile system is far from complete, especially in the poorly documented Sudanese part. In addition, the endemic cichlid fauna of Lake Albert contains many species that are still to be described (Snoeks pers. obs.).

The Cross River forms the border of the Nilo-Sudan and the Lower Guinea province. While the river is considered to be part of the Lower Guinea province, its fauna includes elements of both provinces (Stiassny and Hopkins 2007). The Lower Guinea province included 577 fresh and brackish water species at the time of a recent review of its ichthyofauna (Stiassny *et al.* 2007a,b), more than half of which are endemic. The region spans the area from the Cross River southwards to just north of the Congo Basin. The Shiloango (Chiloango), with its lower reaches in Cabinda (Angola), is regarded as the southernmost large basin of this area. However, some smaller coastal basins with probably a mixed fauna occur in the region between the Shiloango and the Congo.

*A freshly caught specimen of the catfish (*Euchilichthys royauxi*) (LC) that lives in large rapids in the Congo River basin.* © JOHN FRIEL

The Congo Basin has the largest catchment area of any basin in Africa and globally is second only to the Amazon (Revenga and Kura 2003). As currently estimated, its fish fauna includes around 1,250 species. In the east it includes part of the Rift Valley region, including lakes Kivu and Tanganyika and the Malagarasi system. However, in ichthyofaunal terms, Lake Kivu belongs to the East Coast province (Snoeks *et al*. 1997). Lake Tanganyika is a quite distinct and noteworthy section of the Congo Basin. It is the oldest large lake in Africa which is reflected in its distinctive ichthyofauna. More than 95% of its approximately 200 cichlids are endemic to the lake, as are more than 60% of its non-cichlid species (Snoeks 2000; De Vos *et al*. 2001). Its major affluent, the Malagarasi contains an ichthyofauna of mixed origin (De Vos *et al*. 2001). Even when disregarding the Lake Tanganyika endemics, an estimated 75% of the Congo species are endemic.

The Quanza province is relatively small, including most of the coastal basins in Angola, south of the Congo and north of the Cunene. An estimate of the number of species is difficult to give, as this region is one of the least well-known ichthyofaunal provinces in Africa. Poll (1967) listed 109 freshwater fish species from this region, including several endemics.

The Cunene, the Okavango Basin, the large Zambezi system and the Limpopo are the major components of the Zambezi ichthyofaunal province. On the eastern part, the southern border is delimitated by the St. Lucia Basin (Skelton 1994). Geographically, Lake Malawi is also part of this system. However, the lake's basin and the Upper Shire

The confluence of the Inkisi River and the lower section of the Congo River, D. R. Congo. Only the Amazon and perhaps the Mekong have greater fish species richness. © ROBERT SCHELLY

The Chobe River, a major tributary of the Zambezi. The Zambezi ichthyofaunal province is relatively well known and contains many typical sub-Saharan African fish families.

© TRACY FARRELL

harbour a unique fauna dominated by some 800 or more endemic cichlids (Snoeks, 2004), and probably many more undescribed species (see section 3.3.1). The remaining part of the Zambezi province is relatively well known, with species numbers in this region characteristically decreasing from north to south (Skelton 2001).

While the Zambezi province includes many of the typically sub-Saharan African fish families, this is less evidently the case for the southern or Cape ichthyofaunal province, which is relatively depauperate in families but high in species endemism. The border between the Cape and Zambezi provinces is not well defined. The Cape province includes the Orange system and all basins south of it. However, the Orange also includes typical Zambezi elements. Forty-two species occur in the well-known Cape province, 36 of which are endemic (Skelton 2001).

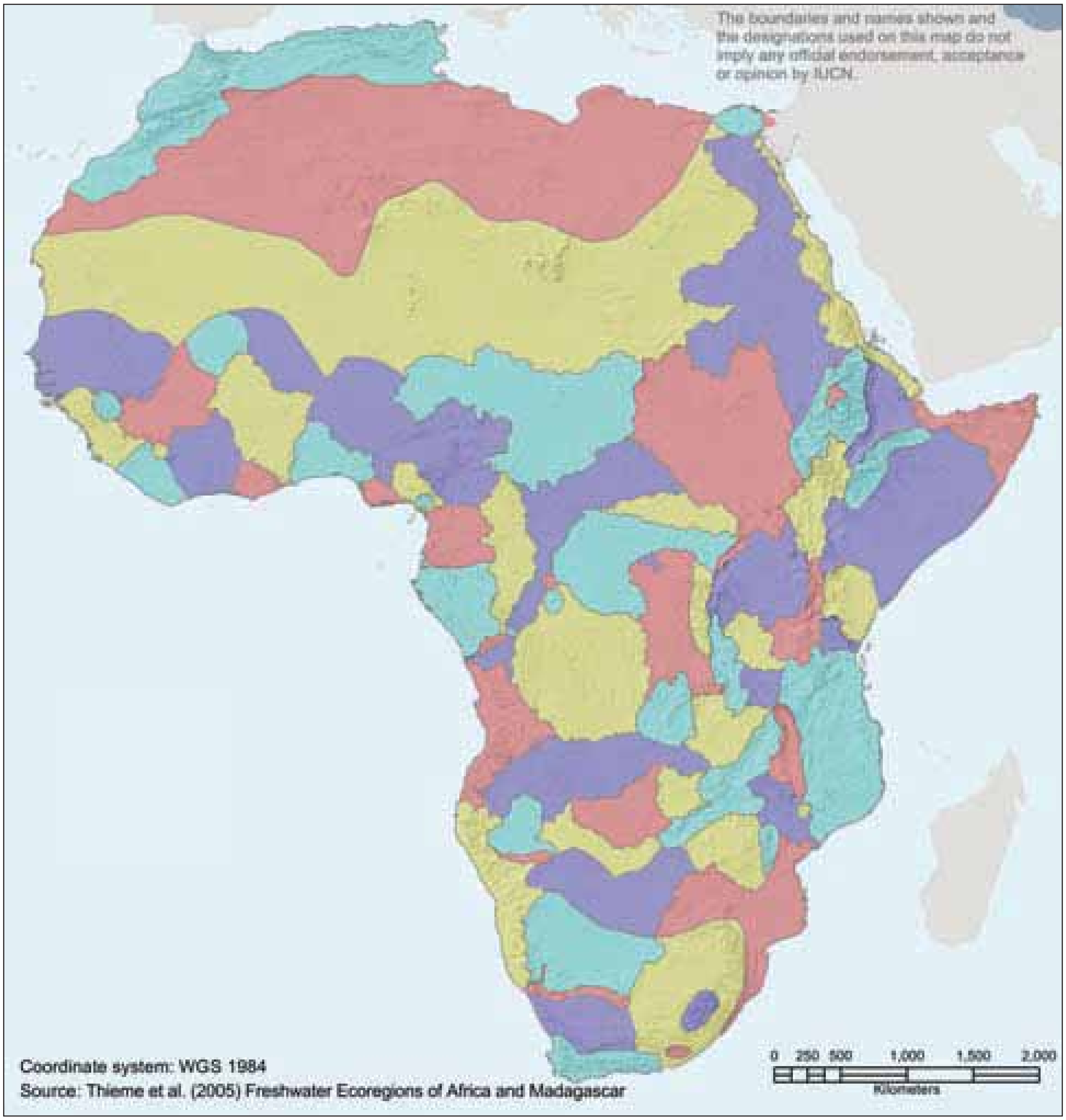
The East Coast ichthyofaunal province is situated to the north of the Zambezi province and is relatively poor in species and dominated by savanna. Skelton (1994) recorded 125 species from the various river systems, with an endemicity of about 60%. These systems include all coastal basins north of the Zambezi to the Tana system in northern Kenya. In this region species richness and endemism may well be underestimated, as many of these rivers are underexplored. The other main component of the province includes a series of lakes of various origins, Rukwa, Kivu, Edward, George, Kyoga, Victoria and its numerous smaller satellite lakes (Snoeks *et al*. 1997). All these lakes, except Rukwa, have elements of a regional super species flock, comprising more than 700 endemic species of haplochromine cichlids, and many undescribed species.

Roberts' (1975) work on ichthyofaunal provinces was continued by Greenwood (1983) and complemented by others (e.g., Skelton 1994; Lévêque 1997; Snoeks *et al*. 1997). While these provinces mostly reflect past and current drainage patterns and are defined mainly

The tigerfish, Hydrocynus vittatus *(LC), a species popular among the sport fishing community. This iconic species is generally common and abundant with a wide distribution across Africa, but is locally depleted by heavy fishing pressure.*

© MELANIE L.J. STIASSNY

Figure 3.2. A map of the freshwater ecoregions of Africa, from Thieme *et al.* (2005)



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

Coordinate system: WGS 1984

Source: Thieme et al. (2005) Freshwater Ecoregions of Africa and Madagascar

on a characteristic combination of endemic taxa, their boundaries are not always straightforward, and transition zones often exist. Thieme *et al*. (2005) developed a slightly different system for defining the biogeographic regions of Africa, based on 'freshwater ecoregions' (See Chapter 1, Figure 1.2).

Thieme *et al*. (2005) recognised 79 freshwater ecoregions on continental Africa (exclusive of Madagascar and offshore islands). Abell *et al*. (2008) subsequently revised this, recognising only 78 ecoregions (incorporating the Thysville caves into the Lower Congo ecoregion and renaming some of the ecoregions) (Figure 3.2). Ecoregions were defined by a combination of physical and biological characteristics, including the hydrological features of the region, the communities of aquatic species present, and associated ecological and evolutionary processes. Consequently, boundaries of ecoregions are not always exactly matched to river catchments; in some cases they may include partial catchments, or may aggregate sub-basins that are components of quite different catchments. While the ecoregion approach provides very useful biological, ecological, and biogeographic information about a region, conservation planning and management for freshwater ecosystems are usually implemented for complete catchments or sub-catchments, rather than partial sub-catchments. For these reasons, the method of describing species distributions by sub-catchments has been adopted by IUCN for the freshwater fishes included in the assessments of the status of freshwater species in Africa (e.g., Darwall *et al*. 2005, 2009; Smith *et al*. 2009; García *et al*. 2010a; Brooks *et al*. 2011).

3.2 Conservation status

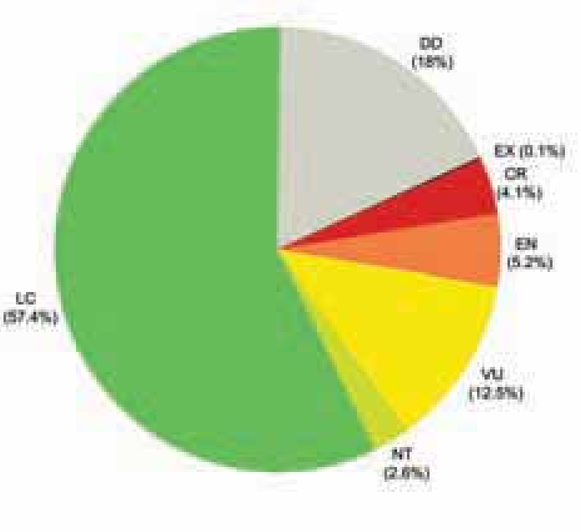
Of the 2,836 African freshwater fish species assessed at the scale of mainland continental Africa (that is, not including the four species ranked as ‘Not Applicable’ (NA)), over half (57.4% are classified as ‘Least Concern’ (see Table 3.1, Figure 3.3). This may be partly explained by the large areas of Africa that are sparsely populated and where there is relatively little agricultural, industrial, or urban development that currently present a severe threat to fishes in other areas (see below). Such undeveloped areas include large parts of the Congo Basin, Lower Guinea, and regions of southern Africa (Stiassny *et al*., 2007a,b; Tweddle *et al*. 2009; Stiassny *et al*., 2011).

Over 500 species (18% of the classified species) are ‘Data Deficient’ (DD), with insufficient information about their taxonomy, ecology or distribution to assess whether they are threatened or not. This underscores the conclusion that a considerable amount of additional surveying and monitoring of African freshwaters is required to provide a more accurate assessment of the conservation status of species in these ecosystems, particularly in parts of central Africa and the Rift Valley lakes of eastern Africa where numbers of Data Deficient species are greatest (see section 3.3.4 below). Nevertheless, even before such surveying and monitoring is implemented, it is possible to say that all existing evidence indicates that many freshwater fishes face significant threats. Six hundred and nineteen species (with an additional 16 sub-species) are classified as threatened – representing 21.8% of all assessed species, or 26.6% of all species if one discounts the Data Deficient species. Most of the threatened species are in the lowest threatened category, classified as ‘Vulnerable’ (57.2% of all threatened species), with another 23.9% of threatened species listed as ‘Endangered,’ and 18.9% as ‘Critically Endangered’. These figures represent large numbers of species (Table 3.1), further highlighting the severity of threats to African freshwater fishes. Three species are reported as ‘Extinct’, although this is probably an underestimate of the true numbers (see section 3.3.5).

Table 3.1. The number of African freshwater fish species in each IUCN Red List Category.

IUCN Red List Category	Number of species	Number of endemic species
Extinct	3	3
Critically Endangered	117	117
Endangered	148	148
Vulnerable	354	353
Near Threatened	75	73
Data Deficient	510	509
Least Concern	1629	1585
Total species	**2836**	**2788**

Figure 3.3. The proportion (%) of freshwater fish species in each regional IUCN Red List Category in mainland continental Africa.



3.3 Patterns of overall species richness

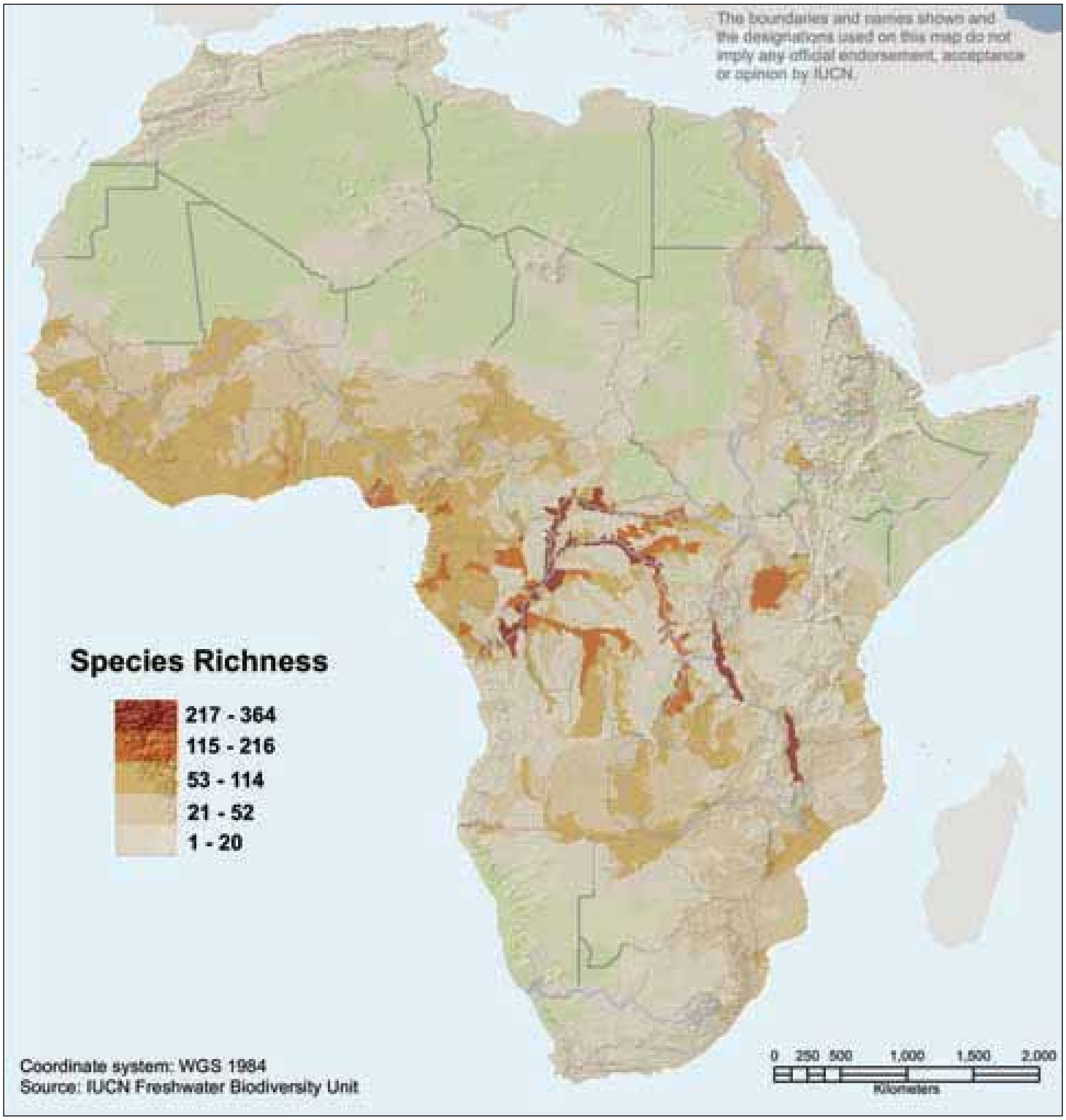
3.3.1 All fish species

Lévêque (1997) undertook a review of the numbers of fresh and brackish water fishes of Africa according to taxonomy (i.e., families, genera, species). Although the numbers will have changed since then, his study provides a useful overview of taxonomic diversity. He recorded 76 families in Africa, with the freshwater fauna dominated by ostariophysans (1,159 species), many of which are typically riverine; however, several families are represented by only a few species. The Cyprinidae (475 species) form the greatest proportion of ostariophysans, and Characiformes are also well represented by the Alestidae (109 species) and Distichodontidae (90 species). The Siluriformes (catfishes) include numerous species of Mochokidae (176 species), Claroteidae (98 species), and Clariidae (74 species).

Among the non-ostariophysan groups, Cichlidae is the most species rich family, with at least 870 species according to Lévêque (1997); most of these are represented by species endemic to the lakes of eastern Africa. Other families with large numbers of species include the former Cyprinodontidae, killifish (at least 243 species are currently classified in Nothobranchiidae and Poeciliidae), and the Mormyridae (elephantfishes), with 198 species.

The geographic distribution of species shows some distinctive areas of high richness as well as areas of very low richness, or even absence of species (Figure 3.4). Not surprisingly, in this study there are no fishes recorded from some of the driest parts of Africa, for example, much of the Sahara, parts of Ethiopia and Somalia, the Kalahari Desert of Botswana, and large parts of Namibia. In contrast, areas

Figure 3.4. The distribution of freshwater fish species across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

of greatest species richness include some of the large lakes of the Rift Valley of eastern Africa (where cichlids dominate the fauna), and the main channel of the Congo River. Of the large lakes, Lake Malawi (in the Zambesi ichthyofaunal province) has the greatest number of species for which assessments have been completed for the IUCN Red List (358 species have been assessed). Lake Malawi and its influents, Lake Malombe and the Upper Shire River that connects the two lakes, comprise the Malawi ecoregion (Thieme *et al*. 2005). This region includes an estimated 800 species of fishes, most of which are endemic (see section 3.3.3). However, many are not yet formally described so are not assessed for the IUCN Red List. The majority of species present are cichlids, mainly represented by mouth-brooding haplochromine species. An estimated 67 of these species (including two introduced species and 10 that are yet to be formally described) are not cichlids (Snoeks 2004). The lake has some economically important cyprinids, including a sardine-like pelagic *Engraulicypris sardella* (usipa) (LC), a salmon-like *Opsaridium microlepis* (mpasa), which is Endangered, and a trout-like *O. microcephalum* (sanjika) (VU) (Thieme *et al*. 2005). Between nine and 12 species of mostly deep-water large catfishes of the genus *Bathyclarias* are endemic to the lake (Snoeks 2004), appearing to have originated from a widespread generalist species, *Clarias gariepinus* (LCRG), that is also present in the lake (Agnese and Teugels 2001). Several of the sub-catchments around the lake are also rich in species, with a total of 54 non-cichlid species found in the affluent rivers (Snoeks 2004).

Haplochromis desfontainii *(EN) is from Algeria and Tunisia, where it is found in warm, freshwater springs. It is a member of the Cichlidae family, the most speciose in Africa.* © ANTON LAMBOJ

The Lake Tanganyika Basin (part of the Congo Basin ichthyofaunal province) harbours an estimated 470 species of fishes, 287 of which had been formally described from the lake itself at the time these numbers were reported by Thieme *et al*. (2005). The lake has high levels of endemism, especially for cichlids (see section 3.3.3). Around 300 of the 470 recorded species (64%) are cichlids, including species-rich lineages of substrate-brooding as well as mouth-brooding cichlids (Coulter 1991; De Vos and Snoeks 1994; Snoeks 2000; Thieme *et al*. 2005). Thieme *et al*. (2005) note that the lake also has species flocks of catfishes (Claroteidae and Mochokidae), snooks (Latidae) and spiny eels (Mastacembelidae). The lake also supports a unique community of pelagic fishes including endemic clupeids (*Limnothrissa miodon* (LC) and *Stolothrissa tanganicae* (LC)) that are prey to several other species and which support an off-shore fishery in the lake (Thieme *et al*. 2005). Affluent drainages at the northern tip of the lake support up to 43 species, while the lower section of the Malagarasi on the eastern shore of the lake holds the highest number of species (71 species have been assessed) for any of the affluents.

Lake Malawi ecoregion includes an estimated 800 species of fishes, most of which are endemic and from the family Cichlidae. © FRANK DOUWES

Mormyrops anguilloides *(LC), a species of elephant fish widespread in Sub-Saharan Africa. It is a member of the Mormyridae family, one of the most species-rich families in Africa.* © JOHN FRIEL

Estimates for the total number of species in Lake Victoria (part of the East Coast province) are variable, although Thieme *et al.* (2005) note there may be more than 600 endemic species. Most of these are cichlids, and several are Critically Endangered or Possibly Extinct (see section 3.3.2 and 3.3.5). Many of the endemic species of cichlids are thought to have gone extinct since the 1980s (Harrison and Stiassny 1999). The sub-catchments adjacent to Lake Victoria hold between 21 and 51 species that have been assessed for the Red List, with the greatest numbers found in the Nzoia drainage to the north-east of the lake.

More than 858 fish species have been assessed for the Congo Basin (i.e., that part of the Congo ichthyological province exclusive of the Rift Valley lakes Tanganyika) (Stiassny *et al*. 2011). This number is certainly an underestimate, and many of these regions are poorly explored or not explored at all; the recorded number is increasing as more species are described each year (Stiassny *et al*. 2011). For example, recent surveys in the lower section of the Congo River downstream of Malebo

The Malebo Pool, one of the most species-rich areas currently known throughout the Congo catchment. © ROBERT SCHELLY

Pool have more than doubled the number of species documented there, including the identification of more than 10 new species in the last five years (Stiassny *et al*. 2011).

The main courses of the major rivers of the Congo Basin have particularly high numbers of species, with more than 150 species reported for most reaches of the Congo River, as well as sections of the Lualaba, Kasai, Ubangi/ Uele, and Sangha rivers. The middle section of the Congo, between Boyoma Falls and Malebo Pool, has the greatest species numbers, with several sections having more than 250 assessed species, while the Malebo Pool region itself has 316 assessed fish species. However, the smaller tributaries distributed throughout the Congo Basin have fewer species; fewer than 30 in many cases, and some sub-catchments had no species recorded in these biodiversity assessments. This apparent distribution of species is likely an artifact of more intensive sampling that has occurred in the larger channels of the Congo Basin compared to the smaller, more inaccessible, tributaries. Recent surveys of small river basins in the lower Congo region such as the Inkisi, Nsele, and Mpozo have, for example, found them to harbour many more species than previously documented (Thieme *et al*. 2008; Wamuini *et al*. 2008; Monsembula pers. comm.; Schliewen pers. comm.), and similar observations are being made throughout other parts of the basin as inventories are undertaken. An excellent case in point is the Léfini River, from which virtually no species were known until recently when, after a thorough exploration of its lower reaches, it was found to harbour 140 species (Ibala-Zamba 2010).

The equatorial location, large size and the relative longevity and climatic stability of the forested, moist tropical regions of central Africa contribute to the high levels of species

This species of freshwater pufferfish, Tetraodon miurus *(LC), captured in the Odzala National Park, D. R. Congo, is quite widespread throughout the Lower Congo River basin.* © JOHN FRIEL

Rapids on the Dja River flowing to the Congo basin. The Dja River headwaters were once captured by rivers of Lower Guinea, possibly the reason why the two regions share some ichthyological fauna. © TIMO MORITZ

Protopterus annectens *(LC), the African lungfish. Lungfish are adapted to survive periods of drought by burrowing to the bottom of mud in drying pools and aestivating there for up to eight months.* © TIMO MORITZ

richness in this area (Kamdem Toham *et al*. 2006; Thieme *et al*. 2008). In addition, the region has a complex mosaic of habitats, contributing to 19 freshwater ecoregions, often with distinct hydrographic barriers between the habitats (for example, waterfalls and rapids); all of these factors appear to promote high species diversification (Thieme *et al.* 2005; Brummett *et al*. 2009; Markert *et al*. 2010; Stiassny *et al.* 2010).

Although the species richness observed in the Congo Basin and the east African Rift Valley lakes exceeds that observed in any other part of Africa, there are several other regions that have a relatively high species richness distributed over large areas. This is particularly noticeable over almost all of the Lower Guinean ichthyological province and large parts of western Africa (covering the western part of the Nilo-Sudan, and the Upper Guinea ichthyological provinces).

The Lower Guinea province is adjacent to the Congo Basin, and the two regions share some fauna, perhaps as a consequence of historic capture of the headwaters of Congo Basin rivers by Lower Guinean rivers (for example, capture of the Dja headwaters by the Nyong, Ntem, Ivindo) (Thys van den Audenaerde 1966; Stiassny *et al*. 2011). More than 550 species have been reported from Lower Guinea (Stiassny *et al*. 2007a,b). The most species-rich drainages are the lower part of the Sanaga (Cameroon), the Ogowe (Gabon), the upper Ngounie (Gabon/Republic of Congo), and the lower Kouilou systems (Republic of Congo), each having over 100 recorded (and assessed) species. Most sub-catchments of the Lower Guinean province have between 50 and 100 assessed species. These include several coastal rivers that are relatively short (i.e., 60km or less) and are disproportionately rich in fish species relative to their small size. Lower Guinea has been a focus for ichthyological survey over the last 20 years. This has promoted extensive taxonomic and revisionary work, including the description of many new species and the production of a guide to the freshwater fish fauna of the region (Stiassny *et al*. 2007a,b).

Similarly, much of western Africa has been well studied, especially over the latter part of the 20th century and early 21st century, with the production of taxonomic revisions and faunal guides (e.g., Paugy *et al.* 2003a,b). It is probably one of the better-known large areas after southern Africa. Western Africa includes 17 freshwater ecoregions, distributed through the western parts of the Nilo-Sudan province and the Upper Guinea province. According to Paugy *et al.* (2003a), there are 584 species of fresh and brackish water fishes distributed through western Africa; 521 of these species (the freshwater component) were assessed for the Red List (Laleye and Entsua-Mensah 2009).

While several river basins in western Africa have relatively high species numbers, the region is less uniformly rich in species than the Lower Guinea province of central Africa. The Niger River, which flows more or less from west to east across a large part of western Africa, and is Africa's third longest river, has a patchy species density pattern. Those parts of western Africa that are richest in species tend to be the coastal basins, moist forests and woodland savanna, whereas those that have fewer species are found in the Sahel, where conditions are drier and rivers are smaller (with the exception of the Niger) or may flow only seasonally. Fishes found in these drier regions often show adaptations to periods of drought. For example, the lungfish, *Protopterus annectens* (LC) is an air breather (and must take lungfuls of air occasionally in order to survive) and can burrow into mud at the bottom of drying pools and survive there, aestivating, usually for up to seven or eight months; this may be extended experimentally to up to four years in *P. aethiopicus* (Helfmann *et al*. 1997). There are also species of killifish (e.g., *Pronothobranchius kiyawensis* (NT)) that have drought resistant eggs (Laleye and Entsua-Mensah 2009).

The turquoise killifish, Nothobranchius furzeri *(LC), from the Bahini National Park in Mozambique. This beautiful killifish is typically found in seasonal pans, which they often share with lungfishes. They lay drought-resistant eggs, and are apparently one of the shortest lived killifishes (four to five months).* © SAIAB/ROGER BILLS

The greatest numbers of species in western Africa are found in the Niger Delta ecoregion (152 species have been assessed). The delta and surrounding areas are also some of the most heavily impacted areas in Africa (see section 3.3.2). To the west, 107 species have been assessed in the Ogun River basin in the region of the Lagos Lagoon, including six threatened species (see section 3.3.2). Several catchments and sub-catchments of western Africa have more than 70 species, particularly those in the Upper Guinea province (covering parts of southern Guinea, Sierra Leone, and Liberia), the Upper Niger and Inner Niger Delta ecoregions (in Guinea and Mali), and some coastal catchments from Ivory Coast to south-western Nigeria. The Volta ecoregion (including Lake Volta) has between 160 and 185 species (Laleye and Entsua-Mensah 2009). According to recent biodiversity assessments, 105 fish species are present in the lake itself; however, this number may be misleading, since it probably includes species found in drainages close to the lake in riverine and marginal habitats. Construction of the Akosombo and Kpong dams has significantly affected the ecology of the region (most noticeably by the formation of Lake Volta) and has contributed to the decline of some species (Thieme *et al*. 2005; and see section 3.3.5).

The northern parts of the Nilo-Sudan province in western Africa, which include the middle reaches of the Niger River, are situated in the Sahel, where species richness is muted (see above). An exception to this is the endorheic Lake Chad (with 69 species) and the region covering the Yedseram and lower Chari river basins (with 72 species recorded), both of which are major affluents of Lake Chad. Many of the species in the region are adapted to patterns of seasonal flooding in the lake and around the lake margins.

Other parts of Africa have lower species numbers compared to western Africa, Lower Guinea, the Congo, and the Rift Valley lakes discussed above. While the Nile River is the longest in the world (Revenga and Kura 2003), fewer than 30 species are recorded and assessed for most of its length. Many affluents of the main channel, in both the Upper and Lower Nile ecoregions, and throughout much of the Ethiopian Highlands province, have fewer than five species recorded. This is probably a reflection of the aridity within much of the Nile's catchment area, where affluents tend to be small, and many flow intermittently and are unable to support large numbers of species. Nevertheless, part of the reason for low recorded species numbers is the limited exploration of large parts of the basin within Sudan (covering some of the Lower Nile and all of the Upper Nile ecoregions), including the vast Sudd swamps in southern Sudan.

There are some exceptions to the low species numbers recorded in the Nile Basin. The greatest numbers of species (where 40 to 50 species have been assessed) are found upstream from Khartoum in the Blue Nile system, and in the wetlands around Gambela National Park (in the westernmost part of Ethiopia) that drain to the White Nile. Forty seven species from Lake Nasser, formed by the Aswan Dam, have been recorded and assessed. Despite this elevated number of species, the overall impact of the dam has been detrimental to the freshwater fish fauna of the Nile system (just as with Lake Volta in western Africa; see above) (see section 3.3.2), with many species apparently extirpated from the former parts of their range below the dam.

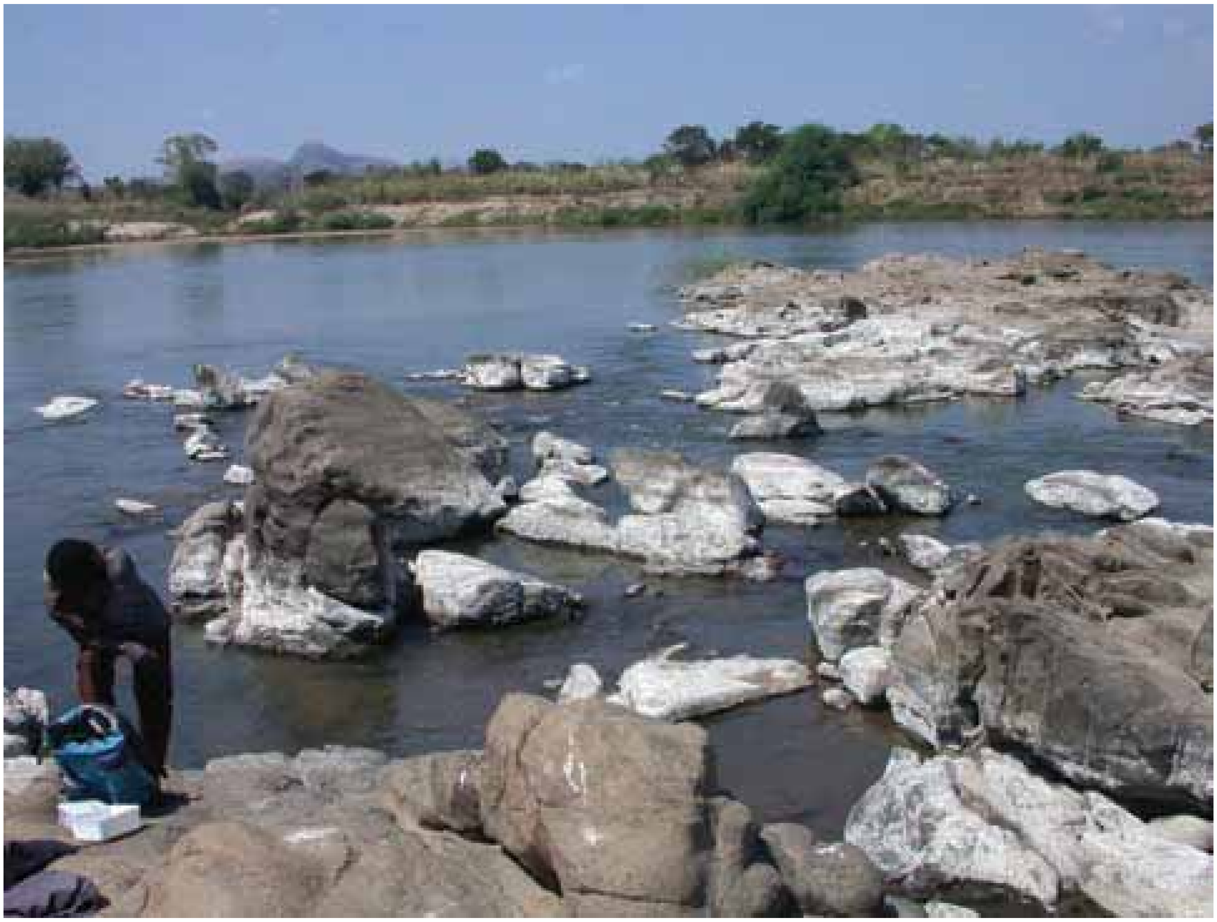
Most of the East Coast province just south of the Ethiopian Highlands, and the eastern part of the Nilo-Sudan province, have low species richness. Lake Victoria and its satellite lakes and affluent rivers (discussed above) are the most noteworthy exceptions to this. Twenty nine species are recorded and assessed for the Tana River basin in Kenya, 39 in the Ruvu and Rufiji river basins in Tanzania, and 25 in the Ruvuma River on the border between Tanzania and Mozambique. Otherwise, most of the east coast basins have fewer than 20 species, providing a striking contrast with the species rich coastal basins of Lower Guinea on the other side of the continent, and probably reflecting a combination of limited survey and the well-documented episodes of aridity experienced by eastern Africa.

Southern Africa encompasses the Quanza, Zambezi, and Cape ichthyofaunal provinces; it includes 22 freshwater ecoregions and some very diverse habitat types. The general pattern is one of declining species richness towards the west and south. For example, most of the sub-catchments of South Africa have fewer than 10 species. Highest species richness is found in parts of the Zambezi basin upstream from Lake Kariba (more than 50 species are recorded in many sub-catchments, and 80 species are present immediately upriver from the lake itself) and in the lowest parts of the basin; in parts of the Okavango basin; some higher parts of the Limpopo basin; the Buzi and Save basins; the Incomati-Pongola system; and some smaller coastal basins in Mozambique. However, some of these densities appear, in part, to reflect the intensity of collection efforts (Tweddle *et al*. 2009).

3.3.2 Threatened species

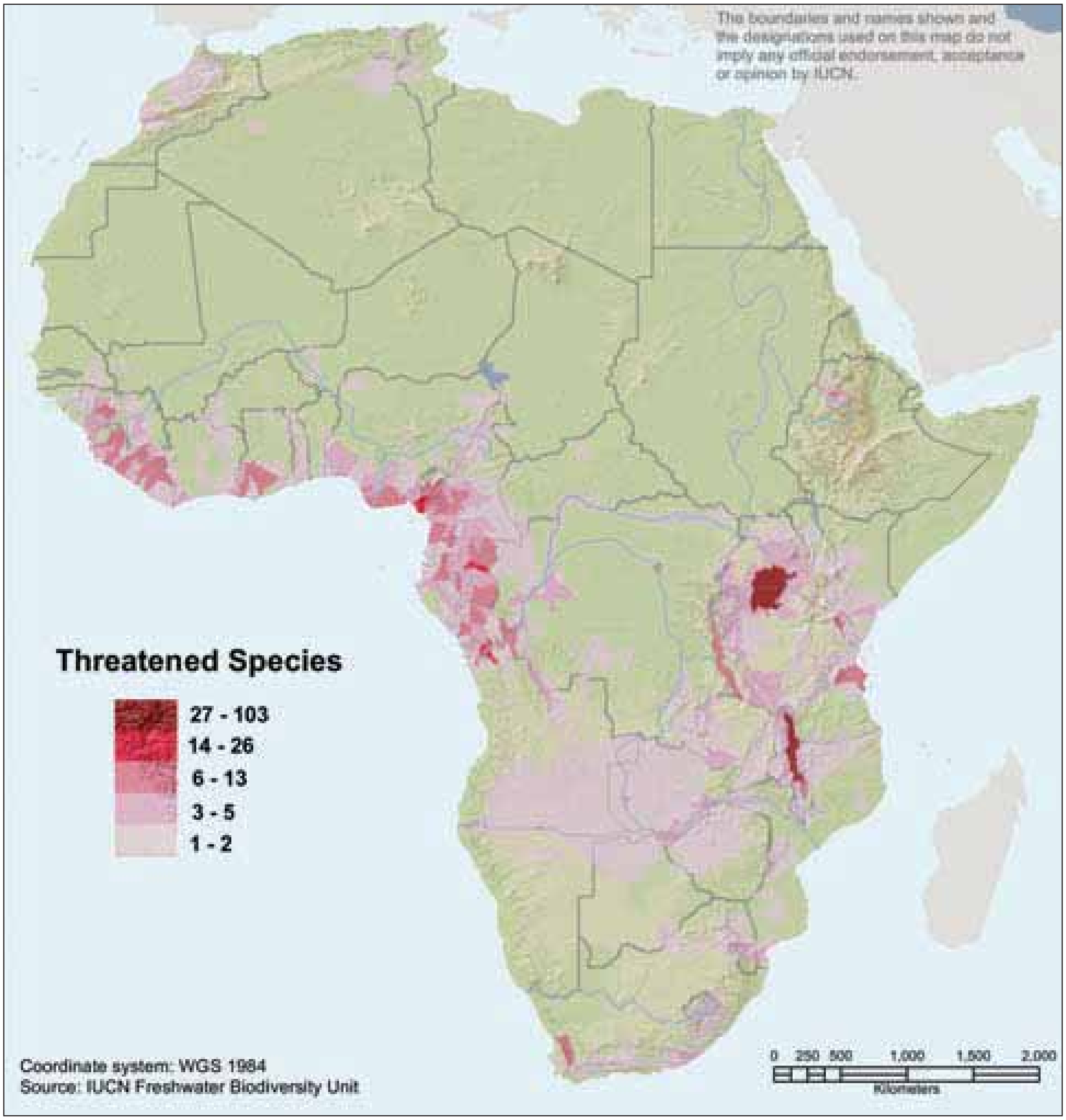
The distribution of threatened freshwater fish species (Figure 3.5) is largely focused in a band that runs along the coast of western Africa and the Lower Guinea province from Senegal to D. R. Congo, throughout the Zambezi/Okavango basins in the northern part of southern Africa, through the river basins and lakes of the Rift Valley of eastern Africa, also including some of the coastal basins of eastern Africa, and some basins in the eastern and southern parts of South Africa. There are a few pockets of threatened species along the Uele River in central Africa, in the region of Lake Tana in north-eastern Africa, and in the Atlantic and Mediterranean Northwest Africa freshwater ecoregions in the Maghreb region of northern Africa

The absence of threatened species throughout most of the arid areas of northern Africa, and parts of the Horn of Africa (comprising Somalia and eastern Ethiopia), as well some parts of southern Africa (especially Namibia and Botswana) is unsurprising; fishes are totally absent from many of these regions (see above). Some other sub-catchments may have only a very small number of species (e.g., fewer than three species) but in these cases



The Lugenda River is located in northern Mozambique, where it flows from Lake Amaramba and forms the largest tributary of the Ruvuma River. The Lugenda River Valley's rich wildlife has led to development of the area as a destination for ecotourism. Within the river itself, species such as Barbus atkinsoni, Labeo cylindricus *and* Oreochromis placidus, *together with around 40 other species of fish, sustain an important local fishery.* © SAIAB/ROGER BILLS

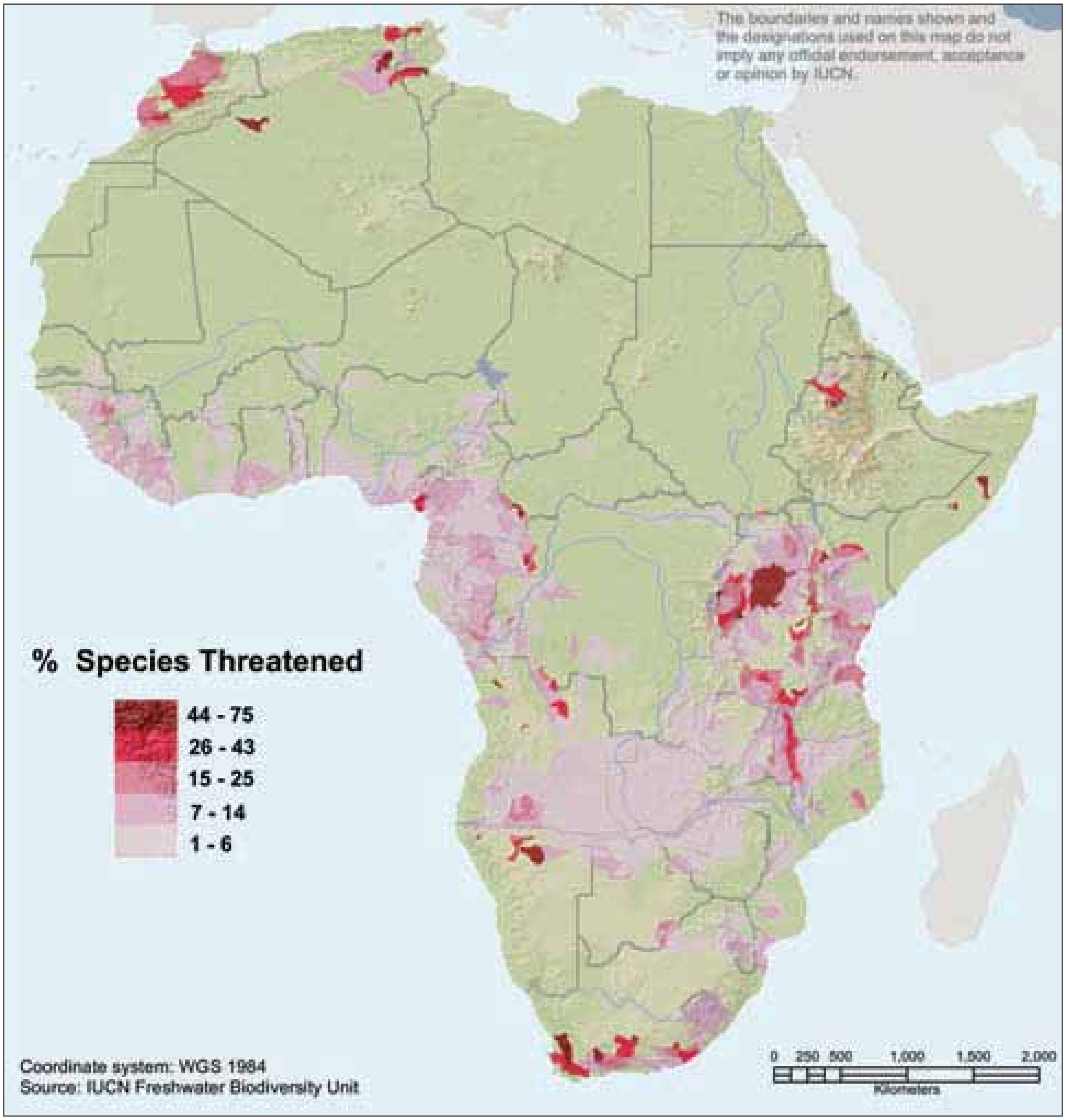
Figure 3.5. The distribution of threatened freshwater fish species across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

Aphanius saourensis *(CR), the Sahara aphanius, is a species of killifish (Cyprinodontidae family) endemic to Algeria. Many killifish species survive periods of drought by having drought-resistant eggs.* © HEIKO KAERST

Figure 3.6. The proportion of freshwater fish species that are threatened within each sub-catchment across mainland continental Africa. Species richness = proportion of species per river/lake sub-catchment that are threatened.



between 44% and 75% of the species are threatened; this is the case for some sub-catchments in the Maghreb and in the Etosha and the Karstveld Sink Holes ecoregions in Namibia (Figure 3.6).

One Critically Endangered species, the Sahara aphanius (*Aphanius saourensi*), is present in the Sahara freshwater ecoregion. This species is endemic to the Oued Saoura Basin, but has disappeared from several parts of the basin and is now restricted to a single population found near Mazzer in the Sahara desert (García *et al*. 2010b). Excessive groundwater extraction for agriculture, pollution of remaining wetlands, and introduction and proliferation of mosquitofish (*Gambusia holbrooki*) are the main reasons for this decline. There are two species of fishes from northern Africa that are considered Endangered. *Haplochromis desfontainii* (EN) and *Pseudophoxinus punicus* (EN), native to Tunisia and Algeria, are threatened by groundwater extraction, dams, water pollution and drought, which widely affect the area (García *et al*. 2010b).

Most of the Nile Basin lacks globally threatened species, with the exception of the upper part of the basin (adjacent to Lake Victoria), and in the vicinity of Lake Tana. High proportions of threatened species (44% to 75% of the species assessed) are found in Lake Victoria and several of the adjoining sub-catchments. Between 26% and 43% of assessed species are threatened in the region of Lake

A Lake Malawi cichlid from the group of rock-dwelling species collectively known as 'mbuna'. These species are endemic to the lake, and many have extremely restricted ranges. © SARAH DEPPER

Tana, with seven threatened species in Lake Tana itself (see **Species in the spotlight– A unique species flock in Lake Tana – the *Labeobarbus* complex**). Although globally threatened species are not recorded throughout the rest of the Nile Basin, it is important to note that several species in the basin have undergone serious declines in the northern African parts of their range. García *et al.* (2010b) note that at least 80% of the 24 northern African freshwater fishes listed as Regionally Extinct (to northern Africa) were previously found in the Nile Basin in Egypt, and the construction of the Aswan Dam was a major cause of these extirpations.

The low numbers of threatened species recorded for much of central Africa, including the species rich Congo Basin, may be partly attributed to the lack of human development in many parts of this region. However, several parts of central Africa are also insufficiently surveyed to accurately assess threats to species found there (see section 3.3.4 on Data Deficient species). Moreover, in some tributaries of the Sangha River, and tributaries of the Kwango River draining to the Kasai, the ratio of threatened species to the total species richness is still relatively high (26% or more).

The highest number of threatened species occurs in Lake Malawi, where there are 105 recorded threatened species (28% of the total species assessed for this lake). A number of these assessments are, however, based on the ecological characteristics of many cichlid species, such as their highly restricted ranges and low numbers of offspring, which make them particularly vulnerable to extinction. Given the more recent requirement to also document evidence of current or imminent threats to a species for it to be assessed as threatened, it is possible some may be downgraded to a lower Red List category when next re-assessed. The rock-dwelling cichlids, often called mbuna, have particularly restricted distributions (intra-lacustrine endemism). These cichlids grow slowly and produce small numbers of offspring, are extremely vulnerable to habitat degradation and exploitation, and recover slowly from population declines (Ribbink 2001; Thieme *et al*. 2005). The potamodromous species that migrate from the lake into affluent rivers to spawn are also threatened by fisheries operations at the river mouths where they congregate during migration, and by degraded spawning habitats within the rivers (Tweddle 1996).

Lake Victoria has the next highest number of threatened species (81 species; 44% of the assessed species in the lake), resulting from a combination of well-documented threats, including: the introduction of the piscivorous predator, Nile perch (*Lates niloticus*), and the water hyacinth (*Eichornia crassipes*) which has reduced light and oxygen levels in the lake's waters; overfishing and use of fish poisons; and habitat deterioration and eutrophication resulting from increasing lakeside agriculture, urbanisation, and deforestation (for further discussion and extensive references see Harrison and Stiassny 1999; Kaufman 1992; Witte *et al*. 1992a,b; Kaufman and Ochumba 1993; Seehausen and Witte 1995; Oijen and Witte 1996; Seehausen 1996; Seehausen *et al*. 1997a,b; Kaufman *et al*. 1997; Witte et al., 2007) (also see Chapter 1, Box 1). Witte *et al* (1992b) initially estimated that as many as 200 species of haplochromine cichlid in Lake Victoria had disappeared or were threatened with extinction within the lake. Harrison and Stiassny (1999) recognised that the lake was undergoing catastrophic ecological and limnological changes that represent a serious threat to the endemic cichlids; nevertheless, they believed it was premature to suggest that many of these species were actually extinct, because Witte *et al* (1992b) were using data limited to an 11-year period for a small part of the lake (Mwanza Gulf), which could not be extrapolated to the whole lake and used as a measure of extinction. Harrison and Stiassny (1999: table 9) listed 48 species of cichlids from Lake Victoria that might be extinct but could not be confirmed as such because of complications in their taxonomy (in most cases, the species had not been scientifically described). They listed another 54 species (Harrison and Stiassny 1999: table 10) that might be extinct but could not be confirmed as such because of inadequate surveying and sampling, and 30 species (Harrison and Stiassny 1999: table 11), which could not be classified as probably or possibly extinct, due to a lack of data. Harrison and Stiassny's caution in classifying the Lake Victoria cichlids as extinct has been supported by evidence of a resurgence in several of the species, with greater resurgence of zooplanktivores compared to detritivores (Witte *et al*. 2007). Even with this resurgence, the threats to many of the species in Lake Victoria are still quite evident, and it is pragmatic to record them in categories of high threat (52 species are Critically Endangered, and many of these are also noted in IUCN's database as Possibly Extinct). Nevertheless, many fish species in the lake remain Data Deficient (see section 3.3.4), and more extensive surveying and sampling are required throughout Lake Victoria to fully assess the conservation status of the cichlid species present. Because Lake Victoria is Africa's largest lake by area, this represents a significant challenge. Moreover, there would be the requirement for a larger number of highly trained taxonomists than currently exist in Africa, or elsewhere, to identify the 600 or more of species amongst the many thousands of specimens that would be collected. In light of this taxonomic impediment, an ecological classification of Lake Victoria's cichlids into trophic guilds may offer a pragmatic, short-term solution (Witte *et al*. 2007).

There are 12 threatened species in Lake Tanganyika (5% of the total number of 245 species recorded in the Red List assessments). The overall number of threatened species is lower than in Lake Malawi partly because there are fewer species present in Lake Tanganyika; the proportion of threatened species (relative to the total number) is lower compared to Lakes Victoria and Malawi because the threats are generally more localized (Cohen *et al*. 1995) (especially compared to Lake Victoria); and the Tanganyikan species tend to have a wider distribution, extending into areas where there are fewer threats.

Outside the area of the large lakes of the African Rift Valley, the regions with high numbers of threatened species occur in and around the rapids in the Lower Congo and some coastal basins in western Africa and Lower Guinea. The Lower Congo has up to 24 threatened species just upstream of Inga, and has one Critically Endangered species of cichlid, *Teleogramma brichardi*, apparently restricted to the Kinsuka rapids near Kinshasa. This species is increasingly threatened by the impacts of urbanization at Kinshasa and Brazzaville (Stiassny *et al*. 2011). However, further collections are necessary to establish the precise distribution of this species. Several other Endangered species are found, especially in the vicinity of Malebo Pool.

At least 13 threatened species are found in the delta region of the Niger River, including two Critically Endangered species that are threatened by the impacts oil exploration in the delta, the distichodontid *Neolebias powelli* and the killifish *Fundulopanchax powelli*. Six threatened species are recorded nearby, in the species rich lower Ogun River at Lagos lagoon. These species are threatened mainly by deforestation (e.g., *Brycinus brevis*, assessed as Vulnerable), as well as agricultural and urban development (e.g., the mormyrid *Marcusenius brucii*, assessed as Vulnerable); however, the small red-eyed tetra, an alestid, *Arnoldichthys spilopterus* (assessed as Vulnerable) is threatened by an extensive harvesting for the aquarium fish trade. Just north of the Niger Delta, in a tributary of the Benue River on the Bauchi plateau, the cyprinid *Garra trewavasae* is Critically Endangered due to the impacts of tin mining.


Teleogramma brichardi *(CR), from Kinsuka rapids near Kinshasa, D. R. Congo.* © MELANIE L.J. STIASSNY

At least 10 threatened species are found in the coastal drainages of Sierra Leone and Liberia; these include some Critically Endangered species (e.g., *Labeo currie, Barbus carcharinoides, Epiplatys ruhkopfi, Tilapia cessiana and T. coffea*), and several Endangered species, especially in the vicinity of the St. Paul and Lofa rivers. These species are threatened by habitat degradation caused by deforestation and mining. In the Konkouré River in Guinea, the catfish *Synodontis dekimpei* is Critically Endangered for the same reasons. In the Fouta-Djalon ecoregion of Guinea, the killifish *Scriptaphyosemion cauveti*, a Critically Endangered species from a tributary to the Kolenté River, is threatened by expansion of the nearby city of Kindia.

Twenty six threatened species are recorded from the Western Equatorial Crater Lakes freshwater ecoregion and the river drainages nearby, at the border of south-west Cameroon and Nigeria (see Species in the spotlight – **Cauldrons for fish biodiversity: western Africa's crater lakes**). Many of these species are Endangered or Critically Endangered, and the majority are cichlids endemic to crater lakes, although there are also several killifishes,


Neolebias powelli *(CR), a small riverine pelagic distichodontid characiform, is endemic to a very localised part of the Lower Niger Delta, where it is threatened by oil exploration within the delta.* © TIMO MORITIZ

Denticeps clupeoides *(VU), from the Iguidi River, south-east Benin (see Species in the Spotlight: Forest remnants in western Africa – vanishing islands of sylvan fishes).*
© TIMO MORITZ

and some cyprinids and catfishes. Within Lower Guinea, high numbers of threatened species (12 to 14 species) are found in sections of the Ivindo, Bouniandjé and Nouna (a tributary to the upper Ivindo) systems.

In eastern and southern Africa, the number of threatened species is low for most basins (excluding the Rift Valley lakes). The greatest numbers in eastern Africa are found in the small Ruvu River, a coastal basin near Dar es Salaam that harbours nine threatened species. Although other basins in eastern Africa have fewer numbers of threatened species, some include one or more Critically Endangered species, which in most cases are are cichlids. For example, *Oreochromis pangani*, is a Critically Endangered species from the Pangani basin, which has been impacted by several different threats. Outbreaks of disease reduced the population in the late 1960s; subsequently, overfishing and fishing with illegal gear, as well as siltation and pollution, have continued to threaten populations. The clearance of macrophytes also removed important refuges and feeding areas for the fish. *Orthochromis uvinzae* is restricted to the middle Malagarasi River drainage to Lake Tanganyika, in Tanzania, and is impacted by habitat loss. *Oreochromis chungruensis* is endemic to Lake Chungruru, a crater lake north of Lake Malawi, and is impacted by siltation and dropping water level.

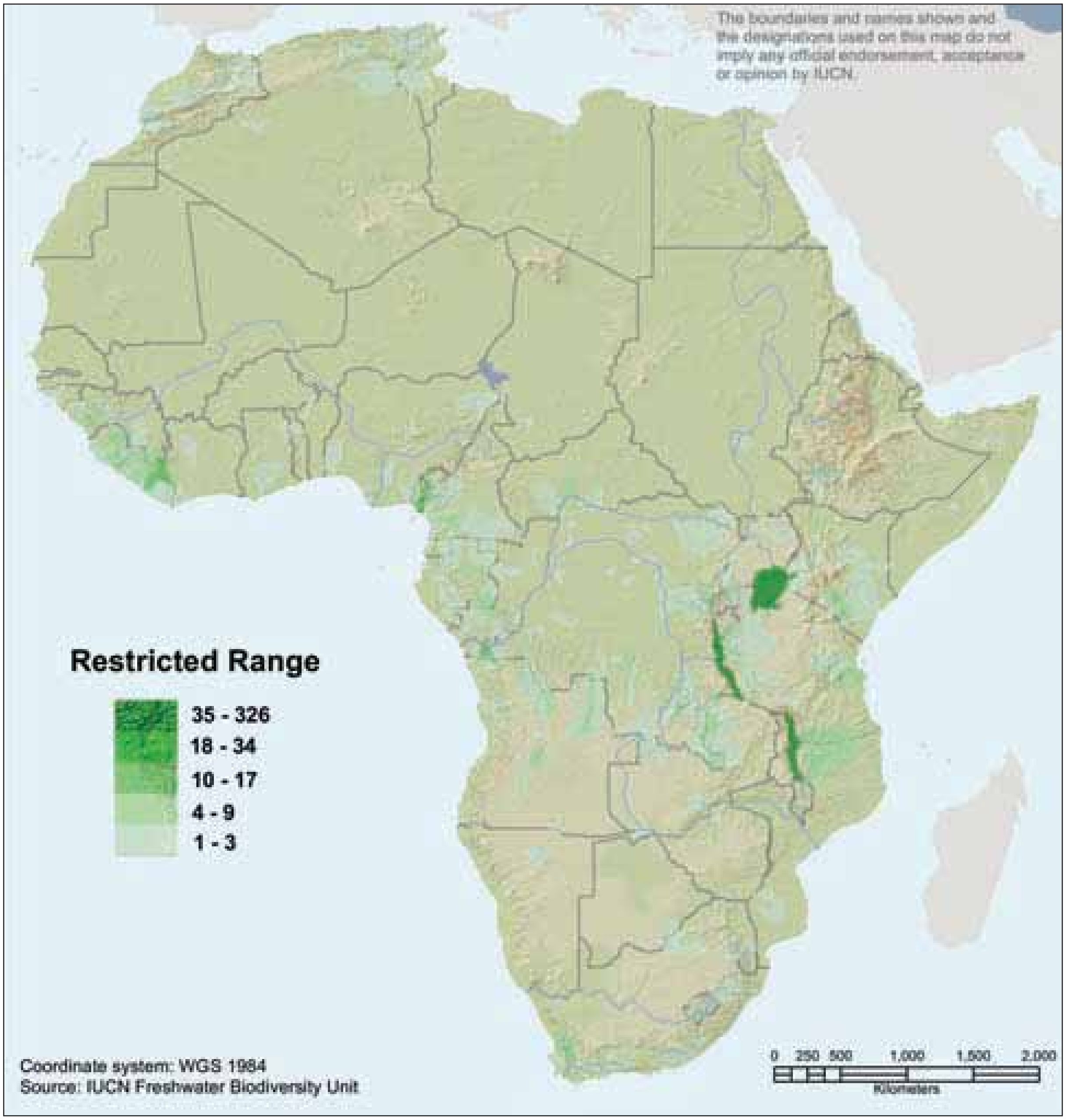
In southern Africa, the Olifants River in the south-west part of South Africa has the greatest numbers of threatened species, with seven species (70% to 75% of all assessed species in the Olifants basin), including two Critically Endangered species, *Barbus erubescens* (see Species in the spotlight– **The Twee River redfin – a Critically Endangered minnow from South Africa**) and an undescribed species of *Pseudobarbus*. Both are threatened by competition with, and predation by, introduced species, as well as deterioration in habitat and water abstraction caused by intensive farming. Slightly to the south, in the Tradou catchment of the Breede River system, *Pseudobarbus burchelli* is similarly Critically Endangered due to introduced species and pollution. A number of other species are also assessed as Endangered in the southern part of South Africa and in Lesotho (e.g., *Pseudobarbus asper* and the Maloti minnow, *Pseudobarbus quathlambae*), where they face similar threats to the above-mentioned species. Tweddle *et al*. (2009) gives a short account of the Maloti minnow conservation project. South Africa and Mozambique also harbour some undescribed but Critically Endangered species of *Pseudobarbus*, *Kneria* and *Barbus*. Two Critically Endangered species are found in the Karstveld Sinkholes ecoregion of central Namibia: one is *Tilapia guinasana*, which occurs naturally only in Lake Guinas. where it is threatened by groundwater extraction, as well as competition and predation from, as well as possible hybridization with, introduced tilapiines; and the other is the cave catfish, *Clarias cavernicola*, known only from a single tiny lake (18m by 2.5m) in the Aigamas Cave, near the town of Otavi, which is threatened by over abstraction of water and might also be impacted by collections made for the aquarist trade.

There are three Critically Endangered species in the Zambezi River basin. An undescribed species of *Barbus* (*Barbus* sp. nov. Banhine) is known from four neighbouring sites at the south-eastern edge of the Banhine National Park in Mozambique, in the Zambezian Lowveld freshwater ecoregion. In the upper Zambezi floodplain ecoregion, *Neolebias lozii* is restricted to the Sianda River that has been canalised, probably to aid drainage for agriculture. Unlike most other Critically Endangered species with restricted distributions, the cichlid *Oreochromis mortimeri* is widely distributed in the Middle Zambezi-Luangwa ecoregion and parts of the Zambezian Highveld ecoregion. This species is threatened mainly by the widespread introduction of *O. niloticus*, which is displacing it throughout much of its range.

3.3.3 Restricted Range species

Restricted range species (identified as those species with distribution ranges of less than 50,000km^2) are found in several African sub-catchments, but mainly in Upper and Lower Guinea, and some parts of the Congo Basin, and in eastern and southern Africa (particularly in the Cape Province of South Africa) (Figure 3.7). Most sub-catchments have only one to three restricted range species recorded (although this is likely to be an underestimate in some areas; see below). The largest of the Rift Valley lakes have many more restricted range species than are found in any other part of the continent. The high numbers of restricted range species found in the Rift Valley lakes are largely due to the endemic species-rich flocks of cichlids found in these lakes. For example, 99% of cichlid species in Lake Malawi are endemic, and more than 95% of the Lake Tanganyika cichlids are endemic (Snoeks 2000). Lake Kivu, to the north of Lake Tanganyika, harbours 15 restricted range species, while the Western Equatorial Crater Lakes ecoregion in Cameroon harbours 12. The restricted range

Figure 3.7. The distribution of restricted range freshwater fish species across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

species in the crater lakes are also mainly cichlids. Many of those lakes with restricted range species, which also hold Critically Endangered and Endangered species, are potential candidates for designation as Key Biodiversity Areas, or possibly Alliance for Zero Extinction sites (see chapter 8, section 8.3).

Lake Turkana, to the north-east of Lake Victoria, has nine restricted range species. Unlike the other large lakes of the Rift Valley, the fish fauna of Lake Turkana is composed mainly of nilotic riverine species rather than cichlids. Lake Tana in Ethiopia has eight restricted range species, mostly represented by the species flock of endemic cyprinids of the genus *Labeobarbus* (see Species in the spotlight – **A unique species flock in Lake Tana – the *Labeobarbus* complex**).

Lake Tanganyika contains many restricted range cichlid species, 95% of which are endemic to the lake. © JOHN FRIEL

A selection of the rocky shore cichlid species endemic to Lake Tanganyika. © SASKIA MARIJNISSEN

A number of rivers also have notably higher numbers of restricted range species. In the Upper Guinea province, the relatively small coastal basins of the Lofa, St. Paul, St. John, and Cess rivers have between five and 12 restricted range species, the greatest number being in the Cess. Up to 17 restricted range species are found in the vicinity of Inga, in the lower part of the Lower Congo Rapids ecoregion. These species, some of which are assessed as Endangered, most likely show restricted ranges because they are adapted to the fast currents, low light intensity, and high turbidity of the rapids. They are also likely to be impacted by development of the hydropower dam complex at Inga (see section 3.3.2). The current state of knowledge of the taxonomy and biogeography of species in the Lower Congo is incomplete, but recent research has identified many more species than were previously known (Lowenstein *et al*. 2011; Stiassny *et al*. 2011). It is probable that more restricted range species will be found in the Lower Congo rapids region as surveys there continue.

The largemouth yellowfish, Labeobarbus kimberleyensis *(NT), is endemic to the Orange River system in South Africa, where it is reasonably common, especially in large deeper pools in the middle and lower Vaal and Orange rivers, respectively. It is promoted as a flagship angling species, with most anglers practising catch and release.* © SAIAB/ROGER BILLS

The Upper Congo rapids ecoregion also has marginally higher numbers of restricted range species (seven species) compared to surrounding areas, probably for the same reason as for the Lower Congo rapids (see above). Other parts of the Congo Basin with high numbers of restricted range species include the Ubangi River in the region of Bangui (six species), the Lubi basin draining to the Sankuru (seven species), the upper part of the Lowa Basin near Lake Kivu, and in several parts of the Lufira, Luvira, and Luapula basins in the Upper Lualaba and Bangweulu-Mweru ecoregions (all with five restricted range species). In the Lower Guinea province, the greatest numbers of restricted range species (five to eight species) are found in the Ivindo and upper parts of the Ogowe, and in the lower Sanaga River.

The rivers of eastern and southern Africa have fewer restricted range species, possibly a consequence of the generally lower numbers of species found there. The sub-catchments with the greatest numbers of restricted range species are: the upper part of the Tana River, near

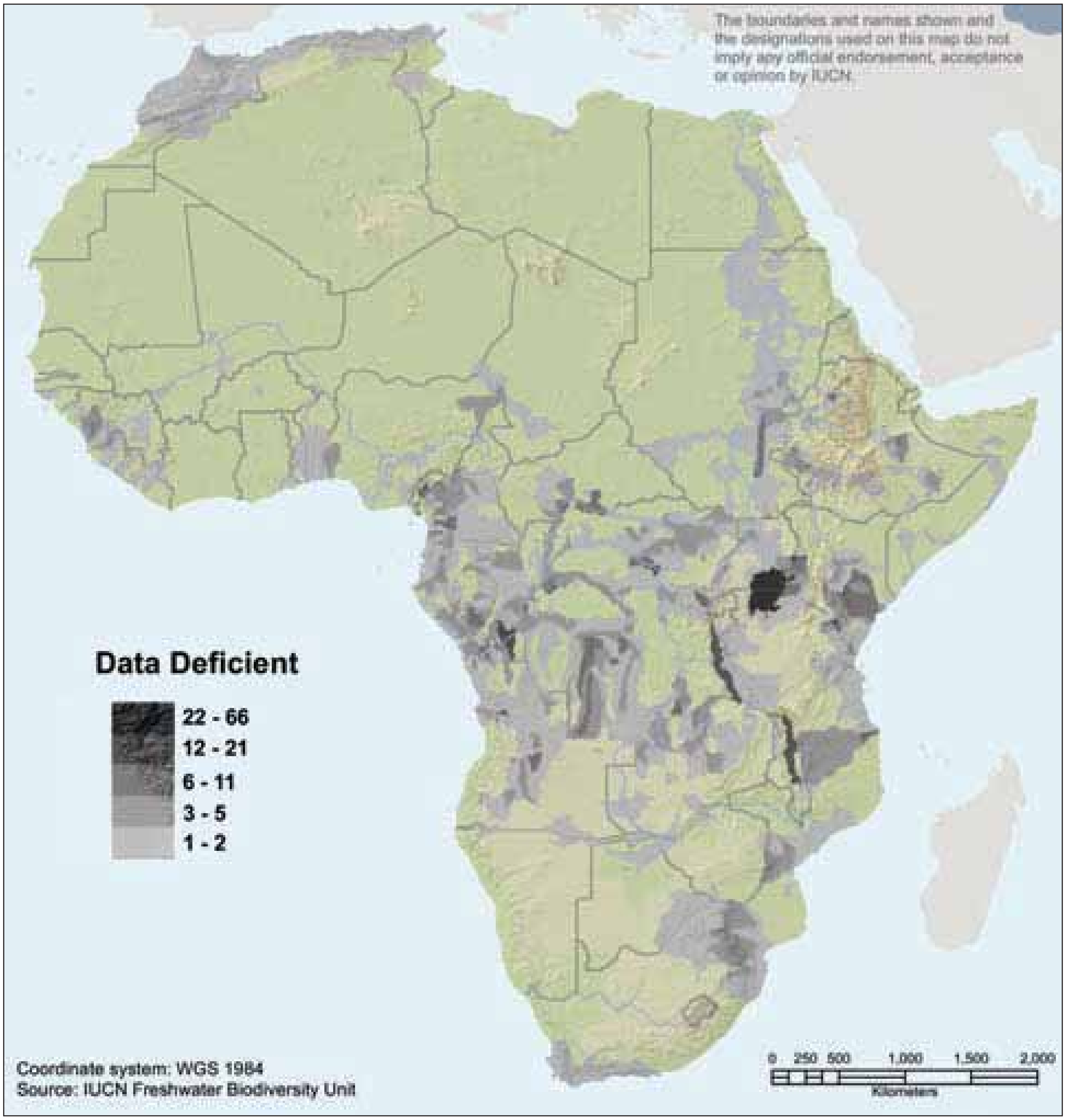
Nairobi (five restricted range species); the Ruvu River near Dar es Salaam (eight restricted range species); and the lower part of the Malagarasi River near its outflow into Lake Tanganyika (seven restricted range species). The only catchment in southern Africa with moderately high numbers of restricted range species is the Olifant River in the Western Cape that holds five restricted range species, representing around 75% of the total number of species recorded in the catchment.

The Lower Congo rapids, home to many restricted specialist species. © ROBERT SCHELLY

3.3.4 Data Deficient species

Species assessed as Data Deficient (DD) (Figure 3.8) are those for which the taxonomy remains uncertain, or for which there is insufficient information to make a reliable

Figure 3.8. The distribution of Data Deficient freshwater fish species across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

assessment of how they are impacted by threats to the freshwaters in their sub-catchment. The most common reason for this is the absence of reliable information about the total distribution of the species. Many species are known from only one or a few specimens from a single collection. Stiassny (1999) took a random selection of catfishes and mormyrids included in the Check List of Freshwater Fishes of Africa (CLOFFA, Daget *et al*. 1984, 1986, 1991), and found that, for the different genera and families selected, 25% to 80% were known only from the type series or the type locality from where the species was first described. Some species may be so poorly represented by collected specimens that their taxonomy is unresolved. There are many species of *Barbus*, for example, where taxonomic complexity precludes assigning the conservation status as anything but Data Deficient. *Barbus eutaenia* is a good case in point. As currently defined, *B. eutaenia* is widespread across much of southern and central Africa, but it probably represents a complex of species that have yet to be diagnosed and described (Tweddle *et al*. 2004). This is true for numerous other poorly diagnosed, putatively 'widespread' species that, on closer taxonomic scrutiny and with broad geographic sampling, will likely be revealed to represent species complexes.

A persistent problem presented by older, historical collections is that they frequently contain ambiguous locality information, such that the presence or absence of a species in a particular river system cannot be determined with certainty. In such cases it may be impossible to reliably map the distribution of these species. Even allowing for this underrepresentation, the map showing distribution of Data Deficient fish species clearly indicates that data deficiency is a significant problem for assessments of African freshwater fishes.

The greatest numbers of Data Deficient species are found in the Rift Valley lakes of eastern Africa. Lake Victoria has the highest proportion of Data Deficient species for any of these lakes, with around 35% of the assessed species being classified as Data Deficient. The high numbers of Data Deficient species found in these lakes results from a combination of factors. The lakes are rich in overall species numbers (see section 3.3.1), extensive areas have not been well surveyed, and data on the complete distribution and ecology of many of these species is still lacking. Another important factor is that the taxonomy of the endemic lake cichlids is notoriously difficult, and many taxonomic problems abound.

Five or more Data Deficient species are found in several parts of the Congo Basin, with higher numbers particularly around Malebo Pool and sub-catchments immediately downstream in the Lower Congo (13 to19 Data Deficient species), the Upper Congo rapids ecoregion (15 Data Deficient species), and the Ubangi River adjacent to the town of Bangui (11 Data Deficient species). The high numbers of Data Deficient species recorded from the Congo Basin tend to be in areas that have been relatively well explored. As with the Rift Valley lakes of eastern Africa, relatively large numbers of species have been collected from these regions, but data on their full ranges and ecology may be lacking. This is also true, to a lesser extent, for the Nile system, where Lake Tana and some parts of the Blue and the White Nile system in Sudan contain more than five Data Deficient species.

Data Deficient species are found in sub-catchments through most of the Lower Guinea ichthyofaunal province of western central Africa, and in several sub-catchments of western Africa, but rarely in large numbers. There are a few exceptions, however. In the Northern Gulf of Guinea drainages freshwater ecoregion, at the border of the Nilo-Sudan and Lower Guinea ichthyolofaunal provinces, the headwaters of the Cross in Cameroon contain nine Data Deficient species. This region is biogeographically interesting, since it includes a mix of species from the two ichthyofaunal provinces (Reid 1989), and there is evidently a need to learn more about the distribution and ecology of many of these species. For example, Teugels *et al*. (1992) found that the number of species in the Cross River had previously been underestimated by as much as 73%. This was a particular surprise because, prior to this, the Cross River was thought to be one of the better-surveyed rivers of western central Africa. Other parts of the Lower Guinea province that are noteworthy for Data Deficient species are the middle reaches of the Nyong River (six Data Deficient species) and the Kribi River (five Data Deficient species) in Cameroon, the lower reaches of the Ivindo River (five Data Deficient species) in Gabon, and a large part of the Niari-Kouilou system (five Data Deficient species) in the Republic of Congo (Brazzaville). In western Africa, the middle part of the Konkouré Basin in Guinea and most of the Rokel Basin in Sierra Leone each have five Data Deficient species.

Data Deficient species are also found in several sub-catchments of the Quanza and Zambezian Headwaters freshwater ecoregions. But, as with western Africa and Lower Guinea, the numbers of Data Deficient species are usually low – the exceptions being a couple of sub-catchments with five Data Deficient species, and one tributary to the middle section of the Quanza that has 10 Data Deficient species. The entire Quanza ecoregion (which roughly corresponds with the Quanza ichthyofaunal province described by Roberts (1975)) is one of the least explored and poorly known areas in Africa.

In the East Coast province there is a small concentration of Data Deficient species in the headwaters of the Pangani Basin at the border between Tanzania and Kenya (seven species), and in the Galana basin (in Kenya). However, the Tana system in Kenya covers a larger area and has more Data Deficient species (five to nine, with up to 32% of the

Rivers in northern Africa typically have a hydrological regime that is unpredictable and which may experience periods of intense flooding. Such conditions present a considerable challenge to the freshwater species that live in these habitats. The region is home to an endemic group of 'Maghreb barbs', which are increasingly threatened by loss of habitat. © JEAN-PIERRE BOUDOT

assessed species being Data Deficient in some parts of the basin). This illustrates that, although most rivers of the East Coast province are characterized by relatively low species numbers, considerably more research is required for several of these species.

The catchments in the Atlantic Northwest and Mediterranean Northwest freshwater ecoregions have consistently low numbers of Data Deficient species; however, in all these catchments, the Data Deficient species represent 25% or more of the species present (and in some cases up to 100%). Similar patterns are seen in the Horn of Africa, and in the south-western Cape of Africa, where there are numerous sub-catchments with only one or two Data Deficient species, but these represent the majority of the assessed species in those catchments. There are also areas where there is a complete lack of data for any fish species. A lack of species is unsurprising in the Sahara, and several other arid areas such as the Kalahari and Namib ecoregions in southern Africa, and the Shebelle-Juba ecoregion in eastern Africa (as discussed in section 3.3.1). However, there are also sub-catchments in parts of the Congo main basin that have no assessed species (Stiassny *et al*. 2011), and some of these catchments are in undisturbed parts of the Congo forest where one would reasonably expect to find large numbers of fish species. A similar situation exists for the Sudd wetland in southern Sudan. Lack of data in these cases is undoubtedly due a lack of surveys in these regions, indicating an urgent need to undertake targeted surveys before rare or undescribed species are extirpated (see Chapter 8).

Some species have not been formally, scientifically described, but are nonetheless recognized by taxonomists as being valid. The reason they are not formally described is usually because taxonomists have not had the time or resources to publish the scientific descriptions. This is evidence of an urgent need for more support and capacity building for freshwater taxonomists in Africa (Stiassny 2002; Lowenstein *et al*. 2011). Without a full scientific description and account of the distribution of the species it is not possible to ascertain their conservation status, and they must remain categorized as Data Deficient. Numerous examples exist in the literature, and some of these are included in the analyses presented here but, according to the Red List guidelines, they are not usually added to the IUCN Red List unless they are thought likely to be threatened.

3.3.5 Extinct species

Three species are classified as Extinct (*Aplocheilichthys* sp. nov. 'Naivasha'; *Barbus microbarbis*; *Salmo pallaryi*); all three had restricted distributions and their apparent extinctions are attributed, at least in part, to introductions of alien species. *Aplocheilichthys* sp. nov. 'Naivasha' is a poeciliid of indeterminate taxonomy that has been reported as *A. antinorii* but, according to Seegers *et al*. (2003), is quite distinct. It has probably been extinct since the 1970s or 1980s, following competition or predation from introduced species. The cyprinid *Barbus microbarbis* was known from its type locality, Lake Luhondo (=Ruhondo) in Rwanda, though it possibly also inhabited the small streams flowing into the lake. Only one specimen was ever caught in 1934, despite intensive sampling in the region (De Vos *et al*. 1990; Harrison and Stiassny 1999). If it is a valid species it is almost surely extinct, possibly as a result of the introduction of species of *Tilapia* and *Haplochromis* (De Vos *et al*. 1990). However, the sole type specimen was suspected to be a hybrid between a *Varicorhinus* and a *Barbus* species (Banister 1973). This hypothesis could be correct because, in other regions, putative hybrids between both genera have been identified (Wamuini 2010). The salmonid, *Salmo pallaryi*, was restricted to Aguelman de Sidi Ali, a high altitude lake in the Atlas Mountains of northern Morocco, and known from at least 19 specimens (Delling and Doadrio 2005). The species apparently went extinct around 1938, probably due to the introduction of common carp in 1934, although Delling and Doadrio (2005) note that an unnamed population of trout ('truite verte') from Lake Isli, to the south-west of Aguelman de Sidi Ali, might be conspecific with *S. pallaryi*.

Harrison and Stiassny (1999) and Helfman (2007) have discussed the possible evidence of extinction for several other species that are not classified as such according to the recent IUCN Red List assessments.

The schilbeid catfish *Irvineia voltae* is known only from the lower Volta Basin and is currently categorized as Endangered in the Red List. However, there have not been confirmed reports of this species since the original collection before 1943. Harrison and Stiassny (1999) note that intensive but unsuccessful attempts were made to collect this species between 1961 and 1988, and it is possible that the species became extinct due to modification of the river flow after construction of the Akosombo dams on the Volta River in the mid 1960s. At least prior to 1995, local fishermen knew the species and had a name for it, but could not confirm that they had seen it (DeVos 1995). More concerted surveying is necessary to resolve whether the species has disappeared. Besides the impacts from the dams, habitat quality is declining due to water pollution from agriculture, and possibly also from inadequately treated human waste. The species may also be affected by aquatic weeds.

Harrison and Stiassny (1999) thought the cichlid *Stomatepia mongo*, endemic to Lake Barombi Mbo, Cameroon, might be extinct, because fishermen had noted its absence (Reid 1991). However, the species is still extant because it was exported in 2007 to the USA for aquarium purposes (GCCA Forum 2007). Nevertheless, the fishes of the crater lake, Barombi Mbo, face several serious threats. These include sedimentation and pollution from slash-and-burn agriculture and oil plantations, deforestation, water abstraction for the neighbouring town of Kumba, commercial development of the region for tourism, and occasional fish kills caused by sudden releases of carbon dioxide contained under pressure in deep waters and sediments (similar to the event that occurred at Lake Nyos in 1986, killing more than 5,000 people and livestock) (Stiassny *et al*. 2011). *Stomatepia mongo*, endemic to this lake, is currently considered to be Critically Endangered.

It is often noted that the largest extinction event in recent historical times (since 1500 AD) may have been in Lake Victoria, with the decline of endemic cichlid fishes in the lake since the 1980s. There are indeed many species of cichlids endemic to Lake Victoria that are possibly extinct, but many of these cannot be definitively categorized as Extinct because there has been insufficient sampling or their taxonomy is not sufficiently well described. As noted in section 3.3.2, many of the species in the lake are categorized as Data Deficient, and there is an urgent need for more research and surveying of Lake Victoria fish fauna, in order to fully understand the geographic and taxonomic scope of this undisputed decline in cichlid species.

Given the abundant threats to species in many parts of Africa (as indicated by the large numbers of threatened species recorded from these regions: see section 3.3.2) and high numbers of Data Deficient species found throughout the continent (see section 3.3.4), it is reasonable to expect that further research and sampling throughout the continent might reveal evidence of extinction for several of these DD species.

3.4 Major threats to species

Deforestation, habitat loss and sedimentation

Habitat modification, through deforestation and associated increased sedimentation, is one of the most widespread threats to freshwater fishes in Africa. The effect of this, even on a micro scale, has been demonstrated recently in the Léfini River, where within a relatively small stretch of shoreline, species composition was found to differ clearly between tree-covered and open areas (Ibala-Zamba 2010). Loss of forest cover deprives many species of fishes of shelter from predators, and changes the water temperature and hydrological regime of rivers (Brummett *et al*. 2009). Excessive sunlight and higher temperatures may then promote algal blooms and eutrophication. The low dissolved mineral and nutrient concentration of many of the rivers in the forested parts of Upper and Lower Guinea, and the Congo Basin, results in food webs dependent on allochthonous materials from the forest. The removal of riparian forest can affect peak flow flooding events, which impacts the freshwater species present and the human communities within the catchments (Bradshaw *et al*. 2007, 2009; Brummett *et al*. 2009; Farrell *et al*. 2010). Thus, deforestation can significantly affect the ecohydrology of river systems (and lakes, such as the crater lakes of western Africa (Stiassny *et al*. 2011)). Deforestation results in significant increases in sedimentation as delicate forest soils, which are easily eroded, are exposed and washed into streams, rivers, and lakes. The sediment covers submerged surfaces, reducing suitable habitat for breeding and feeding of many fish populations. The increased turbidity can clog the gills of fishes and suffocate their eggs (Roberts 1993), as well as reducing the light levels so that submerged plants cannot photosynthesize and so die, exacerbating eutrophication of the waters.

Expansion and intensification of logging and agriculture are common causes of deforestation. Threats from deforestation are particularly strong and widespread in the Upper and Lower Guinea provinces, and in the Congo Basin, given that these encompass the last remaining extensively forested regions on the continent. Smith *et al*. (2009) note that in western Africa (which includes the Upper Guinea and Nilo-Sudan ichthyofaunal provinces), deforestation is especially prevalent along the banks of the Volta, Niger, and Senegal rivers. Some examples of fishes in the Upper Guinea region that are impacted by deforestation are discussed in section 3.3.2. The central African region has already lost an estimated 46% of its rainforest to logging and conversion to agriculture, and continues to lose forested watershed at an average rate of 7% per year (Revenga *et al*. 1998). The Kasai, Sanga, and Upper Congo freshwater ecoregions are some of the more seriously impacted areas in terms of ongoing deforestation, while the Lower Congo has been almost entirely deforested for many decades (Stiassny *et al.* 2011). Deforestation is a major threat in many parts of the Lower Guinea province, and much of this is associated with logging (e.g., in the Nyong (Cameroon), the Ogowe/Ivindo system (Gabon), and Kouilou/Niari systems (Republic of Congo)). However, as well as slash-and-burn agriculture, charcoal production, banana, rubber, and oil palm plantations are other major drivers of deforestation and associated sedimentation through Lower Guinea (especially in Cameroon), and in some parts of the Congo Basin (Brummett *et al*. 2009). Extremely biodiverse rainforest along the Cameroon coast, roughly from the Ndian to the Kribi (Kienké) rivers, has been converted to oil palm, as have parts of the Upper Congo freshwater ecoregion, and there are plans for development of oil palm plantations around Lake Tumba (Brummett *et al*. 2011). Deforestation has also taken place to allow for the development of eucalyptus plantations along the coast of the Republic of Congo and Cabinda. Eucalyptus is mainly used for building materials and for firewood and charcoal. Deforestation specifically for the production of firewood and charcoal is a more serious problem for parts of western and central Africa, especially near areas of urban development, where remnant riparian vegetation is particularly under threat (Smith *et al*. 2009; Brummett *et al*. 2011).

Deforestation for logging also opens up large tracts of forest for further exploitation, for example, by mining and agriculture ventures, bush meat hunting, and settlement. Mining has significantly contributed to further habitat loss and high levels of sedimentation in many regions. Small-scale alluvial mining, larger commercial mines, and extraction of sand or clay have impacted rivers basins in parts of southern, western, and central Africa (Darwall *et al*. 2009; Smith *et al*. 2009; Brooks *et al*. 2011). Mining is especially common in the Congo, Sanga, and Kasai basins. Land conversion for agriculture impacts riparian forests, as well as many other habitats. In eastern Africa, the high number of threatened fishes in the Malagarasi Basin is due to encroachment of agriculture into the wetlands (Darwall *et al*. 2005). Similarly, the high number of threatened species in the Ruvu River, draining to the coast of Tanzania, probably results from many regionally endemic species being found in areas at high risk of habitat modification.

Mining, such as observed here in the East Nimba Forest Reserve in Liberia, has significantly contributed to habitat loss and high levels of sedimentation in many regions across Africa. © K.-D.B. DIJKSTRA

Livestock are frequently placed on the cleared land, causing overgrazing, and these poorly managed processes of land clearing and grazing result in accelerated soil erosion and increased sedimentation. The Ubangi River in central Africa is so severely impacted by sedimentation from mining and agriculture in the region of Mpoko that the reduced river depth prevents shipping for four or five months in most years (Brummett *et al.* 2009).

Not surprisingly, loss of riparian habitat and deterioration of freshwater ecosystems are greatest in areas of high human settlement. For example, several species of fishes are impacted by habitat loss in the heavily populated lower Ogun Basin in Nigeria, as well as in the northern parts of Lower Guinea, and close to the large cities of Kinshasa and Kisangani in the Congo Basin (Stiassny *et al*. 2011). In several parts of the Congo Basin (particularly the eastern part of the basin and in the vicinity of the Sangha; see Brummett *et al*. 2011) and Upper Guinea, war and civil unrest have displaced local communities into previously undisturbed regions of forest, with these communities often settling along waterways (Thieme *et al*. 2005), with consequent loss of forest cover.

Pollution

Water pollution is a problem in many parts of Africa. The impacts of pesticides and fertilizers from agriculture on freshwater systems have been reported in all regional studies (Darwall *et al*. 2005, 2009; Smith *et al*. 2009; García *et al*. 2010a; Brooks *et al.* 2011). The effects of pollution are usually also coupled with impacts from increased sedimentation caused by soil erosion, and frequently result in eutrophication of the lakes and rivers (e.g., the Malagarasi Basin, which is impacted by agriculture (see above)). Pollution from mining is a serious threat in the regions where small-scale or commercial mining is prevalent (see above). The use of pesticides in vector control programs for diseases like malaria, schistosomiasis, and trypanosomiasis (e.g., in parts of western Africa (Smith *et al*. 2009)) may also impact fishes, with low doses possibly compromising their physiology and behaviour. The use of such pesticides as a method of fishing is an additional problem in central Africa.

Organic pollution from human and domestic waste threatens fishes in all areas where there are sizeable settlements. Pollution from oil exploration, factories or other urban industries, cars in the cities, and from boat traffic on rivers impacts the freshwater systems, especially those close to large cities, such as Kinshasa and Lagos. Pollution from oil exploration, and associated loss of habitat, specifically threatens several restricted range species in the Niger Delta, and may pose a threat to species in coastal freshwater systems of Gabon, Cabinda, the Republic of Congo and Angola.

Dams

Some 1,207 dams have been constructed on small and large rivers of Africa; at least 135 of these are classified as large dams (> 500,000m^3) (FAO 2010) (see also Chapter 1, Figure 1.3). The greatest concentrations of dams, and some of the largest, are in the Maghreb province of northern Africa, much of western Africa, and Zimbabwe in southern Africa. Dams prevent the longitudinal migration of fish, and create lake-like conditions upstream that are uninhabitable for many of the riverine fishes that were originally present. These lake reservoirs also attract the attention of anglers for the introduction of exotic lacustrine species that may become invasive in the lake environment, especially in southern Africa. Downstream flow and sediment load may be changed to such an extent that the habitats immediately below the dam are also unsuitable for habitation by previously native fishes. The overall impact of dams may be severe, as noted for the Aswan Dam (see section 3.3.2). The potential for future development of hydropower projects in Africa is also large, including plans for some very large dams, such as the 39,000MW ‘Grand Inga’ dam proposed for development on the lower section of the Congo River by 2025 (see Brummett *et al*. 2011) (but see Chapter 1, section 1.2.2.1).

Dams, such as the Akosombo Dam on the Volta River in Ghana, will have a significant impact on freshwater species. These impacts need to be evaluated before construction, and operation procedures, for new dams are approved. © WILLIAM DARWALL

River channelization and water abstraction

The geomorphology and flow of many rivers is affected by channelization (often for irrigation or inter-basin transfer of water) and abstraction of water to supply agriculture, and industrial and domestic consumption. In South Africa, inter-basin transfer schemes of water have facilitated the spread of introduced species (Darwall *et al*. 2009), and may also allow the migration of native species to new basins beyond their normal range, with the possibility of interbreeding between populations that are normally isolated. This may result in detrimental genetic homogenization of the populations.

Water abstraction is a threat particularly in arid areas that have human settlements, such as northern and southern Africa (see section 3.3.2). In western Africa, water abstraction (coupled with climate change), has severely impacted the wetlands of Lake Chad, greatly reducing the surface area of the lake from 25,000km^2 in the early 1960s to around 1,350 km^2 in 2001 (García *et al*. 2010a). When water removal significantly disturbs the environmental flow of a stream or river, this may pose a significant threat to any endemic species whose range is restricted to the

The geomorphology and flow of many rivers is affected by channelization, as is the case here on the Kou stream in Burkina Faso. © TIMO MORITZ

The high diversity of fish communities, such as seen here on the Malagarasi, Tanzania, are often impacted when dams are constructed. © JOHN FRIEL

area where the water removal is occurring. Small dams or weirs, river channelization, and water abstraction may all operate together in some places, where the weirs are installed to divert water and create deeper pools from which it is easier to extract the water by pump.

Overfishing

Overfishing is a major threat to many species in the Great Lakes of the African Rift Valley, such as in Lake Malawi (see section 3.3.2), particularly where fisheries are focused along the migration routes of species as they move from the lake into river mouths to spawn. Smith *et al*. (2009) also note that many freshwater bodies in western Africa are overfished, particularly the Volta. Those authors report that there has been a disappearance of larger species in some western African rivers such as the Oueme, as a result of sequentially fishing down the food web. Allan *et al*. (2005) note that this decline in fish size is accepted in parts of Africa, due to some regional preference for small fish in the cuisine. García *et al*. (2010b) note that *Lates niloticus, Anguilla anguilla, Barbus bynnii, Hydrocynus forskahlii,* and *Alestes dentex* are unsustainably harvested in northern Africa. Threats from poorly managed fisheries (overharvesting or the use of small mesh, unselective fishing gear, fish poisons and explosives) have also been reported for the Congo Basin, particularly in areas such as Malebo Pool, Lake Tumba, and Mai N'dombe. Some fish species are also the focus of commercial and artisanal fisheries for the aquarium trade, for example, some killifishes in Lower Guinea (Stiassny *et al.* 2011) and *Arnoldichthys spilopterus* (see section 3.3.2).

Invasive species

Invasive species are a problem in many parts of Africa, and their success has been aided by habitat modification and the development of dams (see above). The impact on haplochromine cichlids and the introduced Nile perch (*Lates niloticus*) to Lake Victoria in East Africa has been extensively documented (see section 3.3.2 and 3.3.5). In eastern Africa, introduced tilapiine and haplochromine

Arnoldichthys spilopterus *(VU), the Niger tetra, is endemic to Nigeria, where it is restricted to the lower Ogun and lower Niger rivers.* © TIMO MORITIZ

Drought is a serious problem for many parts of Africa, with many lakes drying out, such as the Mare Bali water hole in Pedjari National Park, Benin, pictured here. © TIMO MORITZ

cichlids are themselves a threat to a cyprinid, *Varicorhinus ruandae*, in Lake Luhondo (a small lake in the northern part of Rwanda), through competition and predation (De Vos *et al*. 1990).

Invasive species pose the greatest recorded threat to fishes in southern Africa, mainly coming from introduced European or North American species (e.g., *Micropterus dolomieu*; *Oncorhynchus mykiss* and *Salmo trutta*; also see Species in the Spotlight– **Tilapia in eastern Africa – a friend and foe**), and from invasive species of the cichlid genus *Oreochromis*. Introduced mosquitofish (*Gambusia*) have had very significant impacts on native species in northern Africa (see section 3.3.2). The water hyacinth (*Eichhornia crassipes*) is one of the most widespread invasive species in Africa, presenting a considerable threat to freshwater ecosystems in most of sub-Saharan Africa. The economic impacts of the water hyacinth are estimated at USD 20-50 million every year in seven African countries, and may be as much as USD 100 million annually across all of Africa (Chenje and Mohamed-Katerere 2006) (see Species in the spotlight – **Water hyacinth, a threat to the freshwater biodiversity**).

Climate change and extreme events

Fish faunas already weakened by many of the threats noted above are especially susceptible to the impacts of natural disasters, such as drought, and to climate change. According to García *et al*. (2010b), natural disasters are the second most serious cause of decline for almost two thirds of the freshwater fish in northern Africa. Drought is a serious problem in parts of northern and southern Africa, where many once permanent streams have become seasonal or have dried completely. Lake Chad, in western Africa, was reduced to 5.4% of its surface area between the 1960s and 2001 (see above), and it is estimated that 50% of this reduction was caused by changes in climate patterns (Pietersen and Beekman 2006) (see also Chapter 1, Figure 1.5). Climate change is also expected to impact the forested regions of Africa, although the precise nature of these impacts is unclear (Schiermeier 2008; Thieme *et al*. 2010; Brummett *et al*. 2011). It is expected that, by the 2050s, more than 80% of Africa's freshwater fish species may experience hydrologic conditions that are substantially different from the existing conditions. A more detailed account of the impacts of climate change are given in Chapter 8, this volume.

In conclusion, there are many types of threat that are impacting the freshwater fish fauna of Africa. In most cases, decline in population size and distribution of any species is a product of a combination of these factors, rather than the result of any single threat. Harrison and Stiassny (1999) discuss how several combined threats resulted in the decline of many of the cichlid species of Lake Victoria in the 1980s (see also Chapter 1, Box 1.1). A more recent example is provided by the calamitous decline of the European eel (*Anguilla anguilla*) (Critically Endangered) throughout its range. In northern Africa, this decline may be attributed to the combined effects of overfishing of silver eels in coastal waters, the impacts of parasitic pathologies, pollution, construction of dams and water abstraction, and gravel extraction from river beds (García *et al*. 2010b). Similarly, the decline of *Aphanias saourensis* to Critically Endangered status in northern Africa is attributable to a combination of factors including groundwater abstraction, pollution, and introduction of invasive species (see section 3.3.2).

3.5 Research actions required

This study highlights specific patterns of the distribution and conservation status of fishes throughout the continent, and has identified some conservation recommendations (see section 3.6) and priorities. However, the study has also confirmed the opinion of Lundberg *et al*. (2000) that significant gaps in our knowledge of this fauna still exist. Considerable additional research is required to provide basic baseline data for several potentially biodiverse regions to support conservation management. The lack of knowledge of even the most basic distributional and ecological data, and the need for further research on the fishes of large parts of Africa (in particular, the Congo Basin), is well exemplified by the increased knowledge resulting from the recent study on the ichthyofauna of the Léfini River (as reported above), a tributary draining from the west into the middle Congo (Ibala-Zamba 2010).

Where information is available on species' presence and distributions within a catchment, there is, however, often very little additional information about the ecology of each particular species. In the absence of such information it is very difficult to accurately assess the conservation status of the species, and to make suitable conservation decisions. A major challenge is to accumulate data that can help reduce the total number of species that are classified as

Data Deficient (514 species, 18% of all assessed species) (see Chapter 8 for discussion of prioritising field work to fill these knowledge gaps).

The impact of climate change on freshwater ecosystems of Africa is an important concern, but one which may be mitigated through a better understanding of the resilience of species to change, and through proper management of freshwater resources (see chapter 8, section 8.6.1). However, this also requires further research on the diversity and ecology of the species present, the environmental flows required to support this biodiversity, and additional meteorological and hydrological data. These features of climate change must then be considered alongside other threats (for example, dam construction, overfishing, or deforestation) in order to predict the overall impact. Spatial modelling is useful for all these studies, although interpretation of the results is often difficult for aquatic species. The difficulties lie mainly in the complexities of modelling characteristics of underwater habitats, and in identifying routes of dispersal within catchments, and barriers to this dispersal both within and between catchments.

The best instrument for evaluating changes in the ichthyofauna of Africa is long-term, standardized monitoring. This will detect shifts in species composition, as well as changes in biomass and local incidences of fishing down the food web. Standardized monitoring should also be implemented as a routine step before any large infrastructure is developed on or along the waterway. In many regions, however, political and socio-economic instability, logistical problems, and lack of finances and taxonomic expertise combine to hamper even the most basic studies, including monitoring programmes. If these problems of infrastructure, training and finance can be remediated, then hopefully the recommended studies of species and population diversity and ecology to monitor the health of the fauna can be initiated.

3.6 Conservation recommendations

The findings of this assessment confirm that the freshwater fishes of Africa are significantly threatened in many parts of the continent, and it is reasonable to assume that even greater stress will be exerted on this fauna in the future. Nevertheless, it may be difficult for policy makers to set conservation recommendations as priorities when there are many other urgent issues associated with ensuring that people are guaranteed an acceptable standard of living. The many actions required to meet basic human requirements may appear to be at odds with the objectives of freshwater biodiversity conservation. There is, however, a need to

The importance of inland fisheries to local economies can been seen by this thriving fish market on the banks of the Congo River, at Mbandaka, D. R. Congo. © R. SCHELLY

The banded distichodus, Distichodus sexfasciatus *(LC), is widespread throughout central Africa. A beautiful species such as this is collected for the aquarium trade – it is also an important food fish.* © SAIAB/ROGER BILLS

protect and sustainably manage freshwater ecosystems to deliver the many ecosystem services that are also essential to people. At the most basic level, effectively functioning aquatic ecosystems with healthy fish populations that can be sustainably exploited are to the benefit of all. But recent studies, such as that by Vörösmarty *et al.* (2010), have shown that the need for sustainable management of freshwater resources goes far beyond ensuring biodiversity conservation and food security through reliable fisheries. Their study has shown that the provision of adequate human water security in wealthy nations (such as in parts of Europe and North America) has only been possible by massive financial investment in water technology to offset the impacts of threats, but this investment is not possible in less wealthy nations, where biodiversity *and* human water security remain vulnerable. In much of Africa, the sustainable management of freshwater resources and biodiversity offers a cost effective and environmentally sustainable alternative.

Habitat loss or modification ranks among the primary threats for extinction of freshwater fishes not only in Africa (see section 3.4) but also worldwide (Harrison and Stiassny 1999) (see Chapter 1, this volume). Adequate protection and management of freshwater and riparian habitats is, therefore, a key recommendation for the conservation of freshwater fishes. Numerous nominal parks and reserves exist in Africa (e.g., see Stiassny *et al*. 2011) but, in practice, many are focused on terrestrial habitats rather than the freshwater ones that exist within them or along their borders, where they are especially vulnerable (Abell *et al*. 2007; Allan *et al*. 2010). For example, it is not uncommon that fishing rights are still exerted within protected areas or parks. Development of parks and protected areas that specifically address the conservation challenges for rivers, lakes and wetlands will be important for the future conservation of Africa's freshwater fishes. For example, in central Africa the Ministry of Environment for D. R. Congo and the Institut Congolais Pour la Conservation de la Nature (ICCN) initiated a country-wide biodiversity assessment to identify priority areas for conservation, and have identified 30 wetland priority areas (Thieme *et al*. 2008).

Lake Malawi National Park was established in 1980, especially aimed at protecting part of Lake Malawi's unique fish fauna; nevertheless, the scope of the park is quite limited, and more initiatives are required to reduce the high levels of threat, such as from overfishing. To this end, special programmes have been implemented, such as the 'chambo restoration strategic plan' to protect one of the more important taxa (*Oreochromis*) in the lake fishery.

Allan *et al*. (2010) discuss the need for a new conceptual framework for developing and managing protected areas that accounts for the need to conserve ecosystems while also allowing for the diverse requirements of people. This concept is based on Abell *et al*.'s (2007) recommendation for a multiple-use zoning framework, where focal areas for freshwater conservation are embedded in critical management zones, and these, in turn, are embedded in catchment management zones. Various other programs, ranging from large-scale management of catchments to species-specific or site-specific programmes, have been shown to be important for conservation of freshwater biodiversity and provision of ecosystem services. García *et al*. (2010b) noted that Integrated River Basin Management (IRBM) is a key conservation action required to stop species decline in northern Africa. Cross (2009) described the catchment-scale actions of the Pangani River Basin Flow Assessment Initiative (FA), co-ordinated by the IUCN-Pangani Basin Water Office (PBWO). Tweddle *et al*. (2009) describe some successful projects and conservation recommendations in southern Africa directed at diverse scales, from whole landscapes to local sites and individual species. These include eradication of invasive species and limitation of the use of alien invasive species in aquaculture programmes. Such actions, at both the site and catchment scales, are covered in more detail in Chapter 9.

Another recommendation is that reliable fisheries catch statistics are maintained and made available. In many areas, little information is available on species composition and catch quantities. This is directly related to the lack of inventories and identification keys in many areas and a chronic lack of taxonomically trained personnel. Trained local staff would then assimilate and translate the knowledge of local fishermen and make it available to resource managers and scientists to inform decisions and policy.

On a more general note, 'Payment for Ecosystem Services' (PES) programs are mechanisms where the beneficiaries of freshwater ecosystem services pay for the supply of these services (Forsland *et al*. 2009). For example, downstream communities that receive clean water for domestic and agricultural use pay the upstream communities to conserve and manage the habitats so they continue to supply clean and plentiful water. Conservation stewardship agreements are another form of PES scheme, where trust funds are set up to supply local communities with financial incentives (for example, money for new jobs, or healthcare) in return for agreement that they manage their freshwater resources sustainably.

Many of the conservation recommendations discussed above will be impossible if not backed by adequate development of policy and enforcement of regulations and laws (Smith 2010). However, many governmental bodies lack the financial and logistical means to enforce existing laws and rules, and therefore mechanisms must be put in place to assist in this process. The Convention of Biological Diversity (ratified by several African countries) and the Ramsar Convention (Landenbergue and Peck 2010) may help with the development of policy and laws. The Convention was supported recently by the agreement at the 10th Conference of the Parties to the Convention on Biological Diversity (CBD-COP10, held at Nagoya in November 2010) that 17% of terrestrial and inland water areas globally should be protected, and that 'By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.'

In conclusion, our objective for the future must be to effectively conserve and manage African freshwater fish biodiversity, at the same time as supporting the livelihoods and economies of the people who are dependent on these resources and are the critical stakeholders in ensuring sustainable management practices. This can only be achieved by multi-disciplinary approaches to scientific research, development of tools for the application of that research to conservation and management, and the implementation of policy that supports recommendations made as a consequence of all of the above (Farrell 2010; Smith 2010).

Species in the spotlight

The Congo blind barb: Mbanza-Ngungu's albino cave fish

Vreven, E.[1], Kimbembi ma Ibaka, A.[2] and Wamuini Lunkayilakio, S[2]

A live specimen of Caecobarbus geertsii *from the cave 'Grotte de Lukatu', D. R. Congo.* © ROYAL MUSEUM FOR CENTRAL AFRICA

The enigmatic, Congo blind barb, *Caecobarbus geertsii*, was scientifically described by Boulenger (1921), based on four specimens collected in 1920, from the 'Grottes de Thysville' in the Lower Congo region (Roberts and Stewart 1976) of D. R. Congo. It was the first African cave fish to be discovered. The species is locally referred to as 'Nzonzi a mpofo' in Kikongo (the local Ndibu dialect) which literally means 'blind barb'.

Although the eyes are not visible, they are present. They are deeply embedded in the head, lack a lens, and have only a rudimentary retina and optical nerve (Gerard 1936). Nevertheless, Thinès (1953), contrary to Petit and Besnard (1937), notes that the species moves away from light, demonstrating a typical photonegative reaction due to the existence of extra-ocular photosensitivity.

The species also lacks pigmentation (Boulenger 1921; Heuts 1951) and is considered a true albino, as placing live animals under light for more than one month does not result in development of pigment (Gerard 1936). However, Poll (1953) reported the presence of melanophores in a specimen kept for seven months in an aquarium. The lateral vein creates a vivid red band along the lateral line. Below the operculum the gills are visible as a purplish region, and the intestinal region is visible through the abdomen (Petit and Besnard 1937). Heuts (1951) estimated longevity at nine to 14 years; Proudlove and Romero (2001) stated the lifespan may exceed 15 years, but this needs to be confirmed. The species reaches a maximum size of 80 to 120mm total length, based on the largest specimen housed at the Royal Museum for Central Africa.

Following explorations of several caves in 1949, Heuts (1951) and Heuts and Leleup (1954) recorded *C. geertsii* from seven caves around Mbanza-Ngungu (formerly Thysville), situated on the western slope and the top of the Thysville mountain ridge (Monts de Cristal: 750 to 850m elevation). One population was reported as extirpated by the exploitation of limestone between 1930 and 1935 (Leleup 1956; see also Heuts and Leleup 1954). Indeed, a visit to the cave site in 2005 found it to have completely disappeared following excavation of the slope.

The presence of *C. geertsii* in at least four of the other caves reported by Heuts and Leleup (1954) has been confirmed by recent surveys by Kimbembi (2007) and the authors. Statistical population surveys have been impossible because the subterranean habitat is extensive and difficult to sample (Heuts 1951); however, a gross population estimate for the seven caves reported by Heuts and Leleup (1954) would be about 7,000 individuals (based on information supplied by those authors). Kimbembi (2007) discovered seven more caves with at least small populations of *C. geertsii*, although no population estimations have been made for these.

Heuts (1951) and Heuts and Leleup (1954) previously considered *C. geertsii* to be present in only two upper tributaries of the Kwilu Basin (an affluent of the Lower Congo), namely the Fuma and the Kokosi. One of the new caves that Kimbembi (2007) identified as holding *C. geertsii* is on the Tobo River, another affluent of the Kwilu Basin. Lévêque and Daget (1984) and Banister (1986) also reported the species from the Inkisi Basin, but at the time had no evidence for this. However, inferred from mapping of the new cave localities identified by Kimbembi (2007), the species' presence in the Inkisi River basin seems to be confirmed by two of them – one on the Tubulu River and another one on the Uombe or possibly the Kela River, a tributary to the Uombe. The

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presence of *C. geertsii* in D. R. Congo, as reported by Lévêque and Daget (1984), is incorrect. Thus, the entire distribution area of the species is about 120km². Heuts (1951) noted important differences between the different populations of *C. geertsii* in the Kwilu basin. Populations present in affluents of the Kokosi River have an opercular guanine spot which may cover one third of the operculum (in addition to a few other guanine spots and marks). This spot is absent in all other populations (affluents of the Fuma River). Furthermore, within one cave the population has a serrated dorsal spine, which was not found in all other populations examined by Heuts (1951).

Traditionally, caves are sacred in the area (Laman 1962) and, as a result, access to most of the caves is restricted still today. A law, passed on 21 April 1937, protected *C. geertsii* from all hunting and fishing, except for scientific purposes (Frenchkop 1941, 1947, 1953; Duren 1943). The species was added to the CITES Annex II (on 6 June 1981), resulting in an international trade restriction which means that the species cannot be traded without appropriate export and import permits. *C. geertsii* is still the only African freshwater fish species on the CITES list. The IUCN Red List status of *C. geertsii* is Vulnerable (VU), due to a limited geographic range and a decline in the area and quality of its habitat (Moelants 2009).

Caecobarbus geertsii was found in only seven of the 45 caves explored by Heuts and Leleup in 1949. This indicates, according to Heuts (1951) and Heuts and Leleup (1954), that caves must have a specific combination of ecological conditions if they are to be populated by *C. geertsii*, and they summarised the following conditions:

1. high calcium bicarbonate concentrations in the water; and
2. a distinct periodicity of the subterranean river flow regime through the caves.

Due to this periodic inundation of the caves inhabited by *C. geertsii*, other typical cave animals, such as terrestrial insects, are absent. Therefore, *C. geertsii* is entirely dependent on an external, exogenous, food supply to the caves during the rainy season with, as a result, important fluctuations in food resources between seasons. Moelants (2009) states that the species may feed on small crustaceans living in the caves, but this needs to be confirmed. Consequently, growth is extremely slow, and all further available data suggest a very low reproduction rate, justifying protection measurements.

A visit to the Kambu cave by the authors in August 2009 failed to find the species, although its presence had been reported by Kimbembi (2007). However, several individuals of at least one species of *Clarias* (± 200mm standard length) were found in the different isolated pools. This observation suggests predation of *C. geertsii* by species of *Clarias*, as previously proposed by Heuts and Leleup (1954) and by Leleup (1956).

Caecobarbus geertsii has, in the past, been traded as an aquarium fish, with large numbers having been exported to industrialized nations. Collection pressure should have been reduced through listing under CITES; however, a CITES certificate was issued to import 1,500 individuals to the Unites States (Proudlove and Romero 2001). Three other primary threats to the species were identified by Brown and Abell (2005): changes in hydrology of the small rivers feeding the caves; increasing human population; and associated deforestation (Kamdem Toham *et al*. 2006). Since 2003, with the attenuation of the political situation in D. R. Congo and the rehabilitation of the Matadi-Kinshasa road, there has been a significant influx of rural people towards Mbanza-Ngungu. Consequently, land use has increased around Mbanza-Ngungu for buildings as well as agriculture. One cave is now used as a quarry, with consequential loss of the *Caecobarbus* population (Leleup 1956; Poll 1956; and see above), and others are at risk of collapse due to human disturbance (Kimbembi 2007; Moelants 2009). Agriculture is practiced preferentially in the valleys near to the caves but may also occur on the hillside slopes surrounding and covering the caves, leading to increased erosion and landslides. In the past, these areas were covered with lowland rainforest and secondary grassland (White 1986), limiting erosion. Further research and conservation initiatives in the field are necessary if this unique species of fish is to survive.

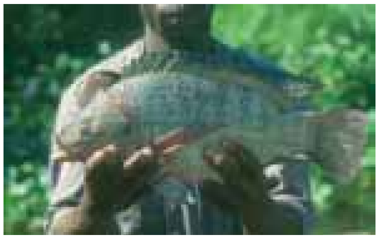
Land use around the entrance of the 'Grotte de Lukatu', with subsequent landslides visible (9 March 2007). The entrance to the cave is directly below the largest trees in the middle of the photograph. © ROYAL MUSEUM FOR CENTRAL AFRICA

Species in the spotlight

Tilapia in eastern Africa – a friend and foe

Nyingi, D.W.[1] and Agnèse, J.-F.[2,3]

Tilapia form the basis for much of the aquaculture industry that is important to so many people across Africa. Its success as a commercially fished and cultured species is attributed to several characteristics: its ability to establish and occupy a wide variety of habitats; its wide food spectrum from various trophic levels (Moriarty 1973; Moriarty and Moriarty 1973; Getachew 1987; Khallaf and Aln-Na-Ei 1987); high growth rate; large maximum size; and high fecundity (Ogutu-Ohwayo 1990). All of these factors accord *O. niloticus* with great competitiveness over other tilapia, which can become a problem where they have been introduced, or escaped, to areas outside of their native range. Aquaculture is also one of the most common sources of invasive species in many parts of the world, and the famous Nile tilapia (*Oreochromis niloticus niloticus*), in particular, is recognised as a significant threat to other native fish species. The popularity of tilapia in Africa is indicated by their high market value and, consequently, the high fishing pressure in most lakes and rivers (Abban *et al.* 2004; Gréboval *et al.* 1994).



The Nile tilapia, Oreochromis niloticus, *(LC), a highly favoured species for aquaculture.* © LUC DE VOS

The Nile tilapia

Eastern Africa is endowed with six sub-species of Nile tilapia: *O. niloticus niloticus* (Linnaeus, 1758), originally from the White Nile Basin but now widely introduced elsewhere; *O. niloticus eduardianus* (Boulenger, 1912) in Lakes Edward, Kivu, Albert and George; *O. niloticus vulcani* (Trewavas, 1933) in Lake Turkana; *O. niloticus sugutae* Trewavas, 1983 in the Suguta river basin; *O. niloticus baringoensis* Trewavas, 1983 in Lake Baringo; and one other recently discovered (Nyingi *et al.* 2009), but still undescribed subspecies from the Lake Bogoria Hotel spring near the Loboi swamp, between Lake Baringo and Bogoria in the Kenyan Rift Valley.

Oreochromis niloticus was introduced to Lake Victoria for the purpose of improving tilapia fisheries in several phases between 1954 and 1962, due to decreasing stocks of native tilapia species *O. esculentus* and *O. variabilis*. *Oreochromis niloticus* rapidly colonized the entire lake and by the end of the 1960s was well established in inshore habitats (Mann 1970; Ogutu-Ohwayo 1990; Twongo 1995). It is thought that the introduction of *O. niloticus* caused the disappearance of the two native tilapia species (*O. variabilis* and *O. esculentus*) from the main part of the lake – *O. esculentus* having once represented the bulk of the fisheries in the lake. It was initially hypothesised that hybridization with subspecies of *O. niloticus* was the main driver of the decline of *O. variabilis* and *O. esculentus*, because *O. niloticus* is well known for its ability to hybridize with other tilapiines (Welcomme 1988; Mwanja and Kaufman 1995; Rognon and Guyomard 2003; Nyingi and Agnèse 2007). However, the competitive superiority of *O. niloticus* subspecies over the two former native species was demonstrated to be the most likely contribution for their extinction (Balirwa 1992; Agnèse *et al.* 1999).

Tilapia and aquaculture

The greatest limitation to development of aquaculture in eastern Africa has been financial, with all new activities in the sector initiated and dependent on foreign financing. In Kenya, the government has stepped up efforts to promote aquaculture under the Economic Stimulus Programme. The government's intention has been to highlight fish farming as a viable economic activity in the country by raising the income of farmers and other stakeholders in the fishing industry. The project, worth 1,120 million Kenya shillings (EUR 10.67 million) was launched by the Ministry of Fisheries Development to construct 200 fish ponds in 140 constituencies by June 2013. According to existing plans, each constituency is geared to receive 8 million Kenya shillings (EUR 70,000) for ponds. In Kenya, the Sagana Fish farm, under the Fisheries Department, provides fingerlings for warm water freshwater species. So far, the centre has been efficient in provision of seed fish to farmers and in research and production of suitable feed. Despite these advances, considerable investment is still needed to ensure the provision of suitable species for

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the various regions, ensuring development of the industry.

With the government supporting new initiatives, the greatest challenge is to identify a suitable species that will ensure high yield, while also safeguarding native species from the impacts of introduced aquaculture species. Unfortunately, in Africa the search for suitable species for aquaculture has often disregarded potential impacts on the native species. The most important culture species are still mainly taken from the wild, and populations are often translocated to basins far beyond their native range, potentially bringing closely related but formerly isolated species or populations into contact with each other. Where there has been inadequate research and planning, an introduced cultured species may directly compete with native species, or may hybridize with them, as noted above for *O. niloticus* when it was introduced to Lake Victoria. Unfortunately, *O. niloticus* has, in many cases, been the species of choice for aquaculture, therefore leading to further problems of competition and hybridisation.

Oreochromis leucosticus was originally known from drainages near the border of Uganda and the D. R. Congo, specifically Lakes Edward, and Albert, and associated affluents. However, it was introduced to Lake Naivasha in Kenya in 1957 (Harper *et al.* 1990). About 150km away from Lake Naivasha is Lake Baringo, in the Kenyan Rift Valley, home to the endemic subspecies of Nile tilapia, *O. niloticus baringoensis*. Nyingi and Agnèse (2007) note that *O. niloticus baringoensis* share genetic characteristics of *O. leucosticus*, suggesting that *O. leucosticus* might have been introduced also to Lake Baringo, with some subsequent transfer of genetic material through hybridization with *O. niloticus baringoensis*. Even though impacts of the possible introduction of *O. leucosticus* are still unknown, introductions of tilapiines continue to be made within the region, either intentionally or accidentally through escape from culture ponds. Such issues are a clear indication of a failure of well-defined policies, or implementation of the existing regulations, for the management of natural fisheries resources in Kenya. Through lack of awareness, and desperation to increase yield, fish farmers are breeding alien species of tilapia that could naturally hybridize in a similar manner – as seems to have occurred in Lake Baringo. Consequently, native species may be lost in several parts of eastern Africa, as already observed in Lake Victoria.

As noted above, a new sub-species of *Oreochromis* was recently discovered from the Lake Bogoria Hotel spring near the Loboi swamp. This population was formerly

Fish farms, such as this one in Malawi, represent an important source of food and income for people throughout Africa. However the traits that make species such as Oreochromis niloticus *suitable for aquaculture mean that they pose a significant threat to local species should they escape.* © RANDALL BRUMMETT thought to have been introduced, but genetic and morphological analysis demonstrated its originality (Nyingi 2007; Nyingi and Agnèse 2007). The main body of the Loboi swamp acts as a physical and chemical barrier between the warm water springs (where the new sub-species is found) that flow into the swamp, and the Loboi River, which drains from it to Lake Baringo. The swamp has a significantly low dissolved oxygen level (around 4% saturated dissolved oxygen, compared to around 60% in the springs and groundwater discharges), which is a consequence of high oxygen consumption during aerobic decomposition of detritus from macrophytes in the swamp (Ashley *et al.* 2004).

The new apparent sub-species from the springs draining into the Loboi swamp offers interesting new possibilities for aquaculture development, if managed properly. The sub-species inhabits high temperatures (approximately 36°C) and may have developed hypoxic resistance mechanisms as dissolved oxygen levels may also be low. This sub-species may also have developed special mechanisms to regulate its sex-ratio, since sex determination is known to be influenced by high temperatures (Baroiller and D'Cotta 2001; Tessema *et al.* 2006). Therefore, the new sub-species may be a model for the study of sex determination in *Oreochromis*.

However, the population from the Loboi swamp and associated rivers is under threat from human encroachment. The Loboi swamp itself has receded by around 60% over the last 30 years due to water abstraction for irrigation since 1970 (Ashley *et al.* 2004; Owen *et al.* 2004). In addition, periodic avulsions have caused changes in the course of rivers in this region. The most recent was during the El Niño-induced heavy rains of 1997, which caused changes in the courses of the Loboi and Sandai Rivers. The Sandai River now partly flows into Lake Baringo and partly to Lake Bogoria.

> “...many challenges still lie ahead, and it will be critical to reinforce policy and management action with programmes of public awareness and education.

Similarly, the Loboi River, which used to feed Lake Baringo, has changed its course and now flows to Lake Bogoria. These changes of flow were also due to intensive agricultural encroachment by local farmers leading to weakening of the river banks (Harper *et al.* 2003; Owen *et al.* 2004). This situation is not unique to the Loboi swamp but is common in almost all lakes and river systems in Kenya. The National Environment Management Authority in Kenya has been actively involved in ensuring rehabilitation of the Nairobi River, which had been greatly impacted due to solid waste disposal, sewage, run-off from car washes, and other human activities within the city and suburbs of Nairobi (Nzioka 2009). The success of this project is a clear indication that the National Environment Management Authority is able to protect hydrological systems in Kenya. There is, however, a need to replicate these successes elsewhere.

Management of tilapia fisheries

A significant challenge has existed where freshwater resources are shared by different countries. For example, fisheries management of Lake Victoria was highly compromised in the early 1960s following independence of the countries bordering the lake (Kenya, Uganda and Tanzania), when they adopted different fishing regulations based on the stocks targeted for exploitation (Marten 1979). These different regulations and priorities for exploitation have made it difficult to manage the lake as a complete ecosystem (Ntiba *et al.* 2001; Njiru *et al.* 2005). Ironically, this lack of management has contributed to declines in the introduced *O. niloticus*, which was previously responsible for the decline in the native sub-species (see above). Stock analyses for *O. niloticus* surveys of 1998 to 2000 and 2004 to 2005 show that artisanal catches were dominated by immature fish, most being below the legally allowed total length of 30cm (Njiru *et al.* 2007). The paucity of mature individuals observed in commercial catches (Njiru *et al.* 2005) may be partly due to the increased numbers of introduced Nile perch (*Lates niloticus*) (Lubovich 2009), but is also probably due to overexploitation. In the past, this overexploitation has been possible because of the laxity and weakness in enforcement of the Fisheries Act of 1991, which is highly explicit on the manner in which fishing activities should be conducted. Significant efforts are being made to address the challenge of providing a comprehensive, consistent set of policies and programs for sustainable management of the lake's fishery resources. For example, in March 2007, Kenya, Tanzania, and Uganda adopted a Regional Plan of Action for the Management of Fishing Activity; this plan called on the respective governments to review their national policies and develop a harmonized fishing framework (LVFO 2007; Lubovich 2009). Nevertheless, many challenges still lie ahead, and it will be critical to reinforce policy and management action with programmes of public awareness and education.

Species in the spotlight

Forest remnants in western Africa – vanishing islands of sylvan fishes

Moritz, T. [1]

A significant part of western Africa is covered by differing types of savanna that are drained by a few large rivers, like the Niger, Volta and the Senegal. The vegetation reflects climatic conditions including a cycle of dry and wet seasons. Closer to the coast, partly bordered by the Guinean highlands (from the highlands of the southern Fouta Djallon in south-eastern Guinea, through northern Sierra Leone and Liberia, to north-western Côte d'Ivoire), the climate is more humid, allowing different types of forest to grow. These forests are inhabited by animals closely resembling or even identical to those of the central African forests. Thus, many sylvan (forest dwelling) fish species and species-groups find their most westerly distributions within the western Africa coastal forests. A number of these westerly sub-populations may be discrete sub-species, or separate species within species complexes, showing distinct colour morphs, or other unique features.

The high number of unconnected coastal rivers in western Africa is thought to have promoted these speciation processes, which have led to noticeably high levels of endemism, such as for characids, barbs and cichlids. Furthermore, several remarkable fishes, which are sometimes called ‘relict‘ species, occur in the Guinean regions. These species belong to phyletically old groups previously represented by more numerous and widespread species but, following evolutionary events, now represented by only a few, often locally restricted species. Examples include the fourspine leaffish (*Afronandus sheljuzhkoi*) and the African leaffish (*Polycentropsis abbreviata*), with their closest relatives in Asia and South America, and the enigmatic denticle herring (*Denticeps clupeoides*), which is the only extant representative of the family Denticipetidae, the sister group of all other clupeomorphs.

The climatic conditions of the Guinean region not only provide good conditions for forest ecosystems, but also support a more diverse and reliable agriculture compared with the Sahelo-Sudan region. This promotes better livelihood opportunities which, in turn, lead to increased population densities and a greater demand for land. With increased demands for agricultural land, deforestation continues, leaving only forest fragments in some areas.

Lokoli swamp forest in southern Benin. This small forest fragment serves as one of the last refuges for many forest dwelling species. © T. MORITZ

Lokoli forest – a refuge

An exemplary forest remnant is the Lokoli swamp forest in southern Benin. This small, (approximately 500ha) piece of forest is permanently flooded by a network of channels from the Hlan River, an affluent of the Ouémé River. It is approximately 20km east of Bohicon and 100km north of Cotonou and can only be crossed by boat. The forest is densely vegetated with high tree density, and the tree cover is usually closed above the channels. Most channels are less than a metre wide and are only navigable using small dugout canoes. Water depth varies by less than one metre within a year, and is usually around 1 to 2.5 metres. The water has a dark brown colouration due to leaf litter decomposition, a moderate acidic pH of 6 to 7 and a temperature of around 26°C. The channel substrate is predominantly

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Barboides britzi*, one of Africa's smallest freshwater fish, is a newly described species endemic to Lokoli forest in Benin.*

© T. MORITZ

sand, with small patches of gravel where the current is stronger; most places have a mud and leaf litter layer of variable depth.

The Lokoli forest serves as one of the last refuges for forest dwelling animals in the Dahomey Gap, including pangolins, flying squirrels and the red-bellied monkey (*Cercopithecus erythrogaster*), which is endemic to Benin. While herpetological surveys have shown relatively few exclusive forest species of reptiles and amphibians (Rödel *et al.* 2007; Ullenbruch *et al*. 2010), the situation for fishes is very different. Despite a direct connection to the main channel of the Ouémé River, fishes of the Lokoli are, to a high degree, typical forest species, otherwise known from the coastal forested rivers of the Niger Delta and the connected network of lagoons parallel to the coast. The reedfish (*Erpetoichthys calabaricus*), butterfly fish (*Pantodon buchholzi*), and elephant nose fish (*Gnathonemus petersii*) in Lokoli are at the most western points of their ranges (Montchowui *et al.* 2007; pers. obs.). The cyprinid genus *Barboides*, consisting of two of the smallest African freshwater species, is also at the most westerly point of its range, with *B. britzi* endemic to the Lokoli forest itself. This miniature fish becomes sexually mature at a smaller size than any other freshwater fish in Africa, at 12.6mm standard length (Conway and Moritz 2006). It is likely that more fish species, especially of smaller body size, await discovery in such unusual habitats. For example, the bottom dwelling distichodontid *Nannocharax signifer* was only recently described, from a small affluent of the Lokoli forest (Moritz 2009).

Impacts to this small forest fragment are significant, with extensive clearance for agriculture along the forest margins. Within the forest itself, despite religious taboos prescribing at least some regulations for hunting, the bush meat trade remains an important source of income and bush meat is openly sold along the main road leading to Cotonou. Palm wine and secondary products are produced by cutting off the tops of the palm *Raphia hookeri*, with evident impacts to the plants themselves. As a result, the abundance of this formerly dominant palm has been significantly reduced through over-harvesting. The forest flora has been further impacted through introduction of alien species such as the taro (*Colocasia esculenta*), an introduced plant valued for its root tubers, which is widely planted, even within clearings in the swamp forest.

Forested coastal rivers, although more spacious than some of the Guinean forested rivers, face similar threats. In addition to pollution, which is heavily impacting certain areas, the primary problem is, once more, habitat degradation due to expanding agriculture. The Iguidi River at the border of Benin and Nigeria provides a good example. The course of this small coastal river is clearly visible on aerial or satellite images, due to its bordering gallery forest. The forest stands out in stark contrast to neighbouring, and continuously expanding, fields. The Iguidi River flows in a north-south direction, starting out as a small forested stream that develops into a swamp. As is typical for a forest stream, the water is brown to dark brown in colour, although the pH is not especially acidic, at 6.5 to 7.5; water temperature is commonly 26 to 29°C; and conductivity is low at 50 to 65µS (Moritz 2010). Despite the river's low salt content, fishes characteristic of brackish environments are also present, such as the freshwater pipefish of the genus *Enneacampus,* and the sleeper goby (*Eleotris daganensis*). The majority of fishes from the Iguidi are, however, typically freshwater, forest-dwelling species such as the dotted catfish (*Parauchenoglanis monkei*), the small distichodontid, *Neolebias ansorgii,* and the cryptic mormyrid (*Isichthys henryi*). This small river represents an outpost of the Lower Guinean forest, and holds the most westerly distributions of several Lower Guinean species, such as the aforementioned *Neolebias ansorgii*, the Niger tetra (*Arnoldichthys spilopterus*), and the catfish *Schilbe brevianalis* (Moritz 2010). Furthermore, the Iguidi River is the type locality for the rare, miniature *Barbus sylvaticus*, the even smaller *Barboides gracilis*, and the denticle herring (*Denticeps clupeoides*), all of which are assessed as Vulnerable or Endangered.

In conclusion, at first glance, small forest fragments seem to be of minor importance for the conservation of forest dwelling species – often being too small to sustain endemic species, or even too small to harbour a discrete population of a sylvan species. Many inhabitants of forest remnants are, therefore, non-specialist or even savanna species. A closer view of the fishes, however, reveals a quite different picture. Forest remnants, such as the Lokoli, can sustain a number of small endemic species. What is more important, however, is the complexity of biodiversity that is found and that needs to be conserved. Forest fragments and remnants of gallery forests are focal points of habitat complexity, edge effects and ecological interactions – and as outposts for species distributions, they may be of high importance for maintaining genetic variability within a species and in ongoing evolutionary processes. Therefore, despite their small size, forest fragments deserve greater focus within conservation plans; their inclusion will help to ensure preservation of biodiversity in all its forms.

The freshwater butterflyfish, Pantodon buchholzi *(LC), a widespread species in Africa, reaches the most westerly point of its range in Lokoli forest, Benin. This species is capable of jumping out of the water to search for insects or to escape from predators. It is not a glider, but a ballistic jumper, with tremendous jumping power.* © T. MORITZ

Species in the spotlight

A unique species flock in Lake Tana – the *Labeobarbus* complex

Getahun, A.[1]

Lake Tana, in Ethiopia, and the rivers that drain into it, are home to a unique, endemic species flock belonging to the cyprinid genus *Labeobarbus*. The lake, which has a surface area of 3,150km², is the largest in Ethiopia. It is situated in the north-western highlands at an altitude of approximately 1,800m. It was formed during the early Pleistocene when a 50km-long basalt flow blocked the course of the Blue Nile near its source (Mohr 1962; Chorowicz *et al.* 1998). Today, several rivers drain into Lake Tana, which itself forms the headwaters of the Blue Nile – the only river flowing out of the lake, contributing more than 80% of the total volume of the Nile River at Khartoum, Sudan.

The wetlands and floodplains that surround most of the lake form the largest wetland area in Ethiopia and are an integral part of the complex Tana ecosystem. The wetlands to the east of the lake serve as breeding grounds for *Oreochromis niloticus* (Nile tilapia) and *Clarias gariepinus* (North African catfish), both of which are important for the lake fisheries (Vijverberg *et al.* 2009).

There are 28 species of fish in Lake Tana, of which 20 are endemic to the lake and its catchments (Vijverberg *et al.* 2009). The fish fauna includes representatives of the genera *Oreochromis, Clarias, Labeobarbus* (i.e., the 'large African barbs'), *Barbus* (i.e., the 'small *Barbus* group'; see De Weirdt and Teugels 2007), *Garra, Varicorhinus* and *Nemacheilus*. The population of *O. niloticus* in Lake Tana was described as a separate sub-species, *Oreochromis niloticus tana*. Two exotic species, *Gambusia holbrooki* and *Esox lucius,* were reported to have been brought from Italy during the late 1930s and introduced into the lake (Tedla and Meskel 1981); there is, however, no trace of these fishes from the lake in recent times.

Labeobarbus macrophtalmus is a benthopelagic species that forms an important component of the Lake Tana fishery. © LEO NAGELKERKE

The *Labeobarbus* species flock

The Cyprinidae are the most species-rich family in the lake, represented by four genera, *Barbus, Garra, Labeobarbus* and *Varicorhinus*. Within the *Labeobarbus* is a unique complex of 17 species (Getahun and Dejen in prep.). It is thought that the lake is able to support such a large number of closely related species because, when it first formed, it offered several new habitats that may have promoted adaptive radiation among the original colonising species, and it has since remained isolated due to the Tissisat Falls, located 30km downstream from the outflow of the lake. Most interesting is the speed of evolution for so many new species, as historical evidence suggests the lake dried out completely as recently as 16,000 years ago (Lamb *et al.* 2007), meaning the evolution of the *Labeobarbus* species complex may have taken fewer than 15,000 years (Vijverberg *et al.* 2009).

Eight of the *Labeobarbus* species are piscivores, and most of them periodically migrate into the rivers for spawning. *L. intermedius* and *L. tsanensis* are abundant in the inshore habitats and are the predominant species at the river mouths. *L. tsanensis* and *L. brevicephalus* are the dominant species offshore.

Spawning behaviour

Limited surveys around Lake Tana indicate that the Ribb, Megech and Dirma Rivers and their tributaries provide ideal breeding grounds for these species in the northern and eastern parts of the lake. Five species were found to migrate from Lake Tana up both the Megech and Dirma rivers to spawn (Anteneh 2005), although slightly greater numbers migrate up the Megech, which has more tributaries with gravel beds, and a slightly higher dissolved oxygen content. Three categories of spawning behaviour are

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observed (Anteneh 2005), obligate river spawners, lake spawners and generalists (spawning in both the lake and its tributary rivers).

At least seven species spawn in the headwaters of the main rivers draining to the lake. As yet, there is no evidence of river-specificity, but this cannot be discounted. After a brief pre-spawning aggregation at the river mouths, the adults migrate upstream in July and August, at the onset of the rainy season. Final maturation and spawning occur in the tributaries of the major rivers, or possibly in gravel reaches in the main channels. After spawning, the adults return to the lake for feeding until the next cycle of breeding. Highly oxygenated water and gravel beds are important for development of the eggs and larvae. Deposition of eggs in gravel beds prevents them from being washed away, and clear water is required to ensure they are free of sediments that might obstruct the diffusion of oxygen.

The juveniles start to return to the lake in September and October as flows reduce, where they feed and grow to sexual maturity. There is good evidence that, during their return to the lake, the juveniles may remain in the pools of the main river segments for an extended period, probably until the next rainy season, at which time they will be carried into the lake.

The lake fisheries

The lake fishery is clearly very important to the local population, employing more than 3,000 people in fishing, marketing, and processing (Anteneh 2005). Traditionally, the main fishery has been a subsistence reed boat fishery targeting a range of species, sometimes including the *Labeobarbus* species. This was conducted throughout the lake until the 1980s; since then it has been replaced in many areas by other methods. The fishery remains important in the more remote areas of the lake, with the catch being sold at small markets or used for household consumption. It mainly employs gillnets, and the main target species is Nile tilapia (*O. niloticus*). However, the reed boat *(tankwa)* fishermen also use hooks and lines, and traps, as well as spears to catch catfish.

In 1986, motorised boats and nylon gill nets were introduced as part of the Lake Tana Fisheries Resource Development Program (LTFRDP) (Anteneh 2005). Data collected from all commercial fisheries recognizes only four species groups: *Labeobarbus* spp., African catfish (*C. gariepinus*), Nile tilapia (*O. niloticus*) and beso (*Varocorhinus beso*). This fishery mainly supplies larger markets, using 100m long gillnets. There are around 25 motorised fishing boats, most of which land their catch in Bahir Dar, the main town on the shore of Lake Tana. The fishery is, however, expanding to all 10 Woredas (districts) bordering the lake, including the Gorgora area (on the northern shore).

Total annual catches increased from 39 tonnes in 1987 to 360 tonnes in 1997 (Wudneh 1998). However, the catch per unit effort for the commercial gill net fishery targeting *Labeobarbus* species dropped by more than 50% over the period 1991 to 2001 (de Graff *et al.* 2004). The same authors have reported a 75% decline (in biomass) and 80% (in number) of landed fish of the species of *Labeobarbus* (*L. acutirostris, L. brevicephalus, L. intermedius, L. macrophthalmus, L. platydorsus* and *L. tsanensis*) in the southern gulf of Lake Tana. The most plausible explanation for the decline is recruitment overfishing by the commercial gillnet fishery (de Graff *et al.* 2004), and poisoning of the spawning stock in rivers using the crushed seeds of 'birbira' (*Milletia ferruginea*) (Nagelkerke and Sibbing 1996; Ameha 2004).

The commercial gill net fishery for species of *Labeobarbus* is highly seasonal and mainly targets spawning aggregations, as more than 50% of the annual catch is obtained in the river mouths during August and September. There is also a chase and trap fishery based in the southern part of the lake, and longlines, cast nets and traps are occasionally used but contribute little to the total fish catch.

Threats to Lake Tana and its *Labeobarbus* species

Overfishing

Although a fishery policy has been developed both at federal and regional levels, it is not effectively

Fishermen cast their lines from papyrus boats ("tankwas") on Lake Tana in northern Ethiopia. Behind them lies the source of the Blue Nile. Near Bahir Dar, Ethiopia.

© A. DAVEY

implemented. Lakes and rivers are, unofficially, considered to be resources that are freely available to everyone. There are still many illegal, unregistered fishermen exploiting the fish resources, and there is little regulation of fishing gears. As reported above, this has led to overfishing of *Labeobarbus* in some parts of the lake, especially in the south around the town of Bahir Dar.

Habitat disturbance

As seasonal flooding recedes, many people use the shores of the lake for 'floodplain recession agriculture'. Human encroachment on the wetlands increases every year, with the subsequent depletion of emergent macrophytes through harvesting and burning, while there is an expansion of submerged macrophyte stands in other areas.

Over the last 15 years, deforestation has become very widespread, facilitating conditions for soil erosion, resulting in sediments draining into the lake and smothering upstream spawning areas. The soil loss rate from areas around the lake is between 31 and 50 tonnes per hectare per year (Teshale *et al.* 2001; Teshale 2003). These huge deposits of sediment into the lake have led to a reduction in the lake's area, a drop in water levels, and a loss of water holding capacity. This reduction in the water level has resulted in fragmentation of the available aquatic habitat, especially around shores. Some of the exposed land is now used for cultivation and excavation of sand.

Water pollution

Run-off from small-scale agriculture around the lake is bringing agricultural fertilizers, pesticides (including DDT), and herbicides into the lake. The use of these agricultural products by farmers is still relatively limited; however, a lack of effective regulation on their use presents a potential threat to water quality in the lake. Other chemicals, such as 'birbira' (*Milletia ferruginia*) seed powder (used as an ichthyocide; see above), may also pollute the lake and kill the aquatic fauna, including *Labeobarbus* species. Domestic waste water from the town of Bahir Dar is, in most cases, discharged directly into Lake Tana – the development of an appropriate sewage system could solve or mitigate these pollution threats.

Many of the Labeobarbus *species migrate up the rivers flowing into Lake Tana to spawn in gravel beds, such as seen here in the Gumara River.* © LEO NAGELKERKE

Water abstraction and impoundment

Water abstraction occurs at some points around the lake as a result of privately run, small-scale irrigation projects. However, because the Lake Tana and Beles sub-catchment is considered a growth corridor by the federal and regional governments, there are several other dam and irrigation projects under consideration or being implemented. These include the Tana Beles inter-basin water transfer project, and the Koga, Ribb, Megech, Gilgel Abay and Gumara dams and irrigation projects. Some of these are intended to impound the lake's tributaries to store water; some to pump water through tunnels from the lake to a hydropower facility before discharging the water into the Beles River; and some to pump water directly from the lake for irrigation purposes. These projects may lower the water level and quality in Lake Tana and its tributaries, with subsequent impacts to biodiversity. As reported above, many species of *Labeobarbus* undergo spawning migrations that, without effective measures to allow passage past newly constructed dams, may be blocked, potentially leading to the extinction of this unique flock of cyprinids. Environmental impact assessment (EIA) studies have been conducted for many of these projects, so it is hoped that the recommended mitigation measures and the management plans suggested will be strictly followed and implemented.

Lack of information and institutional capacity

Comprehensive scientific studies on the biology, behaviour, and ecology of the different species of *Labeobarbus* are still lacking. This makes it difficult to recommend mitigation measures in some of the EIA studies and follow up with implementation. In addition, the implementing agencies for EIAs still lack the strength and capacity to enforce and implement any recommendations made. The development of a Lake Tana sub-basin authority is an option for solving this problem. Concerted action by all stakeholders is required if the unique fish fauna of this lake is to be conserved for the future.

The Twee redfin, Barbus erubescens, *a Critically Endangered fish from the Twee River, South Africa, where it is threatened by alien fish species.* © D. IMPSON

Species in the spotlight

The Twee River redfin – a Critically Endangered minnow from South Africa

Skelton, P.H.[1]

The Twee River redfin (*Barbus erubescens* Skelton) was described in 1974, following an investigation that included extensive field observations. The species is named for the bright reddish breeding dress assumed by spawning males, with females being less intensely coloured. The common name indicates that the species' distribution is restricted to one tributary system of the Olifants River in the Cedarberg Mountains of the Western Cape, South Africa. This tributary system includes the Twee and some of its affluents, the Heks, Suurvlei and Middeldeur rivers.

At the time of discovery, only one other fish species was known to be indigenous to the Twee River, and both species were isolated by a vertical waterfall of about 10m, located close to the confluence of the Twee and Leeu rivers. This other indigenous fish is a species of South African *Galaxias,* formerly named as the Cape galaxias (*Galaxias zebratus*)*;* however, more recently it has become evident that a number of populations of *G. zebratus* might represent distinct species. The population of *Galaxias* in the Twee River is one of these distinct populations. The Cape galaxias is currently assessed in the IUCN Red List as Data Deficient, due to the taxonomic confusion associated with the species complex. Below the falls several other indigenous freshwater fish species are found, most of them endemic to the Olifants system. One of these species, *Barbus calidus*, is the sister species of *B. erubescens* (i.e., it is the phylogenetically most closely related species to *B. erubescens*). *Barbus calidus,* the Clanwilliam redfin, itself classified as Vulnerable, due to threats

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from invasive species, and habitat degradation caused by agriculture, is discussed below.

Much has been learnt about the Twee River redfin since its original description. In common with a disproportionately large number (80%) of barbine minnows from the temperate reaches of southern Africa, the Twee River redfin is tetraploid (that is, it has four sets of each chromosome), with 100 chromosomes in total. Its most distinctive external character is the high number of branched anal fin branched rays – six or, more usually, seven – more than any other African barbine species. It has several other distinctive features, such as small scattered nuptial tubercles on both sexes, two pairs of well developed mouth barbels, and an unbranched ray in the dorsal fin that shows either incipient or vestigial serrations.

The Twee River in the Cedarburg Mountains, the Western Cape, South Africa.

© SAIAB/P. SKELTON

The species' breeding behaviour features males congregating and forming a dense, swarming, nuptial school against rock surfaces to which individual breeding females are attracted and enticed to spawn over cobbles or rock crevices with several pursuant males. This occurs in spring or early summer (October to December) when streams are swollen by frontal rains. The species is a 'broadcast spawner' (releasing the gametes into the water) and does not practice any form of parental care. It can live for up to five or six years. The species feeds on drifting insects and other invertebrates or from rocks and other benthic surfaces.

Conservation concerns

When first discovered, the species was common and widespread in the tributary system – with larger adults occupying open water habitats in pools and runs, and juveniles shoaling along marginal zones. Since the 1970s, the population has declined markedly and is absent from large sections of its former range. The reasons for this decline are several, including likely impacts from agricultural developments (riparian fruit orchards) impacting both water quality and quantity, and alien invasive fish species. The first alien fish species to be recorded was a South African anabantid, the Cape kurper (*Sandelia capensis*) which, although not a large fish, is widespread throughout most of the tributary and an avid predator on small fishes and invertebrates. The Clanwilliam yellowfish (*Labeobarbus capensis*), a large cyprinid of the Olifants River system, was introduced to the Twee River above the barrier waterfall by Nature Conservation authorities seeking to conserve that species in the face of threats from other introduced species! The Clanwilliam yellowfish is found mainly in the downstream reaches of the Twee and, although its precise impact is not known, it is a predator and grows much larger that the Twee River redfin. Bluegill sunfish (*Lepomis macrochirus*), a North American centrarchid species, and another predator on small fishes and invertebrates, have also invaded the system. Rainbow trout (*Oncorhynchus mykiss*) have been recorded from the Twee River but are not common.

The Twee River has been extensively surveyed on several occasions to determine the conservation status of the redfin and the *Galaxias* species. The decline in their populations is of great concern, as the tributary system is restricted in size and subject to increasing agricultural pressures as well as the invading alien species. There are few natural sanctuary reaches and, unless determined action to remove the alien species is taken, the fate of the threatened indigenous species might be sealed forever. Two things are essential for conservation action – political will by the authorities to do what they must in the face of contrary perceptions by the public (who, for example, may support introductions of species for fishing), and a properly informed public, especially the local landowning public. If those elements are in place, the survival of these and other indigenous species in South Africa might be secured.

Species in the spotlight

Cauldrons for fish biodiversity: western Africa's crater lakes

McGregor Reid, G.[1] and Gibson, C.[1]

Stomatepia mongo*, a Critically Endangered cichlid endemic to Lake Brombi Mbo, Cameroon.* © OLIVER LUCANUS/BELOWWATER.COM

Globally, crater lakes are comparatively rare, usually small and specialised freshwater habitats formed in geological depressions, such as the Ojos del Salado in the Andes mountains, bordering Argentina and Chile – probably the highest altitude permanent lake of any description (68°32'W, 27°07'S, elevation 6,390m, diameter 100m, depth perhaps 5 to 10m). Crater lakes are well represented in tropical Africa, especially in the Guinean rainforest zone of Cameroon, where there may be 36 or more. The entire region is a celebrated 'biodiversity hotspot' for both lacustrine and riverine fishes (Reid 1989; 1996; Teugels *et al.* 1992; Schliewen 2005; Stiassny *et al.* 2007). Contemporary general studies on the world's crater lakes address important topics such as: lake formation; physical, chemical, geological, geographical and biological evolution; paleoecology; historical biotic colonisation; and recent ecology – including the assessment of conservation status and threats to the survival of the contained habitats and species. The potential for (and impacts from) human use is studied, including water supply, agriculture, fisheries and also recreation and ecotourism – such lakes often being scenic locations.

Crater lakes everywhere may contain a substantial number of endemic fishes and other aquatic and amphibious taxa. Among African fishes endemic to craters, small phyletic and trophic assemblages of species and genera representing the family Cichlidae have attracted much international scientific attention. Crater lake cichlids, their taxonomy, phylogeny and ecology were documented early on in Cameroon, notably in Lake Barombi Mbo (Trewavas 1962; Trewavas *et al.* 1972; see below); and they continue to be discovered – for example, the recently documented 'flock' of eight new species of *Tilapia* from Lake Bermin or Beme (5°9'N, 9°38'E; diameter around 700m, depth around 16m, and age probably far less than 1 million years) (Stiassny *et al.* 2002; Schliewen 2005). Such Cameroonian assemblages are often regarded as small-scale tilapiine counterparts to the better known large haplochromine and other cichlid 'species flocks' of the East African Great Lakes (Klett and Meyer 2002; Salzburger and Meyer 2004).

Formation

Whatever the location, all craters on earth are formed either by *impact* of extraterrestrial bodies or by *vulcanism* (Decker and Decker 1997; Sigurösson 1999). They are often visible in photographic, radar and other imagery taken from space (Hamilton 2001).

Impact crater lakes

The impact of a meteorite, asteroid or comet creates a depression. This can be a simple bowl (depth to diameter ratio typically 1:5 to 1:7) or a larger, shallower, more complex depression (depth to diameter ratio 1:10 to 1:20) sometimes incorporating a central island or islands. Such islands are caused by a gravitational collapse of the rim and a rebound of material to the centre, analogous to the splash effect seen when raindrops hit water. An island may itself incorporate a hollow that later forms a 'lake within a lake', as in Lake Taal, Philippines (Reid pers. obs.). In geological terms, impact depressions occur frequently but are often temporary, and only some 120 are currently known

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Lake Barombi Mbo, Cameroon. This lake is considered to be the oldest radiocarbon-dated crater lake in Africa. © U. SCHLIEWEN

worldwide, most commonly from North America, Europe and Australia. Their occasional occurrence in Africa is therefore of considerable scientific interest. It is postulated that multiple terrestrial impacts, particularly large ones, are of importance in both geological and biological terms and are likely associated with periodic species extinction events on land and in the marine environment occurring since at least the Cretaceous period (around 60 million years ago). The nature, persistence and effects of impact depressions depend on the 'target' substrate, the velocity of the impactor, its composition and identifying 'signature' – the physical and chemical outputs, such as meteorite shards, shock metamorphism, 'rock melt' and silica rich glasses. All of this may become biotically significant at some later stage of lake evolution. Other factors determining nature and persistence include the location, scale and form of the depression, and subsequent chemical, geological, geographical and biological processes including any underlying volcanic activity, erosion, deposition of sediments and ecological colonisation.

Aorounga, in the Sahara Desert of northern Chad, contains a rare western Africa example of a large, ancient, much eroded impact crater (19°6'N, 19°15'E; diameter 17km; age around 200 million years ago (Hamilton 2001)) which supports isolated temporary pools in rainy periods. Across the Sahelian region such pools may contain a remarkable density of life, albeit briefly, including anacostracan crustaceans ('fairy shrimps') emerging from eggs resting in the sand since previous inundations of water; and anuran (frog and toad) tadpoles which appear 'as if from nowhere' (Reid pers. obs.). However, the craters are usually dry and contribute a fine diatomaceous lake substrate to dust storms generated within the Bodélé Depression and which, in winter, amount to an average of 1,200,000 tonnes of dust per day carried for hundreds or thousands of kilometres (Todd *et al*. 2007). The Arounga crater is one of a local series, which may have been part of the more permanent and far more extensive 'Mega Lake Chad' dating from the Pleistocene to Holocene periods (around 2 million years ago to 10,000 years ago) and persisting to some extent until a few thousand years ago. Lake Chad is now only 5% of its volume in the 1960s, mainly due to excessive human abstraction demands. The Mega Chad has been crucial in determining much of the large-scale aquatic and terrestrial patterns in historical and recent biogeography for western Africa and the Nilo-Sudan ichthyological province (Reid 1996).

Lake Bosumtwi, Ghana is a better known, but still scarce, example of a comparatively young, permanent impact crater lake (06°32' N, 01°25'W; rim diameter 10.5km; maximum depth 75m; age 1.3 ± 0.2 million years). The largest single natural lake in sub-Saharan western Africa, it lies over crystalline bedrock of the West African Shield and research indicates that sediments associated with Lake Bosumtwi have spread to the Ivory Coast and to oceanic deposits, nearby in the Gulf of Guinea (Hamilton 2001; Embassy of the Federal Republic of Germany 2011).

Volcanic crater lakes.

Craters formed through vulcanism, and their associated lakes, are sometimes divided into two classes: *calderas* which are deep inverted cones; and *maars* which are shallower with a low profile. However, these distinctions are not always obvious, and the nature of the volcanic activity can be complex (Decker and Decker 1997). The rocky rim is often created in a gaseous explosion when hot volcanic lava or magma in a subterranean chamber makes contact with groundwater.

By contrast, Lake Barombi Mbo is small (see above) and estimated to be biologically mature since about 25,000 to 33,000 years ago; it is considered to be the oldest radiocarbon-dated crater lake in Africa

Subsidence of materials creates a depression within the rim that may later fill with water. A diatreme often persists under the lake bed, that is, a pipe-like vertical volcanic vent that is filled with broken and cemented rock created by a single explosion. Such diatremes may remain active. Lake Nyos (around 322km north-west of Yaoundé, Cameroon, close to the border with Nigeria) is an example of a simple maar lake, but a comparatively deep one (6°26′17″N, 010°17′56″E; 1,091m above sea level; 2km long by 1.2km wide; and 208m maximum depth). Lake Barombi Mbo in south-west Cameroon is formed in a caldera, albeit a fairly small one (4°39'46"N, 9°23'52"E; 303m above sea level; 2.15km wide; and around 110m maximum depth) (Schliewen 2005; Lebamba *et al.* 2010).

Lake development

Whether formed by impact or vulcanism, craters that persist anywhere may periodically or permanently fill up with water from snow, rainfall, groundwater, a captured drainage, spring or swamp or a larger inundation. Depending on water supply, drainage and evaporation, the lake may reach the lowest point on the rim and then overspill as a waterfall if the rim is high; or as a stream, if at the outset the rim is low or becomes water eroded. At a critical point of attrition there can be catastrophic breakout flooding. If the crater contains an active volcanic vent (see 'diatreme' above) the water will have an elevated temperature and be turbid and acidic from high concentrations of dissolved volcanic gases and distinctly green, or red-brown if iron rich. Gases include carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrogen chloride (HCl) and hydrogen fluoride (HF), which may persist in solution and are lethal to invertebrate and vertebrate life.

Lake Nyos, with a diatreme some 80km below the lake bed, is one of only three known contemporary 'exploding' and periodically lethal lakes, all of which are African (the others being nearby Lake Monoun, Cameroon (5°35'N, 10°35'E) and Lake Kivu, Rwanda). Nyos and Monoun are located within the Oku Volcanic Field near the northern boundary of the Cameroon Volcanic Line, a zone of volcanoes, maars, calderas and other tectonic activity that extends south-west to the large, inactive Mount Cameroon composite volcano (stratovolcano) and beyond to the island of Bioko in the Gulf of Guinea, which also contains an unexplored crater lake (Flesness, pers. comm.). Nyos has periodically been supersaturated with carbon dioxide (CO_2, forming carbonic acid) leaching from the underlying magma and with a peak lake density of approximately 90 million tonnes of CO_2. In 1986, there was a gaseous explosion, perhaps precipitated by an earthquake or landslide, releasing approximately 1.6 million tonnes of CO_2 into the atmosphere. This killed some 1,800 people, 3,500 livestock, and gas in solution presumably killed fishes and other aquatic life. Degassing pipes were installed in 2001 to prevent a repetition of the catastrophe (Kling *et al.* 2005). Some 2,000 times larger than Nyos, Lake Kivu has also been found to be periodically supersaturated – with evidence for outgassing every thousand years or so. The general ability of crater lakes to store carbon dioxide at depth for long periods and also release it is clearly important when calculating lake stability, contemporary carbon sequestration and 'footprints' – and in determining the survival, ecology and evolution of fishes and other aquatic animal populations.

> "The craters represent a younger, less complex (if potentially more volatile) ecosystem – a 'microcosm' more easily studied than the East African Great Lakes

In the case of large mature impact craters and inactive or dormant volcano craters, the water normally becomes thermally and eventually ecologically stratified. The deep, cold, dense, aphotic and anoxic water above the lake bed is usually quite separate from the warm, less dense, sunlit surface layers which support most of the animal and plant species and biomass. Lake surface waters down to around 40m are usually life supporting and fresh but can, in some instances, be saline. The clarity or transparency (and hence transmission of sunlight, level of photosynthetic activity and primary production) can be high, but this is determined by the nature of the crater rim soil and biota above the waterline (Elenga *et al.* 2004; Lebamba *et al.* 2010), nutrients, water movements (including inflows, outflows and overturns of thermal strata), and by other limnological processes. Some crater lakes are of considerable maturity and scale, for example, the Lake Toba caldera, Danau Toba, Indonesia was formed around 70,000 years ago, with an area of over 1,000km^2. By contrast, Lake Barombi Mbo is small and estimated to be biologically mature since about 25,000 to 33,000 years ago; it is considered to be the oldest radiocarbon-dated crater lake in Africa (Elenga *et al.* 2004; Lebamba *et al.* 2010). The physical origin of the lake has been estimated as around 1 million years ago (Schliewen 2005). In any event, there is contemporary evidence that substantial permanent bodies of water can form very quickly in craters, for example, the lake that developed post 1991, following the eruption of Mount Pinatubo, Philippines.

Lake colonisation and the evolution of species. Western African and other small crater lakes have attracted the attention of evolutionary biologists and conservationists mainly because of their endemic cichlid fishes and the natural and anthropogenic threats to their survival. The craters represent a younger, less complex (if potentially more volatile) ecosystem – a 'microcosm' more easily studied than the East African Great Lakes. Such craters provide an opportunity to investigate stages in ecological colonisation from an initially lifeless environment, and the processes of population differentiation and speciation. While invariably occupied by invertebrates, not all western African crater lakes contain fishes and shrimps (Schliewen 2005). For those which contain cichlids, and which are geologically isolated, the question of how they came to occupy the crater is intriguing. In some cases, there are potentially testable hypotheses of natural migration through large-scale paleo-historical indundations of water, or via crater stream outflows (some still extant). Notions of paleo-historical introductions of fishes or eggs by humans or birds are less credible and difficult, or impossible, to test scientifically. Setting such possibilities aside, western African models of tilapiine cichlid speciation or adaptive radiation are being tested against the classical grand-scale eastern African model (Klett and Meyer 2002; Salzburger and Meyer 2004; Seehausen 2006).

Evidently, the evolution of species flocks is not invariably an enclosed, lacustrine phenomenon or confined to cichlid taxa. However, for Salzburger and Meyer (2004): 'Species richness seems to be roughly correlated with the surface area, but not the age, of the lakes. We observe that the oldest lineages of a species flock of cichlids are often less species-rich and live in the open water or deepwater habitats.' Based initially on Lake Victoria, the general eastern African hypothesis is that haplochromine and other cichlid taxa evolved into lacustrine species flocks numbering in the hundreds through a process of allopatric speciation, that is, one involving periodic geographical separation of populations. It was suggested that a regular rise and fall of waters in geological time created satellite lakes to isolate cichlid populations, which then differentiated ecologically, morphologically, behaviourally and genetically into distinct species. These isolates supposedly later returned to the main lake during high paleo-historical water levels ,but by that time did not interbreed with their congeners.

An alternative model is that species can arise as monophyletic flocks within the body of a lake without such total isolation, that is, through a process of sympatric speciation. In testing these competing (but not necessarily mutually exclusive) models, Schliewen *et al.* (2001) conducted a 'gene flow' study within five tilapiine morphs endemic to Lake Ejagham, western Cameroon (5°44'59"N, 8°59'16"E; surface areas 0.49km^2; maximum depth around 18m (Schliewen 2005)). Comparisons with a closely related riverine outgroup of cichlids suggest that synapotypic colouration and 'differential ecological adaptations in combination with assortative mating could easily lead to speciation in sympatry' (Schliewen *et al.* 2001). More generally, it is postulated that a dynamic network of gene exchange or hybridization among populations creates a process of 'reticulate sympatric speciation' among Cameroonian crater lake cichlids (Schliewen *et al.* 1994; Schliewen 1996, 2005; Schliewen and Klee 2004). Comparable empirical research on post-colonisation cichlids in a young crater lake in Nicaragua also supports the idea that sympatric endemic 'morphs' of individual cichlid species may diversify rapidly (say, within a hundred years or generations) in ecology, morphology and genetics and this can be interpreted as 'incipient speciation' (Elmer *et al.* 2010). Again, this is postulated to be through disruptive selection, perhaps sexual selection, mediated by female mate choice.

Conservation of crater lake fishes. The phylogenetic and associated data on crater lake cichlid species flocks (above) are at different levels of generality and, among other criteria, important in the evaluation of conservation priorities (Stiassny and de Pinna 1994). However, a paucity of well-worked and wide-ranging studies has until recently limited such contributions (Stiassny 2002; Stiassny *et al.* 2002). Even so, western African crater lakes are included as an important biogeographic category within standard recognised freshwater ecoregions of the world and Africa (Thieme *et al.* 2005; Abell *et al.* 2008).

Thieme *et al.* (2005) designate closed basins and small lakes as a 'major habitat type', whose ultimate conservation status within most of the western African block of ecoregions is under threat 'based on projected impacts from climate change, planned developments, and human population growth'. Recent research on pollen, biomes, forest succession and climate in Lake Barombi Mbo crater during the last 33,000 years or so suggests the persistence of a humid, dense, evergreen cum semi-deciduous forest: 'These forests display a mature character until *ca* 2800 cal yr BP then become of secondary type during the last millennium probably linked to *increased human interferences* [our emphasis]' (Lebamba *et al.* 2010).

The recent conservation status of small Cameroonian crater lakes, including Barombi Mbo, and their endemic fishes and invertebrates, is considered in detail by Reid (1989, 1990a,b, 1995, 1996) and Schliewen (1996, 2005). Such unique lake environments and endemic species are clearly of national and international importance. There is, from the outset, an inherent vulnerability of these ecosystems resulting from the geological instability in craters; their small physical size; the small size of the contained populations and their genetic isolation; and, for cichlid fishes, their methods of reproduction and limited fecundity. Actual or potential general threats are widely familiar, including: overfishing and other socio-economic factors, including pressure from external visiting tourists; the introduction of alien species (for example, crustaceans and fishes (Slootweg 1989)); siltation and a reduction or loss of allochthonous food supply of terrestrial plant material and invertebrates (both resulting from deforestation and slash and burn agriculture within the crater rim); adverse water level fluctuation (from damming the lake outflow and from excessive abstraction); and water pollution (from natural volcanic gases, from aerial and industrial emissions travelling from a distance; and from locally applied agrochemicals, pesticides and ichthyotoxic molluscicides used to control the aquatic snail vectors of human schistosomiasis, at least endemic in Barombi Mbo).

Among conservation recommendations that have been proposed by the authors (above) are: systematic Population and Habitat Viability Analyses, as formulated by the IUCN Conservation Breeding Specialist Group; Red List threat assessments (as summarized in this volume); the formal designation of lakes as legally and practically protected aquatic nature reserves of national and international importance, with an accompanying conservation action plan (Lakes Barombi Mbo and Ejagham have now been designated as forest reserves (Schliewen 2005)); and ex situ programmes for the conservation breeding of species at risk, with the prospect of eventual reintroduction in appropriate circumstances (such ex situ aquarium breeding programmes have been in operation since 1999 through European and North American Fish Taxon Advisory Groups). Despite the persistent threats outlined above, a survey of Lake Barombi Mbo in 2002 found all fish species to still be present (Schliewen 2005). However, many of the species present are threatened (even Critically Endangered), but there have been no recorded fish or invertebrate population declines to the point of extinction in any of the crater lakes. Nevertheless, continued vigilance, conservation monitoring, threat assessment, mitigation and protective measures remain highly appropriate.

Chapter 4.

Freshwater molluscs of Africa: diversity, distribution, and conservation

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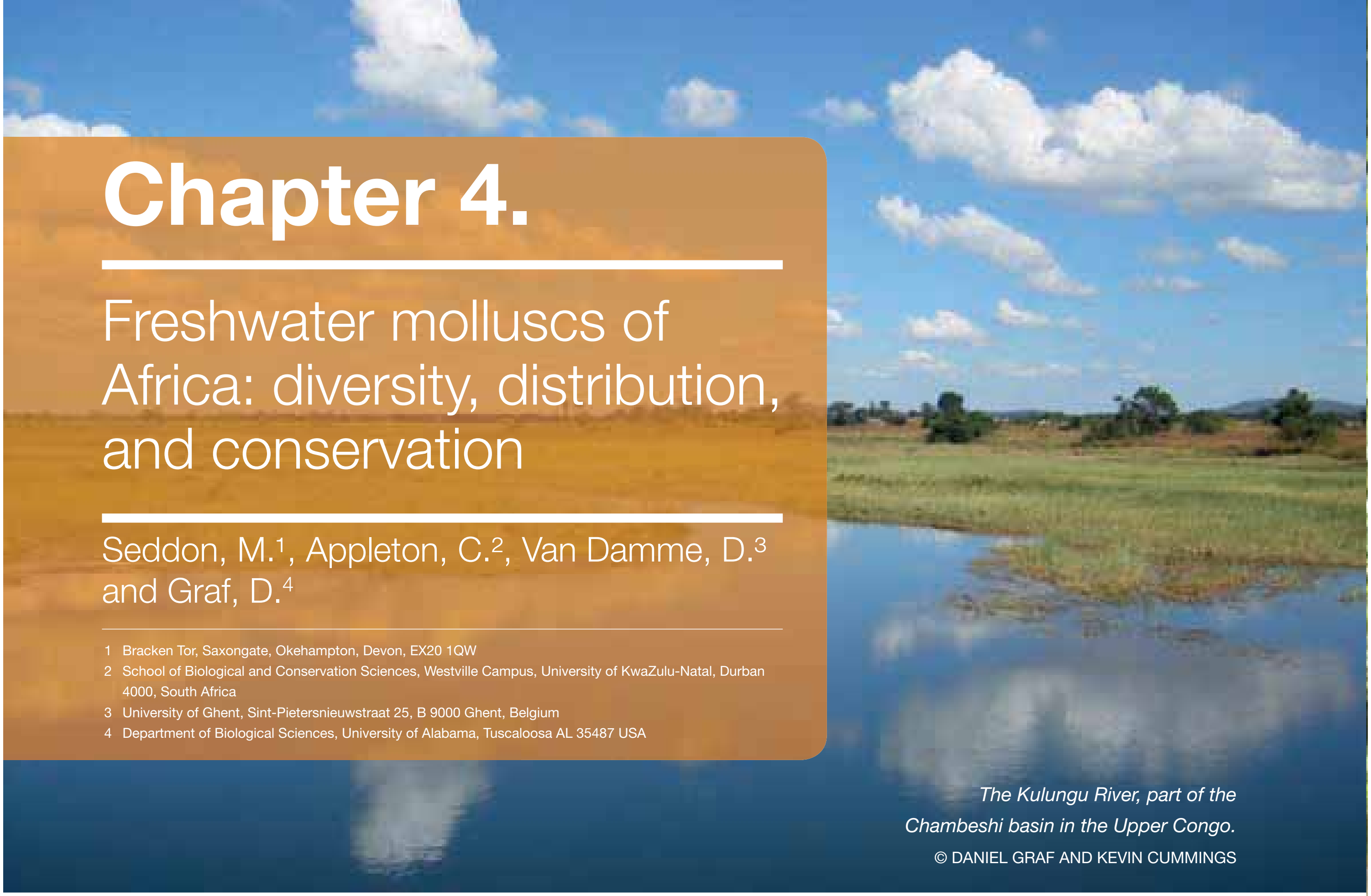

The Kulungu River, part of the Chambeshi basin in the Upper Congo.
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Diving for mussels in the Upper Chambeshi River, Upper Congo.
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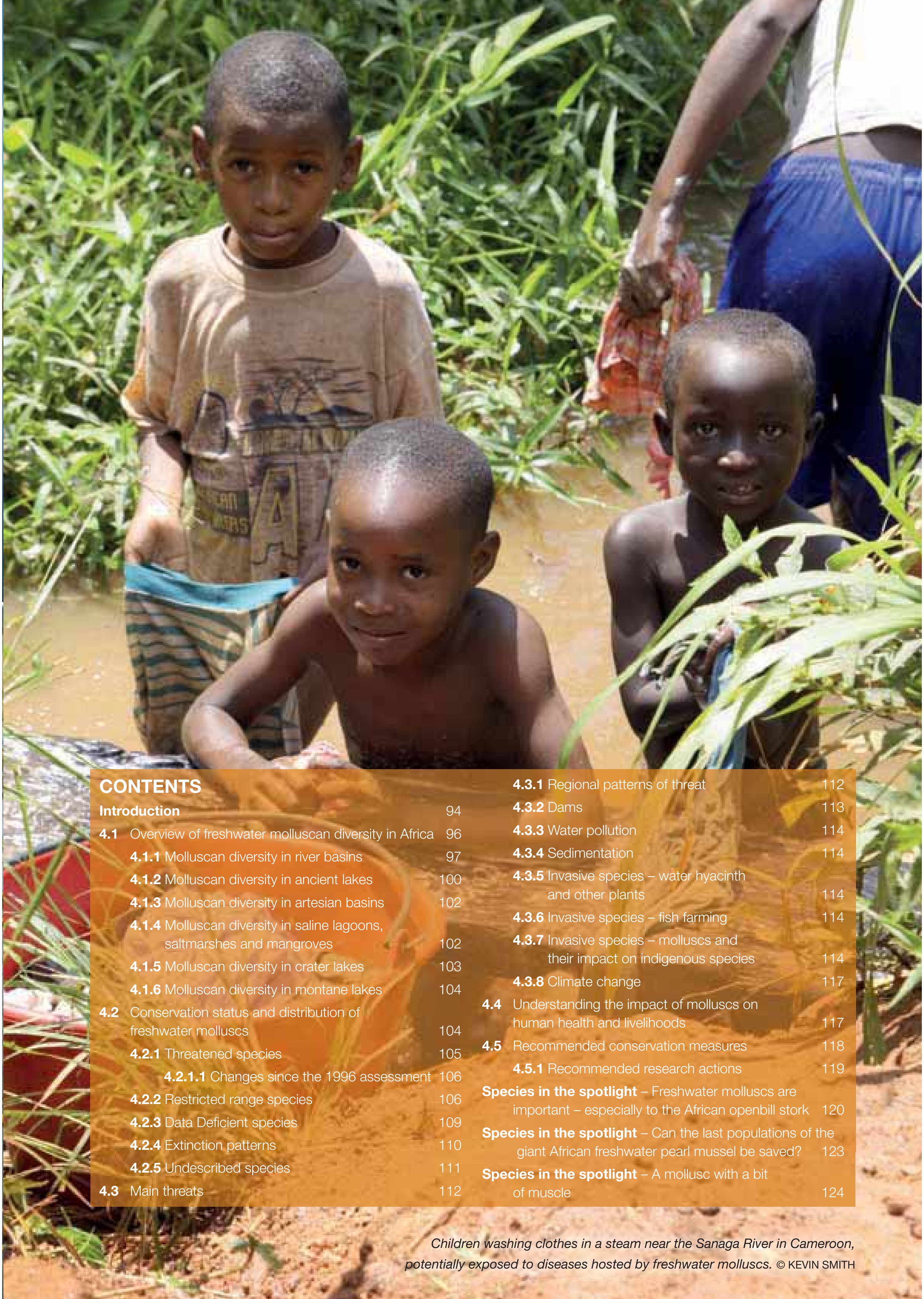

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Children washing clothes in a steam near the Sanaga River in Cameroon, potentially exposed to diseases hosted by freshwater molluscs. © KEVIN SMITH

Introduction

Freshwater molluscs (bivalves and gastropods) are found in a wide range of freshwater habitats, have varied life-history strategies and exhibit complex ecological interactions, all of which underscore their use as proxies for understanding our changing freshwater diversity. In general, the freshwater molluscs of Africa are less diverse than some continental faunas such as in North America and Europe, with only an estimated 560 species compared to around 880 species for North America and around 1,540 species for the Palaearctic (of which there are about 780 European species) (Seddon pers. comm.; Bogan 2008). Freshwater molluscs fall into two main groups, the Bivalvia and the Gastropoda, with the latter dividing into two informal groups, the prosobranchs and the pulmonates. The Bivalvia are less numerous than the Gastropoda, with the pulmonates containing a higher proportion of the widespread, more cosmopolitan species. Most research efforts in recent years have, however, concentrated on the freshwater Unionid mussels and the prosobranchs. We need to recognise that the tropical freshwater molluscs have not yet received the same level of attention as European and North American faunas, and that as taxonomic reviews continue – especially those utilising molecular systematics – the number of known species may well multiply, as has happened in studies of some genera already. In northern Africa, the level of field survey, combined with review of historical collections, is rapidly changing the number of known species (Van Damme *et al.* 2010), as is also the case in Lake Tanganyika (West *et al.* 2003), and these areas can be expected to have an increased number of endemic species described over the next five years.

From 2003 to 2009, the regional status of molluscs in eastern, southern, western, northern and central Africa were determined through a series of assessments (Darwall *et al.* 2005; Kristensen *et al.* 2009a,b; Van Damme *et al.* 2010; Graf *et al.* 2011). This chapter synthesises the results for the entire pan-African molluscan fauna, providing an overview of the threats to the continental fauna and highlighting the regions and species that require further conservation actions. For a synthesis of results presented by taxonomic grouping rather than region, please see the accompanying DVD.

Exploration of African freshwater molluscs commenced during the periods of colonial expansion throughout the continent (Brown 1994). Adanson was one of the earliest malacologists in Africa, and described some of the first molluscs from regions including western Africa. Some regions, such as southern Africa, have received attention throughout the last two centuries, with Connolly's various monographs (e.g., Connolly 1939) as well as Germain's studies for Mozambique (Germain 1935). In comparison north-eastern Africa, central Africa and western Africa have received relatively little attention in the last 50 years. The eastern African fauna received more attention, partly due to the unusual fauna of the ancient Rift Valley. The early studies of Lake Tanganyika by researchers such as E.A. Smith and K. von Martens have been considerably revised as the result of more recent survey work. In the 1950s, E. Leloup (1935) and G. Mandahl-Barth both published volumes on East African lake faunas. More recently, a revised handbook to Gastropods of Lake Tanganyika has been produced (West *et al.* 2003), and further research incorporating molecular systematics continues on selected prosobranch families. Recent research by C. Albrecht is revealing more on the origins of the Ancylinae (now a subfamily in the Family Planorbidae), and further research efforts are looking at the origins of other pulmonate genera. Africa has, for the last 50 years, also been the focus of attention for taxonomic studies related to molluscs of medical importance. Two notable scientists contributed the majority of the work in the early days, Mandahl-Barth and D. Brown. Brown's monograph (Brown 1994) remains the most complete handbook to the identification of the freshwater gastropods to date. Mandahl-Barth established the Danish Bilharzia Laboratory, which hosted many training programmes supporting a generation of young scientists in Africa, and produced many research papers and small handbooks. Many of the host species are pulmonates, and as such, these taxa have been the focus of various studies over the last 30 years.

By contrast, there are few studies of the Bivalvia, with most activity presented in the catalogues of Daget (1998) and Mandahl-Barth (1988). These volumes provide two rather different views of the status of bivalves, reflecting the nature of the two taxonomic schools of splitting and lumping, but neither is based on definitive data, mainly on opinions of the variability of the form of species shells (Graf pers. comm.). As such, the regional treatments in this project have differed depending on which was taken as the initial basis for the taxonomic list. For example, in freshwater mussels, the genus *Chambardia* has been assigned in different ways in the various regional reports. Through the late 1990s, Mandahl-Barth (1988) and others referred to the genus as *Spathopsis*. However, given the species circumscribed under this taxon, it has since been recognized that the name *Chambardia* has nomenclatural priority (Vaught 1989; Daget 1998). The basis for the confusion seems to have been that the type species of *Chambardia, C. letourneuxi*, was described from (sub)fossil shells, and neontologists took a conservative approach to relating that material to living forms (Graf, pers. comm.). Regardless, while the name has changed, the taxonomic concept of the genus *Chambardia* is interchangeable with that of *Spathopsis*, so confusion should be limited. As such, there are some species which the pan-African project considered valid, that were omitted in the earlier regional assessments, and hence could not be evaluated for their overall pan-African status. Most of these would

Tiphobia horei *(LC), a species endemic to Lake Tanganyika, where it is locally impacted by sedimentation, dredging and collection for the shell trade.* © HEINZ H. BÜSCHER

be assessed as Data Deficient or Least Concern. This variability in knowledge from family to family and between regions presented a considerable challenge to this assessment and, although ongoing research has considerably increased our knowledge of the fauna, there remains a pressing need for continued investment and training to build on the current knowledge base.

Freshwater gastropods

Freshwater gastropods represent about 75% of all freshwater molluscs in the African continent, dividing into two informal groups, the prosobranchs and the pulmonates. Bouchet and Rocroi (2005) revised the higher phylogeny of Mollusca, noting that "Prosobranchia" could no longer be supported as a formal designation, as it was polyphyletic, with multiple origins within the group. Now there are two major clades, the Caenogastropoda and the Heterobranchia, along with smaller clades such as Neritimorpha. Within the informal group "Pulmonata", similar problems have also been found, however most of the freshwater species lie in the Basommatophora, within the Eupulmonata. Brown (1994) estimated that there were 326 species in Africa, but more species have been recognised in this current study as new species have been described and molecular systematics allowed some taxa to be revised.

Freshwater prosobranchs are most varied within the lakes and larger river systems, whereas freshwater pulmonates are more often associated with small water-bodies and many are tolerant of seasonal drying. In total, 353 species of prosobranch and 143 species of pulmonates are recognised here, in the families Lymnaeidae, Planorbidae, and Ancylinae. There are also a number of introduced species in the family Physidae that have not been evaluated given that Africa is outside their native range.

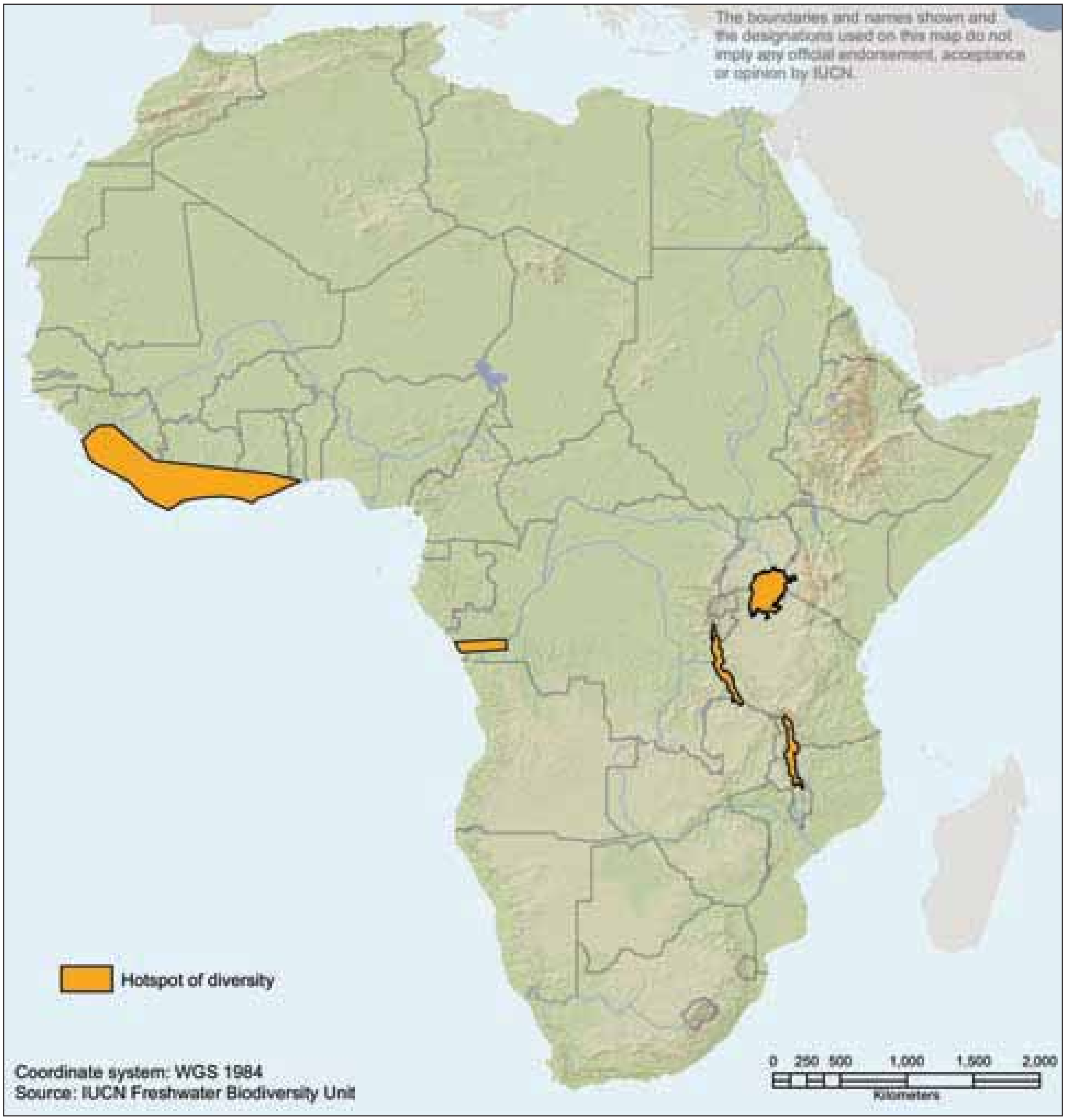
Freshwater bivalves

The freshwater bivalves represent approximately 25% of the freshwater mollusc fauna of the African continent. In total, we recognise 158 species (28 genera, nine families, two orders) of bivalves in Africa, including 17 species that were not evaluated as part of this project due to differences in taxonomic treatments in the regional assessments that provide the basis for the final pan-African assessments.

The bivalves are divided into two globally distributed orders: Unionoida (otherwise known as freshwater mussels) and Veneroida (otherwise known as clams and pea-clams). Freshwater mussels contain the higher number of species (82 species). All unionoid species are strictly freshwater, and in Africa these molluscs are common and often locally abundant inhabitants of both rivers and lakes. Similarly, the Veneroida (56 species, including five species not evaluated) occupy a wide range of habitats, from brackish estuarine waters to interior lentic and lotic environments, although there are more cosmopolitan taxa in the pea-clams (Sphaeriidae). All of the freshwater bivalves possess a common suite of adaptations to life in freshwater. These include larval brooding, direct development, and, in the case of freshwater mussels, obligate larval parasitism upon freshwater fishes (Wächtler *et al.* 2001; Cummings and Graf 2009). Despite these common characters derived

Unionid mussels collected from Malebo Pool in the Republic of the Congo; Chelidonopsis hirundo *(LC),* Mutela legumen *(VU),* Aspatharia pfeifferiana *(LC),* M. "rostrata"*,* Coelatura rotula *(VU),* C. gabonensis *(LC) and an unidentified snail.* © OLIVERLUCANUS/BELOWWATER.COM

Figure 4.1. Hotspots of freshwater mollusc diversity across continental Africa (highlighted in orange) (data compiled by Bouchet and Gargimony, adapted from Groombridge and Jenkins 1998).



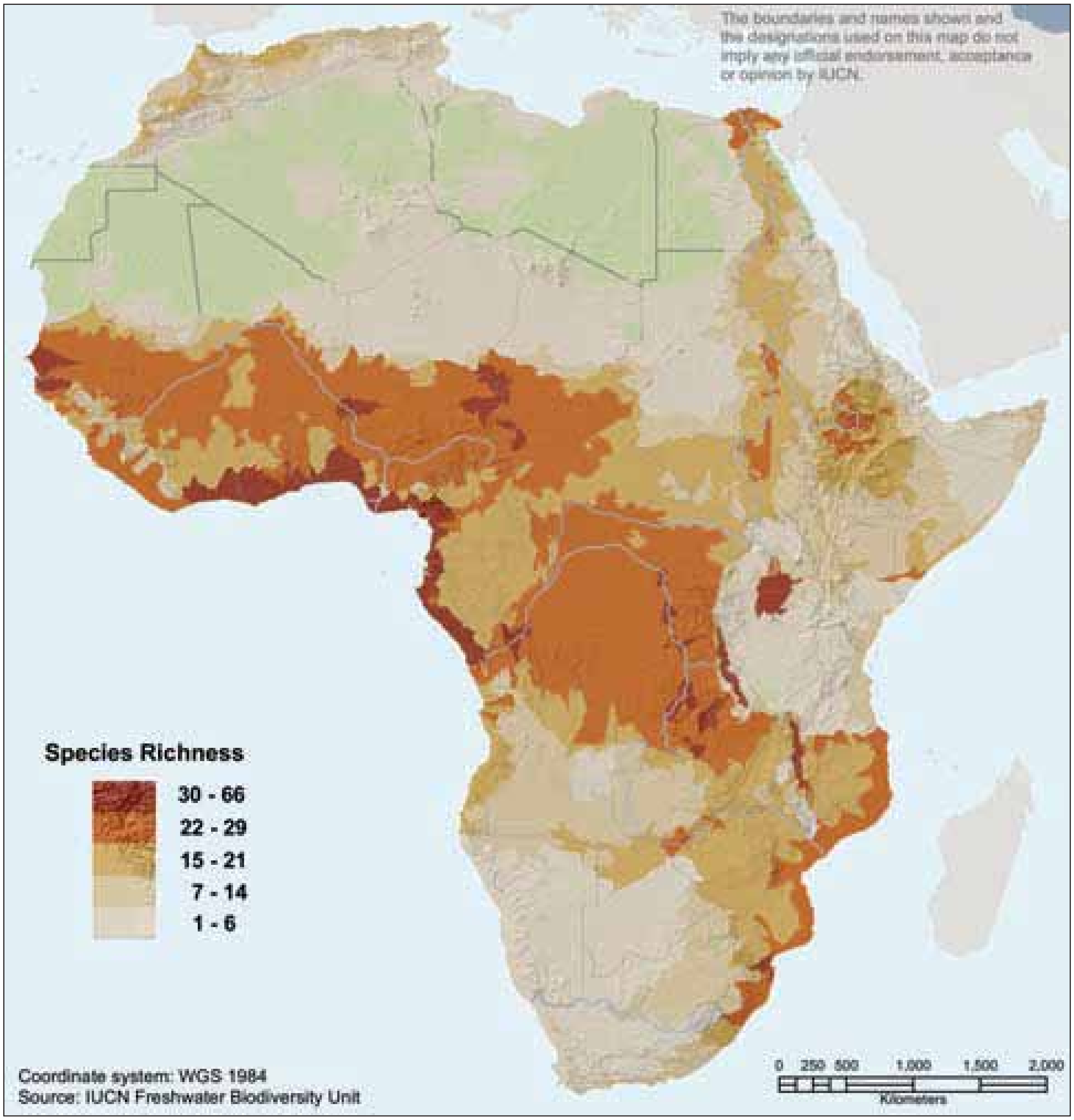
from shared environmental pressures, these bivalve taxa represent different evolutionary lineages and, as a result of their disparate life histories, demonstrate a range of patterns of dispersal and abundance.

4.1 Overview of freshwater molluscan diversity in Africa

Freshwater molluscs find their highest levels of endemism and diversity in ancient lakes, large river basins and artesian basins (Seddon 2000), and all of these habitats can be found in the different regions of Africa. Bouchet and Gargimony (in Groombridge and Jenkins 1998) provide a generalised map of the projected hotspots of molluscan freshwater diversity in the world, highlighting various parts of Africa, namely the East African Rift Valley Lakes and the river rapids of western Africa (Figure 4.1). The outputs of the current pan-African project now allow an in-depth comparison (Figure 4.2) of the hotspots of species diversity of Africa as defined in 1998, and enable this picture to be refined on the basis of actual mapped species distributions, rather than experts' best estimates.

African freshwater mollusc fauna is geographically divided into the regions north of the Sahara, where the affinity of the fauna lies with the Palaearctic fauna, and the regions south of the Sahara where an Afrotropical fauna dominates. The exception is north-eastern Africa which has elements shared with the Palaearctic fauna, the Arabian fauna and

Figure 4.2. Patterns of species richness for all mollusc species. Species richness = number of species per river/lake sub-catchment.



Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

the African fauna (Van Damme *et al.* 2010). The southern line for the Palaearctic fauna is generally drawn through the Ahagger Mountains, north-east towards Libya and west to Mauritania (Sparks and Grove 1961).

The regions highlighted in this study as having the highest species diversity (Figure 4.2) include the East African Lakes (Lake Victoria, Lake Tanganyika and Lake Malawi), the Upper Congo catchments around Lake Mweru, the river rapid regions of western Africa, and the Lower Congo Rapids. Additional regions of interest not previously highlighted in Bouchet and Gargimony's analysis (Figure 4.1) include the North African spring-snails, the East African coastal rivers, Lower Nile River, the Lake Chad basin and Malebo Pool in the Congo Basin.

4.1.1 Molluscan diversity in river basins

The two largest freshwater systems in Africa are the Nile and the Congo rivers. The habitats of the largest, the Congo River, are the less diverse, consisting mainly of rainforest rivers and large rift lakes (Thieme *et al.* 2005). Brown (1994) and Van Damme and Van Bocxlaer (2009) compared the species richness of the fluvial mollusc faunas of these two river basins, with exclusion of the large lakes. Brown pointed out that the number of gastropods known from the Nile Basin (51) is about half that of the Congo (96) (if we take the taxonomically deficient genera *Ferrissia* and *Burnupia* as genera only), and the proportion of basin endemics is much lower, namely 10 out of 51 species. Similarly, for the bivalves, species diversity is lower in the Nile Basin, with a

The Kulungu River, part of the Chambeshi basin in the Upper Congo. © DANIEL GRAF AND KEVIN CUMMINGS

total of 28 species compared to 38 in the Congo drainage, and the degree of bivalve endemism is dramatically lower in the Nile Basin with only five species endemic to the Nile Basin as compared to 18 in the Congo Basin (Daget 1998; Graf and Cummings 2007a,b). Van Damme and Van Bocxlaer (2009) also observed dissimilarity in the habitats where this diversity is found. While the highest species richness of the Congo Basin is for specialist taxa that live in the rivers and lakes, the highest diversity in the Nile Basin is of generalist taxa living in fringe habitats, such as temporary pools. In the Congo Basin prosobranch snails and unionoid bivalves are overwhelmingly dominant, while in the Nile Basin pulmonate snails and smaller clams and pea mussels (Families Sphaeriidae and Corbiculidae) are more abundant. In the Lower (Egyptian) Nile and in the Ethiopian Highlands, as with the Maghreb zone (Morocco, Algeria, Tunisia and Libya), components of the Palaearctic fauna occur, including widespread species at the southern limits of their range, along with a limited number of endemics with a Palaearctic origin. Van Damme *et al*. (2010) suggest this pattern stems from the main invasion of freshwater molluscs into Africa via the Horn of Africa in Middle and Late Miocene times (23 to 5.3 million years ago).

Congo Basin: The fauna from the Congo Basin includes some rare and range restricted species. For example there are three monotypic genera in the family Bithyniidae, *Gongodoma, Liminitesta* and *Funduella,* which are all adapted to life on stones in fast flowing streams, and are exclusively found in the Lower Congo area. These genera are probably relicts, as are the similar taxa in western Africa. In the family Ampullaridae, another species, *Lanistes neritoides,* which was recently discovered in a tributary of the Kouilou River (Republic of the Congo), inhabits similar habitats, where it lives like a limpet fixed on rocks in shallow fast flowing water. This species is the only *Lanistes* species listed as Critically Endangered. In the family Assimineidae, one of the five genera recognized in Africa by Brown (1994) is *Assiminea* (which is fairly cosmopolitan, as it is spread by birds), another (*Eussoia)* is African and ranges from Somalia to Mozambique (four species), whilst *Pseudogibbula*, *Valvatorbis* and *Septariellina* (four species) are restricted to the fast flowing part of the Lower Congo River. All representatives of these three genera are listed as Critically Endangered due to their restricted ranges and identified threats. In the family Paludominidae, the genus *Pseudocleopatra* is restricted to the Lower Congo and the Volta River, and its representatives are rare within these basins. Fossil evidence shows that this is a relict distribution and that the genus' range formerly extended to eastern Africa (Van Damme and Pickford 2003). In the family Thiaridae the Afro-Asian genus *Melanoides* is highly speciose, but only one species, *Melanoides tuberculatus*, is found throughout Africa (and Asia), while most of the other *ca* 30 parthenogenetic species are restricted to the large African lakes and the Congo, with the highest species richness found in the Congo Basin, where 12 species are recorded. Species of *Potadoma* (which was moved from Thiaridae to Pachychilidae on the basis of molecular research (Köhler and Glaubrecht 2002)) are found in the rapids of the Lower Congo and also in eastern and north-eastern Congo, and some of these are threatened.

Western Africa: The western African region is recognised as one of the hotspots of terrestrial biodiversity (Mittermeir *et al.* 1998), and the presence of some unique Prosobranch genera in the short, fast-flowing rivers draining the west Africa plateau is a reflection of the area's high diversity. The rivers draining the west Africa plateau have localized range restricted species, including two genera, *Sierraia* and *Soapitia* (family Bithyniidae), that are adapted to life on stones in fast-flowing streams in Sierra Leone and Guinea, and these genera are considered to be threatened as well as being potentially quite ancient and relict in origin. The River Niger is less diverse than many of the smaller, fast-flowing rivers that drain the west African plateaus (Thieme *et al.* 2005). In this region and in the Congo, the *Potodoma* species in the family Pachychilidae has a disjunct dispersion (in the Atlantic rivers from Liberia to Lower Congo and also in eastern and north-eastern Congo). This ancient taxon formerly had a much wider distribution, reaching as far east as the Turkana Basin (Van Bocxlaer *et al.* 2008). The highest species richness is found in Cameroon, with seven species, most of which are threatened. Within the freshwater mussels the genus *Nitia* is limited to Nilo-Sudanic Africa, including the Senegal, Niger, Chad, and Nile Basins. The species of this genus have frequently been subsumed under the catchall genus, *Coelatura* (Mandahl-Barth 1988; Scholz and Glaubrecht 2004), but we regard *Nitia* as a morphologically distinct group of species, worthy of separate recognition (Daget 1998; Graf and Cummings 2007a). Three species of *Nitia* are listed from Africa (plus one that was not evaluated), all of which are assessed as either Least Concern or Data Deficient.

The Niger River basin contains fewer endemic species of freshwater molluscs than the Congo and Nile river systems. Similarly, other rivers such as the Senegal, Orange, and Zambezi, whilst having reasonable species diversity, have relatively few endemic species. Some of these western African rivers do, however, require specific conservation actions to safeguard the few rare and unique species occurring in the fast-flowing, highly oxygenated waters of the river rapids.

North-west Africa: The freshwater mussels of this region are largely within the genera of *Unio, Anodonta, Leguminaia* and *Potomida* that inhabit the Palaearctic region of northern Africa, the Maghreb, and parts of Europe. The genus *Anodonta* is a widespread Eurasian and North American genus that, in the western Palaearctic, reaches

The Oued Za in Morocco, a typical river of the Maghreb.

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its southern limit in north-western Africa. Populations in the Maghreb are represented by two species, although there is disagreement among malacologists as to which two species of *Anodonta* they are. The more traditional view has been that the populations in Morocco and Algeria are conspecific with two widespread but declining European species, *A. cygnea* and *A. anatinus*. Those taxa are both morphologically variable and widespread in the western Palaearctic, extending east from the British Isles and Iberia into Russia and Central Asia (Araujo *et al.* 2009). However, the traditional concepts of Palaearctic genera and species are holdovers from early in the last century, and they have only just begun to be re-evaluated using modern analytical methods and species concepts (Graf 2007). More recent work (Van Damme *et al.* 2010; Araujo pers. comm.) suggests that these north-western African populations may represent endemic species *A. pallaryi* and *A. lucasi*. Due to their restricted distribution ranges, and the threats to the rivers they inhabit, both species are ranked as Critically Endangered. *Unio* is another typically Palaearctic genus, but with a wider distribution in northern, eastern, and southern Africa. In total, four *Unio* species are recognized from the continent, three of which are threatened. Four new species, *Unio gibbus*, *U. delphinus*, *U. ravoisieri*, and *U. mancus*, have recently been recognized as occurring in the Maghreb of north-western Africa; all four are also found in the adjacent Iberian peninsula (Araujo *et al.* 2009). Neither *U. ravoisieri* nor *U. delphinus* were evaluated as part of this project, being only recently removed from synonymy with other species. Here we treat the north-western African populations of *U. gibbus* as a separate endemic species, *U. foucauldianus* (Critically Endangered). Moreover, we regard the African populations of *U. mancus* to be another African endemic species, *U. durieui* (Endangered). The latter species is the most widespread of the Palaearctic-*Unio* assemblage, extending from the Maghreb to the Nile, as well as the Turkana Basin.

4.1.2 Molluscan diversity in ancient lakes

In Africa, the ancient lakes are mainly located in the rift valleys that lie between eastern and central Africa and have long-been recognized for their high endemism and diversity of molluscs (West *et al.* 2003; Michel *et al.* 2004), and this is confirmed here (Figure 4.2). Other smaller lakes do not have the same levels of isolation and evolutionary change recognized in the ancient lakes, although Brown (1994) points out that even these small lakes may have been isolated for sufficient periods for the presence of distinctive species to evolve.

A Lake Tanganyika gastropod (demonstrating shell repair) from the genus Lavigeria. © HEINZ H. BÜSCHER

In general, the prosobranchs are most diverse in the three largest lakes, Tanganyika, Victoria and Malawi (Table. 4.1), whilst there is a more limited diversity and endemism of the pulmonates (Brown 1994).

Lake Tanganyika is viewed as one of the oldest and deepest of the East Africa Rift Valley lakes, with approximately half of the Metazoan fauna being endemic to the lake (West *et al.* 2003). The endemic prosobranchs are principally found in the littoral and sub-littoral zones (Leloup 1953; Brown 1994), and some endemic species have spectacular ornamentation, with shell-forms called thalassoid, meaning

Table 4.1. Freshwater gastropod fauna of the largest African lakes (Based on Brown 1994 and additional data):

Lake	Altitude (m)	Area (km^2)	No. of species	No. of lake endemics
Lake Tanganyika	773	32,900	83	65 species
Lake Victoria	1,240	75,000	28	12 species/subspecies
Lake Malawi	473	29,600	27	17 species
Lake Chad	280	20,000	21	3 species/subspecies
Lake Albert	615	5,600	16	8 species/subspecies
Lake Mweru	922	4,850	15	8 species/subspecies
Lake Edward	920	2,150	15	4 subspecies
Lake Tana	1,829	3,156	10	0 species
Lake Kivu	1463	2,700	7	1 subspecies
Lake Turkana	375	7,200	4	1 subspecies

Table 4.2. Freshwater bivalve fauna of the largest African lakes.

Lake	Altitude (m)	Area (km²)	No. of species	No. of lake endemics
Lake Victoria	1,240	75,000	17	6 species/subspecies
Lake Chad	280	20,000	12	1 species/subspecies
Lake Mweru	922	4,850	12	4 species/subspecies
Lake Tanganyika	773	32,900	11	8 species
Lake Turkana	375	7,200	10	1 subspecies
Lake Malawi	473	29,600	8	3 species

‘sea-like’, as there is a marked convergence with marine shells. Brown (1994) suggests that few molluscs are found below 125m depth, due to the concentration of hydrogen sulphide.

Freshwater prosobranchs: In the family Paludomidae, 20 genera belong to the subfamily Hauttecoeuriinae, and 19 of these are restricted to Lake Tanganyika. The most speciose genus is the non-thalassoid rock dwelling genus *Lavigeria,* which is thought to include 18 species. However, although a diagnostic key does exist, a number of these species have not yet been fully described, being indicated by *Lavigeria* sp P, *Lavigeria* sp X, etc. (West *et al.* 2003). These species vary in their threatened status, depending on their range and the localized impacts of sedimentation along the lake shore. These species groups would benefit from review once the taxonomy has been revised, as more species may be found to be threatened if their ranges are more restricted than currently thought. The numerous prosobranch species, with extremely variable shapes, led Michel *et al.* (2004) to suggest that the lake molluscs formed species flocks in the same way as the cichlid fishes (West *et al.* 2003). Various fish, also endemic to the lake, are dependent on the presence of these molluscs as their food source.

Freshwater bivalves: Richness of bivalves is lower than that of gastropods in the largest African Lakes (see Table 4.2) There are three genera of African freshwater mussels that are each monotypic and endemic to Lake Tanganyika. *Grandidieria burtoni* and *Pseudospatha tanganyicensis* are assessed as Least Concern, but *Brazzaea anceyi* is considered Vulnerable. Other mussels, such as *Nyassunio ujijiensis*, are known from few specimens, and as a result their status is Data Deficient. Another genus, *Moncetia,* is represented by a single species *M. anceyi,* which is apparently also endemic to Lake Tanganyika and is listed as Near Threatened. Mandahl-Barth (1988) considered *Moncetia* to be a synonym of *Chambardia* (and *Spathopsis*), and reported that this species had never been collected alive; however he was apparently unaware of the study by Kondo (1984).

Lake Malawi is less saline and shallower than Lake Tanganyika, with a mollusc fauna which is about 60% endemic to the lake and with no gastropod taxa shared between the two lakes (Brown 1994). The shore is mixed, with rocky shores separated by sandy bays and small estuaries, and the lake-level is known to be subject to seasonal changes in rainfall since the Quaternary Period. Currently, no endemic genera are recognized in Lake Malawi, unlike in Lake Tanganyika. Again, there are a number of lake endemic molluscivorous fish that are dependent on the presence of molluscs as their food source. A number of genera are highly specious in Lake Malawi. For example, the family Thiaridae includes eight endemic species in the genus *Melanoides* (Brown 1994). Recent molecular studies have shown that these eight endemic species, with highly distinctive shells, do not differ genetically and are parthenogenetic clonal lineages (Genner *et al.* 2007). Some of the more widespread families also include localized endemic species, such as *Lanistes nasutus,* an apple-snail (Ampullaridae) that is restricted to Lake Malawi. *L. nasutus* is a thin shelled elegantly shaped deep-water species found at a depth of 46 to 82m. Of the freshwater mussels endemic to Lake Malawi, two species, *Mutela alata* and *Chambardia nyassaensis*, are categorized as Vulnerable, due to impacts of sedimentation, *Coelatura hypsiprymna* was assessed as Near Threatened, whilst the other endemics such as *Nyassunio nyassaensis* were considered Least Concern.

Lake Victoria is shallower than the other great lakes (maximum depth of 80m), has a lower salinity than Lake Tanganyika, and possesses a shoreline with extensive papyrus swamps, open sandy beaches and stony shores (Brown 1994). There is considerable variability within some species, and Brown (1994) suggests these may either be in a status of partial speciation from periods of low lake levels, or are just poorly defined requiring further investigation of their genetic distinctness. The African viviparid fauna in the lake included six species in the genus *Bellamya*. Ongoing investigations by Lange (pers. comm.) should provide better knowledge of the true distribution ranges of populations within the lake as, for example, *Bellamya phthinotropis* has a restricted range within the lake, being currently only found in the south-west part. Freshwater mussels of note are *Eupera crassa*, which is assessed as Critically Endangered, and *Aspatharia divaricata*, which is considered Vulnerable (Graf *et al.* 2011), and the taxonomic status of *Mutela bourguignati* in Lake Victoria has yet to be rigorously determined.

View of the Great Lakes region from near Kigali, Rwanda. © IUCN/ INTU BOEDHIHARTONO

Lake Mweru, a lake in the upper part of the Congo Basin in Zambia, has several endemic species of mollusc. Some of these species are restricted to the lake, whereas others are also present in the lower reaches of the Luapula River which drains into the south edge of lake, which is very shallow (15m depth (Brown 1994)), with extensive marshes and papyrus swamps along the fringes. Pilsbry and Bequaert (1927) commented on the vulnerability of the fauna, and Brown (1994) commented on the unusual richness of this shallow lake. There are eight endemic Gastropoda taxa, as well as two endemic monotypic freshwater mussel genera. Species of note are *Mweruella mweruensis*, which is regarded as Vulnerable, and *Prisodontopsis aviculaeformis*, which is assessed as Endangered.

4.1.3 Molluscan diversity in artesian basins

The highest diversity of freshwater molluscs is, as for many other parts of the world, found in artesian basins, and largely comprises the spring-snails from the family Hydrobiidae. In Africa, especially the Maghreb region, spring-snails form a lower proportion of the endemic fauna (69 species – 11%), in contrast with Europe (around 610 species – 69% (Seddon pers. comm.)), North America (around 105 species – 18%) and Australia (252 species – 49% (Strong *et al.* 2008)). The majority of this diversity in the Maghreb region is found in springs fed by aquifers in the limestone mountainous regions (Ghamizi 1998; Van Damme *et al.* 2010). More than 75% of the Maghrebian prosobranchs are assessed as threatened or are locally extirpated (Van Damme *et al.* 2010). By contrast, there are proportionately few endemic hydrobiids in the Afrotropical fauna south of the Sahara, possibly a reflection of the origin of these radiations and the lack of limestone regions. One of these, *Lobogenes*, is a central and southern African endemic genus. In neighbouring Europe, the greatest radiations are found in the limestone regions south of the glacial limit (e.g., the Balkans and the Iberian peninsula (Arconada and Ramos 2003; Benke *et al.* 2009)). In northern Africa, the Maghreb is a centre of evolution and radiation of subterranean hydrobids. At least 13 genera are known from the region, but it is likely that further investigation, in particular in Algeria, could raise the number to more than 20 genera. There are, however, large parts of the region with artesian waters that remain to be surveyed, largely due to the difficulty of sampling interstitial groundwaters and, as such, there may be further unknown diversity within these systems.

The freshwater bivalves and most of the pulmonates found in these habitats are typically more widespread species tolerant of drying-out and, as such, are not considered to be threatened.

4.1.4 Molluscan diversity in saline lagoons, saltmarshes and mangroves

Molluscs of the coastal habitats of Afrotropical Africa show little spatial variation. However, some of the more range-restricted species are found in the saline lagoons, saltmarshes and mangroves that fringe large parts of the coastline. The saline lagoons have some very restricted range species, such as the species of *Tomichia* found in southern Africa. All species of *Tomichia* are sensitive to changes in their habitats caused by pollution and interference with the seasonal wet-dry regime (Kristensen *et al.* 2009a), so the majority have been assessed as threatened.

By contrast, the mangrove species tend to be more widespread, and are found in suitable habitats throughout the continent. For example, the family Littorinidae is a cosmopolitan family represented in Africa by a few species of *Littoraria*. Most of the African littorinids are not considered to be threatened. However, in some regions, such as the coastal swamps of western Africa, you find the "living fossils", *Afropomus* and *Saulea,* which are monotypic, are considered to be rare, and are threatened.

Three families of bivalve are typically found in brackish water habitats, and these families are mainly comprised of marine species. Recent checklists have listed 19 species of the family Donacide from tropical western Africa (Daget 1998; Bogan 2010). However, only 14 of these have been evaluated for the IUCN Red List. Ten species of *Egeria* occur in coastal western Africa (plus four species of unknown distribution that were not evaluated; one species that was evaluated is now considered invalid). Two species of *Cyrenoida*, of the family Cyrenoididae, are found in brackish/estuarine habitats in tropical western Africa, extending from Senegal to the Congo. The sole Afrotropical representative of the Dreissenidae is *Mytilopsis africanus*, which is distributed widely in the estuarine/brackish waters of coastal western Africa, from Senegal to the mouth of the Congo. Most of these species are assessed as Least Concern, although some, where the distributional data were uncertain, are categorized as Data Deficient.

4.1.5 Molluscan diversity in crater lakes

Crater lakes are present in many parts of Africa, including Cameroon, Ethiopia and eastern Africa. These small, sheltered, but deep lakes are usually species-poor, as they are often oxygen deficient below 20m depth and, in some cases, are too saline for molluscs. Some species have, however, managed to colonise these lakes, probably though transportation by birds, and their relative isolation may have driven their evolution into new species. The Cameroon crater lakes have a richer fauna than might be expected, including one possibly endemic species, *Bulinus camerunensis* (EN). In the western Uganda crater lakes eight gastropods and three bivalves were recorded by Mandahl-Barth, including two endemics, *Gabbiella kichwambae* and *Bulinus tropicus toroensis*; these taxa require further investigations, using molecular systematics, to establish their status (Brown 1994).

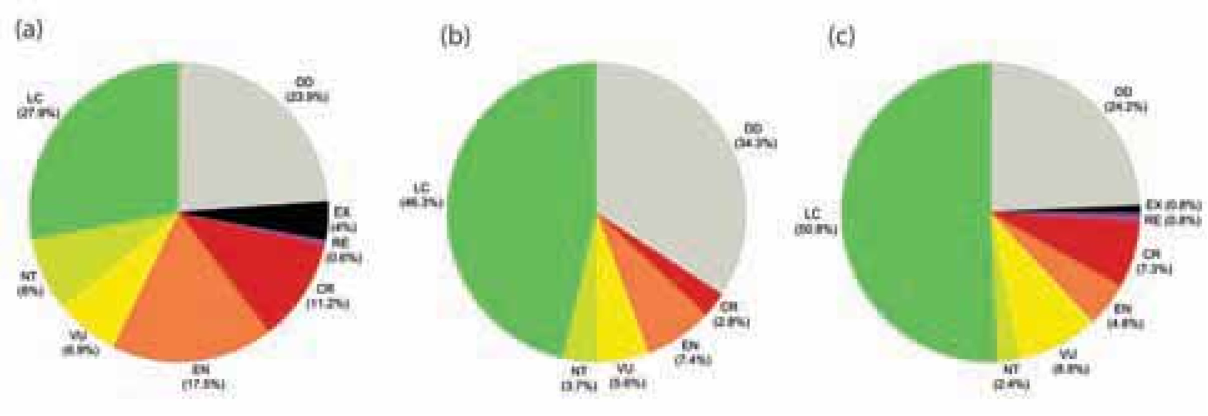
A team of Moroccan and Spanish malacologists aided by local youngsters collecting Margaritifera marocana *in the Oued Abid (Morocco). After tissue samples were taken, the animals of this last viable population of the species were placed back in the river.*

© MOHAMMED GHAMIZI

Lake Awing, one of the crater lakes in Cameroon.

© KLAAS-DOUWE DIJKSTRA

Figure 4.3. The proportion (%) of freshwater mollusc species in each regional IUCN Red List Category in mainland continental Africa, in the gastropod groups: a) the prosobranchs; b) the pulmonates; and c) the bivalves.



4.1.6 Molluscan diversity in montane lakes

The high mountain areas in eastern Africa and Ethiopia have small tarns (a mountain lake or pool) at high altitude. As for the crater lakes, these are isolated, and support some endemic species, possibly also as a result of their isolation. Although most species of the Afro-tropical pea-clams (*Pisidium* spp.) are assessed as being of Least Concern (six species) or Data Deficient (six species), some species, such as *P. ethiopicum,* are considered Critically Endangered, having a distribution limited to a few lakes in Ethiopia. Two more species occurring in high-elevation montane lakes in Eastern Africa (Warui *et al.* 2001) are assessed as Vulnerable (*P. artifex*) and Near Threatened (*P. montigenum*). Species in these montane lakes are threatened by the introduction of non-native fish species for sport fishing, as well as by their vulnerability to potential changes in lake levels due to climate variability and increased frequency of drought.

4.2 Conservation status of freshwater molluscs

The first species from the region to be placed on the IUCN Red List of Threatened Species came from a major review of the freshwater gastropods undertaken by David Brown in 1994. This survey used the first set of quantitative IUCN criteria (version 2.3) and resulted in the listing of 68 species, mainly those found in the regional hotspots in the African Rift Valley lakes and western Africa. However, Brown's review, published by IUCN (Baillie and Groombridge 1996) did not include assessments for any of the Data Deficient or Least Concern species, and so the figures obtained could not provide an overview of the status of freshwater biodiversity for the continent.

This IUCN pan-African project is the first study that provides a comprehensive overview of the conservation status of the region's freshwater molluscan fauna. In this project, the conservation status of each species of freshwater mollusc was assessed by applying the IUCN Red List Categories and Criteria: Version 3.1 on a regional scale (IUCN 2001). For those species endemic to continental Africa, their regional IUCN Red List status is equivalent to their global status, such that assessments for all endemic species are added to the global IUCN Red List. For those species with distributions extending beyond Africa, regional assessments have also been completed to determine their status within the African part of their ranges. These regional assessments will contribute to an ongoing global assessment of all freshwater molluscs.

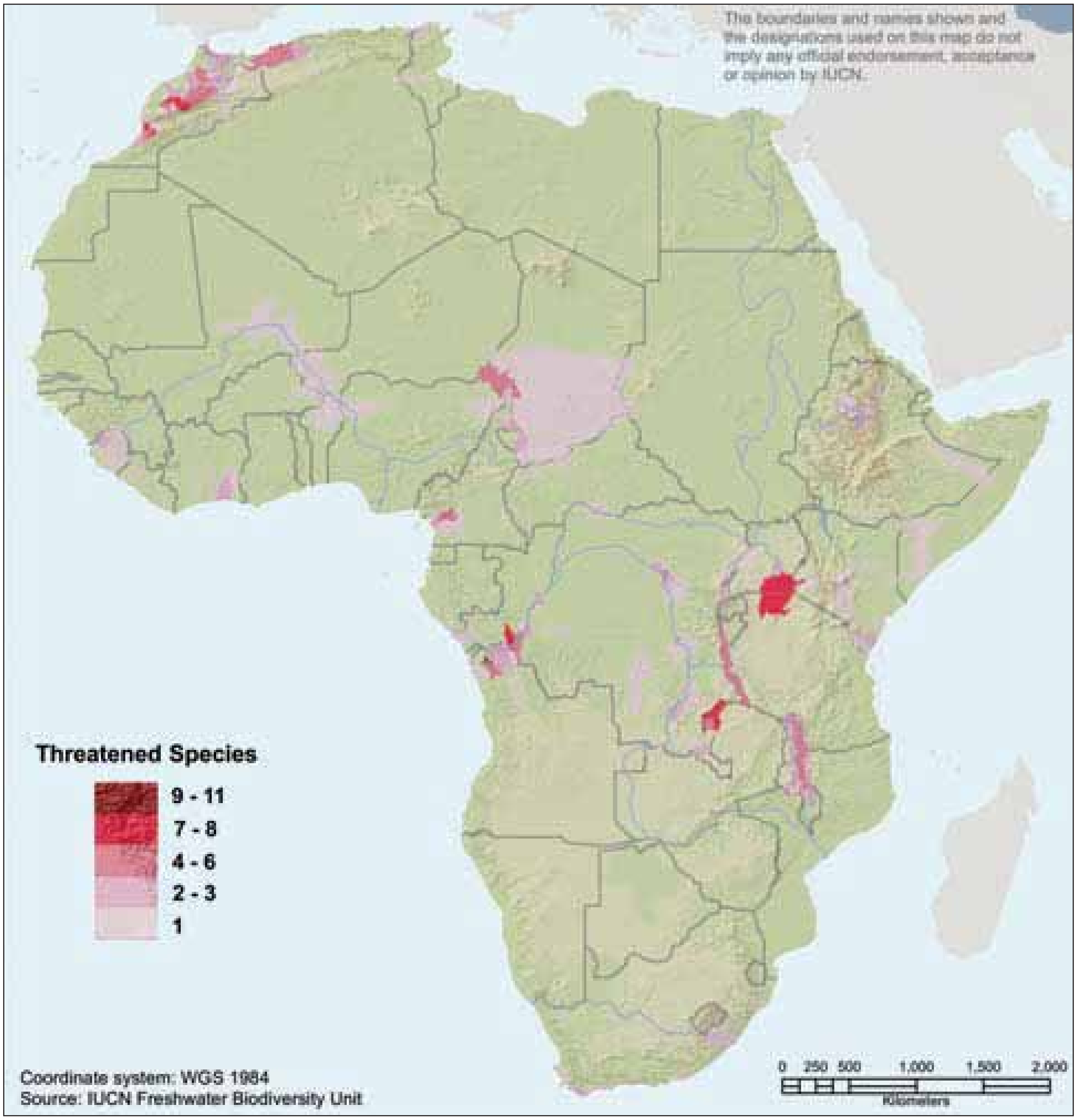
There is considerable variability between the regions in the proportion of threatened species and the proportion of Data Deficient species. This, in part, reflects the level of recent

Table 4.3. The number of African mollusc species in each IUCN Red List Category, by region.

Region	No of Species	% Threatened	% Data Deficient
Eastern Africa	228*	22%	38%
Southern Africa	122	9%	24%
Western Africa	95	12%	16%
Central Africa	159	31%	19%
Northern Africa	155	45%	17%
Pan-Africa	**624***	**29%**	**28%**

*Some subspecies regarded as species in regional treatments, and undescribed taxa included in regional treatments, are as a precautionary measure not included in the pan-Africa listings for endemic species.

Figure 4.4. The distribution of threatened freshwater mollusc species across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

taxonomic research, the amount of recent field survey, the application of molecular systematic, and the number of local scientists and overseas researchers working on each taxonomic group. In general, the prosobranchs are the most threatened of the freshwater molluscs group, followed by the bivalves and then the pulmonates (Table 4.3; Figure 4.3).

4.2.1 Threatened species distribution patterns

Apparent regional variations in the distribution patterns of threatened species in part reflect regional differences in the status of taxonomic research, levels of survey work, and numbers of range restricted endemic species, which are often threatened. These factors should be taken into consideration when interpreting the species distribution maps.

Sites highlighted as having the most threatened species include the Maghreb, the East African Lakes (Lake Victoria, Lake Tanganyika and Lake Malawi) and the Congo Basin (Figure 4.4). The Lake Chad catchment is shown to include a number of threatened species, but these require taxonomic review and, as such, have not been highlighted as requiring conservation actions. In the Congo Basin, the majority of endemic species in the Lower Congo Rapids and Malebo Pool were assessed as threatened, representing a quarter of the total molluscan richness in those areas (Graf *et al.* 2011). Most of these were range-restricted species living within specialised habitats, such as rapids.

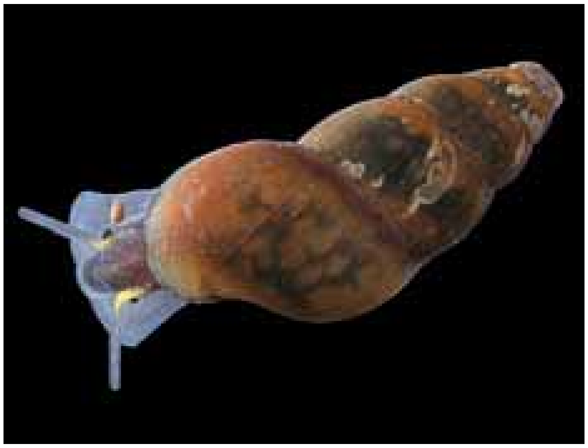
Pilsbry and Bequaert (1927) commented on the vulnerability of the fauna of the Lake Mweru in central Africa to its gradual infilling. There is, however, an ongoing debate as to whether the rate of infill is likely to impact both the endemic species and those species also present in the lower reaches of the Luapula River that were not considered threatened. Here, we have followed the precautionary approach, such that the three endemic species in the genus *Bellamya* are assessed as Critically Endangered. Two monotypic freshwater mussel genera are also endemic to Lake Mweru, of which *Mweruella mweruensis* is regarded as Vulnerable and *Prisodontopsis aviculaeformis* is assessed as Endangered.

In southern Africa, some of the more unusual endemics are found in the coastal regions in habitats ranging from temporary saline pans to perennial freshwater streams. Herbert (1998) noted that of the seven species of *Tomichia* occurring in South Africa, three species were included in the 1996 IUCN Red List (Baillie and Groombridge 1996), one assessed as Extinct (*Tomichia cawstoni*), one Critically Endangered (*Tomichia natalensis*), and one Endangered (*Tomichia rogersi*), as the habitats of all were considered vulnerable to destruction by man (Brown 1994). This more recent review of the present status of populations of all *Tomichia* species in South Africa noted that although *T. rogersi* has a restricted range, it cannot be assessed as threatened, as there are no known plausible threats to the springs that these snails inhabit, and it is therefore assessed as Near Threatened. Taking into consideration its limited occurrence, it is still important that populations are monitored closely.

The Zambezi headwaters were considered important for other groups of threatened freshwater taxa (Darwall *et al.* 2009), but less so for molluscs, as the majority of the species are relatively widespread.

4.2.1.1 Changes since the 1996 assessment

There have been several major changes in taxonomy since the previous assessment in 1996, and some of these have changed the total number of species and the number of range restricted species, with consequent impacts to species conservation status.



Tomichia cawstoni*, a Critically Endangered species currently only known from one location, a stream near the Eastern Cape Province, South Africa.* © DAI HERBERT

The family Melanopsidae was split from the family Thiaridae on the basis of anatomical characters (Houbrick 1988). One genus in this family, *Melanopsis,* occurs in the Maghreb, where it is represented by about 13 species, some of which are Critically Endangered. These are currently considered as distinct species (Heller *et al.* 2005) rather than belonging to a single species, *M. praemorsa*, as was Brown's (1994) opinion. Brown considered them a single species, arguing that asexual reproduction creates clonal lineages that differ spectacularly in shell form and colour but vary very little in genetic make-up. Heller *et al.* (2005) reviewed the geological history and found that the different morphs have been very stable, and that their descendants are exact copies of the mothers. As a single species, *M. praemorsa* was considered widespread and therefore Least Concern; however, now the species has been spilt into more than 13 species, some are regarded as range restricted, with threats from exploitation of water sources, and hence are now considered to be threatened.

There have also been new species descriptions within the Lake Tanganyika gastropods resulting from recent research and survey work by West *et al.* (2003). This work, along with the GEF Lake Tanganyika Biodiversity Project, has increased our knowledge of the distribution of the previously known fauna and the newly described species.

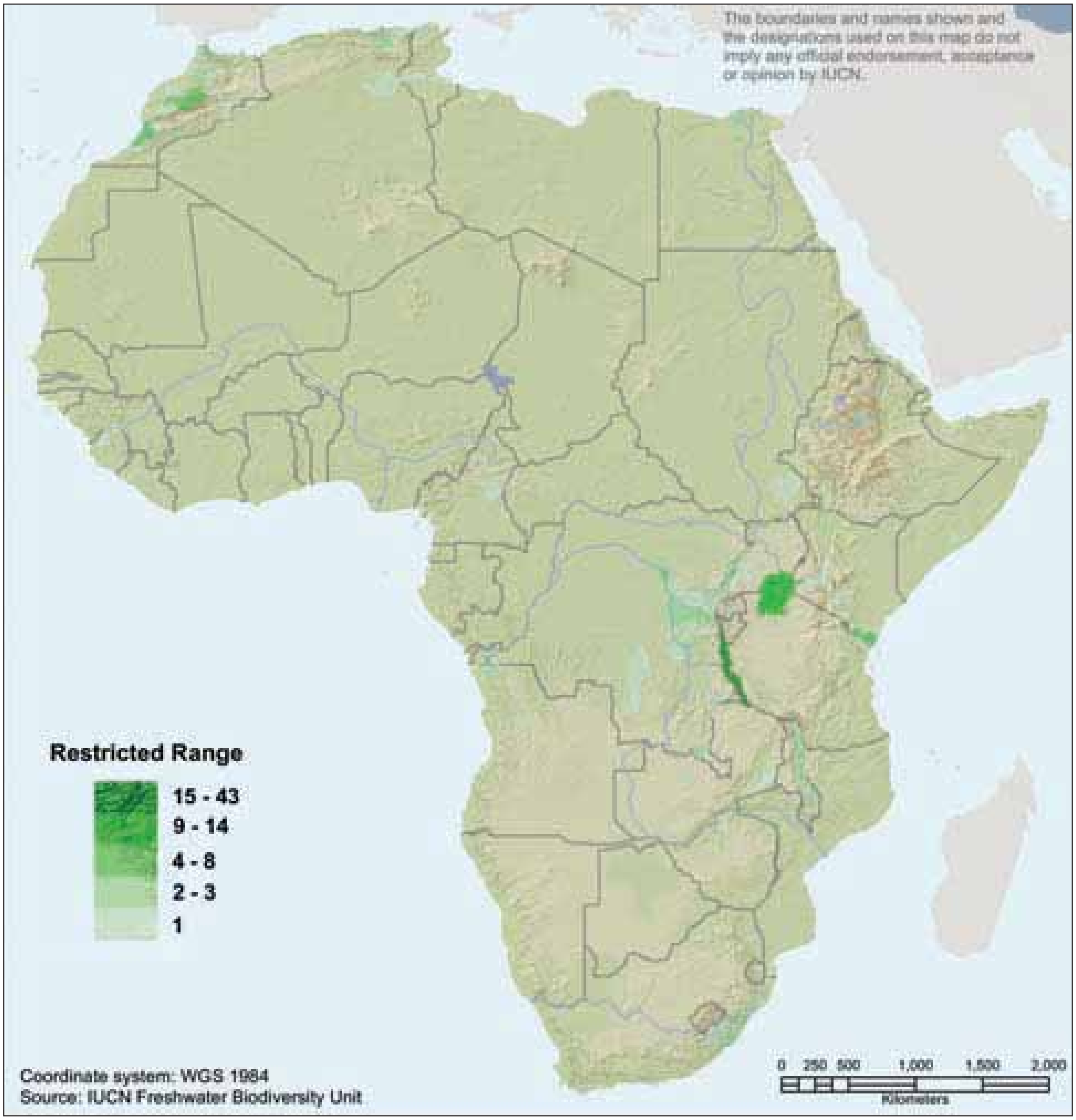
In addition to the taxonomic changes and increased survey effort mentioned above, the latest version of the IUCN Categories and Criteria (version 3.1) and the guidelines have led to a number of changes in the way assessments are conducted, including, for example, the way that range data should be interpreted. In conclusion, few of the observed changes in category from the 1996 assessments made by Brown (1996) reflect genuine changes in the status of the species but rather taxonomic changes, new information, and changes to the thresholds of the Red List criteria themselves.

4.2.2 Restricted range species

Africa is a continent with many restricted range freshwater gastropods, most of which are prosobranchs. This is partly due to a number of reasons: the great relative age of some of the smaller coastal drainages, particularly in the southern part of western Africa and in Cameroon; the presence of the large lakes in the eastern rift system, and of the vast, diversified and old hydrographic system of the Congo; and the isolated Haut Atlas, Atlas Saharien, Anti Atlas, and Moyen Atlas mountain ranges in the Maghreb.

Restricted range species are found only exceptionally throughout the rest of Africa. This is true for most of the northern African region, as well as south and east

Figure 4.5. The distribution of restricted range mollusc species in mainland continental Africa, showing hotspots of diversity in the Maghreb and the Rift Valley Lakes. Species richness = number of species per river/ lake sub-catchment.



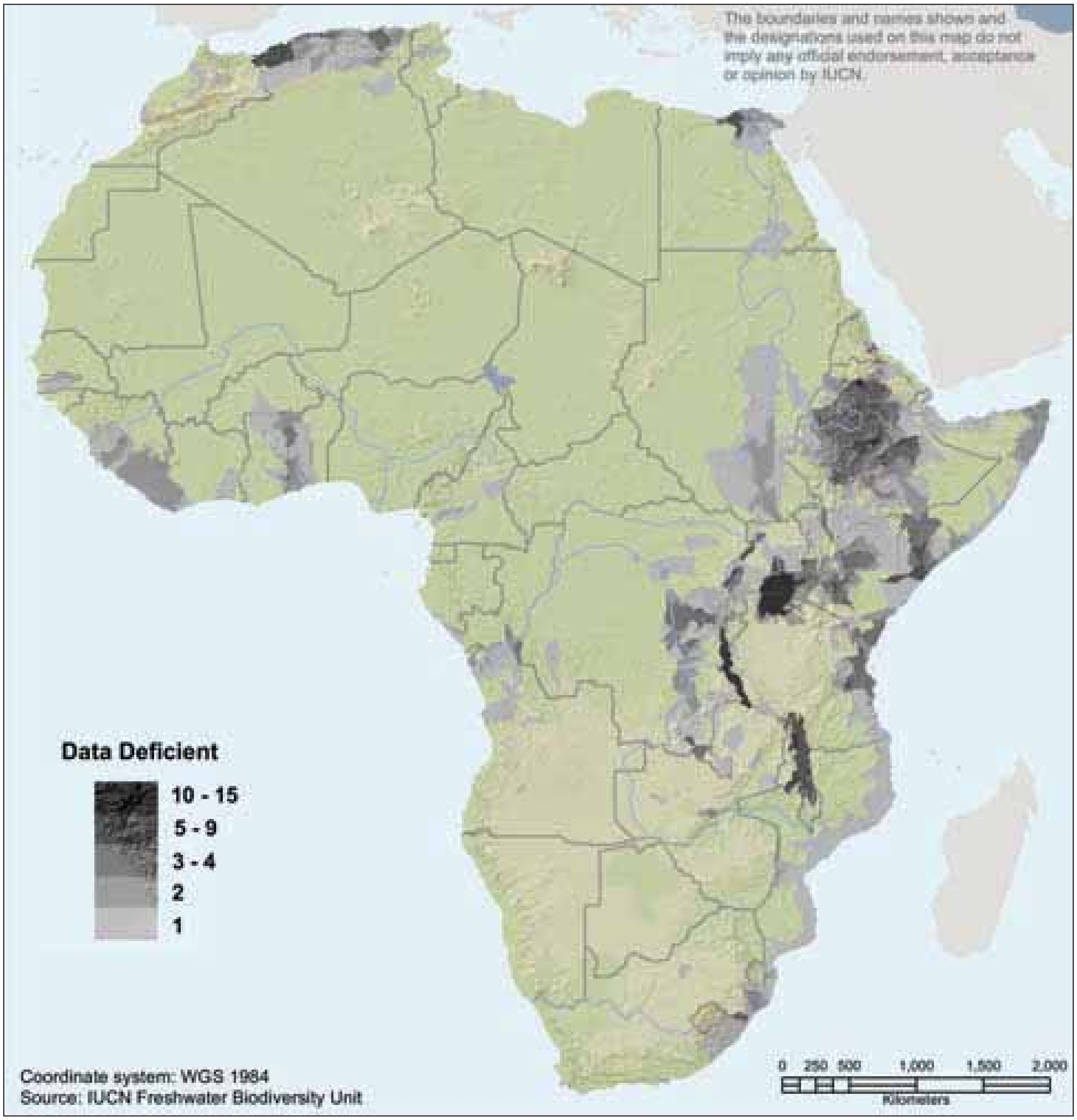
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

of the Atlas range, i.e., Mauritania, Mali, Libya, central and southern Algeria and Egypt, the whole of the north-eastern African Region (Eritrea, Sudan, Ethiopia, Djibouti and Somalia), with the exception of a couple of endemic species in south Somalia and south Ethiopia. The same is also true for the northern part of the western African region, i.e., the basins of the Niger and Senegal that suffered severe drying events during the Pleistocene some 20,000 years ago.

In southern Africa, severe climate fluctuations during the Pleistocene made this region inhospitable for Afrotropical prosobranchs, so there are no restricted range species with the exception of species within the genera *Septaria* (found on the coast of Natal) and *Tomichia,* some of which are confined to small stretches of the coast of Natal and the Cape Province.

Species with the most restricted ranges, sometimes of only a few square metres, are the Maghrebian hydrobids that are found in one or two springs or wells. Although their true range underground may be more extensive, they are assessed as threatened on a precautionary basis, as the extent of their range in artesian waters is uncertain; some species may be truly restricted to the wells, whereas others which are only seen in flood events at outlets are actually distributed more widely in the groundwater supplying the outlets.

Figure 4.6. Distribution of the freshwater molluscs assessed as Data Deficient, showing that large numbers of species in the centres of diversity in the African lakes and northern Africa require additional taxonomic research, field survey, and information on relevant threats in order to make an assessment of their conservation status. Species richness = number of species per river/lake sub-catchment.



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

In small river basins and marshes along Africa's Atlantic coast, from Côte d'Ivoire to the Republic of the Congo, as well along the coast of the Indian Ocean from southern Somalia to Mozambique, a number of species and even monotypic genera (e.g., *Soapitia dageti* from the Konkouré River near Soapiti, Liberia, and *Valvatorbis mauritii* in the Congo River at Ango-Ango near Matadi, Republic of the Congo) are only known from the type locality. This is only the case for small sized species belonging to the families Hydrobiidae, Assimineidae and Bithyniidae, which are easily overlooked. While their true range must be larger than the type locality (the stretch of rapids near Matadi is not the easiest place to sample), many are habitat specialists confined to a specific habitat of limited extent, such as stones in rapids. These species have, therefore, also been assessed as threatened.

Finally, there are the endemics of the large Rift Valley lakes. In the report on the molluscs of the eastern African region (Darwall *et al.* 2005), the original assessors apparently did not apply the same criteria for all lakes, some considering threats likely to spread throughout and impact a whole rift lake, while others did not. Admittedly, it is not an easy exercise, as this depends on the level of threat and the area over which it can impact within a short period of time. In deep, meromictic lakes like Lakes Tanganyika and Malawi,

Diving for mussels in the Upper Chambeshi River, Upper Congo. © DANIEL GRAF AND KEVIN CUMMINGS

the benthic fauna is confined to a small oxygen-rich stretch close to the coast (upper 80m in Lake Malawi, and upper 100 to 200m in Lake Tanganyika). In the anoxic or hypoxic zones there is no macro-life. Barring a few exceptions, all Lake Tanganyika endemics have been assessed as not threatened (Least Concern, Data Deficient or Near Threatened) as many, whilst range-restricted, occur in a greater number of locations than meets the threshold for a threatened category, given the localized nature of the threats to the lake's sublittoral zone. In contrast, some Lake Malawi endemics, though found throughout the sublittoral (e.g., *Lanistes nyassanus* and *L. solidus*) are considered as Endangered, but poor quality of data available at the time of assessment may require the assessments to be revised. Ongoing investigations leading to a better knowledge of the real distribution ranges of populations in these lakes will soon be available. The same is true for the prosobranchs of other lakes where current information shows species to have restricted distributions within lakes, such as *Bellamya phthinotropis*, which is reported as only being found in the south-west part of Lake Victoria, and *Gabbiella neothaumiformis*, which has only been recovered from a very restricted area in the south-west part of Lake Chad (Kristensen *et al.* 2009b). Such species have been assessed as threatened. For other endemics, such as *Gabbiella humerosa alberti* of Lake Albert, the status of Endangered may need re-evaluation during the next assessment as more information becomes available.

4.2.3 Data Deficient species

The two main reasons for Data Deficiency in molluscs are taxonomic uncertainty and poor geographic knowledge. The regions with the highest proportion of Data Deficient species are northern Africa, the east African Lakes, and western Africa (Figure 4.6).

In southern Africa, taxonomic issues relating to a number of small limpet species in the genera *Ferrissia* and *Burnupia* are the main reasons behind these species being classified as Data Deficient. This contrasts with western Africa, where there is little recent survey data available and, as such, more species were identified as Data Deficient due to lack of recent data on distributions (Figure 4.6). In the eastern, western and southern African regions, knowledge is, in general, reasonable due to surveys conducted in the second half of the 20th century, funded by the World Health Authority (WHO) to study African freshwater snails that play a role in the transmission of schistosomiasis and other parasites. As no schistosomiasis occurs in northern Africa, this region was not incorporated in the research campaigns funded by WHO, and there are subsequently a higher number of species listed as Data Deficient due to a lack of distributional data. In northern Africa, the high level of taxonomic disarray within the freshwater molluscs is largely a consequence of many species being described by members of the 19th century French “Ecole Nouvelle”,

Table 4.4. Extinct mollusc species in Africa.

Family	Genus	Species	IUCN Status
Bithyniidae	*Bithynia*	*tentaculata*	Regionally Extinct
Bithyniidae	*Bithynia*	*leachii*	Regionally Extinct
Hydrobiidae	*Bythinella*	*limnopsis*	Extinct
Hydrobiidae	*Bythinella*	*mauritanica*	Extinct
Hydrobiidae	*Bythinella*	*microcochlia*	Extinct
Hydrobiidae	*Bythinella*	*punica*	Extinct
Hydrobiidae	*Hydrobia*	*gracilis*	Extinct
Hydrobiidae	*Mercuria*	*letourneuxiana*	Extinct
Hydrobiidae	*Pseudamnicola*	*doumeti*	Extinct
Hydrobiidae	*Pseudamnicola*	*globulina*	Extinct
Hydrobiidae	*Pseudamnicola*	*barratei*	Extinct
Hydrobiidae	*Pseudamnicola*	*desertorum*	Extinct
Hydrobiidae	*Pseudamnicola*	*oudrefica*	Extinct
Hydrobiidae	*Pseudamnicola*	*ragia*	Extinct
Hydrobiidae	*Pseudamnicola*	*latasteana*	Extinct
Hydrobiidae	*Pseudamnicola*	*singularis*	Extinct

where all variants were given a different species name. Few recent taxonomic revisions have been made, so that, for quite a number of species described between *ca* 1850-1920, there remains doubt as to their taxonomic validity, and we still lack sufficient information on the status of their populations since that period. This situation is gradually changing as a new generation of Maghrebian malacologists has emerged who are starting to do some outstanding work. In Egypt, Ethiopia and Sudan the number of Data Deficient species is relatively low, as these countries were also included in the WHO campaigns.

In north-eastern Africa, the regions of Eritrea and Somalia have received little attention. Eritrea has virtually no freshwater, and hence there has been little survey effort in the region. However, by contrast, the brackish water fauna is quite rich, but apparently no efforts have been made to re-examine it since the late 19th century. As such, many mangrove species, some of which were described from the Eritrean islands only, are also recorded as Data Deficient.

Difficulties in accessing some countries due to political unrest have also limited the available knowledge for a number of areas. For example, there are virtually no data available for Somalia since 1930, and even before 1930 only a few malacologists ventured into the region. Similarly, countries in southern Africa, Angola and Mozambique, all with a long history of conflicts, have large areas where little survey work has been conducted. These regions require extensive field survey in order to better understand species distributions patterns and the impacts of threatening activities.

4.2.4 Extinction patterns

There are a few possible extinctions or regional extinctions in Africa south of the Sahara, but most confirmed extinctions lie in the Maghreb region of north-western Africa (Morocco, Algeria and Tunisia), where 14 species are considered to be Extinct (Table 4.4). This region has a high proportion of small hydrobid snails that are range-restricted, occurring in only one or two springs, wells or thermal sources. These species have suffered from a combination of water pollution and the over-abstraction of water from the springs and underlying aquifers, which has led to many springs drying out. The number of extirpated species may be considerably higher, as this subterranean malacofauna was taxonomically lumped in the 19th century. By the time researchers such as Boeters (1976) tried to re-investigate the sites in the 1970s the water sources and freshwater springs were already lost or disturbed at many locations, so it was no longer possible to review the taxonomy such that the true number of extirpated species will never be known; they could be two or three times the number cited above.

The Regionally Extinct gastropods are also restricted to northern Africa. These are widespread Palaearctic species still found throughout Europe and Asia Minor that have been lost from the southern edges of their ranges in a few localities in Mediterranean Africa. In the rest of Africa there are no prosobranchs listed as Extinct, though it is probable that some of the central African species, such as *Potadoma kadeii* (here listed as Critically Endangered) from Cameroon and *Tomichia cawstoni* (also listed as Critically Endangered) from South Africa, may be already Extinct, but more extensive field surveys are required before this can be confirmed.

Table 4.5. Undescribed threatened freshwater molluscs endemic to Africa.

Family	Genus	Species	Subspecies	RL Category
Hydrobiidae	*Belgrandiella*	sp. nov. 'ramdanii'		CR
Hydrobiidae	*Bythinella*	sp. nov. 'tiznitensis'		CR
Hydrobiidae	*Heideella*	sp. nov. 'valai'		CR
Hydrobiidae	*Heideella*	sp. nov. 'kerdouensis'		CR
Hydrobiidae	*Heideella*	sp. nov. 'makhfamanensis'		CR
Hydrobiidae	*Semisalsa*	*aponensis*	subsp. nov. 'taramtensis'	CR
Hydrobiidae	*Giustia*	sp. nov. 'meskiensis'		EN
Hydrobiidae	*Heideella*	sp. nov. 'boulali'		EN
Hydrobiidae	*Heideella*	sp. nov. 'salahi'		EN
Hydrobiidae	*Horatia*	sp. nov. 'aghbalensis'		EN
Hydrobiidae	*Horatia*	sp. nov. 'haasei'		EN
Hydrobiidae	*Mercuria*	sp. nov. 'mirlheftensis'		EN
Hydrobiidae	*Belgrandia*	sp. nov. 'wiwanensis'		VU
Hydrobiidae	*Heideella*	*andraea*	subsp. nov. 'boulanouari'	VU

4.2.5 Undescribed species

There are some recognized species in northern Africa and Lake Tanganyika that have not yet formally been described which are clearly threatened with extinction (Table 4.5). These species require formal descriptions in order to be included in the IUCN Red List. Other species that have yet to be described also exist in Africa, and have yet to be fully investigated (Table 4.6).

Most of these are range-restricted species known from northern Africa, where the water sources in which they are found have been severely depleted through habitat loss due to over-abstraction of water, and through habitat degradation resulting from pollution and saline intrusions into their groundwaters (Van Damme *et al.* 2010). In Lake Tanganyika, Michel *et al.* (2004) and West *et al.* (2003) report many new possible *Lavigeria* species along the lake margins. Many of these appear to be quite widespread, and hence, when formally described, will probably be assessed as Least Concern. However, at least three, possibly four, of these undescribed taxa have a limited range, and once confirmed as valid species may be classified as threatened by sedimentation and pollution from adjacent urban areas.

Table 4.6. Undescribed Data Deficient freshwater molluscs endemic to Africa.

Family	Genus	Species	Source	RL Category	Possible Status
Paludomidae	*Lavigeria*	sp. B	West *et al.* (2003) p. 55	DD	Probably LC
Paludomidae	*Lavigeria*	sp. C	West *et al.* (2003) p. 51	DD	Probably LC
Paludomidae	*Lavigeria*	sp. D	West *et al.* (2003) p. 53-4	DD	Probably LC
Paludomidae	*Lavigeria*	sp. F	West *et al.* (2003) p. 52	DD	Probably LC
Paludomidae	*Lavigeria*	sp. G	West *et al.* (2003) p. 50	DD	Probably LC
Paludomidae	*Lavigeria*	sp. H	West *et al.* (2003) p. 54	DD	Probably LC
Paludomidae	*Lavigeria*	sp. J	West *et al.* (2003) p. 41-2	DD	Limited range, but uncertain threats
Paludomidae	*Lavigeria*	sp. K	West *et al.* (2003) p. 42	DD	Limited range, but uncertain threats
Paludomidae	*Lavigeria*	sp. M	West *et al.* (2003) p. 52	DD	Probably LC
Paludomidae	*Lavigeria*	sp. N	West *et al.* (2003) p. 47	DD	Probably LC
Paludomidae	*Lavigeria*	sp. O	West *et al.* (2003) p. 43	DD	Uncertain range extent and threats
Paludomidae	*Lavigeria*	sp. P	West *et al.* (2003) p. 45-6	DD	Probably LC
Paludomidae	*Lavigeria*	sp. Q	West *et al.* (2003) p. 46	DD	Probably LC
Paludomidae	*Lavigeria*	sp. R	West *et al.* (2003) p. 49	DD	Uncertain range extent; DD?
Paludomidae	*Lavigeria*	sp. S	West *et al.* (2003) p. 56	DD	Probably LC
Paludomidae	*Lavigeria*	sp. T	West *et al.* (2003) p. 56-7	DD	Probably LC

These are all species that have been listed in books or PhD. theses but are yet to be formally described, so are not yet placed on the IUCN Red List.

4.3 Main threats

4.3.1 Regional patterns of threat

There are multiple sources of threats to freshwater molluscs in Africa. In the majority of cases there is usually a series of threats that combine to lead to declining populations (Figure 4.7). The most significant of these threats is habitat loss or degradation, through multiple actions such as agricultural expansion, infrastructure development (e.g., dams) and deforestation, with 58% of threatened species suffering the consequences. Although this problem is widespread throughout Africa, the causes of habitat decline vary between regions, as explained below. Water pollution from a range of sources is another major threat, which impacts 63% of threatened species, but again, the sources of the pollution vary from region to region. A number of species are also suffering from the direct impacts of molluscicides employed to reduce gastropod species, which are vectors of bilharzia (Kristiansen and Brown 1999). In contrast to other taxa, such as fishes, invasive species do not appear to have had a notable impact on native species of mollusc. Invasive mollusc species are present and have had an impact on some species, but they are only recorded as a significant threat for fewer than 5% of threatened species. Finally, some species are threatened by "natural disasters", which in this case refers largely to the increased frequency of drought.

In western Africa, the habitat quality in rivers is declining primarily as a result of the extensive use of pesticides in crop plantations, expansion of bauxite mining and damming river flows for hydro-electric power generation. This impacts a number of restricted range endemic species from Sierra Leone, Côte d'Ivoire and Guinea, through the combination of water pollution, sedimentation, altered river flow regimes and increased water temperature. *Sierraia outambensis* (CR) and *Soapitia dageti* (CR) are two notable species facing these combined threats.

In eastern Africa, threats from declining habitat quality are due to increased levels of sedimentation from agricultural activity in the catchment, use of molluscicides, and the impact of invasive species such as water hyacinth and Nile Perch. Although, as yet, there are no specific studies on the impact of sedimentation on molluscs, the impact of increased sedimentation is recognised to impact most benthic organisms in Lake Tanganyika (McIntyre *et al.* 2005). Lake Victoria and the Ethiopian lakes have been stocked with introduced fish species, many of which are molluscivores or omnivores, whose predation on molluscs could have long-term impacts on the population levels of the native species.

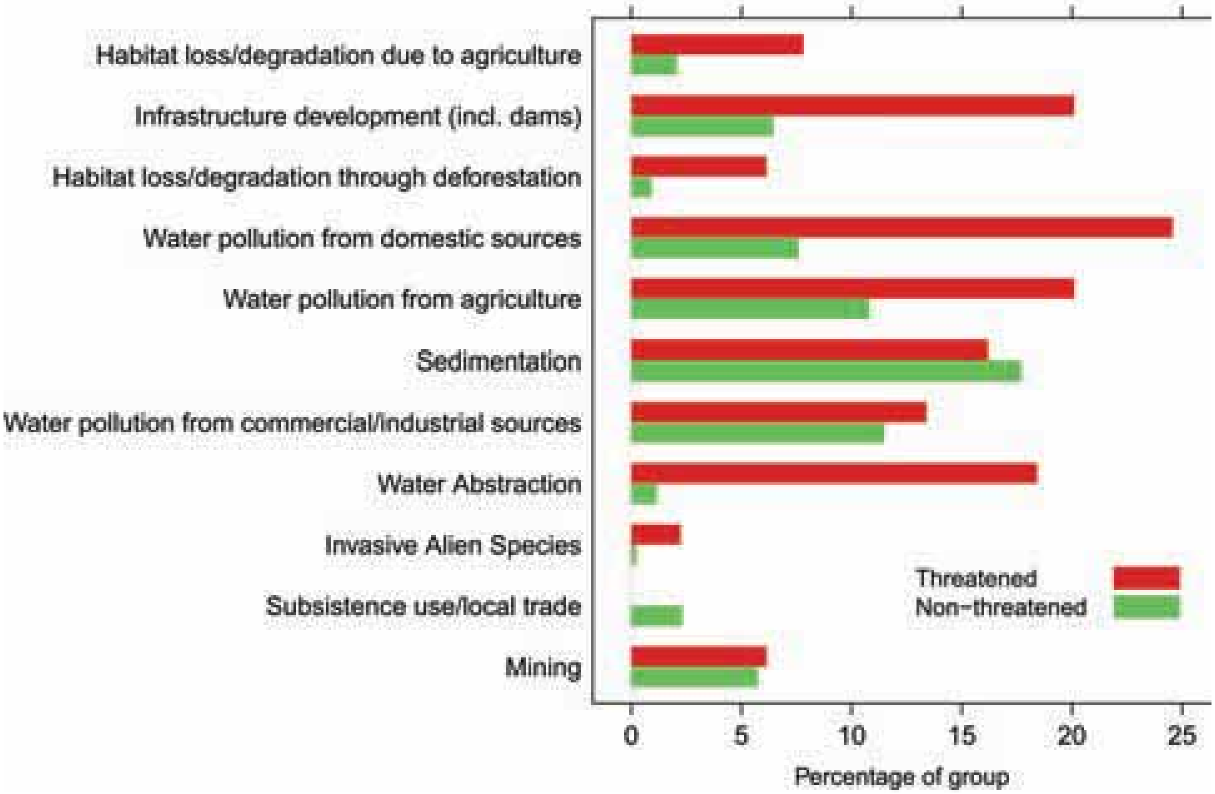
In southern Africa, the decline in habitat quality is associated with dam construction for hydro-electric power generation, over-abstraction of water for irrigation, water pollution from domestic and industrial sources, sedimentation from mining waste, dune mining in southern Africa, and use of molluscicides (Kristiansen *et al.* 2009a).

In northern Africa, habitat quality has declined as a result of the over-abstraction of surface and underground waters for domestic, industrial and agricultural use, and the subsequent return of waters that are heavily polluted and untreated (Van Damme *et al.* 2010). Even in regions that are sparsely populated, water pollution is often quite significant, in many cases as a result of the now common use of detergents, chemical fertilizers and pesticides (Van Damme *et al.* 2010). The most dramatic effects can be clearly observed in the Mediterranean part of the northern African region which is relatively green and fertile, and where demographic growth has by far overreached the ecological carrying capacity of the environment (Van Damme *et al.* 2010). In this area, species are rapidly disappearing, particularly in the lowlands, where urban expansion and agricultural exploitation are highest. In the Maghreb, with its numerous underground hydrobid endemics, water extraction from the aquifers has resulted in the intrusion of seawater into the karstic underground systems, changing the water quality and leaving the habitats in aquifers unsuitable for many species. In Egypt, the reduced flow of the Nile has resulted in a retreat of the Nile Delta with subsequent impacts on the local ecology (Van Damme *et al.* 2010).

Pollution of a small river close to Ouagadougou, the capital of Burkina Faso. © TIMO MORITZ

Newly built dam for irrigation, south-west Burkina Faso. © TIMO MORITZ

Figure 4.7. Principal threats to freshwater molluscs in mainland continental Africa.



In tropical western and central Africa, the major threat is the siltation and flow alteration of clear streams shaded by gallery forest, often resulting in open waters coloured red from laterite muds during the rainy season. Pollution by raw sewage is another important threat in this region, as is fish farming. After clearing gallery forests, areas of swamp are often formed that are too wet for farming and too dangerous for raising cattle. As a consequence, and in an effort to diversify local livelihoods, the FAO has introduced methods and provided material for stocking fish in existing lakes as well as in man-made fish ponds along riverbeds. Such actions have changed the ecology, which is now no longer suitable for many of the endemic prosobranchs.

4.3.2 Dams

In North America, dam construction during the early 1900s led to severe declines in the native molluscan faunas (Bogan 1993, 2008), and similar patterns are now beginning to be seen on other continents. In Africa, large dams are already constructed or proposed for many of the river catchments, to generate electricity for industrial and domestic use. The impacts of these dams are already being seen for a number of species, and the scale of this development is set to expand greatly over the next few years (Economic Commission for Africa 2003). Dam construction can impact freshwater molluscs in different ways, depending on the life-history strategy of the animal, making the impact of the construction of dams neither uniformly negative nor positive (Seddon 2000). Dams and their reservoirs form insurmountable barriers that will:

a) Cut off upstream populations of molluscs from downstream populations;

b) Lead to a loss of the underlying riverine habitats and their fauna;

c) Cause changes downstream of the dam, where part of the river is impacted by fluctuations in water level plus changing water-chemistry and water temperatures, potentially impacting life-cycles through changing reproductive patterns and reproductive success; and

d) Cause a loss of fish-host movement, potentially changing freshwater mussel reproductive success.

There are examples of beneficial construction. For example, Van Damme *et al.* (2010) reported that the gastropod fauna of the Nile downstream of the Aswan Dam seems to have improved, although this might alternatively be an effect of cessation in the use of huge amounts of molluscicides, as employed during the anti-bilharzia campaigns. According to Brown (1994), large prosobranch populations have also developed in the man-made Lake Kariba, but that seems to be an exception. In contrast, after the construction of Lake Volga in Ghana, there was an increase in the number of bilharzia-carrying species, and a corresponding loss of the native pulmonate species (Seddon 2000), with an overall decline in species diversity and species richness. In general, data from Europe and North America indicate biodiversity loss following dam construction, with the exception of opportunistic species such as *Melanoides tuberculatus* and some *Gabbiella* and *Hydrobia* species that appear to be transported by birds (Van Damme 1984). Studies of the effects of dam construction on gastropod faunas in Africa have not yet been carried out, but it is generally assumed that hydrological alterations from reservoirs, in particular reservoir release, are one of the two main causes of the local extirpation of gastropod populations in the USA (Pyron *et al.* 2008), and there is no reason to suspect that this is not also the case in Africa.

The planned Gibe III Dam on the Lower Omo River in Ethiopia will decrease the amount of water reaching Lake Turkana, which is the most alkaline of the African Great Lakes that still harbours a gastropod fauna, albeit a strongly impoverished one. One described species, *Gabbiella rosea*, is endemic to this lake, and a second species, referred to as "*Tomichia* sp.", is probably also an endemic. *Gabbiella rosea* presently occurs in vast densities, and is currently assessed as Least Concern, but it may rapidly become Extinct if water levels decline, increasing the alkalinity in the lake.

In central Africa, plans for the Grand Inga and the Inga III dams (see section 1.2, this volume) may have significant impacts on the high diversity hotspots, as any changes to the patterns of water flow and water quality may impact these species (Graf *et al.* 2011).

4.3.3 Water pollution

Decline in habitat quality in freshwater rivers and lakes is a problem throughout Africa. The causes of habitat decline are, however, quite variable. In western Africa, water quality in rivers is declining due to the expansion of bauxite mining. Some restricted range endemic species from Sierra Leone, Côte d'Ivoire and Guinea are impacted by a combination of mining waste and sedimentation, along with changing flow regime and increased water temperature. The most notable of these species are those in genera which are restricted to western Africa, such as *Sierraia outambensis* (CR) and *Soapitia dageti* (CR) (García *et al.* 2010; Kristiansen *et al.* 2009b). Raw sewage is also a problem in many parts of Africa. In most cases, domestic waste water and sewage is discharged directly back into rivers and lakes, polluting the downstream or local waters. In some areas these have had distinct impacts on range restricted species – for example, downstream of Brazzaville and Kinshasa on the Congo River, and bays close to Kigoma on Lake Tanganyika. Even in regions that are sparsely populated, water pollution is often quite dramatic because of the now common use of detergents, chemical fertilizers and pesticides.

4.3.4 Sedimentation

In tropical western and central Africa and in the East Africa lakes, a major threat to molluscs is siltation and subsequent alteration of the microhabitats required by some freshwater snails. Most African prosobranch species (unlike pulmonates) are benthic or epibenthic, tracing furrows through the surface of the bottom sediment, or they live within the sediment (e.g., *Melanoides* species). When river banks are cleared of their forest cover, nutrient-enriched soils rapidly accumulate in the rivers. These accumulations change the physical and chemical characteristics of the sediments through increased quantities of fine organic muds and depleted oxygen levels. Prosobranchs adapted to life on hard surfaces in swift running forest waters are also impacted as there is an increase in films of mud and fine silts that cover these stones, and the sediments foul their gills. Increased exposure to sunlight and decreasing stream velocities will also favour aquatic plant growth, which may benefit most pulmonates and some small prosobranch species, but it causes problems for the bottom dwelling prosobranchs that do not tolerate the change to extreme fluctuations in diurnal dissolved oxygen levels.

4.3.5 Invasive species – water hyacinth and other plants

Herbert (1998) noted that alien and highly invasive aquatic weeds (e.g., *Pistia stratiotes* and *Eichhornia crassipes*) present major environmental and economic problems in southern Africa. Although their influence on the native molluscan fauna in general has not been evaluated, they are known to increase habitat available to bilharzia-carrying snails (*Bulinus* spp. and *Biomphalaria* spp.). Lange (pers. comm.) noted that the increase in invasive weed species has also led to an increase in the abundance of bilharzia-carrying snails (*Bulinus* spp. and *Biomphalaria* spp.) in Lake Victoria.

4.3.6 Invasive species – fish farming

The stocking of non-native fish, such as trout in the upper tarn lakes of eastern Africa, the various fish farmed in Lake Victoria, and the development of fish farming in western Africa, has possibly had an impact on the native molluscs in these habitats, although there have not been any studies that have confirmed this. As mentioned above, the clearance of gallery forest cover along rivers and streams in western Africa has led to changes in land use, and the expansion of aquaculture as an alternative source of income, but again the impact on the mollusc fauna is yet to be evaluated.

4.3.7 Invasive species – molluscs and their impact on indigenous species

Invasive mollusc species do not, at the moment, pose significant problems across Africa but do have localized impacts. Fourteen alien gastropod species have been reported in Africa within the past two decades, belonging to five families, two prosobranchs and three pulmonates. Eleven of these species originated in South America or Asia. Four species, *Thiara granifera, Pseudosuccinea columella, Physa acuta* and *Aplexa marmorata* have become invasive in Africa, and a further three, *Pomacea difusa, R. rubiginosa* and *Gyraulus chinensis*, could potentially become so, as they

Danger crocodiles! Field survey has to be conducted with care! © DANIEL GRAF AND KEVIN CUMMINGS

are invasives in other countries. The other thiarid, *Melanoides tuberculatus*, may represent an invasive morph of the species from Asia, but this needs to be confirmed by DNA analysis. Several species that have been reported as introduced seem not to have survived. Only one alien freshwater bivalve, the introduced Asian clam *Corbicula fluminea*, has been recorded in African waters (Van Damme *et al.* 2010a).

Most invasive freshwater snails in Africa originated in tropical or sub-tropical regions of the world and, in terms of their thermal tolerances, are warm water species. Introductions can also be divided into those introduced (i) accidentally, often via the aquarium trade, and those introduced (ii) deliberately, usually for the biological control of the intermediate hosts of schistosomiasis. Inter-basin transfer water schemes and, on a much smaller scale, tanker transport of water, may also distribute freshwater molluscs to new water bodies, as has happened in Namibia (Appleton pers. comm.).

Some invasives have been recorded widely across Africa, while others are known from only a few or even single countries. Despite the wide distributions of several species, quantitative information on their impacts on indigenous African molluscs is scarce and often anecdotal. Several species, notably the apple-snails, *Pomacea* spp. and *Marisa cornuarietis*, and the thiarid *Tarebia granifera*, have been identified as potential biocontrol agents of schistosomiasis host snails because they prey on or compete with pulmonates such as *Biomphalaria spp.* and *Bulinus spp.*. Whether this competition is for resources, such as food, or due to interference (e.g., physical contact) facilitated by the invasives' greater population densities, is not clear. Each case seems to be different and more-or-less unique. Nevertheless, these are species that should be monitored. It may be that some or all of these invasives have not been in Africa long enough to have had impacts as serious as the extirpations reported in other parts of the world, such as the Caribbean islands. Inevitably, recourse has to be made to research done on these same invasives elsewhere, but even here it is unlikely that observations in, for example, small tropical islands such as Puerto Rico and Martinique can be extrapolated directly to Africa. Valuable quantitative information is, however, coming from N.A.F Miranda's ongoing study (Miranda *et al.* 2010) of the impact of *T. granifera* on the indigenous gastropods of the coastal lakes of northern KwaZulu-Natal, South Africa.

Some introduced species have caused major changes and impact on native species, whereas others aren't known to have had any significant impact. In some cases, such as *Melanoides tuberculatus,* the native forms are being displaced by the south-east Asian morph. For example, where the south-east Asian morph has invaded Lake Malawi it has displaced the indigenous form in the southern parts of the lake (Genner *et al.* 2004). The characteristic pattern of shell ornamentation and sculpture of this invasive morph of *M. tuberculatus* falls within the wide range of characters seen in the polymorphic indigenous form (Brown 1994; Samadi *et al.* 2000), making it unlikely that its introduction and spread will be easily noticed. Just as the invasive morph of *M. tuberculatus* has displaced the indigenous form in Lake Malawi, there is evidence that it may also have happened in western Africa and in KwaZulu-Natal province, South Africa, in recent years.

Another parthenogenetic south-east Asian thiarid species in the family Thiaridae, *Tarebia granifera,* probably has the greatest potential of any invasive species to threaten native species. Following its discovery in South Africa in 1999, *Tarebia granifera* has spread rapidly through the provinces of KwaZulu-Natal and Mpumalanga, as well as Swaziland (de Kock and Wolmarans 2008; Appleton *et al.* 2009). Although it is currently also moving southwards towards the Eastern Cape, its spread is predominantly northwards, and it will undoubtedly reach Mozambique and Zimbabwe soon if it has not already done so. In fact, the three northernmost rivers in which it has been found (Pongolo, Sand and Crocodile) all flow into southern Mozambique. There seems no reason why it should not continue spreading northwards into eastern and central Africa. The high salinity tolerance exhibited by *T. granifera* has allowed it to invade several estuaries, lagoons and coastal lake systems in KwaZulu-Natal (Miranda *et al.* 2010). Although *Tarebia granifera* is often regarded as a detritivore, its diet includes large quantities of benthic microalgae – up to 68% of daily primary benthic productivity (Miranda *et al*. unpublished data). Where *T. granifera* is present in large numbers, it is likely to have an important impact on primary production, consuming as it does a substantial portion of the available food resource, which may explain the dominance of *T. granifera* over pulmonates and may be the cause of the loss of *M. tuberculatus* at some sites. Another

Children washing clothes in a steam near the Sanaga River in Cameroon, potentially exposed to diseases hosted by freshwater molluscs. © KEVIN SMITH disruption caused by *T. granifera* is sediment disturbance, as it is an active snail that ploughs its way through the sediment leaving "trails" several millimetres deep as it does so. The freshwater mussels (families Unionidae and Iridinidae) are unlikely to be severely affected, since they occur mostly in water deeper than is favoured by *T. granifera*. However, pea-clams (*Sphaerium* and *Pisidium*) are common in shallow water and could be exposed to impact. The invasion of the brackish water zone along the south-east and east coast of Africa by *T. granifera* is worrying, since it will surely endanger the prosobranch community there (including the rarer species of *Septaria* spp. and *Neritina* spp.). This factor may become more significant in the future, as invasions by thiarids are documented to have resulted in great reductions in numbers or, in some cases, the extirpation of several indigenous gastropods and bivalves in several Caribbean islands and the USA (Pointier 1999; Karatayev *et al.* 2009).

4.3.8 Climate change

At present few freshwater molluscs are known to be directly threatened by climate change. In most cases, an increased frequency of drought events will be a secondary threat to these freshwater species where there are already problems, such as over-abstraction of water for domestic and agricultural purposes, that are leading to low water levels in the rivers and springs.

In western Africa, the decline of water levels in Lake Chad has been consistent and ongoing since the 1970s, leading to the reduction in the size of the lake. This has led to the listing of four endemic taxa within a threatened category, although, as mentioned above, these taxa are all in need of taxonomic review to confirm their status as full species.

4.4 Understanding the impact of molluscs on human health and livelihoods

The economic importance of African freshwater molluscs rests primarily on their roles as intermediate hosts for parasites causing disease in people and domestic stock. They serve as intermediate hosts for a wide variety of trematode flukes. Porter (1938) reported 112 morphologically distinguishable types of larval trematode in 28 mollusc species from across South Africa, while Loker *et al.* (1981) recovered 38 types in 14 mollusc species from the Mwanza region of Tanzania. Several of these trematodes cause economically important diseases in people and domestic stock, with those causing schistosomiasis and fascioliasis by far the most important.

Many freshwater snails serve as intermediate hosts for the nematode *Angiostrongylus cantonensis*. Rats are the usual definitive hosts for *A. cantonensis*, but when people ingest its larvae, either by eating infected snails or in mucus trails left by infected snails on salad material, they penetrate the central nervous system and cause eosinophilic meningitis. Although predominantly an Asian parasite, isolated reports from northern, western and southern Africa suggest that angiostrongyliasis may have become widespread in Africa too. Yousif and Lämmler (1975) and Yousif and Ibrahim (1978) reported natural infections in *Lanistes carinatus* in Egypt, and showed experimentally that species of *Biomphalaria* and *Bulinus* as well as the invasive *Physa acuta* were also susceptible to infection.

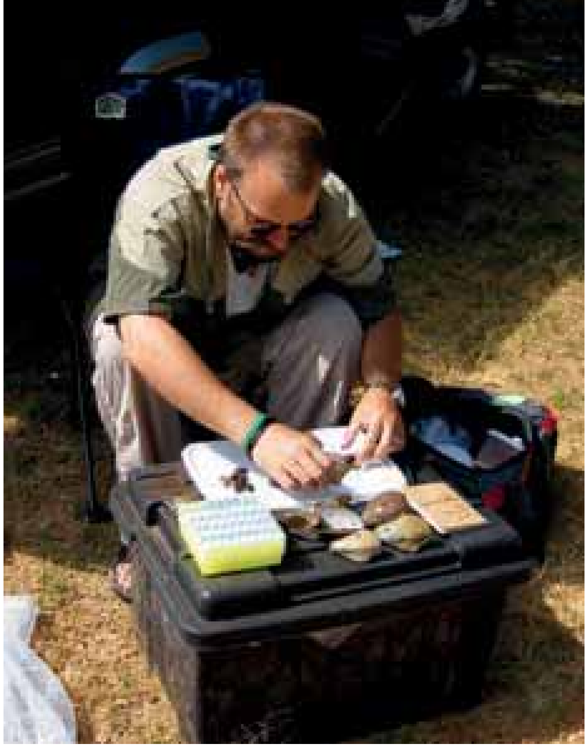
Schistosomiasis

Human schistosomiasis occurs in every country in Africa, except Lesotho. It has been known since the early decades of the 20th century that the life-cycles of the two most important schistosomes, *Schistsoma haematobium* (cause of urogenital schistosomiasis) and *S. mansoni* (cause of intestinal schistosomiasis), involve species of *Bulinus* and *Biomphalaria* (Gastropoda: Planorbidae), respectively, as intermediate hosts. A third human parasite, *S. intercalatum*, affects people in parts of western Africa, and also uses species of *Bulinus* as its snail host.

The number of people, mostly children, infected with either *S. haematobium* or *S. mansoni*, or both, in sub-Saharan Africa is estimated at around 170 million, with another 600 million at risk of infection (WHO 2002; Southgate *et al.* 2005). Approximately 300,000 people are estimated to die each year from the disease (Hotez and Fenwick 2009), mostly from kidney failure in the case of *S. haematobium* infections and haematosis in the case of *S. mansoni* infections.

The economic impact of human schistosomiasis is difficult to gauge in monetary terms because of difficulties in accurately measuring the effects of subtle variables like absenteeism, loss of productivity and reduced educability on a continent-wide or even national scale. Certainly, costs to Africa run into hundreds of millions of US dollars per year. A widely used alternative measure of morbidity is the DALY

Bulinus tropicus *(LC), a widespread species in southern Africa and beyond is known to act as the intermediate host for the conical fluke* Calicophoron microbothrium*, a common parasite of domestic animals. Within the genus* Bulinus *is found the intermediate host species for urinary schistosomiasis, a serious human disease.* © CHRIS APPLETON



Preserving specimens after a field survey at Lake Bangweulu, Zambia. © DANIEL GRAF AND KEVIN CUMMINGS

(disability-adjusted life year), which measures the number of years lost to a disease due to morbidity, disability and early death. Recent estimates of DALYs lost to schistosomiasis in Africa are as high as 70 million – more than losses due to malaria or tuberculosis, and almost equivalent to HIV/AIDS (Hotez and Fenwick 2009).

Veterinary schistosomiasis is also common, and is due mostly to the ungulate schistosomes *S. bovis* and *S. mattheei.* Like the common human parasites, these veterinary schistosomes are widespread over the continent. Both *S. bovis* and *S. mattheei* use species of *Bulinus* as intermediate hosts, as do three other less widely distributed veterinary species, *S. curassoni*, *S. leiperi* and *S. margrebowiei* (Brown 1994). Heavy infections may result in death, with prevalence in cattle of up to 90% in some areas. Localized outbreaks accompanied by significant morbidity and mortality have been recorded. Sheep are more susceptible than cattle.

Fascioliasis

Species of *Lymnaea* serve as intermediate hosts for the liver flukes that cause fascioliasis; *L. natalensis* for *Fasciola gigantica*, the most common fasciolid in sub-Saharan Africa, and *L. truncatula* for *F. hepatica* (Mas-Coma 2004). Studies elsewhere have shown that the North American *L. columella*, which is invasive in Africa, is susceptible to both *F. hepatica* and *F. gigantica*, so its role in the transmission of fascioliasis in Africa needs investigation.

Human *Fasciola* infections are uncommon in Africa, except in Egypt where fascioliasis is regarded as an emerging disease. An estimated 830,000 people are thought to be infected in the country, most in the Nile Delta, with prevalences up to 17% (Soliman 2008). The severe pathology caused by the immature flukes as they migrate through the liver has resulted in the disease being recognized as a public health problem in Egypt. In chronic infections the bile duct and gall bladder become inflamed as well.

Animal fascioliasis is more common than the human disease, and is known across the continent where it affects a range of stock animals. Prevalences above 50% are frequently reported in cattle and chronically infected animals show reduced growth, lower milk production and lower calving rates. The marketability of such animals is poor, due to condemned livers and underweight carcasses. These effects are, however, difficult to quantify. Nevertheless, significant economic losses are experienced by farmers in fascioliasis-endemic areas. Infections in sheep are more difficult to assess.

4.5 Recommended conservation measures

At present, despite the few omissions from our species list and underestimates incurred as we wait for species to be described, we believe that the data presented are reasonably representative of the status of molluscan biodiversity and the threats to these species across Africa. Even with these omissions, the conclusions and suggested actions would still apply once additional data have been included.

There are no known targeted conservation measures in place to protect any of the threatened freshwater molluscs of Africa. In fact, the freshwater mollusc faunas get little conservation attention, more often being the focus of eradication programmes as part of bilharzia management schemes to improve the health of local populations (Kristiansen and Brown 1999). Whilst in other parts of the world freshwater molluscs, such as the river rapids species and the spring-snails, have benefited from the extension of protected areas as conservation actions for the species, in Africa there are, with the exception of Ramsar Sites, few protected areas designed specifically for protection of freshwater fauna. The majority of protected areas include rivers and lakes as boundary markers rather than as targeted conservation features in their own right (Darwall, pers. comm.), and, in cases where they are included, the protected area boundary will not stop the spread of threats such as pollution, invasive species, sedimentation, and altered flow regimes. Protected areas need to be designed specifically to protect upper catchments and to include entire river and lake systems within their boundaries, if they are to provide effective protection to freshwater species.

Capacity and awareness of the value and ecological importance of molluscs needs to be raised. Rarely do the relevant governments or indigenous communities appreciate the value of their molluscan biodiversity, so capacity building projects, such as is ongoing in Morocco (IUCN 2010) through community outreach and collaboration with local wildlife and fisheries departments, are recommended to raise awareness and facilitate monitoring of local populations of gastropods and bivalves.

Environmental Impact Assessments need to include assessments on the impacts to mollusc diversity, and should be mandatory for any proposed developments likely to impact mollusc species, such as: dam construction; fish farm developments; large-scale timber extraction involving clear-felling of gallery forests; and mining developments using open surface extraction methods.

The indiscriminate use of molluscides needs to be better controlled, as it currently also causes decline of populations of non-carrier endemic species that do not provide a threat to human health or livelihoods. The loss of these species has two major effects:

a) Increase in the carrier species, filling the niche vacated by the non-carrier species; and

b) Decline of food supplies for the other native species that predate on these molluscs, such as crabs, aquatic birds and fish.

Finally, sewage treatment needs to be improved, and there needs to be tighter control on the import of invasive species to reduce the impact on native species.

4.5.1 Recommended research actions

i) Description of new species

Although the freshwater molluscs of Africa, with an estimated 560 species (Bogan 2008; Strong *et al.* 2008), are less diverse than some continental faunas, the current number of species is underestimated. There are some regions, such as the north African Maghreb and eastern Africa lakes, where there are many recognised species that have yet to be named (Ghamizi 1998; West *et al.* 2003). There are also regions in western and central Africa where there has been little active field survey or taxonomic research since the 1960s, and these regions will be under-recorded and may potentially support unrecognised species. The current estimates of species diversity may well, therefore, need revision over the next 10 years. The lack of "value" placed on new species descriptions by the scientific community has led to pressure to publish overview papers or synthesis papers, rather than traditional alpha-taxonomy. This, combined with a decline in journals that will take large papers dealing with descriptions of new species, is undoubtedly slowing the speed with which new species are described.

ii) Facilitate information flow for conservation management

It is critical to ensure that information on range-restricted endemic species is passed to the relevant authorities, and that any proposed developments in these regions take account of these endemic species.

iii) Research studies on species demography and ecology

For many freshwater molluscan taxa in Africa, demographic, ecological and life history data are insufficient to make meaningful predictions about how gastropod and bivalve species will respond to changing freshwater environments. For example, information on the host-fish for the parasitic larvae of freshwater mussels of the families Unionidae, Iridinidae and Etheriidae are minimal, prohibiting evaluation of the specific impacts of dam construction, overfishing or aquaculture on these bivalves (Graf *et al.* 2011). The decline in native freshwater mussels could also lead to fundamental changes in the river ecosystems, as the mussels provide water purification services, as well as habitat for commensal species living on the mussels (e.g., freshwater acari). Many such studies could be suitable as undergraduate and MSc. student projects if small sources of funding could be provided.

iv) Field survey for Data Deficient species

Many freshwater molluscs in the region are known from only a relatively small number of specimens, and most of those have not been corroborated by recent collecting. For example, as Graf *et al*. (2011) note, in western Africa the freshwater mussel *Mutela joubini* (Iridinidae) is known from only five museum lots, mostly in the Chad-Chari Basin of the western African region. As another example, the family Ancylidae is represented by 49 species belonging to two main genera, *Burnupia* and *Ferrissia,* as well as a few species of *Ancylus*. Most of these species are assessed as Data Deficient, awaiting the results of ongoing research by C. Albrecht. As these freshwater limpets are very small they are likely to be overlooked by collectors in the field, which may explain why they are so poorly known. Identifications are currently best made on the basis of proximity to the type localities of the described species. Finally, the genus *Burnupia* is usually considered to be indigenous to Africa, but a species of *Burnupia* has recently been identified from South America by dos Santos (2003), raising biogeographical questions as to the true distribution of the genus. Species such as these are clearly in need of further field-survey and taxonomic review in order to make informed conservation and management decisions, especially in the more poorly surveyed regions of Africa, such as the smaller lakes in eastern Africa (e.g., Lake Albert), the fast-flowing rivers in western Africa, and parts of the Congo basin where many of the least known species were described in the last century.

v) Control of invasive species

Research to better understand the impacts of invasive species, especially in regions where *Tarebia granifera* has become established, should be a priority.

Species in the spotlight

Freshwater molluscs are important – especially to the African openbill stork

Appleton, C.C.[1] and La Hausse de Lalouvière, P[2]

It is not an easy task to convince people outside of the conservation community (or in some case even within it) that molluscs are important and should be conserved, but in this short essay we can see clearly how important they are to the African openbill stork, *Anastomus lamelligerus*. The openbill stork feeds almost exclusively on freshwater snails and mussels. In particular, it feeds on large operculate snails of the family Ampullariidae (*Lanistes ovum* and *Pila* spp.), and less commonly on *Bellamya* spp. (Viviparidae), as well as unionoidan bivalves such as *Unio caffer* and *Coelatura framesi* (Unionidae), and *Chambardia wahlbergi* and *Mutela zambesiensis* (Iridinidae). Terrestrial snails, such as the Achatinidae, are sometimes also taken. The question is: how does a bird use a great big beak to extract the bodies of snails and mussels from inside their protective shells?

Photo 1. The African openbill stork with its characteristic "open" bill. © DAVID ALLAN

Various books and scientific papers on African birds have reviewed literature on the stork's feeding behaviour and the role that the iconic "open" bill plays in extracting the soft parts from their molluscan prey (e.g., Huxley 1960; Kahl 1971; Hockey *et al.* 2006). Not only is the function of the gap in the storks' bill still the subject of debate, but so also is the actual technique used by the birds to extract the soft parts from the shells of their prey. The characteristic gap between the mandibles, 5mm on average for South African storks, is not thought to be used for crushing shells, but is proposed to enable the tips of the mandibles to operate like pincers and pick up and manipulate individual molluscs prior to removing their soft parts. The process of manipulating shells to remove the soft parts is intricate and difficult to observe because it is usually done under water or amongst vegetation, but apparently always with the prey resting on some kind of solid surface. Examination of shells discarded by openbill storks in the Okavango Delta, Botswana, and the Pongolo floodplain in north-eastern KwaZulu-Natal, South Africa, and comparison of the damage to the shells with the shape of the birds' bills, presents new hypotheses on this unresolved question.

On two occasions in July 2000, near Chief's Island in the Okavango Delta, accumulations of *L. ovum* shells were found on flattened

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platforms, approximately 40cm across, made by openbill storks at a height of 30-40cm above the water, in clumps of the reed *Vossia cuspidata* (Photo 2). A total of 46 shells were collected from these platforms, and all were large adults of 40 to 55mm shell height. These shell larders seem analogous to the accumulations of empty shells reported from river banks in eastern Africa, and suggest that the openbill stork reuses the platforms as surfaces for extracting the soft parts from prey snails over a period of time – a sort of kitchen workbench! No bivalves were found here, but since they live in deep water, they are inaccessible to the birds. Curiously though, no *Pila occidentalis*, a second large ampullariid occurring in the delta (Appleton *et al*. 2003), were present even though they grow to 55mm and form part of the openbill's diet elsewhere in Africa.

Most shells from these platforms (72%) had a single more-or-less triangular notch in the apertural lip 5 to 21mm (mean 15mm) deep (Photo 3). A further six had shallow chipping and the remaining seven showed only slight irregularities to the outer lip – not very different from empty shells found elsewhere in the delta. Allowing for uneven breakage of the shell, the shape and depth of these notches match the storks' lower mandible which is also triangular in cross section.

Photo 3. L. ovum *collected from the reed platforms in the Okavango Delta, Botswana, showing the triangular notches in the lip of the basal whorl.* © CHRIS C. APPLETON

A comparison of these notches with the bills of museum specimens of the openbill stork suggests that the birds use a sophisticated technique to extract the soft parts of snails like *L. ovum*. Having picked the shell up, and secured it between the tips of its grooved upper mandible and the knife-like lower mandible, the stork uses the lower mandible to take a triangular notch out of the outer apertural lip to expose the operculum. Using the upper mandible to hold the snail firmly on a surface like the reed platform described above, it then pushes the sharp lower mandible through the notch to sever the operculum and then the columellar muscle, probably in one movement. The lower mandible of the openbill stork is, in fact, slightly curved, and Kahl (1971) proposed that this curvature made it easier for the bird to sever the snails' operculum and columellar muscle. Five of the museum specimens examined had the lower mandible curved to the right, one to the left, and three were not curved at all. Nevertheless, this action frees the snail's soft parts from its shell so that they can be eaten by the bird.

A similar technique is used by openbill storks for bivalves or mussels, but with the difference that bivalve prey is initially held crosswise in the bird's bill. This allows the stork to chip into the ventral margins of both valves with its lower mandible. It then flicks the shell into a lengthwise position with its dorsal hinge line lodged in the grooved under surface of the upper mandible (or puts the mussel with its notched valves onto the bank), inserts its lower mandible between the valves via the notch and, starting at the posterior end and drawing it towards the anterior end, severs the two adductor muscles as it does so. Once these muscles have been cut, the soft

Photo 2. An openbill storks' larder – a platform in a clump of Vossia cuspidata *with numerous empty* Lanistes ovum *shells.* © CHRIS C. APPLETON

parts can be removed and eaten. These adductor muscles are cut so close to their scars on the shell's inner surface that the discarded shells are remarkably clean.

Triangular notches, seldom as deep as in *L. ovum*, were also present near the posterior ends of the ventral margins of articulated valves of approximately 60% of *Co. framesi* and *Ch. wahlbergi* collected on the Pongolo floodplain (Photos 4a-d). A smaller number of valves of both species had shallow chips taken out of the posterior end (Photos 4c and d).

Using the characteristic damage to bivalve prey described above as markers, and bivalve density data for 1983/4 from Appleton and la Hausse de Lalouvière (1987), we have assessed the extent of predation by openbills on the standing crop of *Co. framesi* and *Ch. wahlbergi* on the Pongolo Floodplain in KwaZulu-Natal.

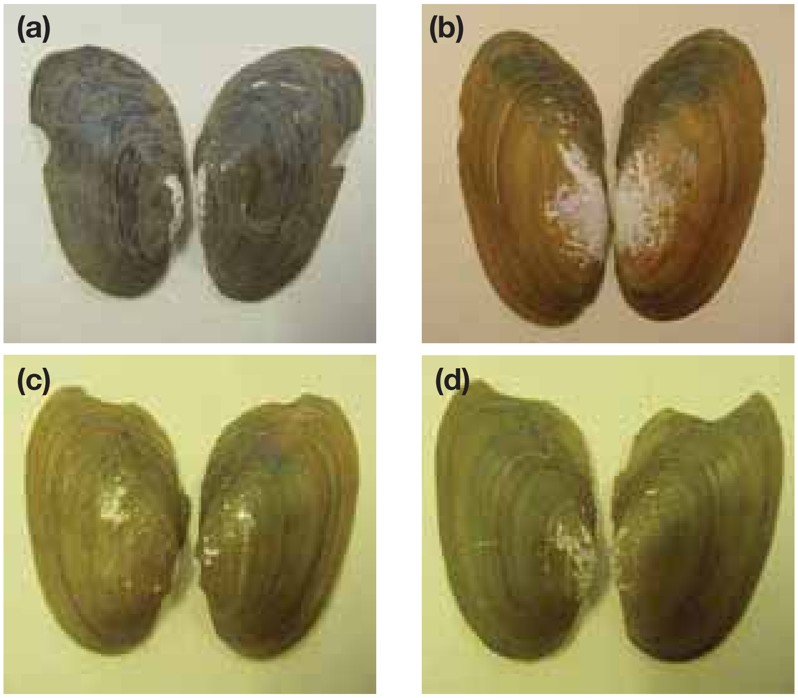

Photo 4(a-d). Examples of notched Co. framesi *(a,c and d) and* Ch. wahlbergi *(b) valves from the Pongolo River floodplain. Photos a and b show characteristic notches in the posterior half of the valves' ventral margins, while c and d show shallow chips at the valves' posterior ends.* © CHRIS C. APPLETON

> **Unionoidan bivalves are in decline worldwide, and in South Africa the endemic *Unio caffer* is classified as Near Threatened**

We estimate that openbill storks consumed 13.0% of the standing crop of *Co. framesi* (or 27 x 106 individuals) and 4.6% of the standing crop of *Ch. wahlbergi* (or 591,560 individuals). These data suggest that bivalves represent a substantial part of the diet of openbill storks on the Pongolo floodplain, with an estimated 20 flocks comprising almost 450 birds counted on the floodplain's lakes in 1983 (P. la Hausse de Lalouvière, unpubl. data). *L. ovum* also occurs on the floodplain, and is eaten by openbill storks, but we have no quantitative data to estimate the numbers consumed in this case.

Various authors, including Huxley (1960), had previously concluded that the openbill stork crushed the shells of its prey using the gap between its mandibles to do so, but the types of shell damage described here are quite different from that resulting from crushing. Crushing is akin to being hit with a blunt object, which was the technique used by Iron Age people in Zambia to open similar shells of *L. ovum*, *Co. mossambicensis* (probably synonymous with *Co. framesi*) and *Ch. wahlbergi*, for food (Appleton 1985). *L. ovum* shells from these archaeological deposits had typically lost their spires and parts of their basal whorl but kept their apertures intact, while the bivalves were represented mostly by fragments incorporating the umbonal areas and anterior ends of the valves.

So how do threats to molluscs such as these potentially impact dependent species such as the openbill stork? Unionoidan bivalves are in decline worldwide, and in South Africa the endemic *Unio caffer* is classified as Near Threatened, probably due to increasing pollution, use of molluscides, and the impact of invasive fish on the indigenous species that serve as hosts for the mussels' parasitic larval stage. This may explain recent reports in birdwatchers' blog sites of openbill storks expanding their range in southern Africa, and foraging in built-up areas and on golf courses for the common garden snail *Helix aspersa* and probably indigenous achatinids too. In conclusion, the humble mollusc is important after all, and often in ways which may not at first be apparent, except to a select few. The challenge now is to spread this understanding to those who make decisions which might determine the fate of these unobtrusive but important species.

Species in the spotlight

Can the last populations of the giant African freshwater pearl mussel be saved?

Ghamizi, M[1] and Van Damme, D[2]

For decades this large mussel was believed to be Extinct, until surveys in the area rediscovered it just a few years ago. Formerly, *M. marocana* was considered to be a local race of the European *Margaritifera auricularia,* found over a large part of western Europe. However, a few specialists, such as Dr. Douglas Smith, disagreed with this view. But on the basis of shell characteristics from a handful of museum specimens collected at the beginning of the 20th century, this taxonomic problem could not be solved. It was only after live specimens were rediscovered three years ago that DNA research by Araujo *et al*. (2009) provided the irrefutable evidence for *Margaritifera marocana*'s specific distinctiveness. The species is, hence, a Moroccan endemic, whose range is restricted to two rivers belonging to the same hydrographical basin. The area that they occupy within these rivers is extremely limited. So far, only two small populations have been found, both at sites strongly affected by human activities. Both populations consist exclusively of specimens of old age-classes, all shells measuring more than 10cm. With no evidence of juvenile mussels, recruitment appears to have been halted, and recruitment patterns remain an unknown.

The same is true for the species of fish host or hosts on which the larvae of *M. marocana* are parasitic. As with other representatives of the genus *Margaritifera*, the larvae (of the glochidium type) attach themselves to the skin and gills of their host fish, and after metamorphosing into a young mussel, detach and drop to the sediment. This way, the fish ensures the distribution of the clam. Host specificity in all *Margaritifera* species is high, restricted to a single or a few fish species. It is not yet known which and how many fish species are used by *M. marocana* as hosts. If its host specificity is very narrow, it may be that the particular fish host has disappeared from the rivers where they are known (for example, as a consequence of the construction of dams), therefore preventing reproduction and the completion of the life cycle of *M. marocana*. Virtual complete extinction of its main host fish, the Atlantic sturgeon, led to the extirpation of the European *Margaritifera auricularia* except in two rivers where populations are associated to another host, and it is feared that the same thing will happen to *M. marocana*, which may result in it being lost forever.

Margaritifera marocana *(CR) is a large naiad species endemic to north-west Morocco.*

All habitats in Moroccan rivers from which populations of *M. marocana* have been recorded during the early 20th century are heavily degraded, threatened by desiccation and polluted by domestic and agricultural effluents. Some Moroccan types of *Margaritifer*a, such as the one originally described as *M. dernaica* from the Oued Derna, are completely gone. Are *M. dernaica* and *M. marocana* one and the same species? Only in the unlikely event that live *Margaritifera* specimens would be rediscovered in the Oued Derna could this question be solved.

The conservation of *M. marocana,* considering the recent IUCN assessment of its threatened status, warrant investigations concerning not only the biological questions already cited above, but should also include sociocultural research on the Amazigh communities that reside along the river at the two sites where *Margaritifera* still occurs.

Nowadays, local children swim, particularly during summer, at both sites without paying attention to the mussels, which look like flattened stones, wearing sandals to protect their feet against cuts from the valves' edges. In 2009, when collecting material for

> **So far, only two small populations have been found, both at sites strongly affected by human activities**

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genetic research, these children enthusiastically joined the research team and helped by diving for mussels. There were mixed feelings about their interest because, due to the fact that part of the team consisted of Europeans, the local youngsters were wondering about the potential commercial value of the mussels.

On returning to these sites on several occasions, it was a great relief to see that no one was offering these large river pearl shells (up to a length of 20cm), with their beautiful nacre (mother of pearl), for sale to tourists, especially given that the most important site for these mussels is also a main stopping point for tourist cars and buses. Fortunately as well, no culinary tradition appears to be linked to these freshwater mussels, at least not in the villages in the vicinity of the two sites. Consumption of clams, oysters and other sea produce in Morocco seems to be confined to the inhabitants of the coastal zone. Yet it should be kept in mind that the villagers living near the two *Margaritifera* sites would, with no hesitation, exploit the last remaining populations if they should discover any use for them.

Margaritifera marocana is presently dying in silence, its disappearance being hastened by the degradation of its habitat and climate changes, in particular the increasing irregularity of precipitation and river flow regime that causes periods of drought and desiccation interrupted by massive floods, during which mussels are swept away or buried in sediment.

It is, therefore, not only imperative that awareness campaigns are set up for the conservation of the species, but it is also equally important to continue our biological research on this species in order to find solutions for the problem of recruitment. This species is Critically Endangered and we should all be concerned for its continued existence.

Species in the spotlight

A mollusc with a bit of muscle

Graf, D.L. [1]

Chambardia wahlbergi (LC), a freshwater mussel, is one of the most widespread species of mollusc in Africa. Whilst the majority of mussel species in the Afrotropics have small distributions, restricted to particular basins, *C. wahlbergi* is recorded from most regions across the continent. The geographical success of this mollusc (in a truly mollusc-hostile continent) can be attributed to the animal's ability to survive the punishment of the dry season. However, there is still a great deal that we don't know about *C. wahlbergi*, and this is typical of tropical freshwater mussels in general. For the majority of species, we are merely aware that they exist and have only an inkling of their true distributions based on the places they have been collected. It is rare to have detailed field observations from living mussels in Africa, and this inhibits our understanding of how these molluscs interact with their environment (including us).

Freshwater mussels of the order Unionoida belong to a species-rich, globally distributed, and ancient group of bivalve molluscs. They originated at the same time as the dinosaurs, and today there are more than 850 species worldwide in six families. Four of these families occur in Africa: Unionidae, Margaritiferidae, Etheriidae, and Iridinidae. The iridinids are known only from Africa, and it is to this family that *Chambardia wahlbergi* belongs. Relative to other regions, the African freshwater mussel

Chambardia wahlbergi, collected from a fisheries pond. This specimen will be used to study the evolutionary relationships of African freshwater mussels. © DANIEL L. GRAF

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[1] University of Alabama

The Lutemwe River (Luangwa Basin) in Zambia at low water. © ALEC LINDSAY

fauna is restricted, with only about 80 species (compare this to 300 in North America, or more than 200 in south-eastern Asia). Africa is a tough place for molluscs, with waters poor in calcium (needed for their shells), and the dry climate limiting for aquatic organisms.

Chambardia wahlbergi ranges from South Africa north to Somalia and west to Senegal. In southern and eastern Africa, *C. wahlbergi* is able to thrive where other mussels cannot because of its ability to survive when rivers dry up seasonally. In 2005, samples were taken from the Lutemwe River of Zambia. During that time of year, the stream is reduced to a mere trickle, but with the generous assistance of the local people who use the subsurface waters for both irrigation and laundry, several living specimens of *C. wahlbergi* were obtained from deep within the sediment. With at least 40% of Africa dominated by desert-like habitats, this ability gives *C. wahlbergi*, and freshwater mussels like it, a distinct advantage.

Chambardia wahlbergi, *collected from a fisheries pond.* © DANIEL L. GRAF

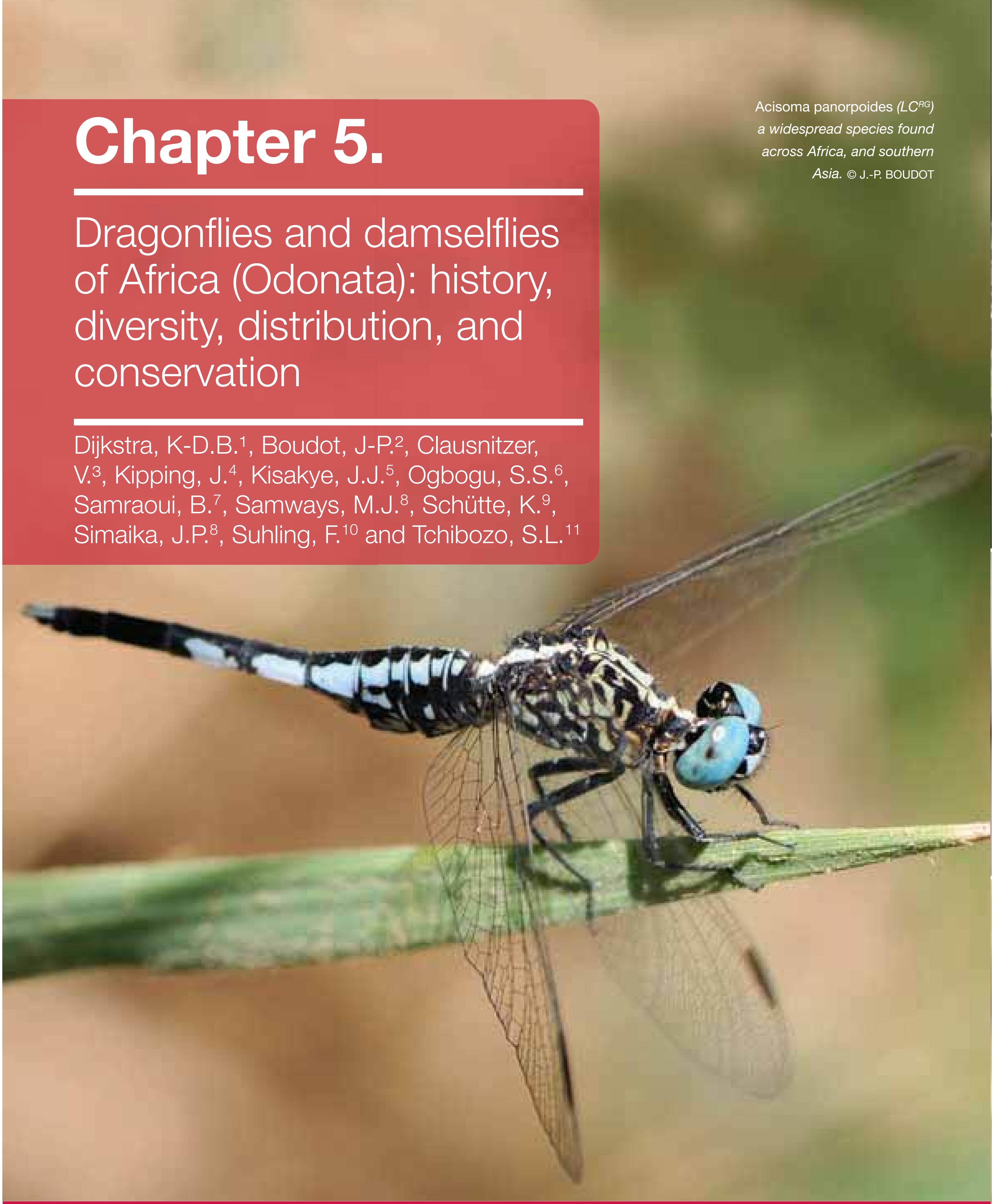
Unfortunately, most of our knowledge of the biology of *Chambardia wahlbergi* is limited to such anecdotes. We can only infer its life history from better-studied freshwater mussels, assuming a great deal from the traits of temperate species. For example, almost all mussel larvae are parasitic upon freshwater fishes. It is very likely that *C. wahlbergi* larvae do the same. In 2008 and 2009, with the help of Alex Chilala of the Zambian Department of Fisheries, it was possible to collect *C. wahlbergi* from artificial ponds stocked with tilapia. This provides strong evidence that the larval mussels had hitchhiked along with the parental stock of fish, but the dynamics of the reproductive cycle of this mollusc remain to be explained.

To the uninformed, freshwater mussels like *Chambardia wahlbergi* may be mere "clams", but they have the potential to capture the imagination of anyone open to acknowledging the complexity and interrelatedness of aquatic ecosystems. However, these animals are threatened worldwide due to the degradation of fresh waters. Basic biological research on the freshwater molluscs of Africa will be crucial for establishing informed conservation priorities, not only for the protection of biodiversity but for the sustainable management of fresh waters into the future.

Chapter 5.

Dragonflies and damselflies of Africa (Odonata): history, diversity, distribution, and conservation

Dijkstra, K-D.B.[1], Boudot, J-P.[2], Clausnitzer, V.[3], Kipping, J.[4], Kisakye, J.J.[5], Ogbogu, S.S.[6], Samraoui, B.[7], Samways, M.J.[8], Schütte, K.[9], Simaika, J.P.[8], Suhling, F.[10] and Tchibozo, S.L.[11]



Acisoma panorpoides *(LC^{RG}) a widespread species found across Africa, and southern Asia.* © J.-P. BOUDOT

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Notogomphus cottarellii *(EN) is an Ethiopian endemic threatened by habitat destruction.* © K.-D.B. DIJKSTRA

The globe skimmer (Pantala flavescens) *(LC).* © VIOLA CLAUSNITZER

Hadrothemis vrijdaghi *(LC).* © K.-D.B. DIJKSTRA

CONTENTS

5.1 Introduction

5.1.1 Odonata in biogeography and conservation

Dragonflies and damselflies (Odonata) are the most conspicuous freshwater insects, thus representing both a vital human resource and the largest class of animal diversity. They are suited for evaluating change in the long term (biogeography, climatology) and the short term (conservation), above and below the water surface (e.g., Clausnitzer 2003; Corbet 1999; Dijkstra and Lempert 2003; Oertli 2008; Samways 2010; Suhling *et al.* 2006), receiving increasing attention from the public, conservationists and scientists on regional and global levels (Clausnitzer and Jödicke 2004; Clausnitzer *et al.* 2009; Córdoba-Aguilar 2008). Due to their attractive appearance, they function not only as flagships for conservation of water-rich habitats such as wetlands and rainforests, but also for habitats where water is scarce and, therefore, especially vital to the survival of life. Human disturbance of water catchments, with the consequent loss of soil and water-sources, is a problem world-wide, especially in the tropics, and certainly in Africa. Considering the ever-changing nature of the African landscape, be it under human, geological or climatic influence, the study of its Odonata will help us understand the past and future of a rapidly changing continent. An overview is provided here, as an elaboration of Dijkstra (2007d), focusing also on conservation and incorporating data from Darwall *et al.* (2005), Dijkstra *et al.* (2010; 2011), Samraoui *et al.* (2010) and Suhling *et al.* (2009a).

5.1.2 Knowledge of African Odonata

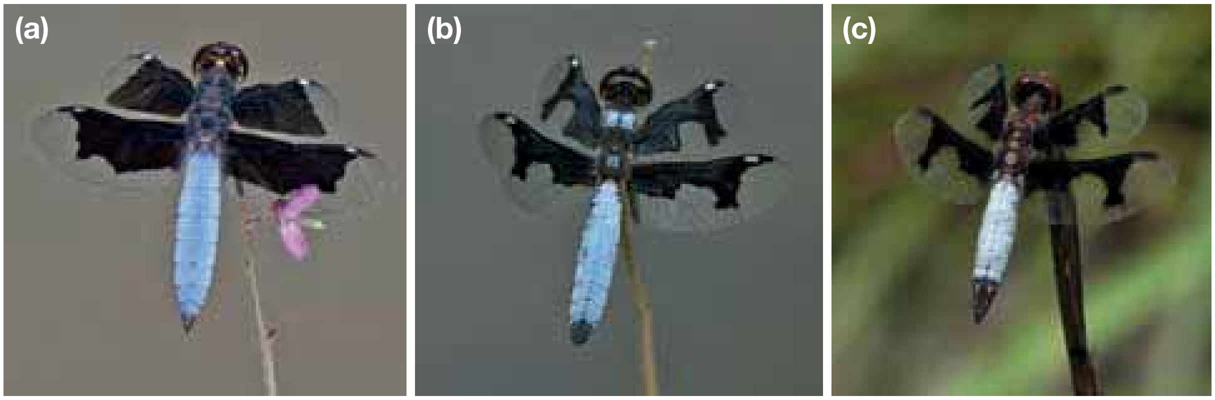
5.1.2.1 Taxonomy and identification

Odonate taxonomy is well-resolved in comparison to other Afrotropical insects (see reviews in Dijkstra 2003b, 2007d) and distributions are sufficiently known for biogeographic studies and threat assessments, although our understanding is still partly obscured by taxonomic problems or the lack of regional data (see 5.1.2.2). Several keys and field guides are already available for the southern part of the continent (Samways 2009; Suhling and Martens 2007; Tarboton and Tarboton 2002, 2005), which has improved surveying in the region. A further stride forward should be made in 2011, when a key to males of over two-thirds of the continent's species will be published (Dijkstra and Clausnitzer in prep.). Two problems have been central to the taxonomic disorder:

(1) An overvaluation of wing venation led to the recognition of more taxa (especially genera) than are supported by other characters, such as genitalia (Dijkstra and Vick 2006). Venation was favoured because it is quantifiable, but is much more plastic than previously believed. Characters that were traditionally treated as primitive may rather be derived reconfigurations of veins induced by changes in wing shape as an ecological adaptation.

(2) Many supposed taxa differ in size and melanism, but are not supported by morphology (Dijkstra 2003a, 2005a, Dijkstra *et al.* 2006a). Such variation is probably environmentally induced, but can also be age-related. This applies mainly at the species level, but has also led to the description of superfluous forms and subspecies. The problem is especially great in Africa, as many species can realise broad geographic and environmental ranges across a huge continent with few natural barriers, and is exacerbated by fragmentary collecting.

The need for taxonomic advancement, and its progress, is illustrated by Africa's most conspicuous family, Libellulidae, where prolonged taxonomic inertia obscured the status of some of the most familiar dragonflies, most striking being the 'former' *Palpopleura*.



(a) Palpopleura lucia *(LC) and (b)* P. portia *(LC) were the first odonates to be named from African soil, in 1773 (Dijkstra* et al. *2003). Despite differences in genital morphology (Karsch 1894), size and wing markings (O'Neill and Paulson 2001), and pruinosity pattern, they were treated as forms of one species until Mitchell and Samways (2005) demonstrated they differed genetically. In sharp contrast, a third species in the complex, (c)* P. albifrons *(LC), was only described from Gabon in 1979. The first records since were only obtained from collections and the field during and after the IUCN Freshwater Biodiversity Assessment.* © W. TARBOTON (a, b) AND N. MÉZIÈRE (c)

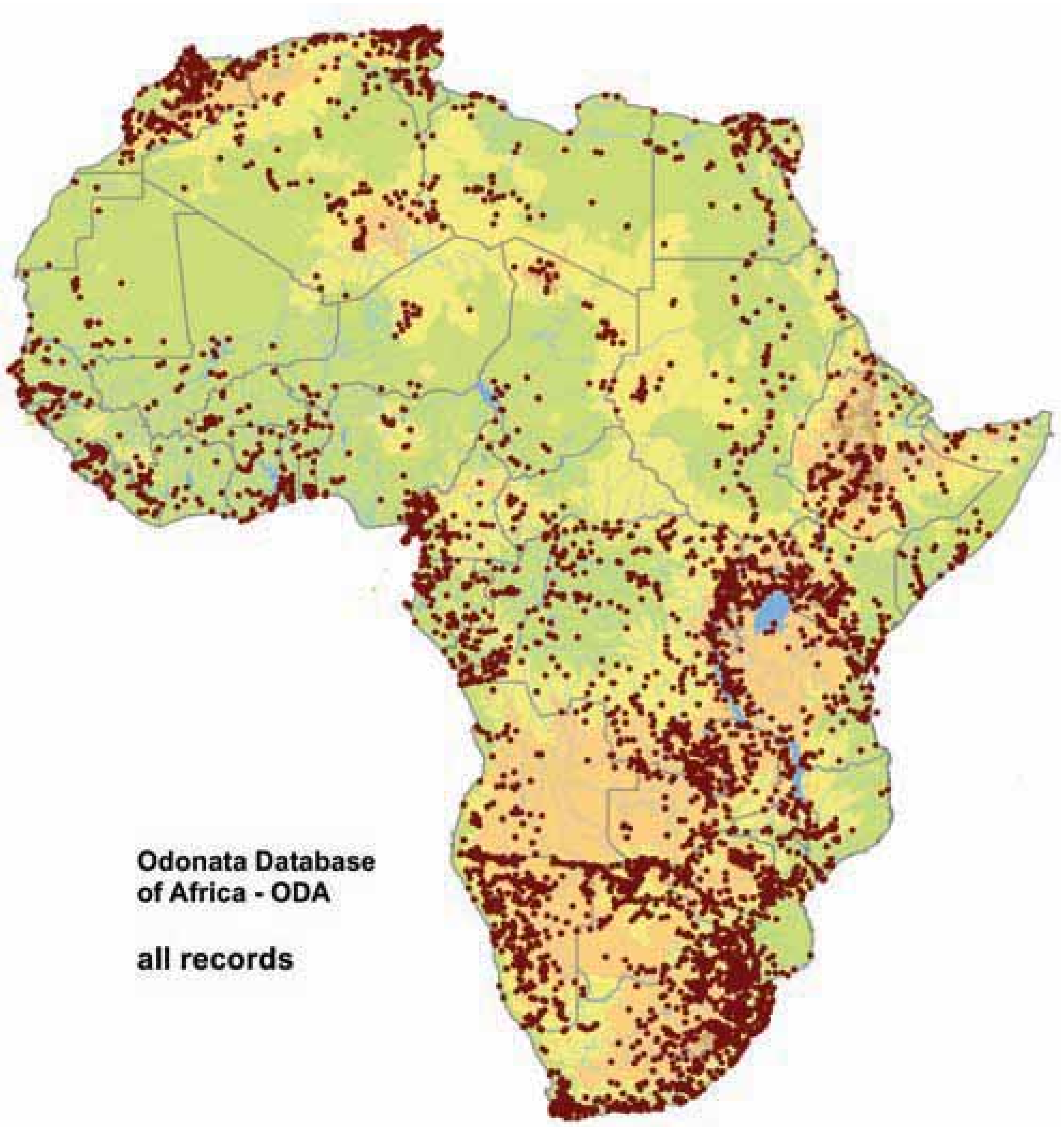
Figure 5.1. Inferred distributions and the overlap for *Brachythemis impartita* (north) and *B. leucosticta* (south). Adapted from: Dijkstra and Matushkina (2009).

Also, while *Brachythemis leucosticta* is one of Africa's most familiar odonates, *B. impartita* remained unnoticed among it for 170 years, despite having a large and widely overlapping range (Figure 5.1; Dijkstra and Matushkina 2009). Structural differences "within" *Trithemis stictica* were only discovered once that "species" was found to be genetically heterogeneous (Damm and Hadrys 2009). These and further cases demonstrate that even inspection of "common" and "recognisable" species is warranted (Dijkstra and Matushkina 2009; Damm *et al* 2010).

5.1.2.2 Distribution and ecology

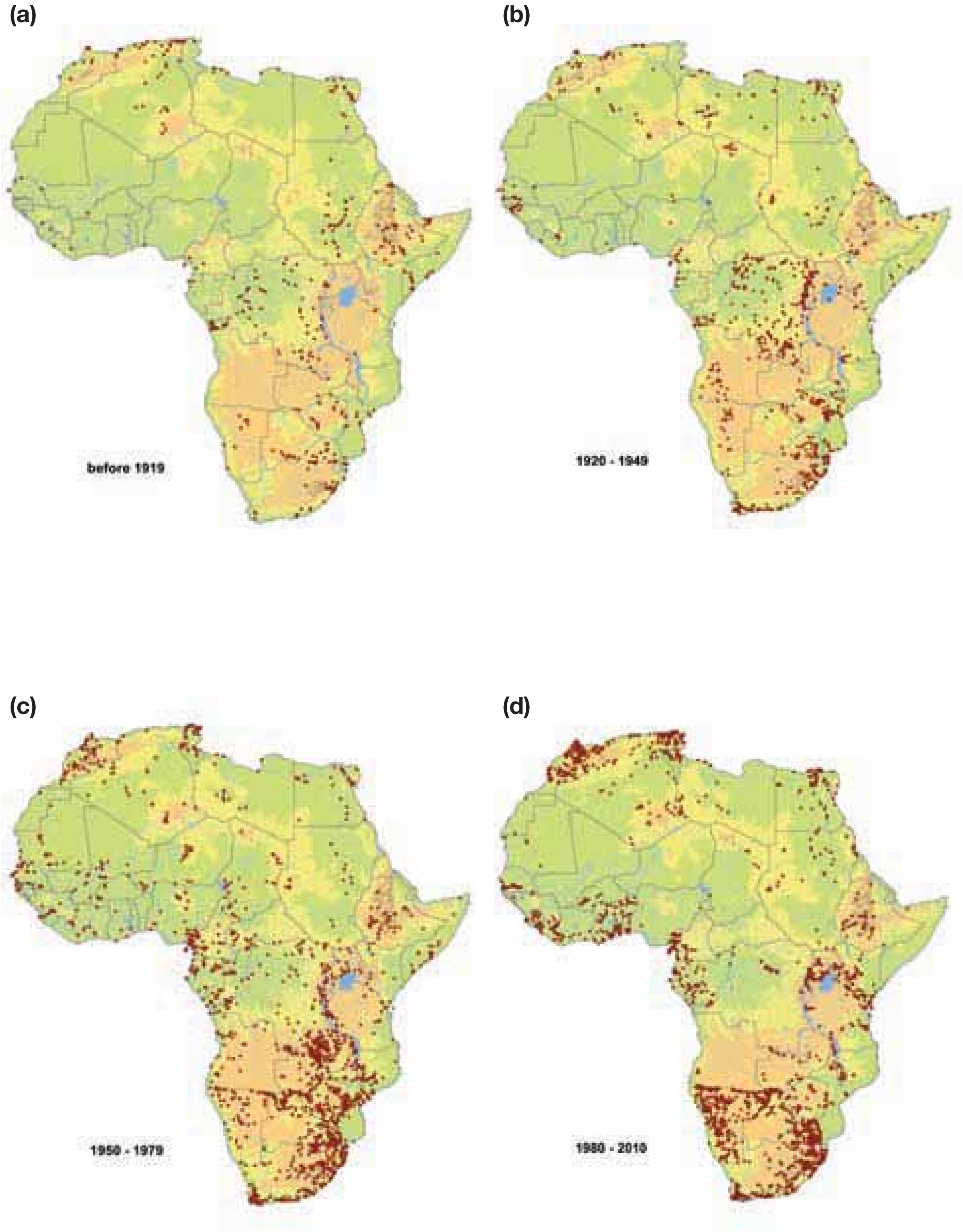
Developed as part of this project, the Odonata Database of Africa (ODA) is the first continent-wide, high-resolution, taxonomically-verified database of a group of tropical

Figure 5.2. Density of locality records in a 100 x 100km grid. Adapted from: Kipping *et al.* (2009).



freshwater insects, thus providing a unique tool to determine patterns of diversity and research intensity. It now contains over 75,000 records, but while the resolution is already impressive, data are patchy in time and space (Figures 5.2 and 5.3). Parts of southern Africa were studied relatively constantly through time, whereas research in countries like Angola, Republic of Congo, Democratic Republic of Congo (D.R.C.), Mozambique and Somalia was impeded by political unrest after independence (see 5.4.3.1 for an overview of recording gaps). Data from some regions, like Nigeria, are available but have not yet been databased. Aside from databasing historic records, a surge in recent fieldwork has taken place, improving distributional knowledge and often providing the first ecological data on the species (see 5.2.2.1; 5.4.3.2-3).

Figure 5.3. Density of locality records over four time periods reflecting variation in the intensity of field survey over time. 1920 to 1949 is a period of high collecting activity during colonial times, especially in D. R. C.; 1950 to 1979 records largely reflect the efforts of Elliot C.G. Pinhey, and the 1980 to 2010 records highlight a lack of information for those areas subject to civil war and political unrest during that time. Adapted from: Kipping *et al.* (2009).



5.2 Diversity and history

5.2.1 Diversity

5.2.1.1 Richness

The Afrotropical odonate fauna is comparatively impoverished at all taxonomic levels (Table 1). Including undescribed species, the total in the tropical mainland must lie above 725 species, with about 150 more on the surrounding islands (mainly Madagascan endemics) and about another 50 in Palaearctic north Africa. The total represents less than one-sixth of the world fauna; both the Neotropical and Oriental regions have twice as many species. The Afrotropical fauna is classified into only 16 families, compared to 21 for both other regions. With both regions it shares all but two of its families; Perilestidae and Pseudostigmatidae are shared with the Neotropics, but are represented by only two species (0.2% of the fauna), while the Chlorocyphidae and Platycnemididae shared with Asia represent almost 11%. Moreover, macromiids do not occur south of Mexico and Old and New World "protoneurids" are not related (Carle *et al.* 2008), and therefore the rich representation of these groups throughout the Palaeotropics is further evidence of the greater similarity between Africa and Asia. Only the Afrotropical diversity of Coenagrionidae and Libellulidae, the largest odonate families on Earth, is on a par with the American and Asian tropics.

5.2.1.2 Patterns of diversity

The distribution of odonate diversity in tropical Africa reveals two vast areas with fewer than 25 species locally in the north (Sahara) and south (Namib-Kalahari), as well as a very rich (more than 100 species locally) area that extends from Guinea and Angola on the Atlantic to Kenya and KwaZulu-Natal on the Indian Ocean (Figure 5.4a

Table 1. Comparison of tropical odonate diversity. Data from Kalkman *et al.* (2008) and Dijkstra (2007d).

	Neotropics		Afrotropics		Oriental	
Family	genera	species	genera	species	genera	species
ZYGOPTERA						
Amphipterygidae	2	3	1	2	1	5
Calopterygidae	3	61	3	17	10	60
Chlorocyphidae	–		3	43	14	80
Coenagrionidae	38	370	11	179	23	185
Dicteriadidae	2	2	–		–	
Euphaeidae	–		–		12	65
Lestidae	2	38	1	14	5	39
Lestoideidae	–		–		1	4
Megapodagrionidae	14	130	5	38	10	298
Perilestidae	2	18	1	1	–	
Platycnemididae	–		9	45	8	130
Platystictidae	1	42	–		5	119
Polythoridae	8	58	–		–	
Protoneuridae	14	94	2	23	8	57
Pseudolestidae	–		–		3	15
Pseudostigmatidae	5	18	1	1	–	
Synlestidae	1	1	2	9	2	1
ANISOPTERA						
Aeshnidae	15	127	5	39	18	138
Austropetaliidae	2	7	–		–	
Chlorogomphidae	–		–		1	40
Cordulegastridae	1	1	–		5	27
Corduliidae	2	37	6	19	7	57
Epiophlebiidae	–		–		1	1
Gomphidae	26	273	15	134	43	358
Libellulidae	44	352	46	217	56	190
Macromiidae	2	2	1	36	2	50
Neopetaliidae	1	1	–		–	
Petaluridae	1	1	–		–	
Total	**186**	**1636**	**112**	**816**	**235**	**1665**

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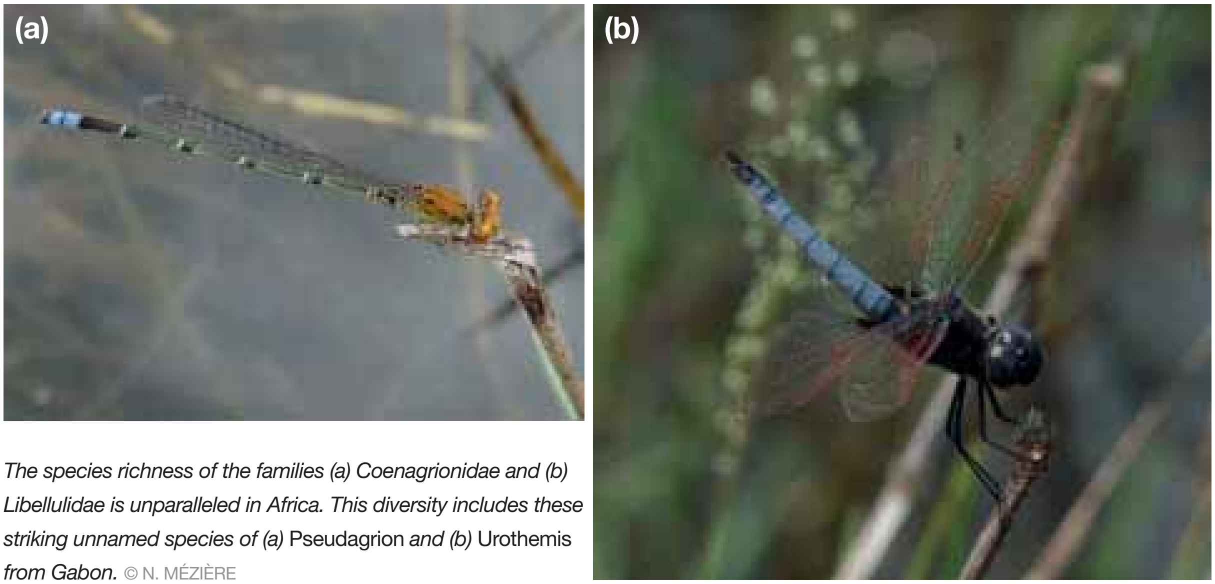


The species richness of the families (a) Coenagrionidae and (b) Libellulidae is unparalleled in Africa. This diversity includes these striking unnamed species of (a) Pseudagrion *and (b)* Urothemis *from Gabon.* © N. MÉZIÈRE

overleaf), with rather abrupt diversity gradients between them. The gradients north and south of the hyper-diverse belt seem to be shaped differently, although that is difficult to demonstrate with the available resolution of data. In the north, diversity rises steeply where desert ends (more than 25 species) and again where forest begins (more than 100), with a rather uniform and equally diverse fauna in the savannah and woodlands in between. In the south, rivers, swamps and gallery forest extend far from the wet centre; diversity diminishes gradually southwards at first, then drops sharply where the tropical African fauna meets the Kalahari desert and South African highlands. This is demonstrated in Namibia, where the Okavango and Caprivi areas have around 100 species, the savannah woodlands of the dry central Namibian highlands 71 species, and the hyperarid Namib and Kaokoveld deserts only 23 and 11, respectively (Suhling *et al.* in press), and in South Africa, where two-fifths of the national fauna is limited to the tropical north-east. This pattern is masked by the lack of data from Angola, large parts of which may have more than 100 species locally. In the east the diversity pattern is complex; the figure suggests a drop from the western rift towards the ocean, but while large high and dry parts of Tanzania are probably truly impoverished, much of Tanzania and Mozambique is simply unstudied.

Although the richest area coincides with the continuous lowland rainforest of western and central Africa, the eastern highlands provide a diversity and stability of habitats that allows it to extend well east and south. Moreover, the four core areas, where local diversity reaches more than 200 species, each include significant highland areas: (1) west, from Sierra Leone to Togo; (2) central, from Nigeria to Republic of Congo; (3) north-east, including Uganda and north-east D.R.C.; and (4) south-east, including Katanga and Zambia. Each core overlaps with an important centre of endemism, the Upper Guinea, Lower Guinea, Albertine Rift and Zambezia, respectively, where rainforest combined with highlands leads to high habitat heterogeneity and thus high species diversity (see 5.3.2; Figure 5.4b). A possible fifth centre of diversity and endemism lacks highlands; the Congo Basin appears comparatively poor with around 125 species locally, but it includes some of the least surveyed parts of Africa (see 5.3.2.4).

5.2.2 History

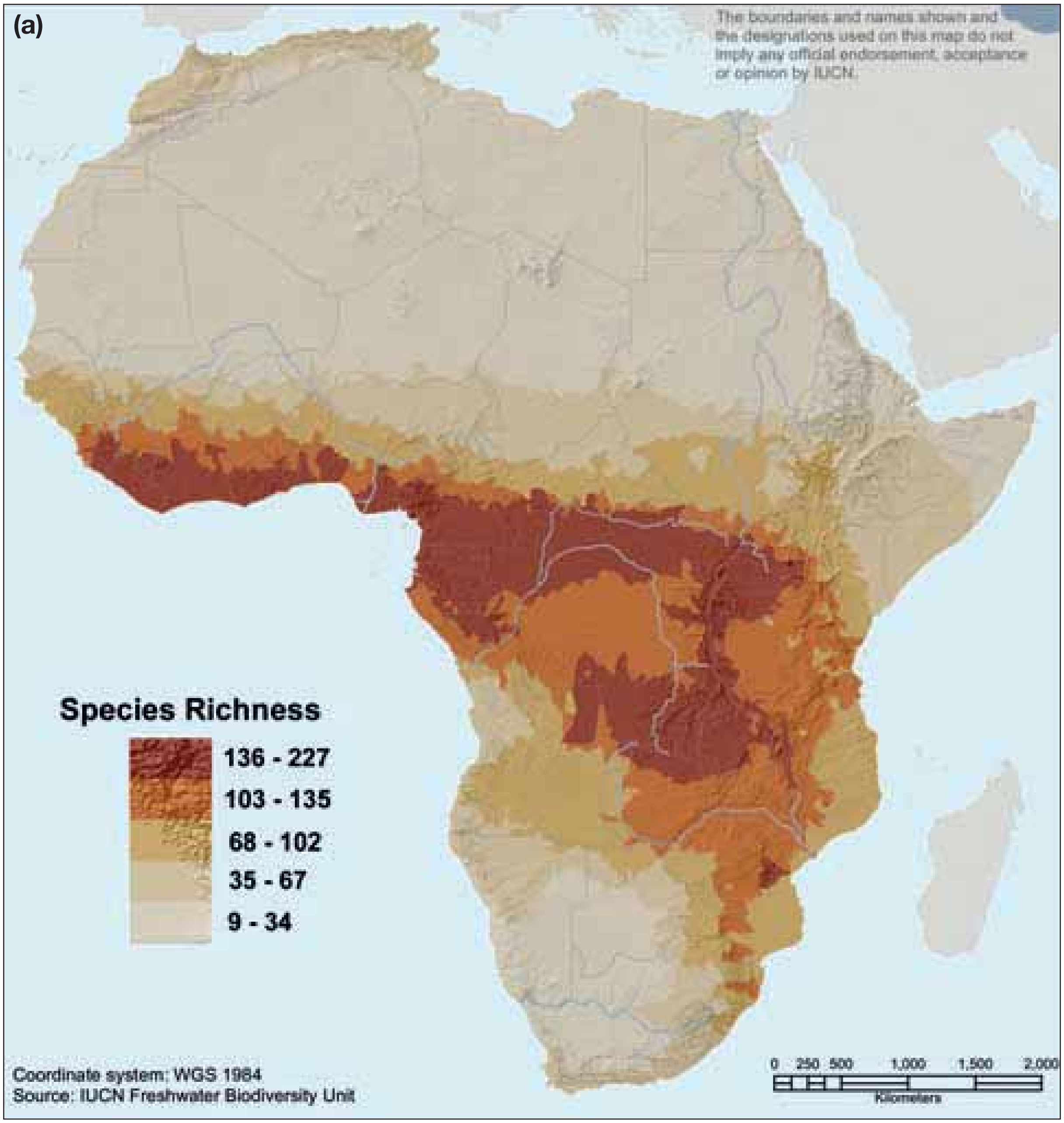
5.2.2.1 Relevance and context

Species' current ecological amplitudes, and thus their future response to complex impacts, were determined by their past (e.g., Samways and Niba 2010). An understanding of history therefore aids the conservation of present diversity by anticipating response to future change. For example, long distance dispersal evolved in response to aridity enables a response to deforestation too. Africa can be seen as the "experimental garden" of global change, experiencing more pronounced climatic shifts than other tropics, with a trend towards drier conditions (for references, see Dijkstra 2007d). The ecological response of dragonflies to arid and seasonal conditions has recently become better understood (e.g., Martens *et al.* 2010; Suhling *et al.* 2006, 2009b, 2010; Van Huyssteen and Samways 2009). For example, certain species retreat to wetter areas in dry years, expanding outwards again in wet years (Samways 2010).

5.2.2.2 Impoverishment and diversification

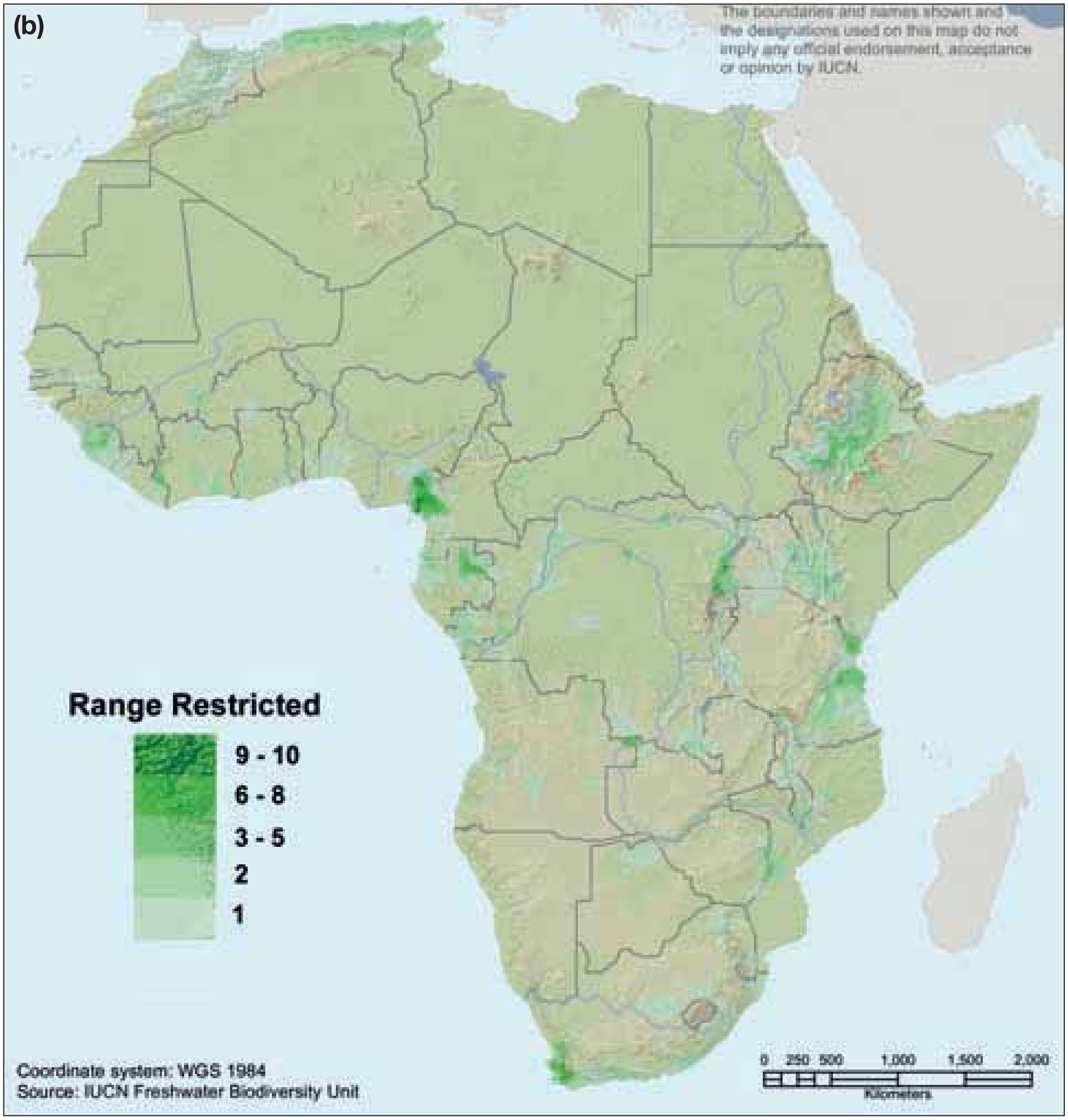
Extinction caused by unstable and progressively drier climates explains much of Africa's impoverishment (see 5.2.1.1). As tropical rainforest harbours most of the world's odonate diversity (Kalkman *et al.* 2008), Africa's proportion is quite reasonable and so its impoverishment

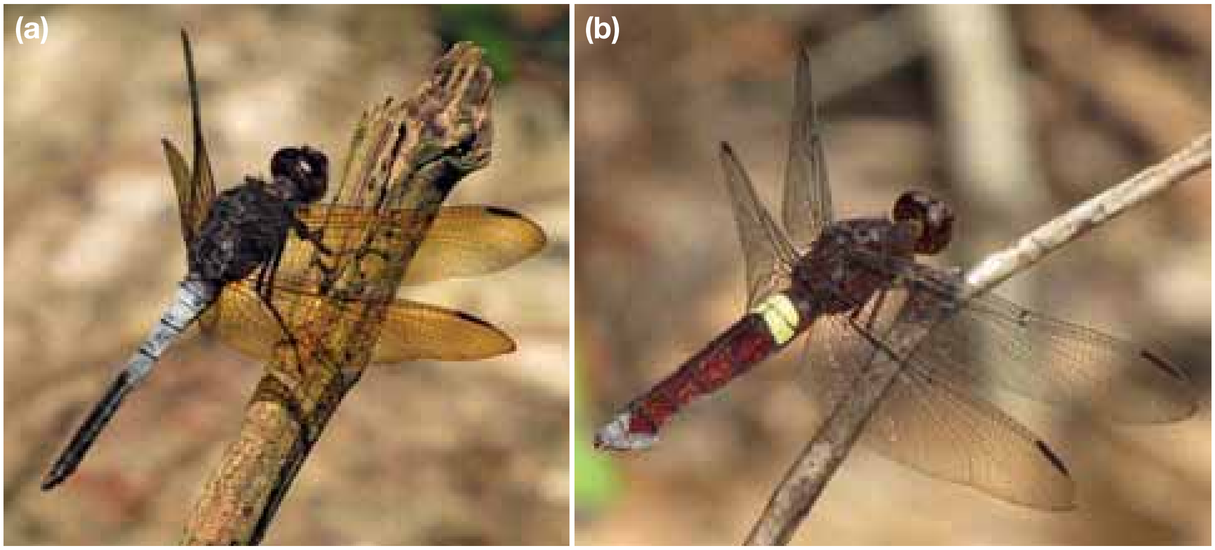
Figure 5.4. Patterns of (a) species richness and (b) range restricted species (ranges < 50,000km²) of African Odonata.



can be considered as much contemporary as historic. Moreover, in response to (recurrent) aridity, African biota may have greater dispersal capacities, enabling larger ranges and more widespread competition, leading to a geographically more uniform fauna. Although Africa's overall impoverishment results from less narrow endemism, large parts of the African savannah and lowland rainforest have local diversity comparable to non-African tropics (Fjeldså 2003; Plana 2004). Also, African odonate species have large ranges on average, but high local diversity: one-third of all *Trithemis* species (see below), for example, can be found in close proximity.

While Africa's lower species count is related to past and present aridity, its missing families may come from its relative isolation since the break-up of Gondwanaland until the closure of the Tethys Sea. It was isolated 60-54 million years ago when most other landmasses were tropical and in contact, and thus "missed out" on many biota that radiated at the time (Morley 2000). This isolation impeded Eurasian warm temperate taxa from retreating into Africa during colder periods. Nonetheless, Africa's loss of families can also be explained by its climatic history. Specialists of forest habitats vulnerable to desiccation (e.g., seepages, temporary streams) are notably rare. For example, only four tree-hole breeders are known (Figure 5.5 overleaf), much less than in America and Australasia (Corbet 1999). Notably, two of the species occur in eastern Africa, rather than in the moister centre and west. In the case of *Coryphagrion*,





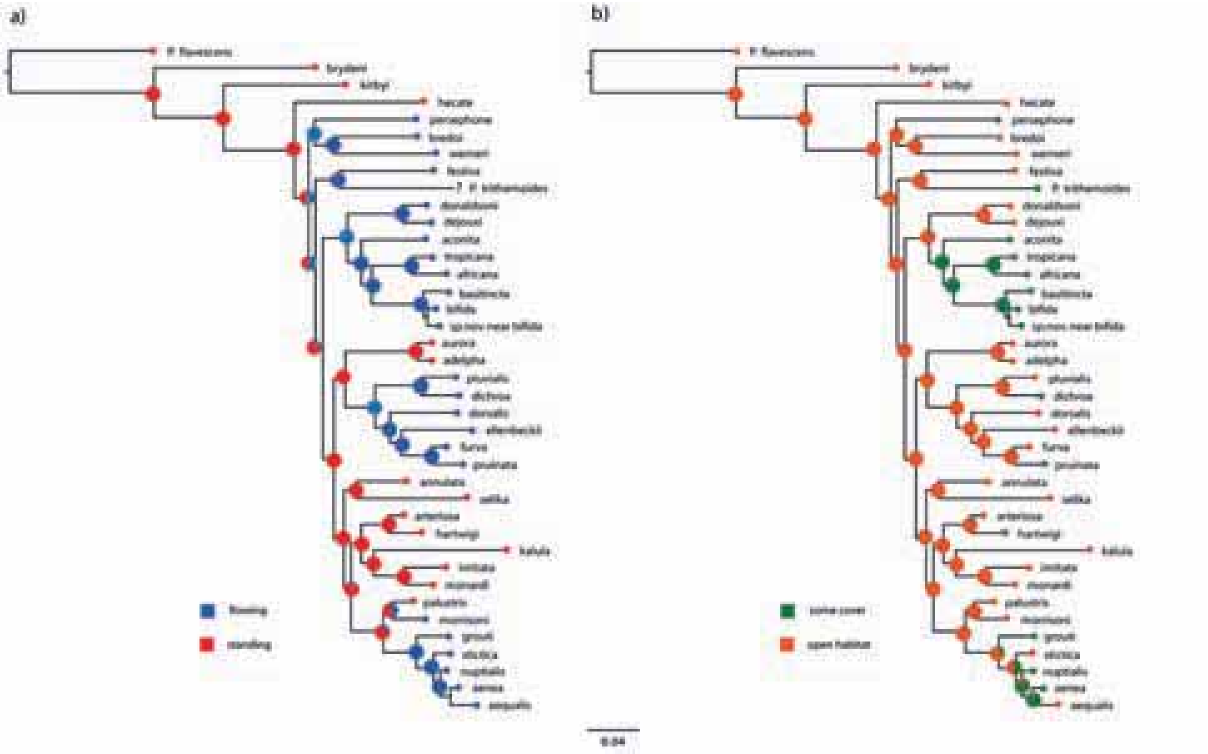
Breeding in tree-holes is comparatively scarce among African Odonata: in the golden-winged Congo basin endemic (a) Hadrothemis vrijdaghi *(LC) this adaptation may have evolved from a species reproducing in forest pools. The latter habitat is evidenced by the muddy abdomen tip of this female (b)* H. coacta *(LC).* © K.-D.B. DIJKSTRA

Figure 5.5. Distribution of dendrolimnetic Afrotropical Odonata. Legend – open circles: *Coryphagrion grandis*; filled circles: *Hadrothemis scabrifrons*; halved circles: both species; shading: *H. camarensis* and *H. vrijdaghi*. From: Dijkstra (2007d).

which even breeds in water held in snail shells and coconut husks (Clausnitzer and Lindeboom 2002), this may be proof of survival in one of the continent's most stable environments (see 5.2.2.3), but the ancestors of the three dendrolimnetic *Hadrothemis* species probably bred in temporary forest pools, the habitat of the genus's four other species. The scarce or absent families Megapodagrionidae, Platystictidae, Pseudostigmatidae and Petaluridae have specialised ecologies: van Tol *et al.* (2009) suggested that platystictids originated in Africa, but were subsequently extirpated.

A lower species count can result from higher rates of extinction and lower rates of colonisation, but also from a lower speciation potential; compared to other landmasses, Africa has been geologically stable since the break-up of Gondwanaland and therefore has less varied relief (e.g., fewer mountain chains) and associated habitat complexity (Fjeldså and Lovett 1997; Morley 2000; Plana 2004; White 2001). Nonetheless, even if speciation rates were lower and change induced extensive extinction, it also geared the rise of species that straddled environmental and dispersal barriers as new habitats became constantly available. Dijkstra and Clausnitzer (2006) and Dijkstra (2007d) formulated diversification scenarios for *Platycypha*, *Pseudagrion* and *Trithemis,* but only the latter has been tested. The genus dominates dragonfly communities across Africa with about forty species, from cool permanent streams to warm temporary pools, from desert to rainforest, and from lowlands to highlands. Combining a dated molecular phylogeny (81% of species) with ecological and geographical data (Figure 5.6), Damm *et al.* (2010) inferred an origin 6 to 9 million years ago in open stagnant habitats, coinciding with savannah expansion; while drying disadvantaged many aquatic species, it favoured those adapted to exposed and temporary conditions. Indeed, *T. kirbyi*, the sister-species of the remainder of *Trithemis* (excluding the atypical *T. bryden*i), is best adapted to live in desert environments (Suhling *et al.* 2009b). The main radiation coincided with a wetter period between 5 and 3.5 million years ago. Possibly forest expansion separated populations in open areas, giving rise to many lineages in little time. As open habitats

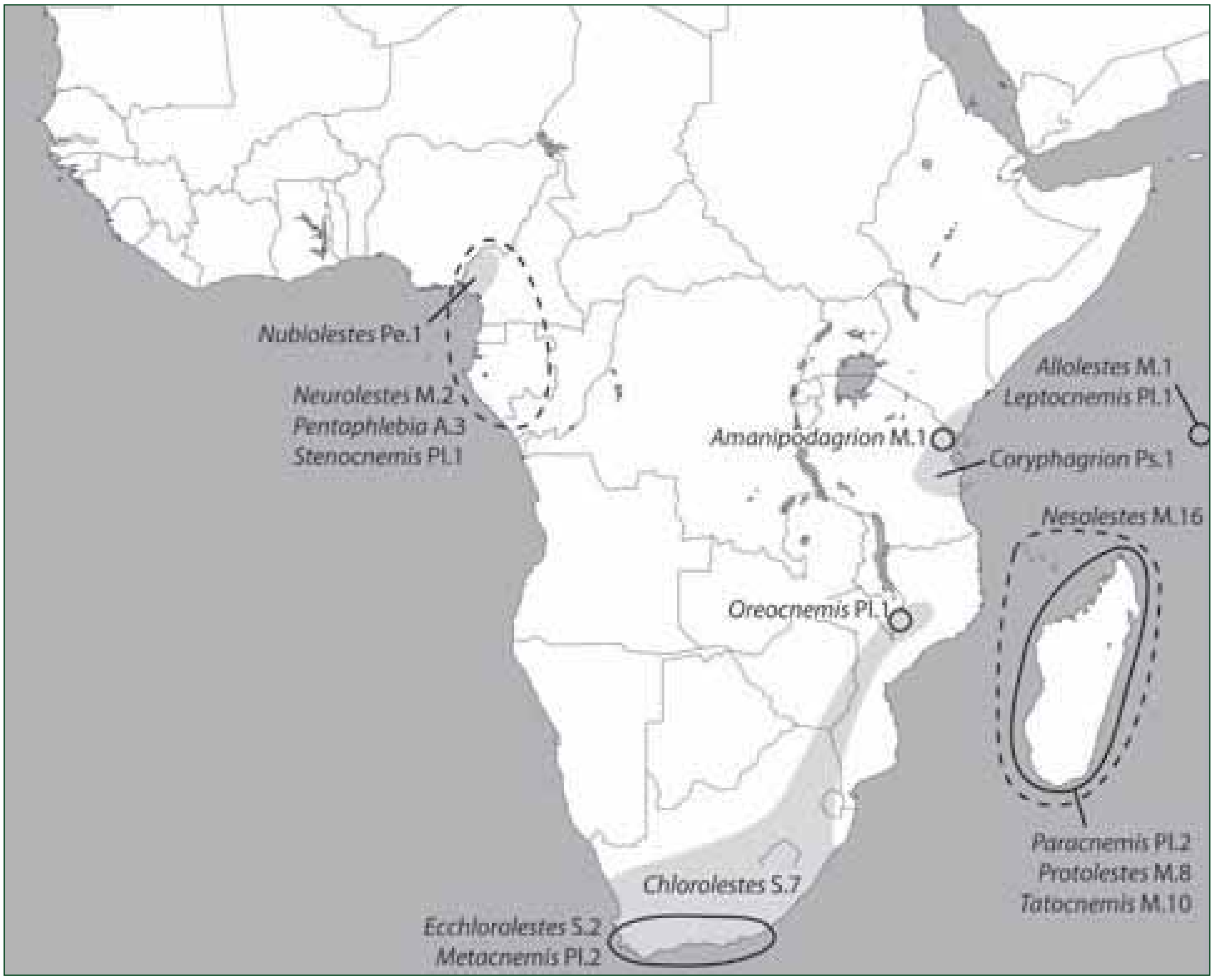
Figure 5.6. Ancestral state reconstructions for (a) larval habitat: flowing vs. standing water; (b) adult habitat: some forest cover vs. open habitats. Based on Bayesian 50% majority-rule consensus phylogram obtained from combined data set of ND1, 16S and ITS regions. Pie charts on each node indicate the posterior probabilities from the stochastic analyses of ancestral state reconstructions using SIMMAP (for details see Damm *et al.* 2010).



began to coalesce after 3.5 million years ago, the species adapted to temporary conditions expanded into largely overlapping ranges. These include *T. annulata* and *T. arteriosa*, two of Africa's most widespread dragonflies, which are currently expanding northwards in Eurasia. At least five more dispersals to Eurasia or Madagascar occurred, demonstrating the variable environment as a cradle for adaptable species and the actuality of history in modern change. However, with such potential for gene flow, these lineages barely radiated further. By contrast, three lineages within the ecological constraints of lowland streams, highland streams, and swampy habitats respectively, diversified excessively in the next 3.5 million years, producing 55% of species diversity. Shifts from open to forested habitats and from standing to running waters occurred at least eight and six times, respectively, the reverse only three and two times. For example, forest expansion 1 million years ago perhaps provided access to suitable shaded streams for two species of the highland group that are now found in lowlands. Present-day diversity in Africa appears to be dominated by groups with such high adaptation potentials. The coenagrionid and libellulid abundance, being the families best adapted to change, is therefore not surprising. Only in temperate regions, impacted strongly by the ice ages, is their dominance and the impoverishment of all other families comparable to that in changeable Africa (Dijkstra and Clausnitzer 2006; Kalkman *et al.* 2008).

The diversity of ecologies and colorations exhibited by the genus Trithemis *is exemplary of an African dragonfly radiation: (a)* T. arteriosa *(LC^{RG}), (b)* T. aenea *(LC) and (c)* T. tropicana *(LC).* © C. VANAPPELGHEM (a), K.-D.B. DIJKSTRA (b) AND E.R. NIELSEN (c)

Figure 5.7. Distribution of relict Afrotropical Zygoptera. The number of species and the family for each genus/area is indicated (A: Amphipterygidae; M: Megapodagrionidae; Pe: Perilestidae; Pl: Platycnemididae; Ps: Pseudostigmatidae; S: Synlestidae). *Nesolestes nigeriensis* is included in *Neurolestes*, *Metacnemis secundaris* in *Paracnemis* (Dijkstra unpubl.). Adapted from: Dijkstra and Clausnitzer (2006).

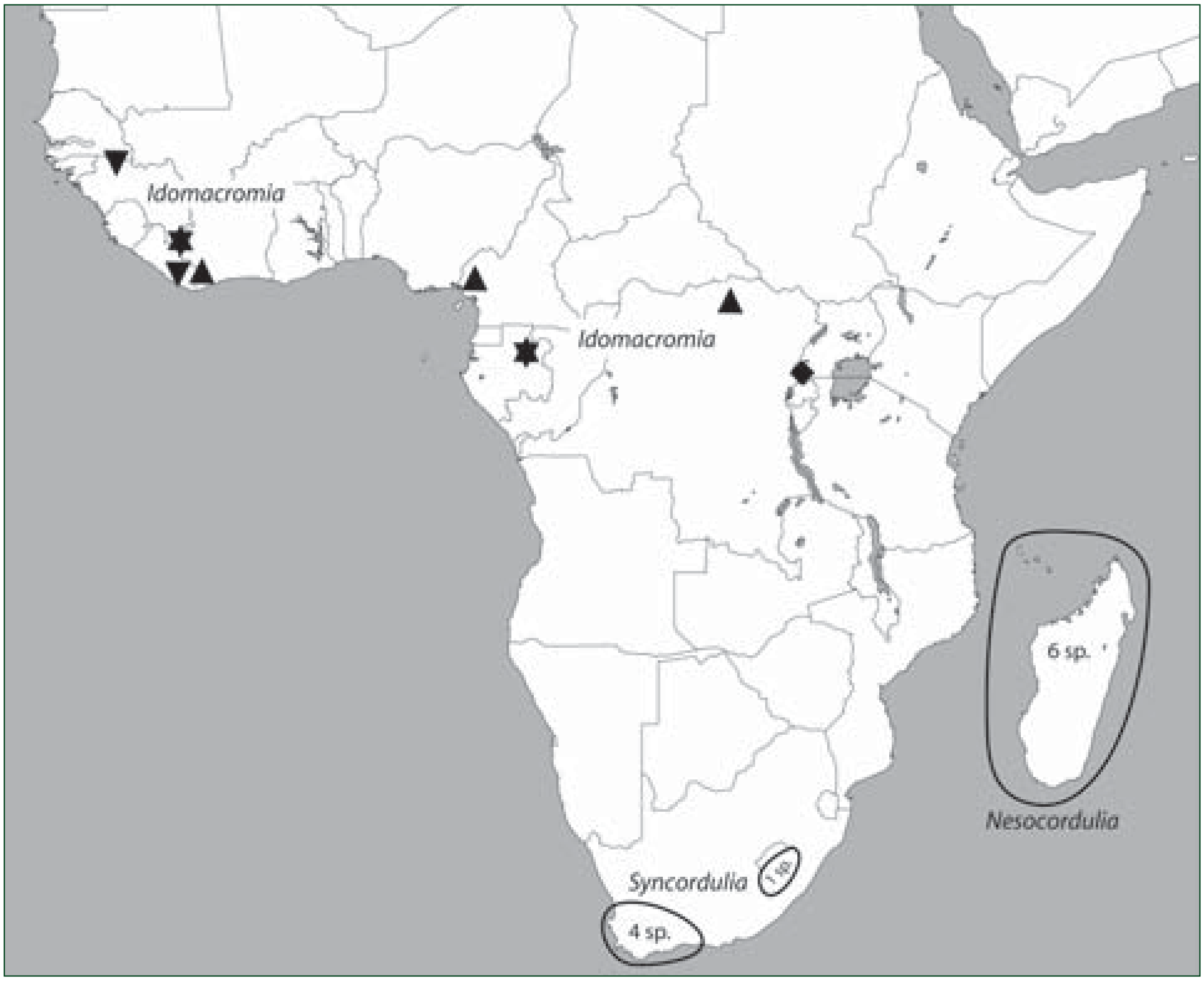


5.2.2.3 Relict fauna

A comparison of the continental African Odonata with the faunas of Madagascar and other tropical areas may identify the oldest Afrotropical species, their presence indicating probable centres of climatic stability. The comparison should focus on ecologically sensitive taxa, which have relatively small or isolated ranges, and that (largely) lack close relatives within the continent. An example is *Stenocnemis*, which inhabits rock faces wetted by waterfall spray (Vick 1998). The presumed relicts include African members of Amphipterygidae, Megapodagrionidae, Perilestidae, Pseudostigmatidae and Synlestidae, several small (mostly monotypic) restricted-range genera of undetermined relations now placed in Platycnemididae (Figure 5.7), as well as three genera (probably) belonging to the sister-group of all Libelluloidea (= Macromiidae, Corduliidae, and Libellulidae; see Ware *et al.* 2007) (Figure 5.8). Strong candidates to be qualified as "old Africans" are taxa well-represented both in Madagascar and locally on the continent, such as the endemic gomphid subfamily Phyllogomphinae, represented by *Isomma* (including *Malgassogomphus*) on Madagascar, *Phyllogomphus* in equatorial Africa and *Ceratogomphus* in southern Africa, and the libellulid genera *Malgassophlebia* and *Neodythemis*, confined to forest streams in central and western Africa and eastern Madagascar (compare Figure 5.8).

Five centres where these "old Africans" survived can be identified (Figures 5.7-5.8, 5.10, 5.13), in order of importance: (1) Madagascar, especially the eastern rainforests (see 5.3.5.1); (2) South Africa, especially towards the Cape (5.3.3.2); (3) the Lower Guinea highlands and surrounding equatorial rainforest (5.3.2.3); (4) the coastal and Eastern Arc forests of eastern Africa (5.3.3.4); (5) the granitic Seychelles (5.3.5.1). The affinities of most of the relict Afrotropical Odonata are unclear. Those of the Synlestidae and *Syncordulia* of South Africa are possibly Australian (Dijkstra *et al.* 2007c; Ware *et al.* 2009). The only relative of *Pentaphlebia* is the monotypic genus *Rimanella* of the Guiana Shield. Besides *Nubiolestes*, Perilestidae is represented by two genera and 18 species in the northern Neotropics. Dumont *et al.* (2005) dated the *Pentaphlebia*-

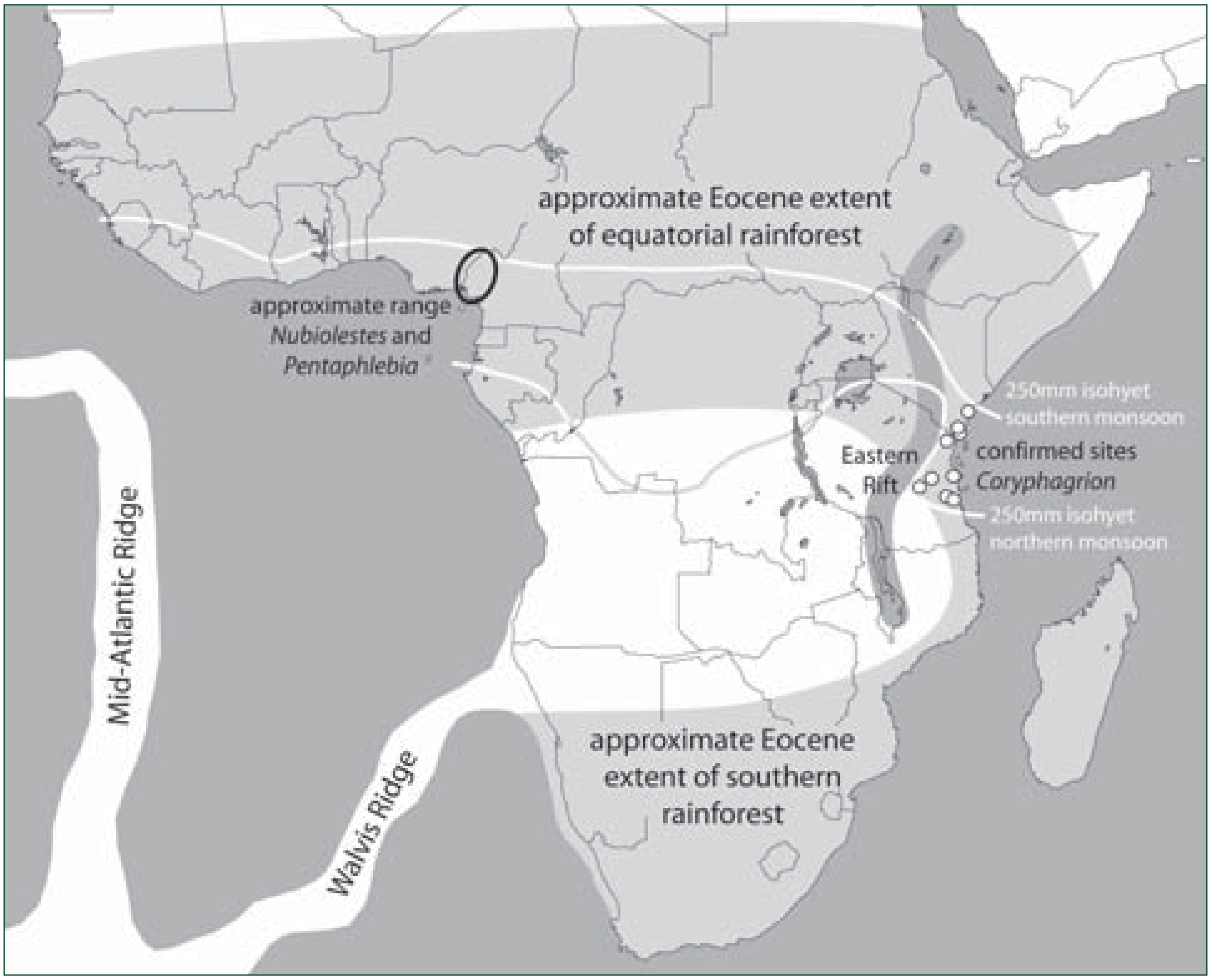
Figure 5.8. Distribution of (probable) Afrotropical "GSI-corduliids" (*sensu* Ware *et al.* 2007). *Nesocordulia* and *Syncordulia* species overlap too widely to be indicated separately (species number provided); *Idomacromia* species are separated (diamond: *I. jillianae*; inverted triangle: *I. lieftincki*; standing triangle: *I. proavita*; star: both *I. lieftincki* and *I. proavita*). From: Dijkstra *et al.* (2007c).



South Africa is home to the greatest concentration of relict odonates in continental Africa. Among these are nine synlestids, represented here by (a) Chlorolestes umbratus *(LC), and four Syncordulia species, like this (b)* S. legator *(NA).*

© W. TARBOTON (a) AND M. SAMWAYS (b)

Figure 5.9. Biogeographic hypothesis for *Coryphagrion*. The pale shading represents the approximate extent of rainforest during the Eocene, the dark shading the zones of uplift in the Eastern Rift Valley. The area between the two thin lines receives >250mm of rain during both halves of the year. From: Dijkstra (2007d).



Rimanella split around 150 million years ago. This, and their distribution, support Gondwanan vicariance, highlighting these damselflies as possibly the oldest surviving odonates in continental Africa, where their range coincides with the (cumulatively and perennially) wettest part (Maley 1989).

The biogeography of pseudostigmatids is more perplexing – 18 Neotropical species, in five genera, are separated by 5,500km of Atlantic Ocean and 2,500km of African interior from the monotypic *Coryphagrion* (Figure 5.9). Gondwanan vicariance implies extinction where other Neotropical relicts survived (see above) and raises the question why these did not survive in the east as well. Although pseudostigmatids breed in lowland forest phytotelmata (Fincke 1992a, 1992b; Clausnitzer and Lindeboom 2002), rather than in submontane forest streams, contemporary Lower Guinean rainforests bear a greater resemblance to the perhumid habitats of Neotropical pseudostigmatids than the East Coast forests. A possible dispersal route between South America and Africa was along the Rio Grande Rise and Walvis Ridge, which connect south Brazil, through the present-day hotspot at Tristan da Cunha, to north Namibia (McDougall and Duncan 1988). The Ridge submerged about 34 million years ago, the Rise subsided around 25 million years ago. Although an intercontinental connection may have been lost before the Cretaceous, (diminishing) opportunities for island-hopping persisted well thereafter (Parrish 1993). At this time, rainforests extended in three circumglobal bands, with two subtropical bands flanking the equatorial one (Morley 2000). Southern forests, roughly opposite the Walvis Ridge, were separated from equatorial forests by more open landscapes. However, forest extended along the Indian Ocean about 55 million years ago, allowing *Coryphagrion* to move north before the southern forests disappeared around 36 million years ago (Morley 2000). Uplift and associated aridification created a barrier to westward dispersal by 18-17 million years ago (Lovett 1993). Given the small volume of larval habitats and the poor dispersal of adults, *Coryphagrion* is vulnerable to short- (desiccation of habitats) and long-term (forest fragmentation) rainfall fluctuations. The coastal climate of Tanzania was little influenced by Pleistocene changes, unlike further south in Madagascar's rain-shadow (Fjeldså 1994; Fjeldså and Lovett 1997; Lovett 1993). The genus's range still coincides with relatively perennial precipitation (Figure 5.9). The above scenario falls within a time frame of 100 million years and only an estimate of the divergence of *Coryphagrion* provides some test of its credibility. A molecular phylogeny was not dated (Groeneveld *et al.* 2007) and the family affiliation of the 120 million years old "pseudostigmatid" *Euarchistigma* from western Brazil (Carle and Wighton 1990) is doubted (Bechly pers. comm.). Carle *et al.* (2008) demonstrated that pseudostigmatids are nested within the Coenagrionidae, but provided no estimate of divergence time. As a biogeographic anomaly, the New World monkeys and caviomorph rodents are the mirror image of *Coryphagrion*, arriving from Africa and beginning to radiate in South America only 26-25 and 31.5 million years ago, respectively (Flynn and Wyss 1998; Opazo *et al.* 2006).

5.2.2.4 Modern fauna

None of the "old Africans" are nowadays dominant in continental Africa and they are even absent from large hyper-diverse areas. Especially the Guineo-Congolian forest fauna is dominated by "new Africans" (see Dijkstra and Clausnitzer 2006), which are absent on Madagascar or represented at most by a few adaptable colonists (Table 5.2). The examples alone represent 35% of Afrotropical (i.e., including Madagascar) species diversity, of which 97% is continental. By contrast, the "old African" examples in Figure 5.7-5.8 form 12% of diversity, with only 48% continental species. The distinction between continental and insular faunas is less clear for open-land species, which are better dispersers, but most of those occurring on Madagascar are considered recent arrivals (Dijkstra and Clausnitzer 2004). All examples have many relatively similar (i.e., classified in few genera) species, suggesting rapid and recent diversification (see 5.2.2.2). They are all related to more diverse faunas in tropical Asia, although they would have ranged widely across Eurasia in warmer and wetter times. European fossils showing Afrotropical affinities are alleged *Sapho* and *Umma* wings (about 25 million years old) from France and *Neophya* (34 myo) from England (Nel and Paicheler 1993; Nel and Petrulevičius 2010; Petrulevičius and Nel 2009). Dijkstra (2007d) inferred that African-Eurasian exchange was associated with the gradual closure of the Tethys Sea 24-10 million years ago, conforming to their virtual absence from Madagascar. Dumont *et al.* (2005) estimated that ancestors of *Sapho* and *Umma* separated from Asian stock 77-85 million years ago and that these genera split 49-53 million years ago, but had they been present in African rainforests this early, they should have reached Madagascar. These authors believed that the separation of continental and Madagascan populations of *Phaon iridipennis* also took place in the Cretaceous, but that is questionable given their morphological similarity. The paradox of Miocene dispersal into Africa is that it coincided with extensive aridification, especially after 16 million years ago: the closure of a marine barrier, the Tethys Sea, lead to the opening of a terrestrial hurdle, the Sahara. African rainforest specialists either arrived earlier, or evolved locally from ancestors of open habitats (see 5.2.2.2). The damselfly *Arabineura khalidi* is endemic to Arabian stream oases, but is closely related to the diverse complexes of *Elattoneura* and *Prodasineura* species in Africa and Asia. *Arabicnemis caerulea* has a similar range and habitat, but more enigmatic affinities. Both species could be relicts of the African-Eurasian exchange of tropical stream Odonata.

Table 5.2. Examples of large (>10 species), morphologically homogeneous groups, which are widespread in tropical Africa and often Asia, but are (largely) absent on Madagascar. From: Dijkstra (2007d).

	Species African continent	Species Madagascar, Comoros and Mascarenes	Relatives in southern Asia
Calopterygidae	17	1 shared with continent	many, but no shared genera
Chlorocyphidae	43	-	many, but no shared genera
ischnurine Coenagrionidae*	35	5 endemics in shared genera	many, *Aciagrion* and *Ischnura* shared
Pseudagrion A-group	41	-	many in genus, probably not related
Pseudagrion B-group	22	1 endemic, 1 shared	many in genus, probably closely related
Allocnemis and *Chlorocnemis*	17	-	none known
Protoneuridae	23	-	many, *Elattoneura* and *Prodasineura* shared
lindeniine Gomphidae**	13	-	many, *Gomphidia* and *Ictinogomphus* shared
Neurogomphus	17	-	none known
Notogomphus	17	-	many, but genus not shared
Macromiidae	35	1 endemic in shared genus	many, but no shared genera

* *Aciagrion*, *Africallagma*, *Azuragrion*, *Ischnura*, *Pinheyagrion* and *Proischnura*; ** *Diastatomma*, *Gomphidia* and *Ictinogomphus*.

Two monotypic genera endemic to stream oases in southern Arabia may represent relicts of odonate exchange between tropical Africa and Asia: *(a)* Arabineura khalidi *(VU) and (b)* Arabicnemis caerulea (*VU*).

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5.3 Regional diversity, endemism and threat

5.3.1 Afrotropical fauna

With few geological barriers, and often adaptable species, range overlap is extensive, making biogeographic classification of both regions and species difficult. Diversity is greatest in forests (see 5.2.1.2.), for which Dijkstra and Clausnitzer (2006) identified three regions of richness (Figure 5.10). Almost two-fifths of species occur predominantly within the extensive lowland forests of the western and central continent (see 5.3.2). Just over a fifth is associated with the eastern and southern part dominated by highlands (5.3.3). Where 'low Africa' slopes up to meet 'high Africa', complex faunas with a "mixed" character occur (5.3.4) (Figures 5.11-5.12). About another fifth of diversity is insular, centred in Madagascar (5.3.5). The remaining fifth is not associated with forests or highlands, but with open and generally low habitats, such as savannahs. Many of these pan-African genera and species occur throughout the Afrotropics, with the possible exception of the wettest, driest and coldest areas, and may extend well into Eurasia or to oceanic islands. Countries with purely pan-African faunas are very impoverished, such as the Sahel nations with mostly fewer than 100 species each. The dominance of Coenagrionidae and Libellulidae in the Afrotropical fauna (50% of species; see 5.2.1.1; 5.2.2.2) is even greater among this widespread fauna (70%), examples being *Agriocnemis exilis*, *Ceriagrion glabrum*, *Ischnura senegalensis*, *Acisoma panorpoides*, *Aethriamanta rezia*, *Chalcostephia flavifrons*, *Crocothemis erythraea*, *Diplacodes lefebvrii*, *Orthetrum trinacria*, *Palpopleura lucia*, *Pantala flavescens*, *Rhyothemis semihyalina*, *Tetrathemis polleni*, *Tholymis tillarga*, *Tramea basilaris*, *Trithemis arteriosa*, *Urothemis edwardsii* and *Zygonyx torridus*. Some mainland species are replaced in Madagascar by a close relative, such as *Hemistigma albipunctum* by *H. affine*, and *Zygonyx natalensis* by *Z.*

Figure 5.10. Schematic representation of Afrotropical odonate diversity. Each ellipse represents about one-fifth (about 150-175 species) of the total species richness, the thick-bordered ellipse two-fifths. The name of the fauna represented by each ellipse is given in upper case; discussed regions are given in lower case. Regions in bold font harbour ancient relicts, often in regionally endemic genera (Figures 5.7-5.8); those in italic font have a "mixed" character where faunas intersect (Figures 5.11-5.12). From: Dijkstra (2007d).

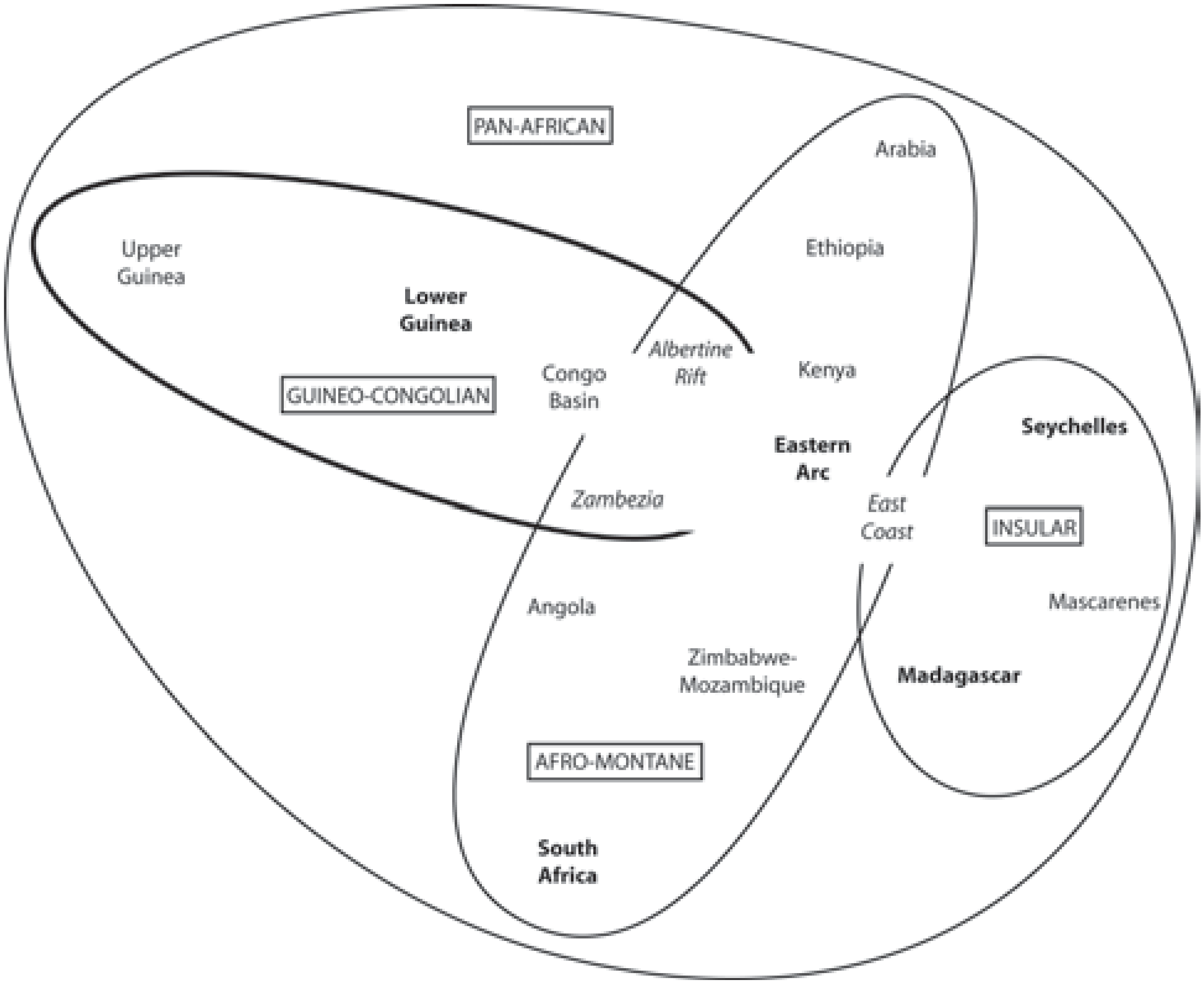
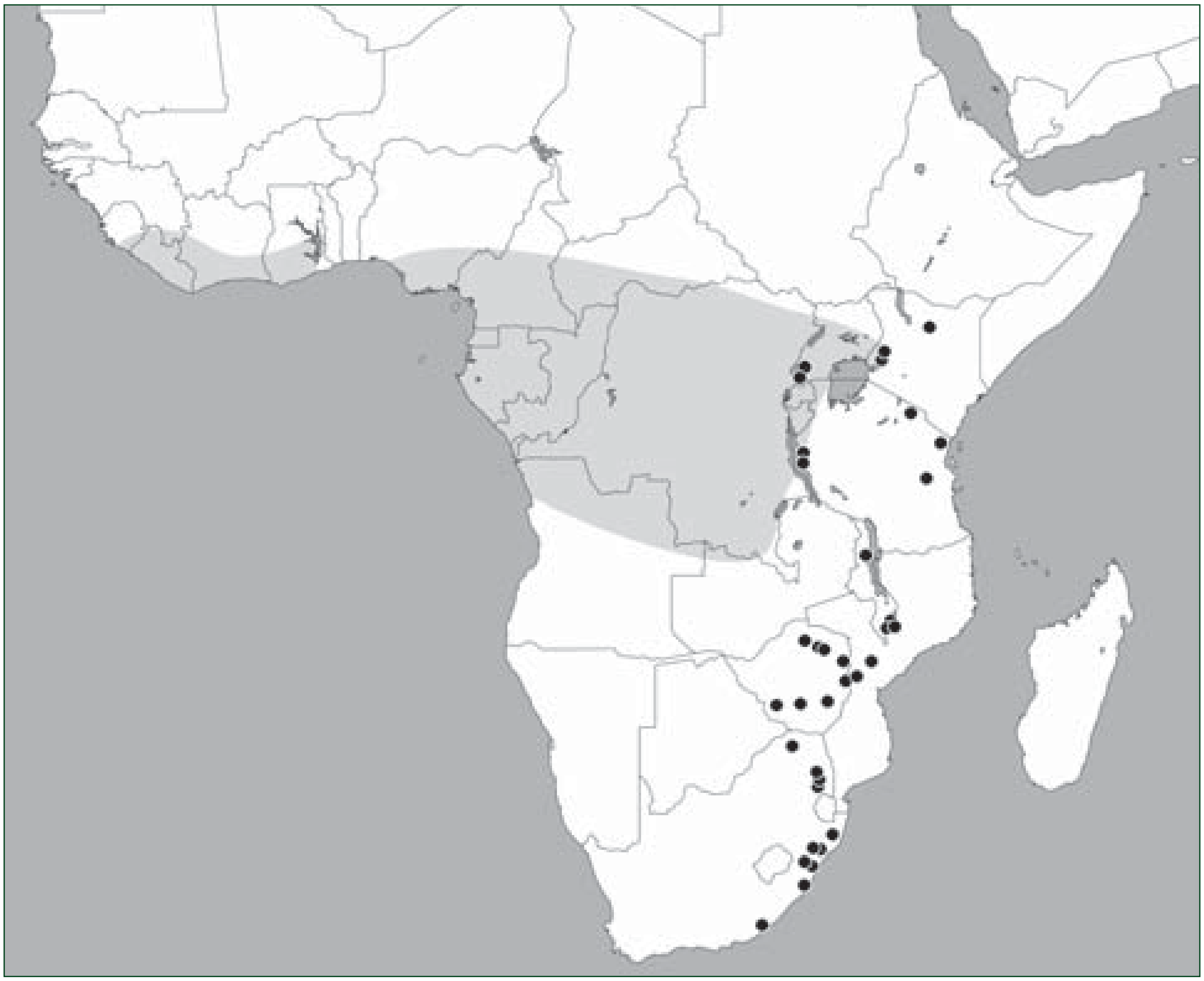
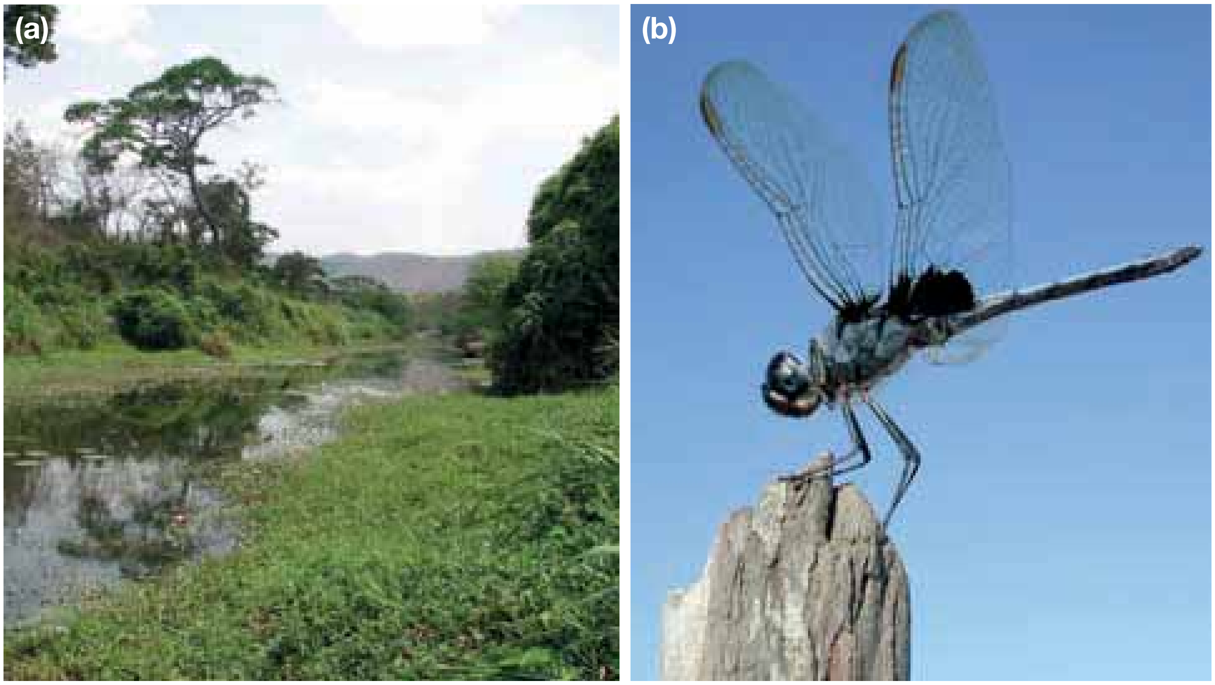


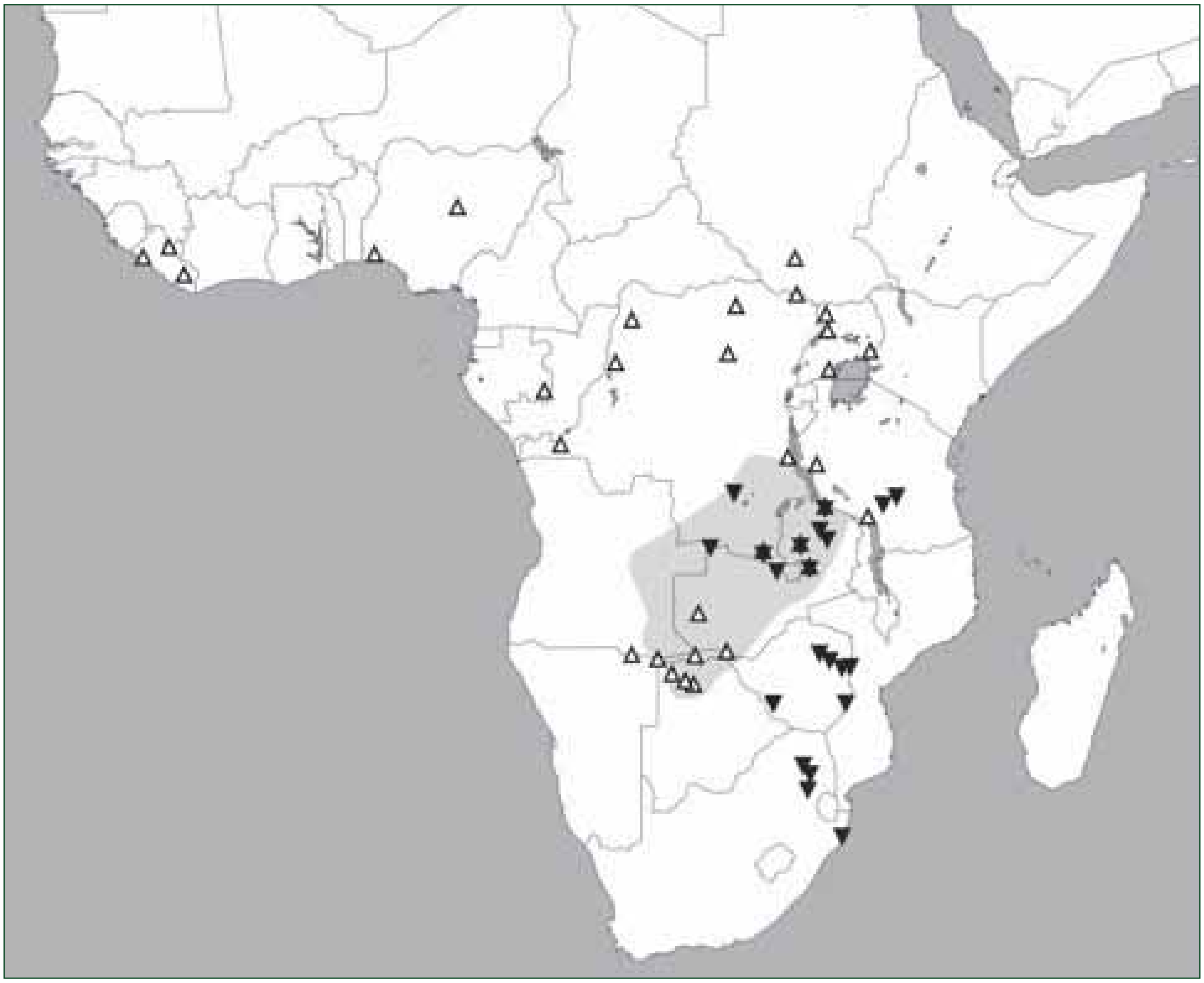
Figure 5.11. Distribution of *Notiothemis* species. The overlap of these two shade-dwelling species approximately demarcates the Albertine Rift. Legend – shading: approximate range of the Guineo-Congolian *N. robertsi*; circles: known sites of the Afro-montane *N. jonesi.* From: Dijkstra (2007d).





South of the Sahara, open swamps as in western Tanzania (a) can harbour almost every pan-African species. In the north only a few species survive in isolated suitable pockets, like (b) Urothemis edwardsii *(LC^{RG}) in northeast Algeria.* © K.-D.B. DIJKSTRA (a) AND B. SAMRAOUI (b)

Figure 5.12. Distribution of small continental African *Diplacodes.* Note the concentration of the pan-African *D. deminuta* in the large swamps in the north and south of the Paleo-Chambeshi region (shading) and that of Afro-montane *D. pumila*, which generally inhabits smaller and more elevated swamps, in the north. Legend – open triangles: *D. deminuta*; closed triangles: *D. pumila*; stars: both species. Adapted from: Dijkstra (2006a; 2007d).



elisabethae. The northern and south-eastern savannah belt may also harbour two vicariants, for example, *Gomphidia bredoi* and *G. quarrei*, *Bradinopyga strachani* and *B. cornuta*, and *Trithemis dejouxi* and *T. donaldsoni*. Such pairs with also a Madagascan relative are *Azuragrion vansomereni* and *A. nigridorsum* with *A. kauderni*, and *Zygonoides fraseri* and *Z. fuelleborni* with *Z. lachesis*. Both latter examples also have isolated siblings within the forest matrix – *A. buchholzi* in the Lower Guinea and *Z. occidentis* in the Congo Basin (see 5.3.2.4; Figure 5.17). Regional diversity, endemism and threatened and Near Threatened (NT) species are discussed below. See Darwall *et al.* (2005), Dijkstra *et al.* (2010; 2011), Samraoui *et al.* (2010) and Suhling *et al.* (2009a) for further details, especially of Data Deficient species and regions.

5.3.2 Guineo-Congolian fauna

5.3.2.1 Overview

Central and western Africa are dominated by almost continuous Guineo-Congolian lowland rainforest, which has a gradual transition of riverine forests and woodland into peripheral savannahs. The highest diversity in the Afrotropics is found here: all countries with well over 200 species have a considerable portion of this forest within their borders (Dijkstra and Clausnitzer 2006). Although many species range throughout the forested region, it can be subdivided into four main areas of endemism (Figure 5.13). The *Allocnemis*-complex can illustrate the distribution and diversity of forest odonates because all species are obligate dwellers of shaded permanent streams (Figure 5.14). The group is widespread in the Guineo-Congolian forest, where up to four species overlap and even up to seven in the Cameroon highlands. The Afro-montane archipelago is inhabited by five allopatric species, but the group is absent in the northernmost sites, despite the presence of suitable habitats (see 5.3.3.5). Further detail is provided by the Saphoinae, an Afrotropical radiation of 15 calopterygid species restricted to forested streams and rivers (Figure 5.15). Diversity is centred on the highlands in the Lower and – to a lesser degree – Upper Guinea, with only single species in the Guineo-Congolian periphery, as

Figure 5.13. Afrotropical forests and their presumed refuges. Legend – pale shading: approximate current distribution of Guineo-Congolian forest Odonata, divided into four main areas of regional endemism; dark shading: approximate position of main Pleistocene rainforest refuges, as traditionally identified; black-bordered ellipses: approximate position of centres of ancient relict Odonata (Figures 5.7-5.8); grey-bordered ellipses: approximate position of Afro-montane centres of Guineo-Congolian odonate relicts, thickness of border indicates relative importance (Figures 5.14-5.15). From: Dijkstra (2007d).

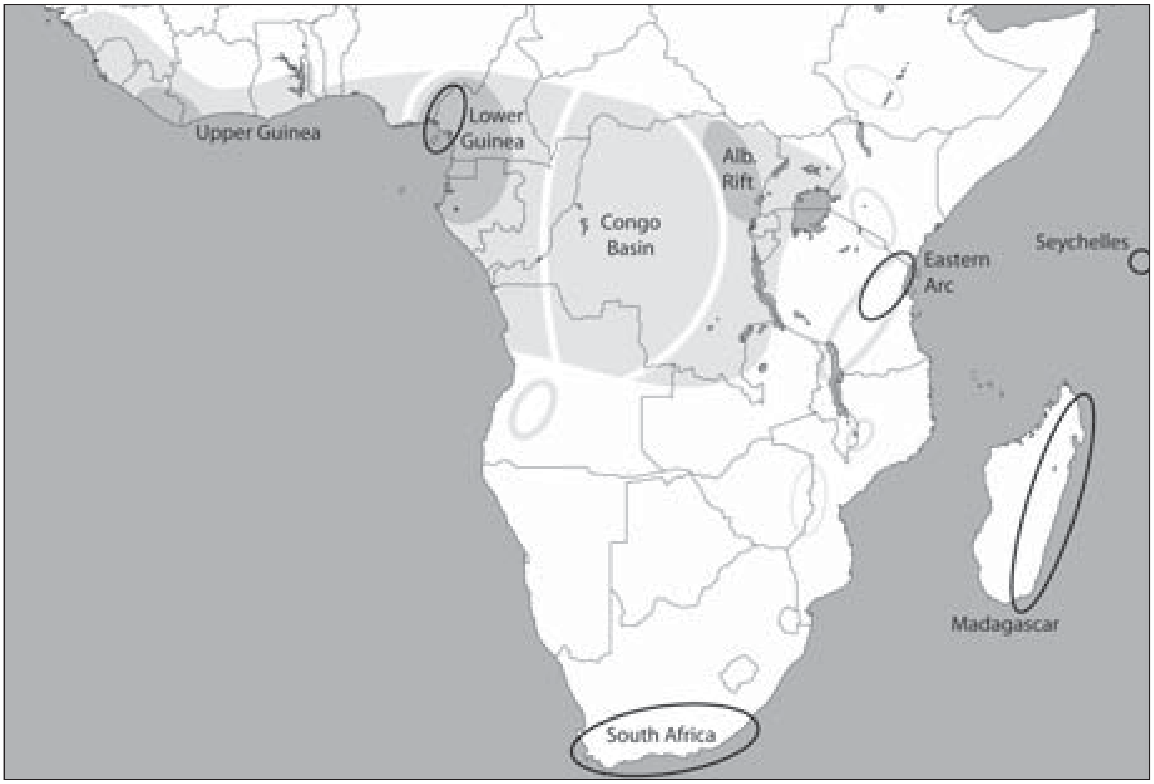
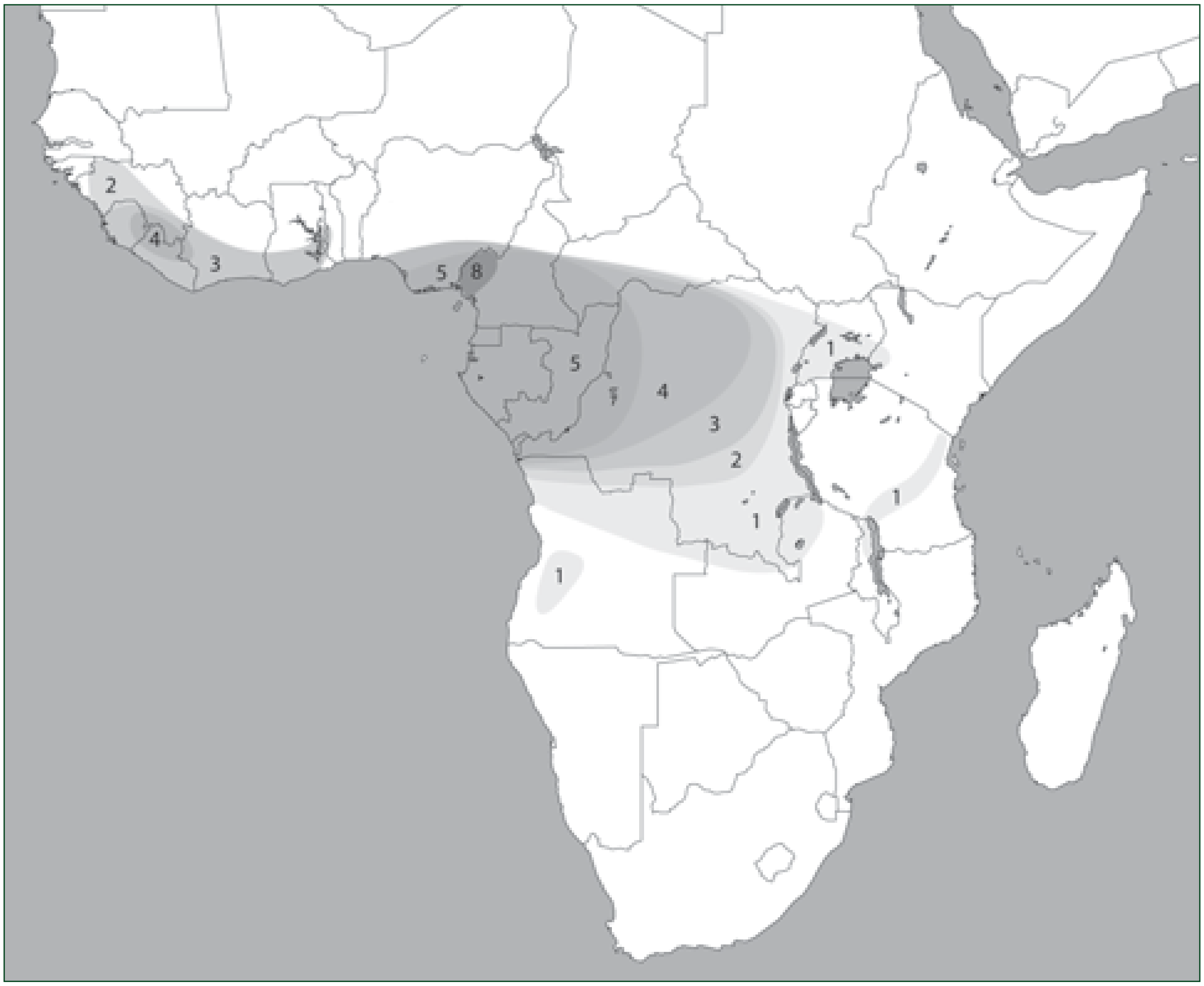


Figure 5.14. Distribution of *Allocnemis* and *Chlorocnemis* (including *Isomecocnemis*). Legend – dark shading: range of *Allocnemis leucosticta*; pale shading: range of Guineo-Congolian species (regional maximal number of sympatric species indicated); squares: *C. abbotti;* circles: *C. montana*; diamond: *C. maccleeryi*; triangles: *C. marshalli*. Adapted from: Dijkstra and Clausnitzer (2006).

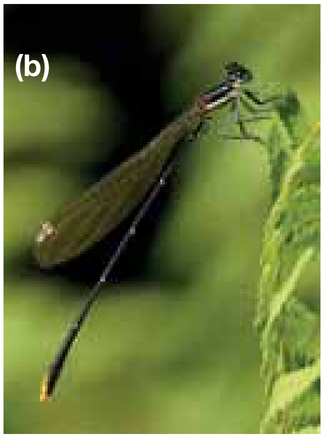
Figure 5.15. Distribution of *Sapho* and *Umma* combined. Shading intensity and figures indicate the number of sympatric species. From: Dijkstra (2007d).



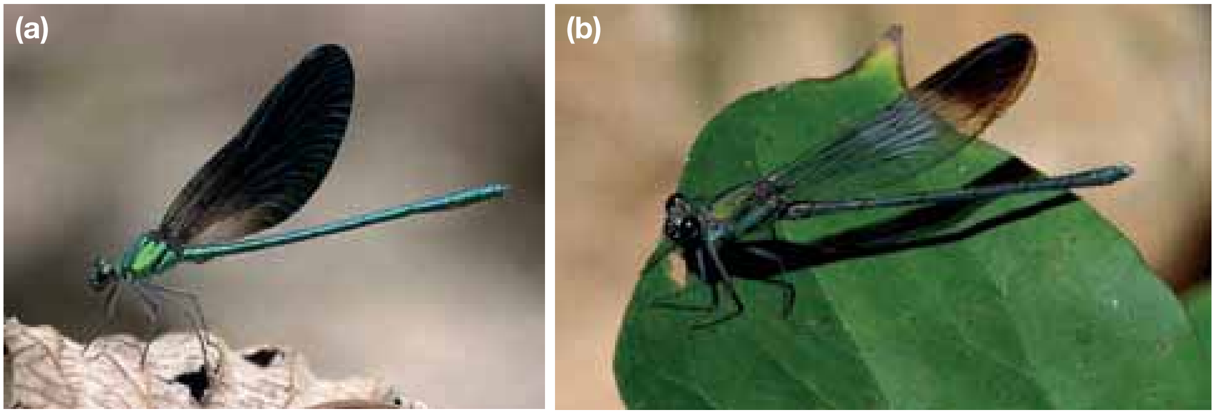
well as the endemic *U. femina* in Angola and *U. declivium* in the Eastern Arc highlands. A similar pattern is shown by *Micromacromia*, with a sympatric species pair in western and central Africa, and the endemic *M. flava* in Angola and *M. miraculosa* in Tanzania (Dijkstra and Vick 2006).

5.3.2.2 Upper Guinea

More than 300 species occur in Nigeria and further west, of which more than 60 are endemic (Dijkstra *et al.* 2010). Many such as *Sapho ciliata*, *Chlorocypha luminosa*, *C. radix*, *Chlorocnemis elongata*, *C. flavipennis*, *Elattoneura girardi*, *Prodasineura villiersi*, *Platycnemis guttifera* and *Phyllogomphus moundi* are present throughout in forest streams (Dijkstra and Lempert 2003) and therefore of Least Concern. The same applies for strict Upper Guinea endemics, not occurring east of Togo, such as *Diastatomma gamblesi*, *Lestinogomphus matilei*, *Phyllogomphus aethiops*, *Phyllomacromia sophia*, *Trithemis africana* and *Zygonyx chrysobaphes*. The threatened and NT endemics are more localised and rather dispersed: *Elattoneura pluotae* (CR) and *Mesocnemis dupuyi* (NT) are known only from the Gambia watershed, and *Agriocnemis angustirami* (VU), *Mesocnemis tisi* (EN), *Elattoneura dorsalis* (VU) and *Pseudagrion mascagnii* (CR) from at most a few sites in



(a) Chlorocnemis wittei *(LC) and (b)* Allocnemis leucosticta *(LC) are two southern African representatives of a platycnemidine radiation concentrated in the Guineo-Congolian forests. The accents of bright colour on their bodies stand out in their gloomy habitats.* © J. KIPPING (a) AND E.R. NIELSEN (b)



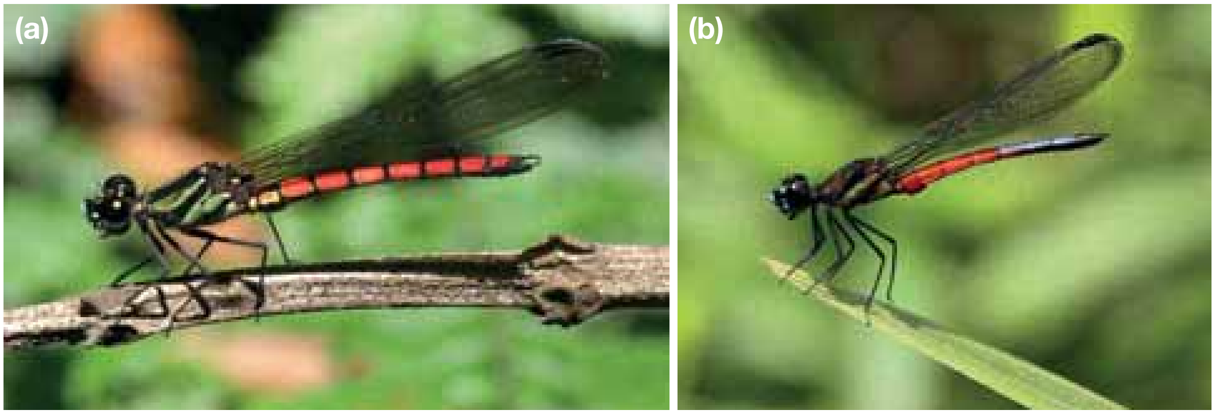
Two Sapho *species endemic to western Africa. While (a)* S. ciliata *(LC) can be found on almost any running water with a bit of forest, (b)* S. fumosa *(DD) is restricted to rocky streams. As a consequence it is largely limited to the Upper Guinean highlands, where deforestation and mining pose an increasing threat to its survival.* © P. NASKRECKI (a) AND W. KAPPES (b)

Sierra Leone and Liberia. *Sapho fumosa* (NT; = *Umma infumosa*) and *Phyllomacromia funicularioides* (NT) appear typical of the Upper Guinean highlands, centred on Mt. Nimba. The unexplored Fouta Djallon Mountains in west Guinea may harbour vital populations of these and other endemics, and a survey is urgently required. *Chlorocypha jejuna* (CR) and *Zygonychidium gracile* (CR) are distinctive and potentially conspicuous species known only from type material from western Togo and northern Côte d'Ivoire, respectively. *Ceriagrion citrinum* (VU) is peculiar in being endemic to gallery swamp forest in the savannah of Benin and western Nigeria that separates Africa's western and central rainforest blocks.

5.3.2.3 Lower Guinea

This region from south-east Nigeria to north-west Angola has Africa's richest odonate fauna: typical rainforest groups such as Calopterygidae, Chlorocyphidae and *Chlorocnemis* are up to twice as rich here as elsewhere (Figures 5.14-5.15). Moreover, several relict damselfly genera with distinct Madagascan and Neotropical affinities are present (see 2.2.3; Figure 5.7): *Pentaphlebia* has its nearest relative in South America and was believed to be endemic to the Cameroon highlands with two species until a third taxon was discovered in south-east Gabon and north-west Republic of Congo (Mézière and Lambret unpubl.). *Neurolestes trinervis* and *Stenocnemis pachystigma* both occur from these highlands to the Mayombe Hills of south-west Republic of Congo. The former is closely related to *Nesolestes nigeriensis* from the Cameroon highlands, which despite the proximity of both to the Madagascan genus *Nesolestes*, probably represents a second *Neurolestes* species (Dijkstra unpubl.). Other characteristic Lower Guinea endemics include *Chlorocypha gracilis*, *Platycypha rufitibia*, *Chlorocnemis contraria*, *Platycnemis rufipes*, *Diastatomma tricolor*, *Phyllomacromia insignis* and *Zygonyx speciosus*. Furthermore, the Lower Guinea highlands have the most distinctly Afro-montane character outside eastern and southern Africa (Figures 5.18-5.19).

The greatest concentration of relicts and restricted range species occurs in and around the southern Cameroon highlands. Several are globally threatened due to deforestation, especially in Nigeria (Dijkstra *et al.* 2010; 2011). The defining species is *Nubiolestes diotima* (VU), the only non-American perilestid (see 5.2.2.3; Figure 5.7). Other

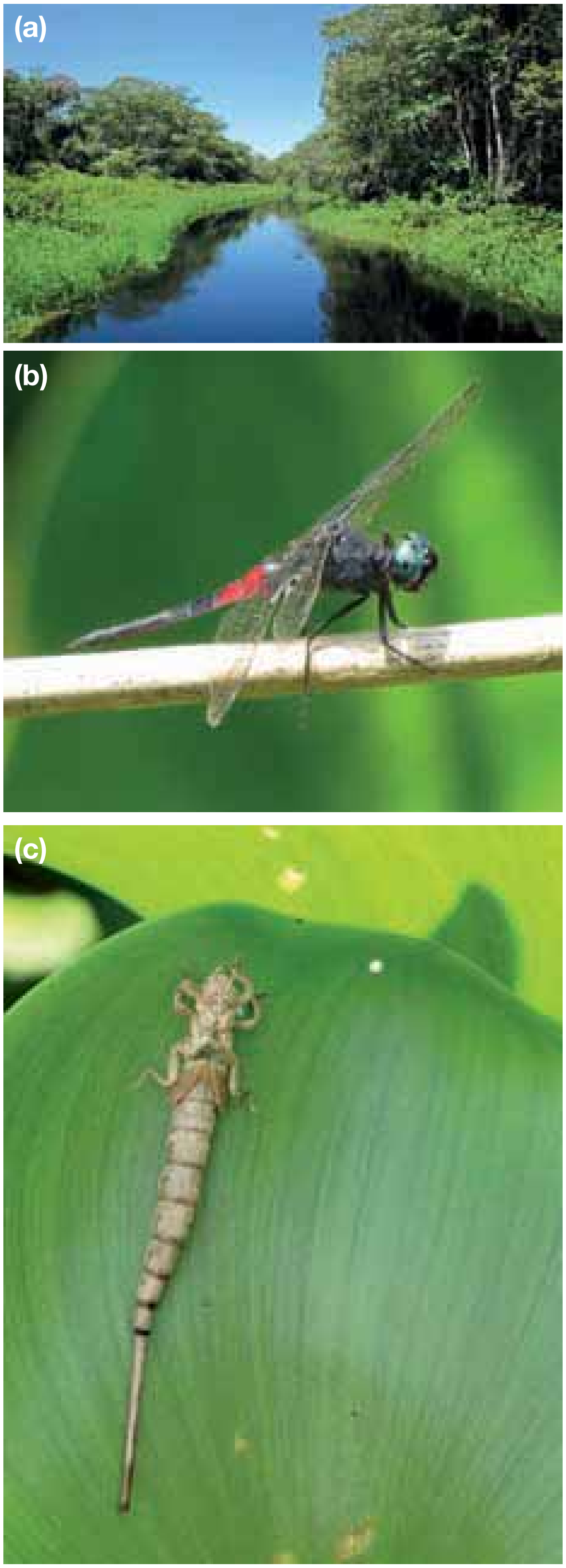


Until recently, the threatened Africocypha lacuselephantum *VU from Cameroon was considered the only species of its genus. Genetic and morphological comparisons suggest the vulnerable (a)* "Chlorocypha" centripunctata *and (b) an unnamed species from Gabon are closely related (Dijkstra unpubl.). The genus remains endemic to the Lower Guinea.* © K. SCHÜTTE (a) AND C. VANAPPELGHEM (b) characteristic endemics are *Pentaphlebia gamblesi* (CR), *P. stahli* (VU), *Africocypha lacuselephantum* (VU), *Chlorocypha centripunctata* (VU), *C. neptunus* (DD), *Sapho puella* (EN), *Umma mesumbei* (EN), *U. purpurea* (VU), *Nesolestes nigeriensis* (CR), *Chlorocnemis eisentrauti* (DD), *Elattoneura pruinosa* (LC), *Pseudagrion risi* (LC), *Notogomphus moorei* (LC), *Tragogomphus aurivilii* (LC), *Phyllomacromia caneri* (LC) and *Neodythemis takamandensis* (CR). Until recently, *Azuragrion buchholzi* (NT) and *Trithemis hartwigi* (DD) were thought to be confined to standing waters, possibly specifically crater lakes, in Bioko and adjacent Cameroon, but both occur in south-east Gabon, while *T. hartwigi* was also found in south-western Cameroon and photographed in east D.R.C. (Windig pers. comm.). Similar finds placing species outside immediate danger are likely. The area, more than any other, may also harbour undiscovered threatened species.

The rainforest of the southern Lower Guinea, from southern Cameroon through Gabon to south-west Republic of Congo, are the odonatologically least known, although it is probably equally rich (Dijkstra *et al.* 2011). This is demonstrated by recent research by N. Mézière in Haut Ogooué Province, south-east Gabon: in two years, in an area of about 200 x 100km at 400-700m altitude, over 180 species have been recorded. Among these are numerous rediscoveries, as well as range extensions of species thought to be (largely) confined to the Congo Basin or to savannah and woodland much further north or south. Illustrative of local diversity and complexity is that many north-south, west-east and forest-savannah species pairs, which were unknown to overlap, meet here, for example, *Gomphidia gamblesi* and *G. quarrei*, *Ictinogomphus fraseri* and *I. regisalberti*, *Nesciothemis nigeriensis* and *N. fitzgeraldi*, *Trithemis aconita* and *T. congolica*, *T. basitincta* and *T. bifida*, and *Trithetrum navasi* and *T. congoense*. The research also produced new species of *Pentaphlebia*, *Africocypha*, *Mesocnemis*, *Elattoneura*, *Pseudagrion*, *Lestinogomphus*, *Malgassophlebia*, *Porpax*, *Trithemis*, *Urothemis* and *Zygonyx*. Remarkably, many are not localised (Dijkstra *et al.* 2011): the *Pentaphlebia*, for example, was found about 350-400km south-west in the north-western Republic of Congo (Lambret pers. comm.), while the *Mesocnemis* and *Zygonyx* are known north of Yaoundé (750km north), and the *Trithemis* in south Cameroon (625km north-west). Most extreme is the new *Urothemis*, which had been photographed 26 years earlier 1,500km east in D.R.C. (Windig pers. comm.). This demonstrates that our knowledge of this incredibly rich fauna will rapidly expand once further areas are studied.

5.3.2.4 Congo Basin

Ever-shifting rivers, swamps, forests, woodlands and savannahs in the Congo Basin create an enormous mosaic of prime odonate habitat in time and space. Africa's heart has always been on a crossroads, between the forests to the west and east in wet periods, and between the

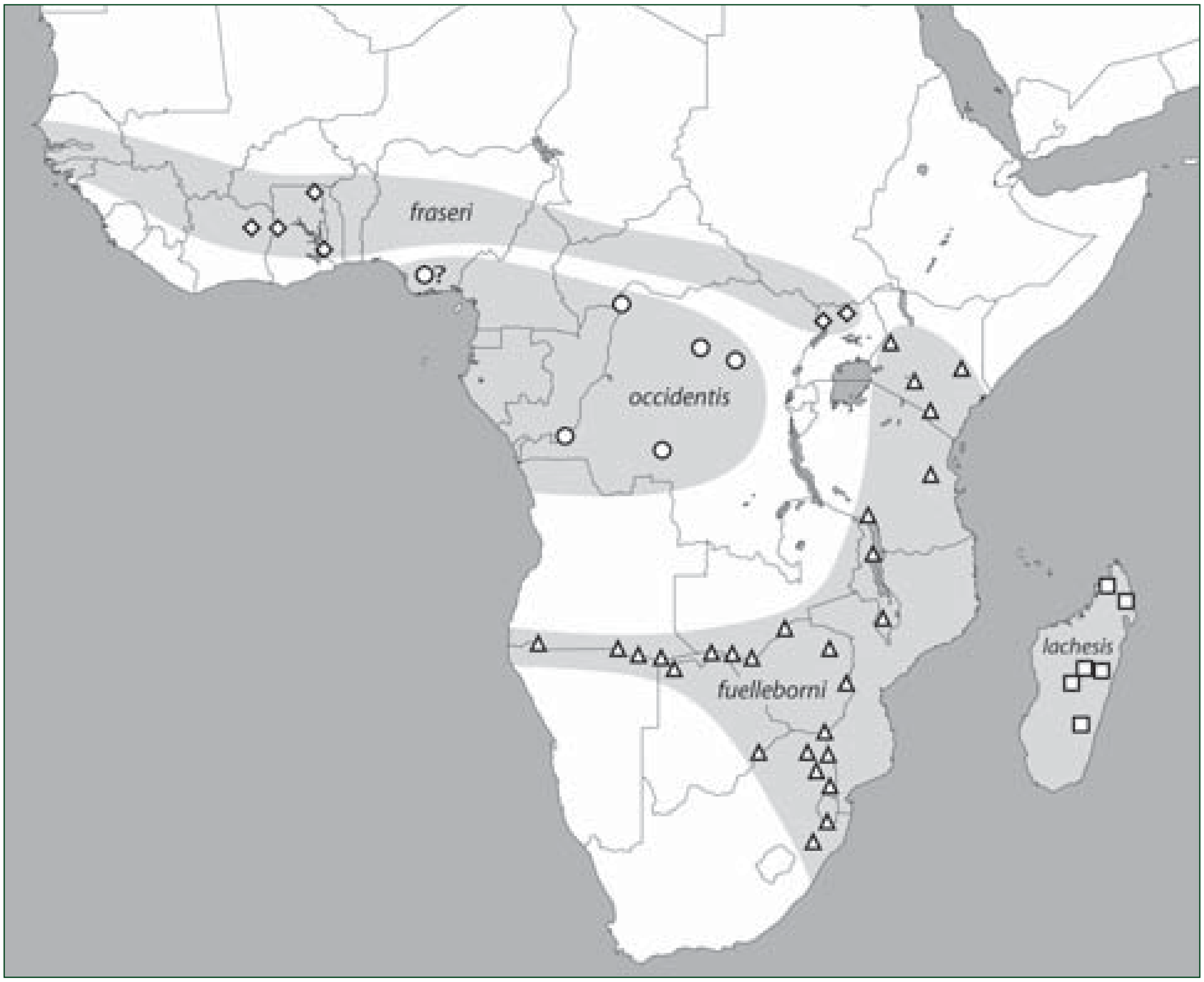


Blackwater swamps and rivers (a) are characteristic of the Congo Basin and are home to endemic species like (b) Lokia erythromelas *(LC) and* Neurogomphus martininus *(c) LC, of which a larval skin is shown.* © K.-D.B. DIJKSTRA

Figure 5.16. Odonatological exploration of the Congo Basin. Legend – open circles: sites of high conservation priority according to Congo Basin Forest Partnership, none of which have been surveyed for Odonata; filled circles: sites with reasonable odonatological data, none of which are CBFP priorities; pale grey area: Congo River watershed; dashed ellipse: approximate extent of "cuvette centrale", defined as part of basin below 500m; dark grey line: route Congo 2010 expedition. Adapted from: Dijkstra *et al.* (2011).

savannahs to the north and south in drier times, when forest species could survive in refuges west and east of the basin and along its rivers. Kingdon (1989) postulated that the basin is an "evolutionary whirlpool" of species diversification, conservation and dispersal, leading to high endemism and diversity, which could be especially true for Odonata (Dijkstra 2006c; 2007d). Unfortunately our knowledge is limited to a handful of peripheral sites, sampled mostly in the 1930s to 1960s (Figure 5.16). These data largely come from the Royal Museum of Central Africa (Dijkstra *et al.* 2011). Species found in a large part of the basin, and largely confined to it, are *Chlorocypha aphrodite*, *Elattoneura centrafricana*, *E. vrijdaghi*, *Prodasineura odzalae*, *Pseudagrion simplicilaminatum*, *P. thenartum*, *Diastatomma multilineatum*, *Ictinogomphus regisalberti*, *Phyllogomphus annulus*, *Phyllomacromia maesi*, *P. schoutedeni*, *P. seydeli*, *Lokia circe*, *L. erythromelas*, *Porpax garambensis*, *P. sentipes*, *Trithemis apicalis* (= *Porpacithemis trithemoides*), *T. congolica*, *T.* (= *Congothemis*) *longistyla*, *Trithetrum congoense*, and *Zygonyx regisalberti*. Species such as *Neurogomphus martininus*, *N. uelensis*, *Paragomphus acuminatus* and *Zygonoides occidentis* are (near) endemic to the region's huge rivers, or at least with the associated swamp forest, like *Agriocnemis stygia* and *Hadrothemis vrijdaghi*. Several widespread non-forest groups (see 5.3.1) are represented in the Congo Basin by larger and darker forms: *Z. fraseri* and *Z. fuelleborni* replace *Z. occidentis* on open rivers

Figure 5.17. Distribution of *Zygonoides* species. Legend – squares: *Z. lachesis*; triangles: *Z. fuelleborni*; diamonds: *Z. fraseri*; circles: *Z. occidentis*; shading: inferred ranges. From: Dijkstra *et al.* (2006b).



and large streams in the dry northern and eastern belts of continental Africa (Figure 5.17). *Gynacantha manderica* and *Trithemis aconita* occupy half-shaded habitats in most of tropical Africa, excluding only the driest deserts and densest forests. The former is represented in the basin by a form that merits species status (Dijkstra 2005c; see below), the latter is replaced by *T. congolica* (Dijkstra 2007a). Both, like *Z. occidentis*, seem associated with large rivers. Forest expansions and contractions may have enclosed these populations within the forest matrix, isolating them sufficiently from the periphery to diverge genetically.

Unlike other centres of diversity discussed, no threatened or NT species have been identified in the Congo Basin. Large parts of the basin are pristine, but also lack data, and quite a few species are DD – for example, *Chlorocypha ghesquierei*, *Elattoneura morini*, *Neurogomphus vicinus*, *Paragomphus interruptus*, *P. maynei*, *Rhyothemis splendens* and *Trithemis fumosa*. The most notable hiatuses are on the eastern slope (see 5.3.4.1) and in the “Cuvette Centrale”, the almost circular area of the central basin below 500m (Figure 5.16). Dijkstra (2007b, 2008) obtained a first recent impression of the remarkable diversity of this seemingly monotonous forested plain crossed by countless rivers, recording 86 species within 13 days in a small area around Lokutu. Only 28% were widespread; the fauna was estimated to number more than 125 species. The survey produced two conspicuous new species, *Mesocnemis saralisa* and *Platycypha eliseva* (both DD), and range extensions over thousands of kilometres. *Ceriagrion ignitum* and *Chlorocypha pyriformosa*, for example, had not been found outside western Africa before, the former not even since its description from Ghana (Dijkstra *et al.* 2011). An expedition in April to June 2010 on the Congo, going downstream from Kisangani (Figure 5.16), yielded many additions: including prior data, 171 species have been found along this 350km stretch of the river. Two new species of *Ceriagrion* were found, the second and first male specimens of two unnamed *Gynacantha* species, and probable new species of *Prodasineura*, *Aciagrion*, *Notogomphus* and *Paragomphus*. Discovery of *Platycypha picta*, *Elattoneura morini* and *Pseudagrion malagasoides* shows that these are not Batéké plateau and western African endemics, as recently assumed (Dijkstra *et al.* 2010; 2011). The extensive sympatry of *T. congoense* with *T. navasi*, the only species of the recently erected genus

(a) Aeshna minuscula *(LC) and (b)* Notogomphus moorei *(LC) represent characteristic Afro-montane genera.*

© E.R. NIELSEN (a) AND K.-D.B. DIJKSTRA (b)

Figure 5.18. Distribution of Afrotropical *Aeshna* species. Legend – filled circles: *A. scotias*; shading: *ellioti*-group (e: *A. e. ellioti*; u: *A. e. usambarica*; m: *A. minuscula*); outlines: *rileyi*-group with northern (black – M: *A. meruensis*; N: unnamed species; X: *A. moori*; Y: *A. yemenensis*; "?": Sudan record, species uncertain) and southern subgroup (grey – R: *A. rileyi*; S: *A. subpupillata*; "?": Angola record, species uncertain). From: Dijkstra (2007d).

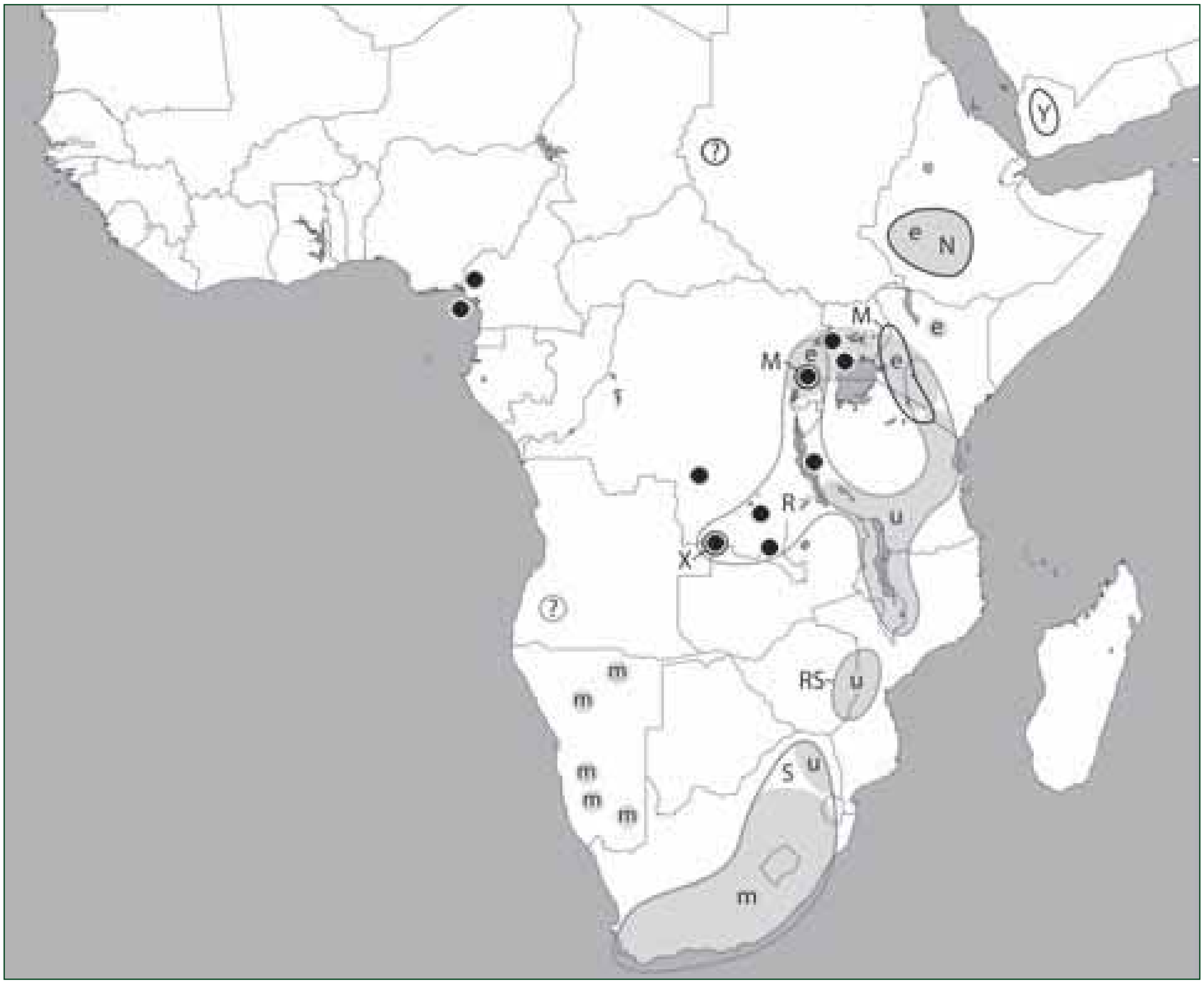
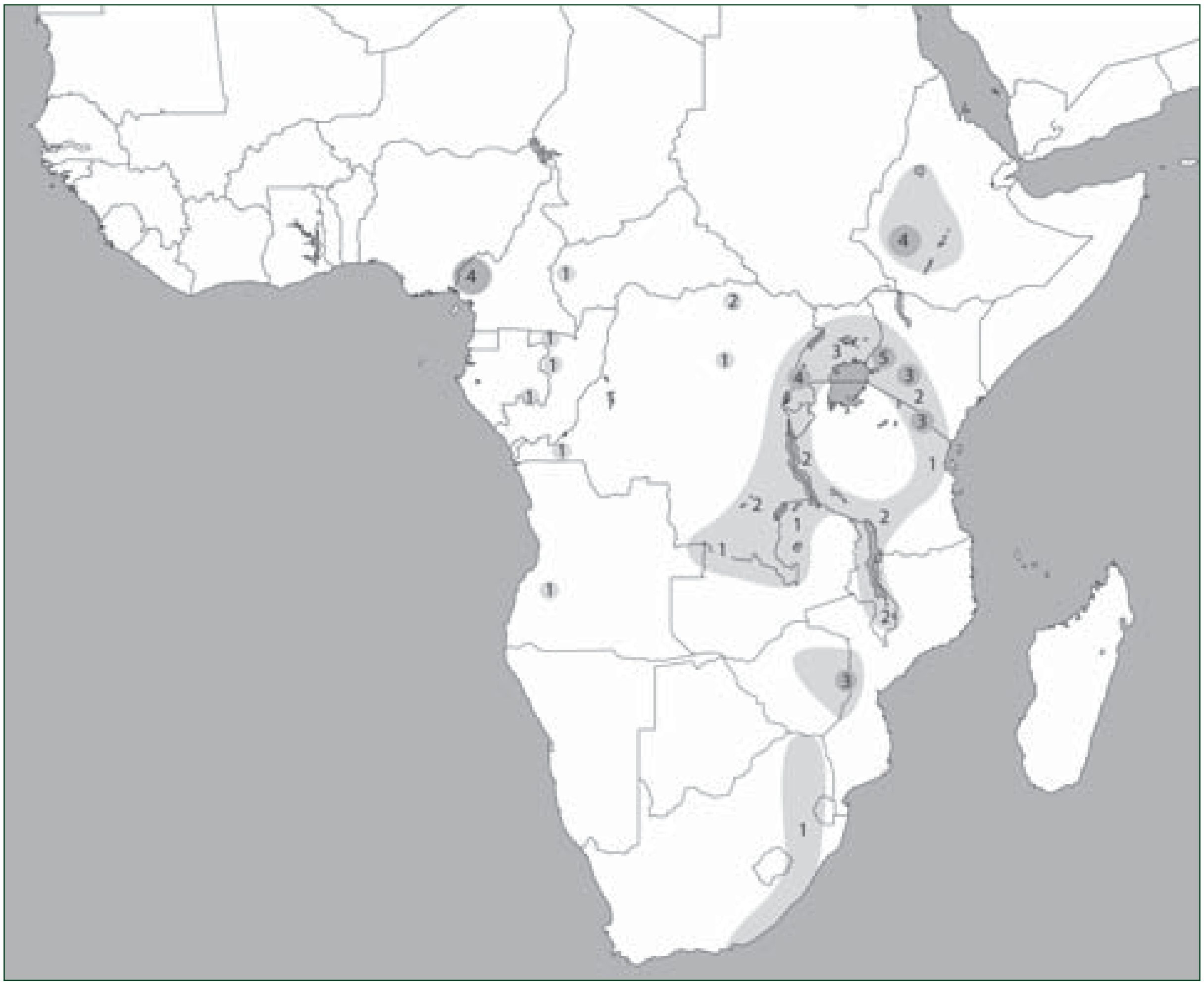


Figure 5.19. Distribution of *Notogomphus*. Figures indicate the number of allopatric species; local peaks in diversity are shaded darker. Scattered Guineo-Congolian records are given as separate sites. Adapted from: Dijkstra (2007d; in prep.).



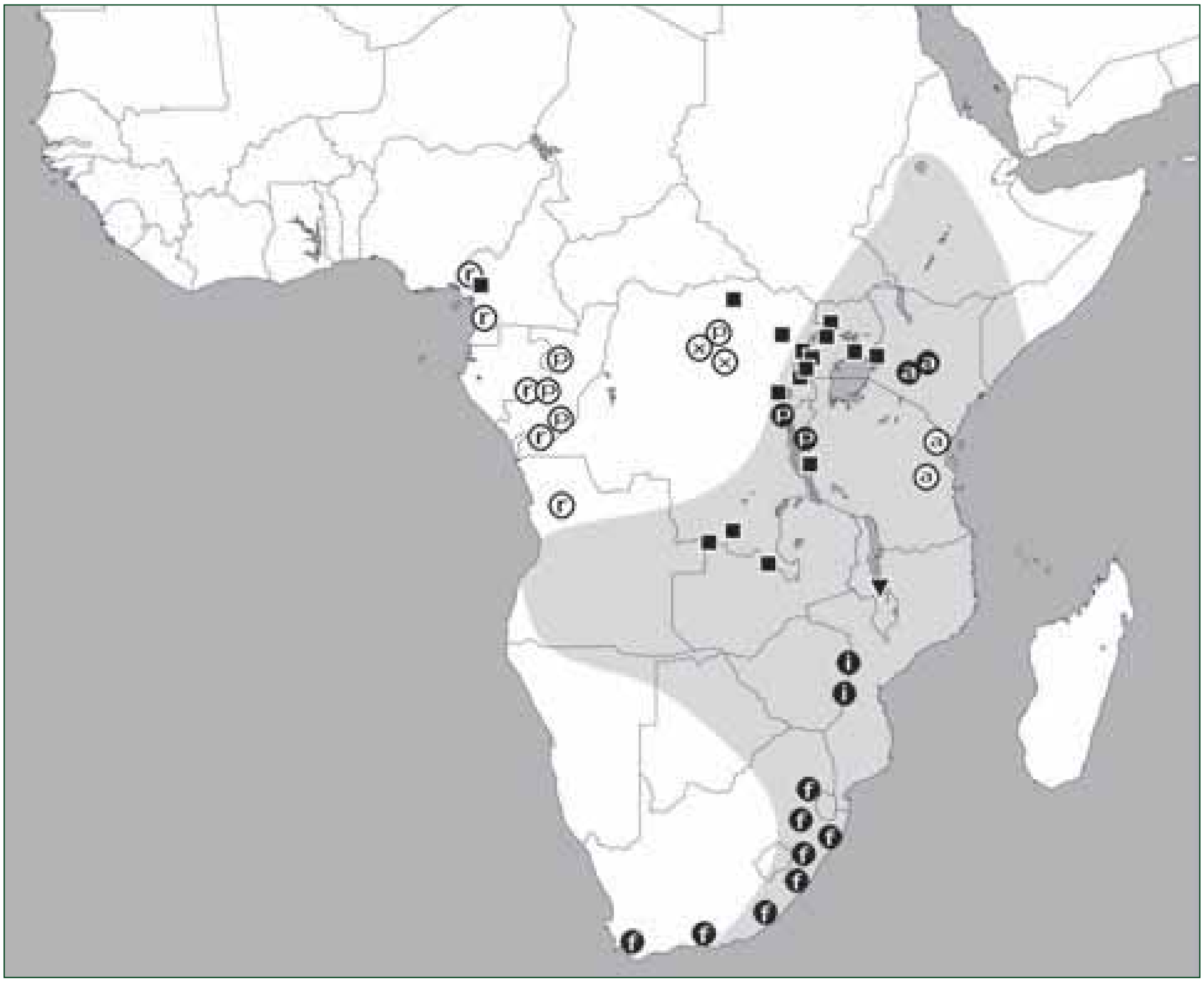
Trithetrum (Dijkstra and Pilgrim 2007) is also notable. Despite these efforts, the southern and western Cuvette, including the swamp forests of north-east Republic of Congo, remain entirely unexplored.

5.3.3 Afro-montane fauna

5.3.3.1 Overview

Eastern and southern Africa harbour diverse but fragmented forests, restricted to areas of higher precipitation, especially at greater elevations. White (1981) characterised these as an "Afro-montane archipelago" because of their isolated and dispersed nature. Dowsett-Lemaire and Dowsett (2001) further identified an "eastern archipelago" of coastal forests. The term Afro-montane is perhaps not apt for the entire fauna: "montane" forest descends to sea-level in South Africa, while localised inhabitants of coastal forests and swamps at moderate altitudes are also included. Nonetheless, almost all of Africa above 1,000m is included within the region where the fauna discussed here occurs, and most of this region is also above that altitude. Species numbers are lower here than in western and central Africa – national diversity generally lies between 100 and 200 species – but regional endemism is greater. Except for some ubiquitous highland species like *Pseudagrion spernatum* and *Proischnura subfurcata*, few taxa inhabit the total expanse of this geographically and climatologically diverse region. The genera *Proischnura*, *Aeshna* (Figure 5.18), *Notogomphus* (Figure 5.19), *Atoconeura* (Figure 5.21) and to some degree *Platycypha* (Figure 5.20) most clearly demonstrate an Afro-montane distribution. For instance, of 19 *Notogomphus* species, 16 occur east of the Congo Basin and four to the west. *Africallagma* and the A-group of *Pseudagrion* also show marked Afro-montane diversity and endemism. All these groups have their greatest abundance above about 1,000m altitude. The transition to montane habitat on the equator is at 1,500-1,800m (Dowsett 1986) and the upper limit of forest at 2,800-3,300m (de Jong and Congdon 1993), but a truly montane fauna, with species occurring exclusively above 2,000 or even 3,000m is virtually absent (see 5.3.3.4). Adding to the Afro-montane complexity is the strong Guineo-Congolian (see 5.3.4.1-2) and even insular influence (5.3.5.1) on the periphery (Figure 5.10).

Figure 5.20. Distribution of *Platycypha* species. Legend – open circles: lowland relict species (a: *P. auripes*; p: *P. picta*; r: *P. rufitibia*; e: *P. eliseva*); filled circles: sub-montane relict species (a: *P. amboniensis*; f: *P. fitzsimonsi*; i: *P. inyangae*; p: *P. pinheyi*); squares: *P. lacustris*; shading: *P. caligata*; triangle: morphologically deviant lacustrine population of *P. caligata*. From: Dijkstra (2008).

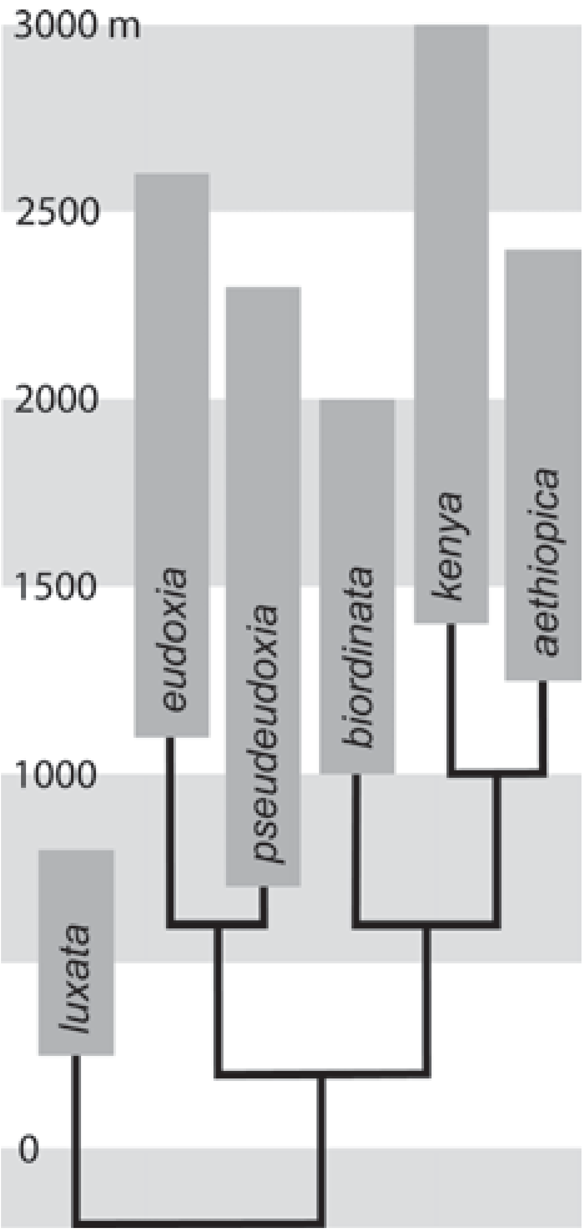


The relative impoverishment of the Afro-montane fauna is related to the more severe impact of climatological vicissitudes at greater altitude, as well as the youth and isolation of the highlands. The genus *Atoconeura* may illustrate the history of Africa's highland dragonflies (Dijkstra 2006b; 2007d; Figure 5.21). While the genus mainly inhabits streams above 1,000m, all records of the western *A. luxata* lie below it. Its phylogenetically and ecologically "basal" position suggests it may be ancestral to the eastern *Atoconeura* radiation. Had the genus dispersed westwards rather than eastwards, it might be expected at much higher altitudes in the west too. Dispersal of the lowland representative is also easier, simply because most intervening habitat is low-lying. Nonetheless, *A. luxata* has a montane character, occurring near waterfalls at the base of highlands. Lowland populations of montane plants similarly survive in specialised habitats, such as spray zones (White 1981). Indeed, Ghana's sole *A. luxata* locality also has the only stand of *Cyathea* tree-ferns there. With a presumed western ancestor, the Albertine Rift is a logical base for the eastern radiation. Four species have interlocking ranges around the dry north of Tanzania, recalling a "ring species": the closest relatives are also most proximal geographically, suggesting expansion by dispersal across montane stepping stones. *A. kenya* probably developed from an ancestor near *A. biordinata* that expanded from the benign Eastern Arc as conditions in Kenya ameliorated. Ethiopian montane forests are recent, and most of its species spread out from Kenya, conforming with the phylogenetic position of *A. aethiopica*. Altogether, *Atoconeura* history reflects phases of habitat opening up, followed by rapid adaptation and dispersal within the new habitat, with an altitudinal upward tendency. *Atoconeura* is notably absent in two highland regions with high endemism and suitable habitat: it may still be found in Angola, but the South African highveld was maybe uninhabitable in cooler periods and unreachable when habitats were suitable.

5.3.3.2 South Africa

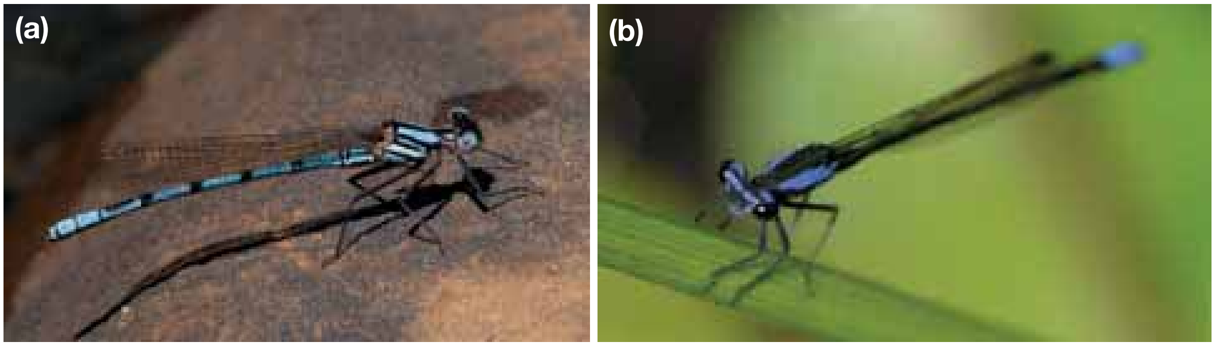
The continent's southern end is one of its most significant centres of endemism, harbouring the greatest number of relict species (Samways 1999, 2008). Almost one-fifth of

Figure 5.21. Biogeographic hypothesis for *Atoconeura*. The phylogeny of the species is superimposed on their observed altitudinal ranges. Distribution of species is *A. aethiopica* (Ethiopia), *A. biordinata* (southern Katanga to Zimbabwe and southern Kenya), *A. eudoxia* (Kivu to western Kenya), *A. kenya* (northern Tanzania to southern Sudan), *A. luxata* (Sierra Leone to Gabon) and *A. pseudeudoxia* (northern Zambia to western Uganda). From: Dijkstra (2006b; 2007d).



(a) Atoconeura luxata *(LC) and (b)* A. kenya *(LC) represent the ecological and morphological extremes of an Afro-montane radiation.* © N. MÉZIÈRE (a) AND A. CORDERO RIVERA (b)

South Africa's approximately 160 species are endemic, a figure approaching one-third if peripheral tropical species are excluded. The 30 or so endemics are split about equally between the "relict" (near) endemic genera *Chlorolestes*, *Ecchlorolestes*, *Metacnemis*, *Ceratogomphus* and *Syncordulia* (Figures 5.7-5.8), and genera (or species groups) with an Afro-montane character: *Platycypha*, *Africallagma*, *Pseudagrion*, *Proischnura*, *Allocnemis*, *Elattoneura*, *Aeshna* and *Orthetrum* (Figures 5.14, 5.18, 5.20). Occurring in the most remote corner of a continent with a prolonged history of isolation, it is tempting to link the history of South Africa's relict odonates with that of the sclerophyll shrubland ("fynbos") they inhabit, which is characteristic of the Cape Floristic Region. Ware *et al.* (2009) estimated *Syncordulia* species diverged around 60 million years ago. simultaneously with important radiations of Cape flora. Cold upwelling off the Cape coast began to block summer rainfall 10-8 million years ago, fynbos only replacing warm temperate forest 5-3 million years ago. *Syncordulia* inhabits cold and nutrient-poor streams almost devoid of more widespread Afrotropical Odonata. This environment suggests that *Syncordulia* represents the last vestiges of an older (>60 million years ago) Afro-montane assemblage, surviving in a habitat to which they are better adapted than, and safe from competition with, modern



Both species of Metacnemis *inhabit tiny and encroached ranges in South Africa. While unpublished genetic research showed (a)* M. valida *(EN) is related to the tropical mainland genus* Mesocnemis, *(b)* M. angusta *(VU) is closer to* Platycnemis *of Madagascar and Pemba (Dijkstra unpubl.).* © W. TARBOTON

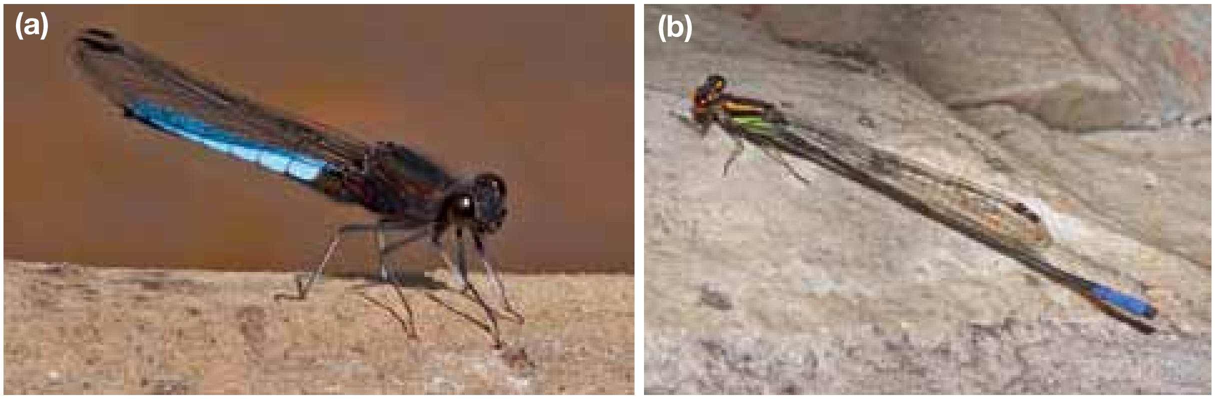
tropical species (Dijkstra *et al.* 2007c). If their isolated habitat is a last refuge from extinction, it is unsurprising that the South African endemics also stand apart with regard to their status and threat. The region holds the second-largest concentration of globally imperilled species in Africa, with almost half of the endemics threatened (Samways 2006a), many of them with very small ranges and often short flight periods (Samways and Grant 2006a): *Chlorolestes apricans* (EN), *Ecchlorolestes nylephtha* (NT), *E. peringueyi* (VU), *Metacnemis angusta* (VU), *M. valida* (EN), *Proischnura polychromatica* (CR), *Pseudagrion inopinatum* (EN), *P. newtoni* (VU), *Ceratogomphus triceraticus* (VU), *Syncordulia gracilis* (VU), *S. legator* (NE as newly described), *S. serendipator* (NE as newly described), and *S. venator* (VU). *Orthetrum rubens* (DD) has not been recorded since 1977 and may be extinct or highly threatened. Moreover, in Africa two of the major regional threats, invasive alien trees and fish, are virtually unique to South Africa (see 5.4.2.4).

5.3.3.3 Angola

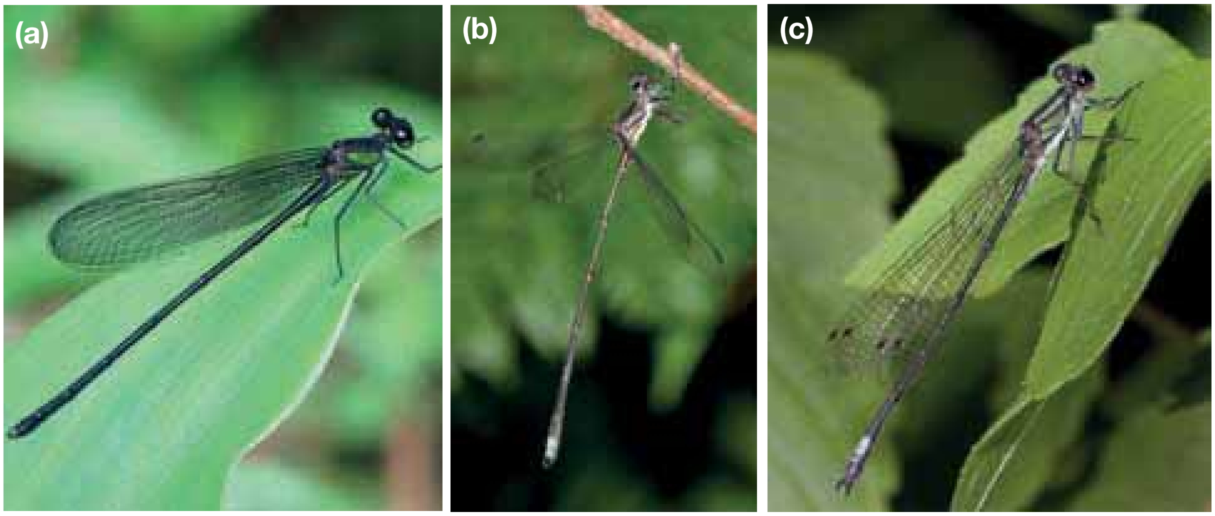
The few Angolan endemics known have Guineo-Congolian affinities (see 5.3.1.1), but the apparent absence of a distinct upland fauna may be due to insufficient research. Indeed our regional knowledge is very poor and only two species are currently assessed as threatened or NT: *Umma femina* (VU) and *Chlorocypha crocea* (NT). Further research will yield new, possibly threatened, endemics. For example, an unnamed *Elattoneura* is already known and the local subspecies *angolensis* of the widespread eastern species *Platycypha caligata* is genetically distinct from the nominate (Dijkstra unpubl.). It is also likely that other species described from Angola, many of which have not been recorded since, mainly occur in the highlands (all DD): *Chlorocypha rubriventris*, *Aciagrion rarum*, *Pseudagrion angolense*, *P. dundoense*, *Lestinogomphus bivittatus*, *Onychogomphus rossii*, *Paragomphus machadoi* and *Micromacromia flava*.

5.3.3.4 Eastern Mountains and Coast

Africa's foremost concentration of threatened or NT species occurs in the mountains stretching from Kenya to north-east South Africa, and the adjacent coast. No fewer than four monotypic genera are endemic and threatened, of which *Amanipodagrion* and *Oreocnemis* (both CR) are completely isolated taxonomically and have among the smallest ranges in African Odonata, while *Coryphagrion* (VU) is one of Africa's greatest biogeographic anomalies (see 5.2.2.3; Figure 5.9). *Nepogomphoides* (VU) is similar to *Tragogomphus* and may represent a Guineo-Congolian



Angola's endemics are very poorly known and these pictures of (b) Chlorocypha crocea *(NT) and (a)* Pseudagrion angolense *(DD) are the only ones available.* © W. TARBOTON

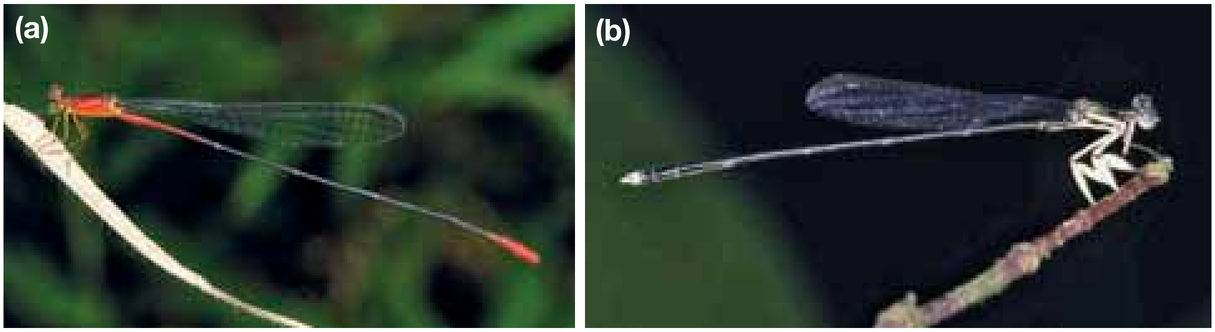


Three threatened damselflies from the eastern highlands: (a) Umma declivium *(VU), (b)* Chlorolestes elegans *(VU) and* Pseudagrion bicoerulans *(c) VU.* © K.-D.B. DIJKSTRA (a), W. TARBOTON (b), A. CORDERO RIVERA (c)

relict (see 5.3.2.1). Most endemic species, however, belong to typically Afro-montane radiations (see 5.3.3.1). This is, for instance, the case for the highest-living Afrotropical odonate fauna, centred in Kenya and north Tanzania around Mounts Elgon, Kenya, Meru, Kilimanjaro and the Aberdares. Their habitat is being encroached uphill, hence the level of threat is related to altitudinal occurrence: *Platycypha amboniensis* (CR) at 1,500-2,000m, *Notogomphus maathaiae* (EN) at 2,200-2,600m, and only *Pseudagrion bicoerulans* (VU) and *Atoconeura kenya* (LC) up to and occasionally over 3,000m. *P. bicoerulans* is the most "alpine" African odonate, typically being above 2,500m and not found below 2,000m (Clausnitzer and Dijkstra 2005b).

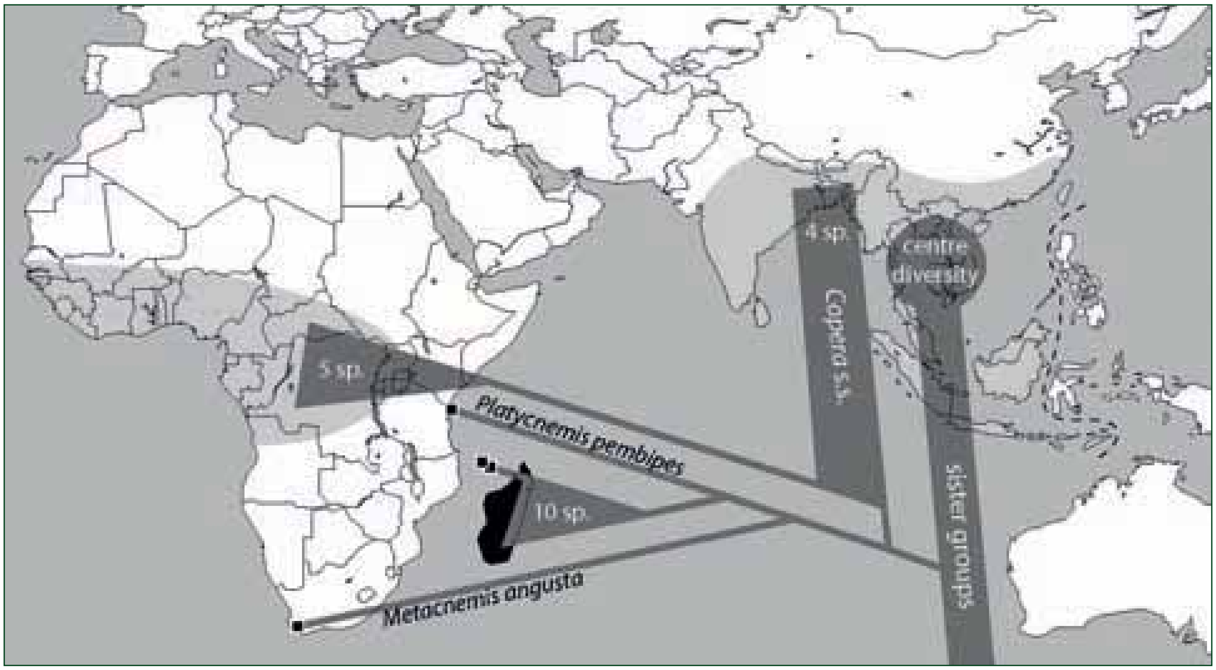
Of species occurring mainly in the Eastern Arc mountains of Tanzania, *Chlorocnemis abbotti* (NT) (Figure 5.14) extends to southern Kenya, *Umma declivium* (VU) to northern Malawi, and *Nepogomphoides stuhlmanni* (VU) to northern Mozambique and southern Malawi. Of the true endemics, *Platycypha auripes* (VU) occurs both in the Udzungwas and Usambaras, but *Amanipodagrion gilliesi* and *Micromacromia miraculosa* are unique to the latter and highly threatened (both CR). *Chlorocnemis montana* (EN) occurs in mountains on both sides of the Tanzania-Malawi border, while *C. maccleeryi* (CR) only inhabits Mount Ntchisi in central Malawi (Figure 5.14). *Oreocnemis phoenix* (CR) is endemic to Mulanje, the highest mountain between Kilimanjaro and the Drakensberg, with a 2,000m high and 24km wide plateau rising almost vertically from the 700m high plains of southern Malawi. The species' 50km² range is entirely vulnerable to bauxite mining. *Chlorolestes elegans* (VU), the only African synlestid outside South Africa (see 5.3.3.2), also has a strong population here, but extends to the Soutpansberg in the north-east of South Africa and Mount Namuli in northern Mozambique. In the mountains of eastern Zimbabwe it occurs with three local endemics: *Platycypha inyangae* (NE, but considered as a species by Dijkstra (2008)), and *Africallagma cuneistigma* (VU) in the Chimanimani and *Pseudagrion vumbaense* (VU) in the Vumba Mountains.

On the coast, the endemic *Coryphagrion grandis* (VU) occurs in Kenya and Tanzania, while *Teinobasis alluaudi* (EN) extends from southern Kenya inland to northern Malawi. The latter, however, is LC if its Madagascan



Both these threatened damselflies occur in the tiny Ngezi Forest on Pemba, but while (a) Teinobasis alluaudi *(VU^{RG}) extends to the adjacent mainland, Madagascar (where this picture was taken) and the Seychelles, (b)* Platycnemis pembipes *(CR) is found nowhere else on Earth.* © J. RENOULT (A) AND V. CLAUSNITZER (B)

Figure 5.22. Biogeographic hypothesis for Afrotropical taxa placed in *Platycnemis*. The phylogeny, based on genetic data, is superimposed on the geographic ranges. The species are more closely related to the yellow-legged *Copera* species of southern Asia, than the white-legged *Platycnemis* species of Eurasia. The Guineo-Congolian taxa are most closely related to the Asians, while the species in the Cape, Pemba, Comoros and Madagascar seem to form the peripheral remains of an older Afrotropical radiation. From: Dijkstra and Stokvis (unpubl.).



and Seychelles populations are considered. *Platycnemis pembipes* (CR) was discovered on Pemba island, off the Tanzanian coast, only in 2001, and is still known only from a single stream. Unpublished genetic data suggests that it is not a recent arrival there from Madagascar, as thought by Dijkstra *et al.* (2007a), but rather an ancient relict (Figure 5.22).

5.3.3.5 Ethiopia

Ethiopia completes the eastern trio of most sensitive assemblages (see 5.3.3.2). Like South Africa, it has a comparatively species-poor but endemic-rich fauna, surviving in a strongly impacted landscape, with nine of 12 endemic odonates considered threatened. The impoverishment rests mainly on the paucity of forest species (Clausnitzer and Dijkstra 2005a). Two *Gynacantha* species, that otherwise range from central Uganda to western Africa, are the only signs of a former Guineo-Congolian forest connection. Forest genera like *Chlorocypha*, *Umma*, *Chlorocnemis*, *Hadrothemis*, *Micromacromia* and *Notiothemis* are absent, despite the presence of suitable habitat (Figures 5.12, 5.14-5.15). In contrast, endemism is high at 12%, versus 1-3% for Kenya, Tanzania and Uganda each (see 5.3.3.4). Among the 14 most widespread high-altitude species in Ethiopia are four endemics. Almost all belong to genera (*Aeshna*, *Pseudagrion*, *Elattoneura*, *Notogomphus*, *Crenigomphus*, *Paragomphus*, *Atoconeura*, *Orthetrum* and *Trithemis*) that dominate further south, most appearing closely related to species in the highlands there (Figures 5.18-5.19, 5.21). Only *Ischnura abyssinica* possibly has Palaearctic affinities (Dumont *et al.* 2009).

High altitude, strong seasonality, as well as Ethiopia's history and isolation, explains its species-poor but endemic-rich character (Clausnitzer and Dijkstra 2005a). Climatic fluctuations were probably relatively severe due to the highlands' large mass of land at great altitude. During cooler periods, species adapted to relatively warm and wet conditions (like Odonata) were literally crushed between the descending cold and arid piedmont. The Red Sea, deserts of Kenya and Somalia, White Nile floodplains and the escarpments of Ethiopia itself are formidable barriers, even for open-land species, hampering colonisation of the highlands. Nonetheless, in warmer or wetter periods tropical African species must have expanded into the Ethiopian highlands. Especially those adapted to montane conditions survived the subsequent climatic vicissitudes. Borne from such adversity, Ethiopia's Odonata might be relatively tolerant to anthropogenic change, which has transformed the natural landscape almost completely to agricultural land. Indeed, about a half of the endemics inhabit wholly altered landscapes, being sensitive due to their small ranges, but not requiring immediate conservation measures: *Elattoneura pasquinii*, *Ischnura abyssinica* and *Pseudagrion kaffinum* (all VU), and *Orthetrum kristenseni* and *Trithemis ellenbeckii* (both LC). Of more concern are those endemics that inhabit

(a) Elattoneura pasquinii *(VU) and (b)* Notogomphus cottarellii *(EN) are Ethiopian endemics threatened by habitat destruction.*

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forest streams: *Pseudagrion guichardi* (VU), *Paragomphus crenigomphoides* (DD), *Notogomphus cottarellii* (EN), *N. ruppeli* (EN), and *Atoconeura aethiopica* (VU). The habitats of the two remaining endemics, *Crenigomphus abyssinicus* and *C. denticulatus* (both VU), are unknown.

5.3.4 Complex faunas

5.3.4.1 Albertine Rift

The low-lying forest of central Africa slopes up to meet the huge elevated area that stretches across eastern Africa (Figure 5.11). Africa's highest forests lie here, along the western (Albertine) rift in east D.R.C. and adjacent Uganda, Rwanda, Burundi and Tanzania. Aside from widespread Afro-montane species (see 5.3.3.1), these highlands have a characteristic forest fauna, with endemism in genera such as *Chlorocypha*, *Chlorocnemis*, *Neodythemis* and *Tetrathemis*, as well as in the more montane genera *Notogomphus* and *Atoconeura*. Many of the species can hardly be called "Albertine", as they range to central, north-east or southern D.R.C. and/or western Kenya. Examples are *Chlorocypha tenuis*, *C. trifaria*, *Chlorocnemis pauli*, *C. superba*, *Africallagma pseudelongatum*, *Notogomphus leroyi*, *N. lujai*, *Onychogomphus styx*, *Paragomphus lacustris*, *P. viridior*, *Phyllomacromia sylvatica*, *Atoconeura eudoxia*, *A. pseudeudoxia*, *Lokia coryndoni*, *Tetrathemis corduliformis* and *T. denticauda*. However, in the Albertine Highlands, more localised species are found that are or may be threatened or (mostly) NT: *Chlorocypha hasta* (VU), *C. jacksoni* (NT), *C. molindica* (NT), *C. schmidti* (VU), *Tragogomphus* (= *Onychogomphus*) *bwambae* (DD), *Notogomphus flavifrons* (DD), *Idomacromia jillianae* (DD), *Neodythemis munyaga* (DD), *N. nyungwe* (NT), and *T. ruwensoriensis* (DD). Most of these are only or mainly known from south-west Uganda, probably because the western (Congolese) slope of the rift is almost completely unstudied (Dijkstra *et al.* 2011), but many endemics or related new species must occur there too. *Agriocnemis palaeforma* (NT) is known only from inside papyrus swamps in Uganda, where it is numerous but difficult to survey, and it too may be more widespread.

While aquatic groups such as fish and molluscs have "explosive" endemism in the region's Great Lakes, only a handful of dragonfly species from Lakes Tanganyika and Malawi may qualify as "freshwater sea" endemics: a new *Pseudagrion* was discovered on reedy beaches of the former near Kigoma, *Platycypha pinheyi* (NT) was numerous on rocky shores, and *Neurogomphus wittei* (LC) may also be endemic (Dijkstra 2009). This paucity

The rocky shores of Lake Tanganyika (a) are the unique habitat of (b) Platycypha pinheyi *(NT).* © K.-D.B. DIJKSTRA

can be explained by the adult, whose link to land makes many lake niches inaccessible for larval development, while its capacity for flight inhibits genetic isolation of lakeshore populations from surrounding habitats. The new *Pseudagrion* is structurally identical to a common species of slow-flowing and stagnant habitats in eastern Africa, but has completely different coloration. The *Platycypha*, and another on Lake Malawi classified as a form of *P. caligata* (Dijkstra 2005b), differs only marginally in colour pattern from its riverine counterpart. The evolution of lake endemic Odonata may be a recent phenomenon, possibly only occurring when initial separation of a lake population from riverine founders is followed by slight divergence in coloration, which in this visually oriented order may be reinforced by sexual selection.

5.3.4.2 Zambezia

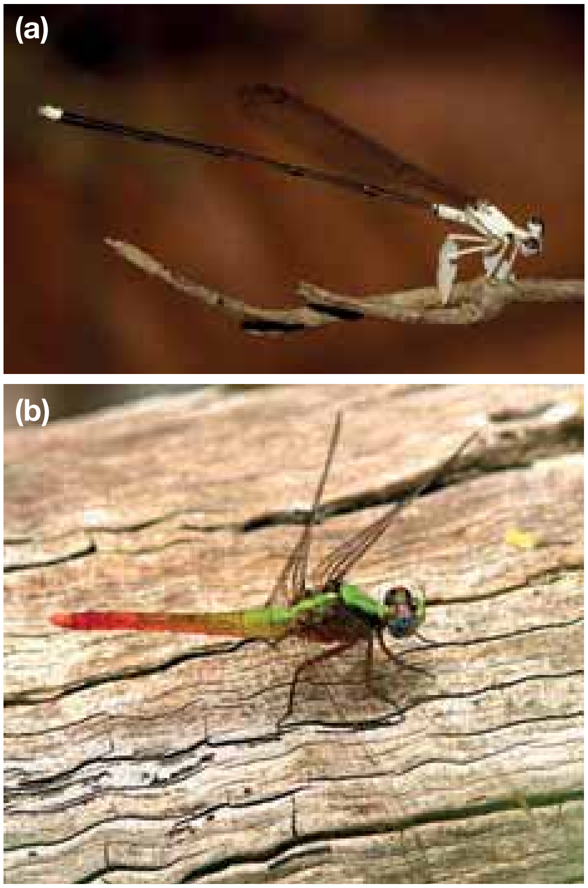
Pinhey (1978) already identified the area from Katanga, through eastern Angola and Zambia to north Botswana, as one of the most important centres of odonate diversity in Africa. About 325 species occur, an estimated 40% of all Afrotropical odonates, with about 55 endemics, of which 16 are in three of the most successful Afrotropical genera: *Aciagrion*, *Pseudagrion* and *Trithemis* (Kipping unpubl.). The area lies in the heart of the Zambezian biome and is delimited by the Paleo-Chambeshi system (Figure 5.12), which drained into the Makgadikgadi Pan in the past, but is now split across the Congo, Okavango and Zambezi drainages. The region's rivers have a complex history of recombination: the Zambezi and even Limpopo once drained headwaters that now feed the Congo (Moore and Larkin 2001). With Africa's climatic history superimposed on this geological complexity, the region is probably a recent speciation centre for Odonata (Dijkstra 2007d). None of its endemics are as yet globally threatened, but seven are assessed as Near Threatened, and owing to this and its unique ecological and evolutionary character, this fauna must be monitored.

The region is a patchwork of plains and plateaus varying 1,500m in altitude, with a corresponding diversity of landscapes: from grassland, savannah and woodland to montane, groundwater and gallery forests. These galleries allow Guineo-Congolian species to penetrate well beyond their main range, while Afro-montane taxa can disperse along the region's rather high relief. The region harbours all varieties of flowing water, from upland streams to large lowland rivers. Characteristic are "streams, tending to swamp formation in parts, and more or less fringed with thick gallery forest", where "a great many [near] endemics are known", known as "litu", "muhulu" or "mushitu" (Pinhey 1978). Among the endemics are *Chlorocypha frigid*, *C. seydeli*, *Allocnemis mitwabae* (NT), *Chlorocnemis wittei*, *Prodasineura flavifacies* (DD), *Pseudagrion coeruleipunctum* (DD), *P. fisheri*, *P. greeni*, *P. symoensii* (NT), *Ceriagrion sakejii*, *Diastatomma soror*, *Neurogomphus pallidus* (NT), *Onychogomphus kitchingmani* (DD), *Paragomphus cataractae* (NT), *Phyllogomphus schoutedeni*, *Phyllomacromia unifasciata*, *Lokia ellioti*, *Neodythemis fitzgeraldi*, and *Zygonyx atritibiae*. Fieldwork in the Ikelenge Pedicle of north Zambia, with the headwaters of the Zambezi River, by J. Kipping and A. Günther in 2010 confirmed the presence of many of the endemics, which were unrecorded since 1972 by Pinhey (1984), and demonstrated that the region's richness not only depends on gallery forests, but also on bogs, rivers, streams, ditches and pools in open grassland.

Especially notable is the regional abundance of swampy habitats. They range from the numerous "dambos" (wet depressions, often associated with gallery forest) to huge swamps such as the Bangweulu, Okavango and Upemba systems. The latter may be a transient feature of river "piracy" (see above) and alluvial deposits suggest these once existed in basins now drier (Etosha, Kafue, Lufira) or drowned (Lake Mweru). While the vast majority of range-restricted African species are found in running waters,

(a) Umma electa *(LC) and (b)* Nesciothemis fitzgeraldi *(LC) are just two spectacular species discovered during recent fieldwork in north-west Zambia.* © J. KIPPING

The genus Pinheyagrion *has only one species,* P. angolicum *(LC), which only occurs in the swamps of Zambezia.* © J. KIPPING



Madagascar's odonates are very poorly known, as demonstrated by this spectacular unnamed (a) Platycnemis species *and (b)* Viridithemis viridula *(DD), the first male of which was photographed about half a centry after the species was first described based on a female.* © K. SCHÜTTE (a) AND C. COHEN (b)

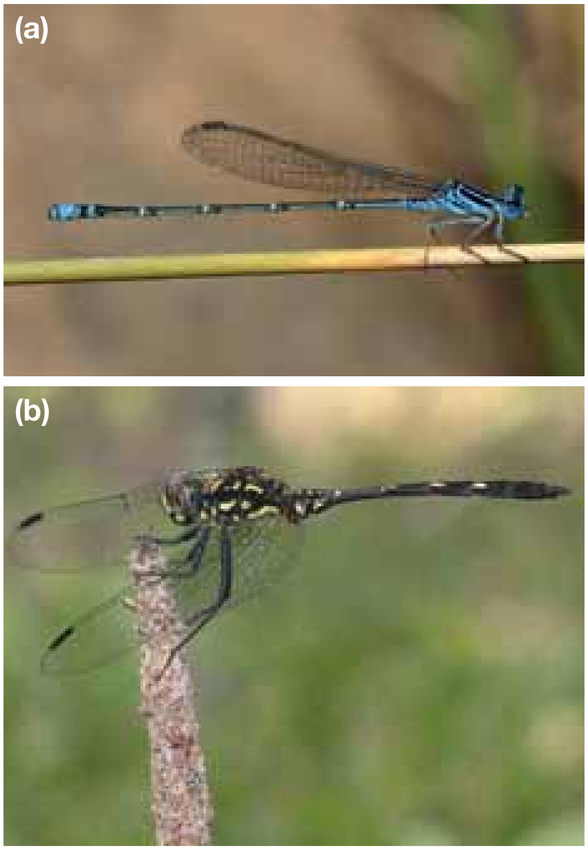
especially in forests and highlands, most swamp-dwelling species are widespread. Zambezia harbours the only restricted-range odonate fauna of open swamps in Africa: (near) endemics include *Aciagrion heterosticta*, *Ceriagrion katamborae* (DD), *Pseudagrion deningi*, *P. rufostigma*, *Anax bangweuluensis* (NT), *Ictinogomphus dundoensis*, *Nesciothemis fitzgeraldi*, *Rhyothemis mariposa*, *Trithemis aequalis* (NT), *T. anomala*, *T. palustris* (NE; incl. *T. morrisoni*) and *T. brydeni* (NT). *Pinheyagrion angolicum* represents the region's only unique genus. The faunal similarity between the Okavango and Bangweulu swamps (Pinhey 1976; 1984) is explained by former connections between the two, but while the odonate fauna of the Okavango belongs to the best studied in Africa (Kipping 2000; 2003a,b) the vast swamps around Lake Bangweulu have not been surveyed for decades. The same applies to the Chambeshi headwaters in north-eastern Zambia, the Upemba system in southern D.R.C. and most other swamp areas.

5.3.5 Insular fauna

5.3.5.1 Indian Ocean

The islands east of Africa also have Afrotropical odonate faunas, and for completeness it is relevant to briefly discuss these and their links to the mainland. Four-fifths of the over 175 species in Madagascar (60% of Anisoptera and almost 95% of Zygoptera) are endemic, of which about 80% belong to endemic genera (*Protolestes*, *Tatocnemis*, *Paracnemis*, *Isomma*, *Libellulosoma*, *Nesocordulia*, *Archaeophlebia*, *Calophlebia*, *Thermorthemis*, *Viridithemis*) or to distinct radiations of *Nesolestes*, *Platycnemis*, *Pseudagrion*, *Malgassophlebia* and *Neodythemis*. These are largely forest species, while the remaining endemic fifth inhabits mostly open habitats, having close relatives on the mainland (see 3.1). Endemism and diversity is greatest on the island's wet eastern coast (Dijkstra and Clausnitzer 2004). While the study of Madagascan Odonata already started with Rambur (1842), research was largely abandoned in the 1960s. In the meantime, Madagascar's forest cover is estimated to have decreased by 40% (Harper *et al.* 2007). Dijkstra and Clausnitzer (2004) estimated that two-thirds of species (more than 100, all endemic) are possibly threatened and require immediate evaluation. However, over 70% of 51 Madagascan odonates assessed so far were DD, and almost 40% are only known from a single collection event, i.e., the holotype or type series. By extrapolation, about 55 species have not been found since they were discovered, more await discovery, and more still became extinct before becoming known.

The smaller islands and archipelagos in the western Indian Ocean typically have around twenty species, of which a quarter to a third are endemic (Table 5.3). As shown by endemic species of *Nesolestes*, *Platycnemis*, *Pseudagrion*, *Nesocordulia* and *Thermorthemis*, the Odonata of the Comoros belong to the Madagascan fauna (Dijkstra 2004). Their vulnerability is illustrated in Mayotte, where the endemic species occur in the very small feeder streams, subject to drought and human impacts, such as high detergent input (Samways 2003b). The Mascarene and Seychelles faunas, whose conservation was summarised by Clausnitzer and Martens (2004) and Samways (2003a), do not contain any Madagascan genera. Both island groups have two endemic genera, but while *Allolestes* and *Leptocnemis* of the Seychelles (ancient continental fragments) have been placed in "relict" families (Figure 5.7), *Coenagriocnemis* and *Thalassothemis* of the Mascarenes (more recent volcanoes) belong to Coenagrionidae and Libellulidae (see 5.2.2). The Seychelles and Madagascar

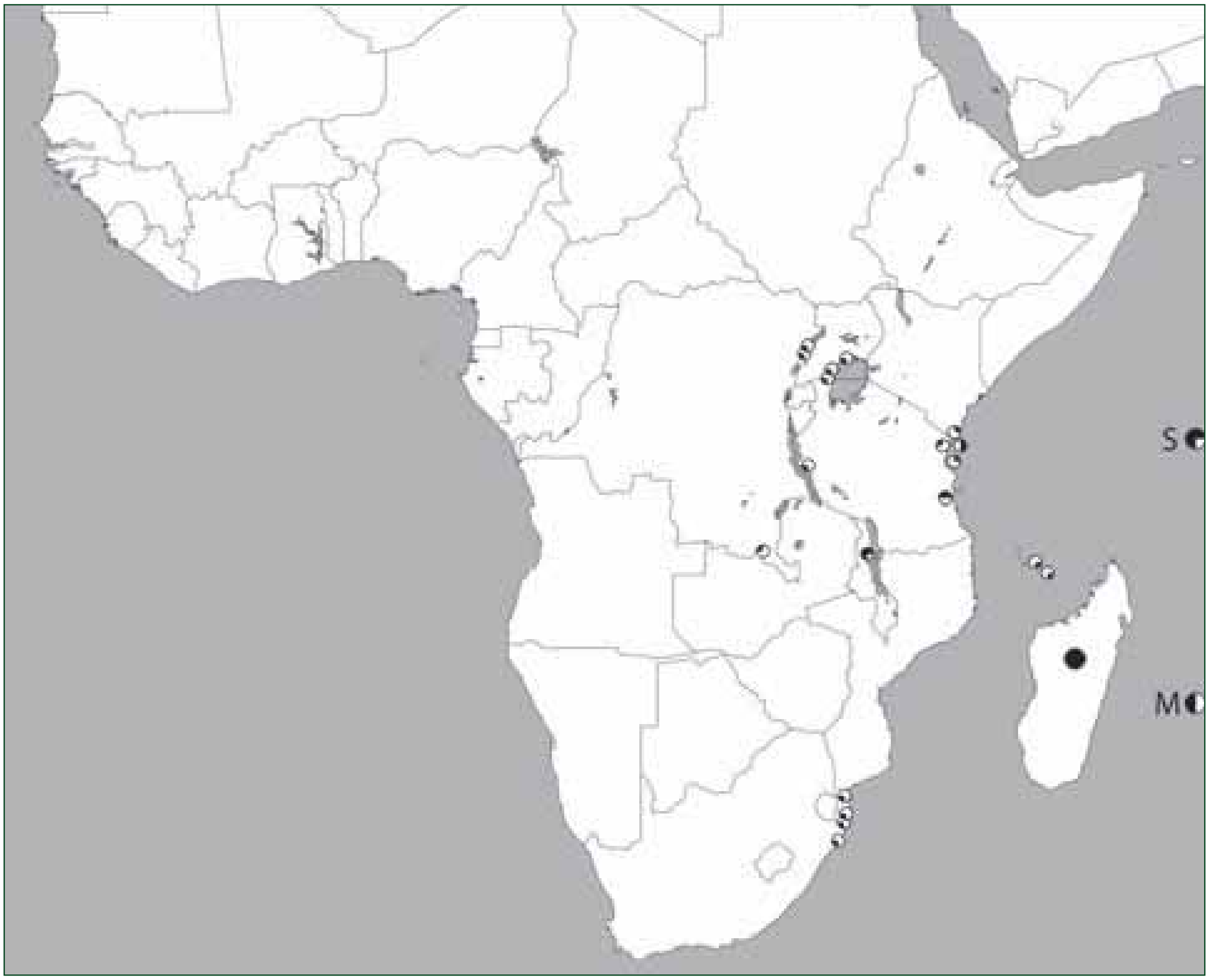


Two spectacular Indian Ocean endemics: (a) Azuragrion granti *(LC) from Socotra and (b)* Thalassothemis marchali *(EN) from Mauritius.* © R. KETELAAR (a) AND A. SKINNER (b)

Table 5.3. Comparison of Afrotropical islands, sorted by distance to Africa or Madagascar (with asterisk). Cape Verde, the Comoros and Seychelles consist several larger islands each. Réunion and Mauritius share one endemic; *Argiocnemis solitaria* of Rodrigues is considered invalid. Adapted from: Dijkstra (2010).

	area (km^2)	max. altitude (m)	dist. to land (km)	end. land birds	dragonfly species	end. dragonflies
Bioko	2017	3011	34	2	48	0
Príncipe	139	948	210	7	7	1
Socotra	3625	1503	230	6	18	1
São Tomé	857	2024	255	16	14	0
Comoros*	2023 / 4	2361	300	19	22	7
Annobón	21	613	340	2	7	0
Cape Verde	4033 / 10	2829	570	4	14	0
Réunion*	2512	3069	600	4	18	2.5
Mauritius*	1865	824	840	7	25	6.5
Seychelles*	223 / 4	905	1040	12	18	5
Rodrigues*	109	393	1470	2	2	0
Ascension	97	859	1500	0	0	0
St Helena	122	823	1900	1	1	1

Figure 23. Distribution of "insular" Afrotropical Odonata. Legend – black bottom-left quarter of circle: *Hemicordulia africana*; bottom-right: *Platycnemis* species of Madagascan radiation; top-left: *Gynacantha immaculifrons*; top-right: *Teinobasis alluaudi*; enlarged circles: presence of these species or close relatives on Madagascar and the islands just east of the map's border, the Mascarenes (M) and Seychelles (S). From: Dijkstra (2007c).



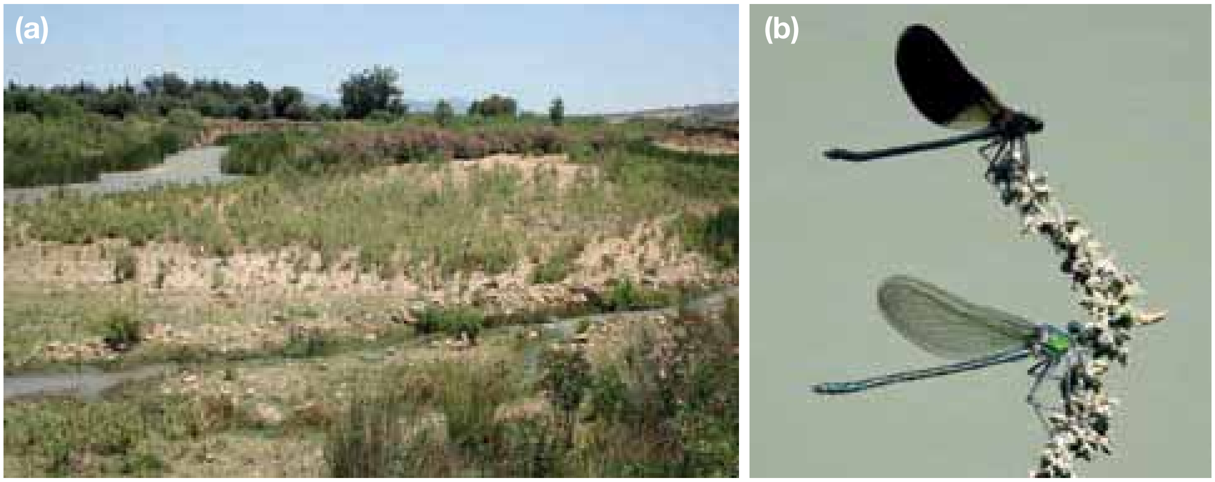
share *Teinobasis alluaudi*, and both the *Gynacantha bispina* and *Hemicordulia* groups. Each of these also occurs in eastern Africa, probably arriving recently from the east (Figure 5.23). Despite its aridity, Socotra harbours one endemic: the "giant" *A. granti* (LC) of the otherwise small-bodied Afro-Arabian genus *Azuragrion*. It is confined to about 10 permanent mountain streams, enclosed in an area of only 450km². Given the island's dry climate, the species is susceptible to water extraction for the increasing (tourist) population, as well as potentially by climate change, and will therefore be reassessed to NT (Ketelaar and Riservato in litt. 2010).

5.3.5.2 Atlantic Ocean

Of the volcanic Afrotropical islands, the forested Gulf of Guinea islands lie comparatively close to the mainland (Table 5.3). Bioko shares all its species with Cameroon, to which it was connected in the past (Brooks and Jackson 2001). A total of only 19 species is known from the other islands, with seven each on Príncipe and Annobón, and 14 on São Tomé (Dijkstra 2010), most of which are common throughout Africa. This figure is low considering the 14 reported from the more isolated desert-like Cape Verdes (Aistleitner *et al.* 2008) and the notably high number of endemic birds. Also the more isolated (but also larger) Mauritius and Réunion have much richer dragonfly faunas, even harbouring two endemic genera (see 5.3.5.1). Therefore, it seems possible that the islands have yet to yield more endemics. The only one known is *Trithemis nigra* (CR) from Príncipe, which was common in 1990 on the entire island (Gauthier in litt. 2007). Pinhey (1974) saw a *Gynacantha* or *Heliaeschna* species on São Tomé and remarks that "forest species of these genera on an isolated island might be expected to be distinctive". Gauthier (in litt.) also saw "the enigmatic aeshnid" in 1991, but believed it might be *Aeshna*. The extremely distant St Helena harboured the "giant" *Sympetrum dilatatum* (EX), last recorded in 1963 (Pinhey 1964).

5.3.6 Palaearctic fauna

Of over 800 Afrotropical species, fewer than 30 reach the Mediterranean, often surviving only locally as relicts from warmer and wetter times, such as 8,000 years ago.


(a) Oued Seybouse is the last known site in Algeria for the endangered North African endemic (b; foreground) Calopteryx exul *(EN). Here a male perches with the West Mediterranean endemic* C. haemorrhoidalis. © B. SAMRAOUI

Consequently, several are Regionally Extinct, or nearly Regionally Extinct in northern Africa, for example, *Rhyothemis semihyalina* and *Urothemis edwardsii* in north-east Algeria. North Africa is inhabited predominantly by Palaearctic species, which together with a few extending from Asia (e.g., *Ischnura evansi*, *I. fountaineae*, *Orthetrum sabina*, *O. ransonnetii*, *Selysiothemis nigra*), number just over 50. Thus the fauna stands apart from that south of the Sahara. Egypt is a notable exception, having been connected to the Afrotropics continuously by the Nile Valley, while the hyper-arid period 2,500-2,000 years ago probably extirpated most Eurasian elements (Dumont 1980; Dijkstra and Boudot 2010). All endemics have close relatives in Europe: *Calopteryx exul* (EN), *Gomphus lucasii* (VU), and *Cordulegaster princeps* (NT) inhabit clean streams and are of global conservation concern. *Enallagma deserti*, *Ischnura saharensis* and *Platycnemis subdilatata* have wider ecological and geographic ranges, as might *Lestes numidicus* (DD).

Natural habitats are severely impacted in north Africa, due to high human populations and shortage of water. The severity is expressed by species that are threatened or NT in Africa, while they have strong populations in (parts of) Eurasia: *Calopteryx virgo* (CR), *Lestes dryas* (VU), *Coenagrion scitulum* (NT), *Pyrrhosoma nymphula* (NT), *Aeshna affinis* (VU), *A. cyanea* (EN), *A. isoceles* (VU), *Boyeria irene* (NT), *Cordulegaster boltonii* (NT), *Libellula quadrimaculata* (VU) and *Sympetrum sanguineum* (VU). Although the African populations of *Coenagrion mercuriale* (EN), *Gomphus simillimus* (NT), *Lindenia tetraphylla* (CR), *Paragomphus sinaiticus* (EN) and *Oxygastra curtisii* (CR) are marginal, these species are threatened or NT in (parts of) their Eurasian range too (Kalkman *et al.* 2010). The reverse is true for the western Mediterranean endemic *Onychogomphus costae* (NT), which is EN in Europe. Two more such endemics, *Coenagrion caerulescens* and *Orthetrum nitidinerve* (both LC), are NT and VU in Europe respectively. The populations of these three in the Maghreb are thus globally important.

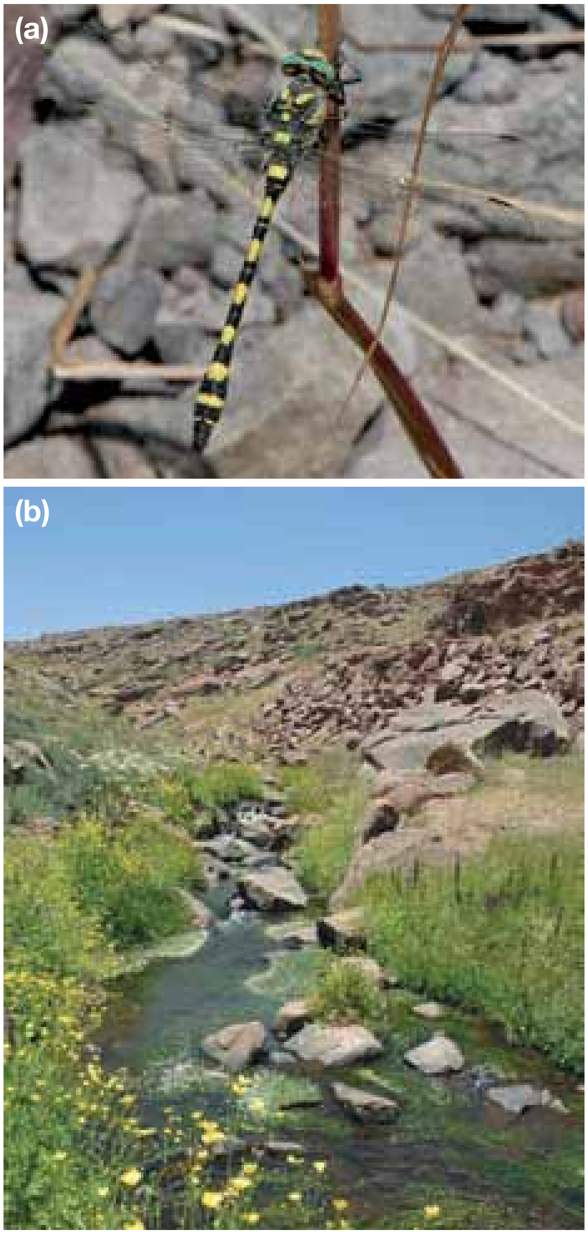
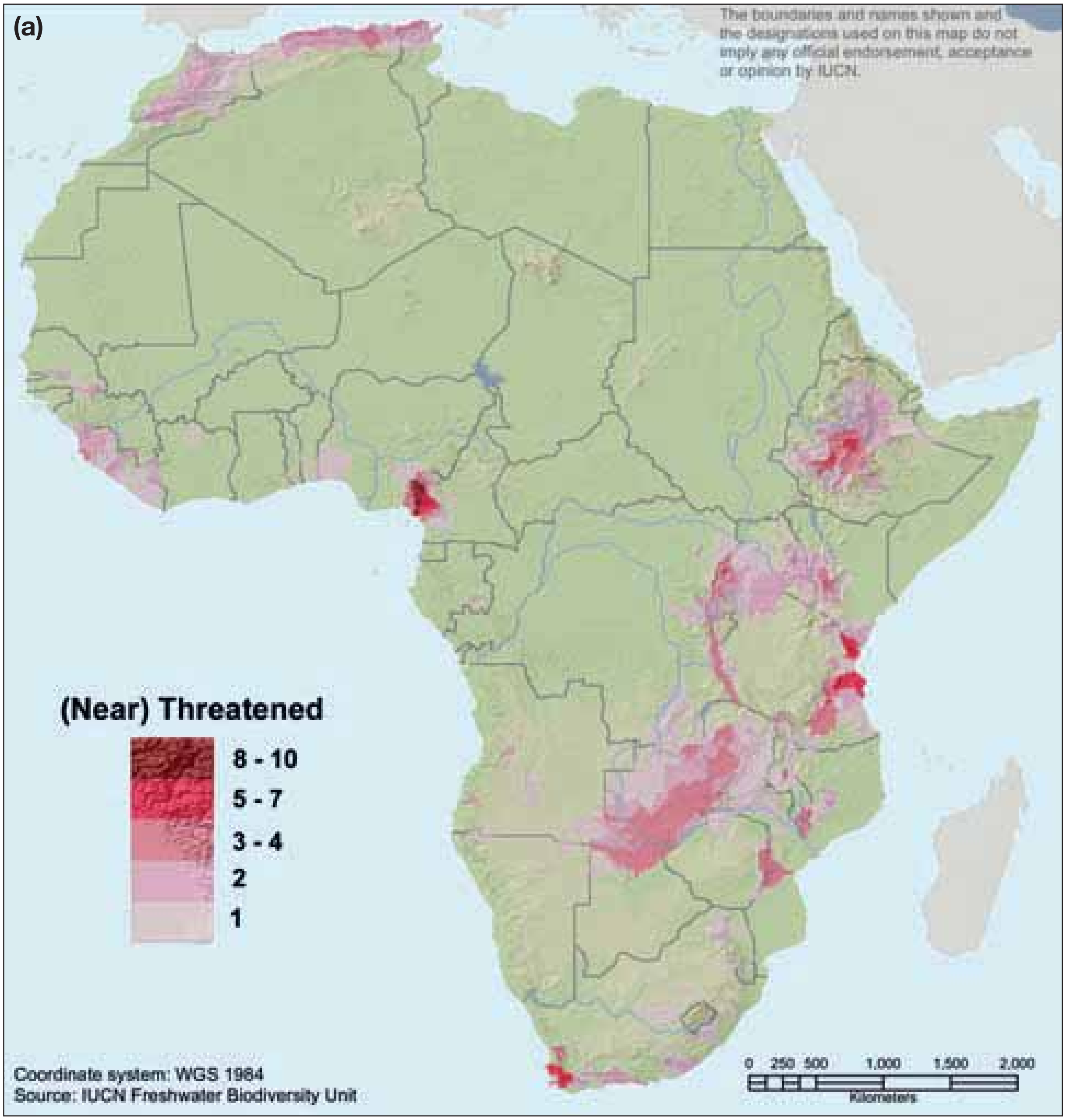

(a) Cordulegaster princeps *(NT) is the only endemic dragonfly of Morocco, where it occurs on small streams in the Atlas Mountains (b).* © J.-P. BOUDOT

Figure 5.24. The distribution of (a) globally threatened and Near Threatened, and (b) Data Deficient Odonata species across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



5.4 Conservation

5.4.1 Status

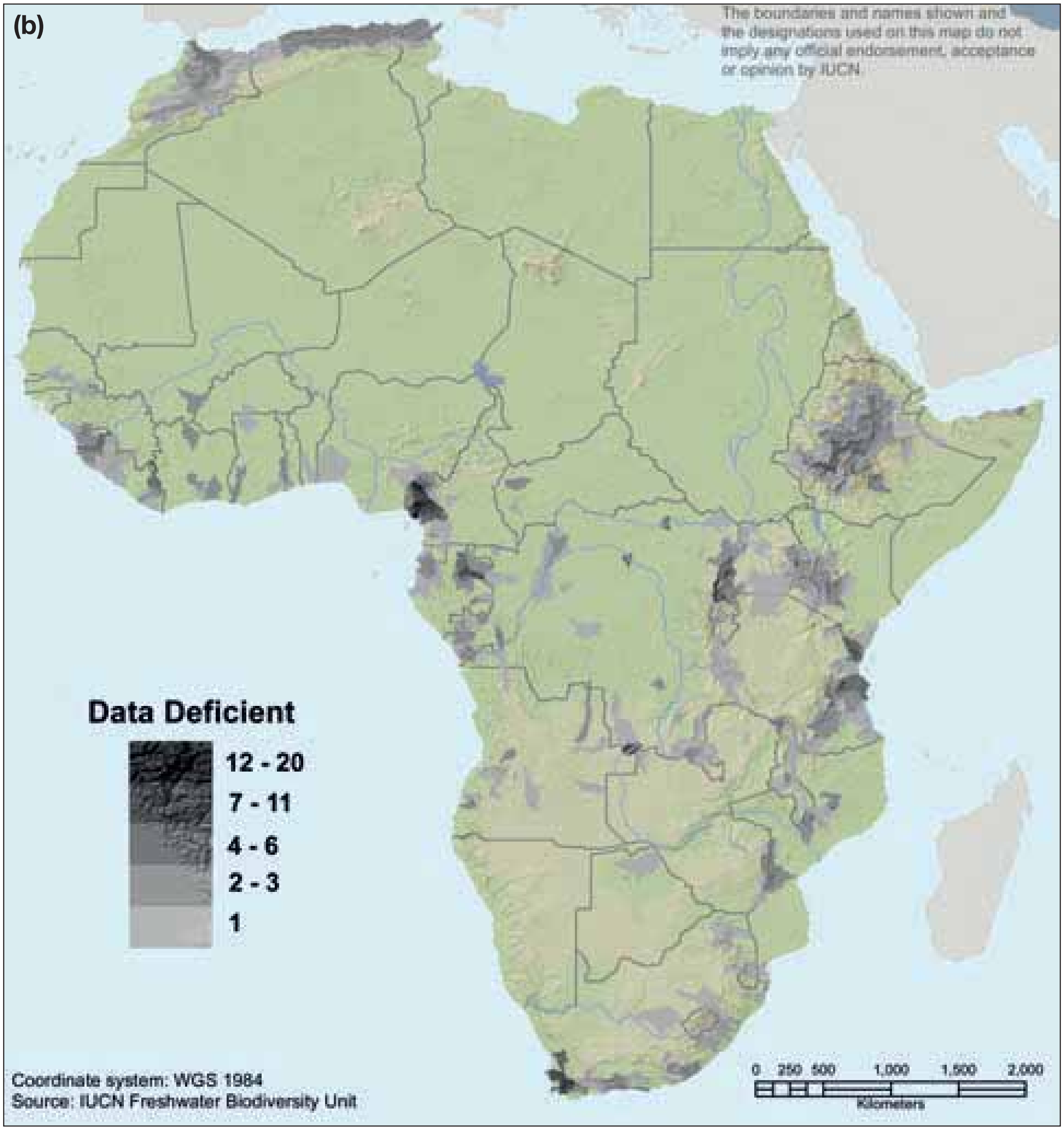
5.4.1.1 Red List assessment of African dragonflies

Slightly more than 700 species were assessed, of which 88% are endemic to the African continent. Of the endemics, 9.2% are considered globally threatened and 3.1% Near Threatened (see table 5.4), with strong regional differences (see 5.4.1.2): in western and southern Africa, for example, 20.4% and 24.1% of regional endemics are threatened, respectively, while as many as 33.3% (two of only six regionally endemic species) are threatened in northern Africa. Overall data-deficiency for the African endemics lies at 14.9%, but regional lack of knowledge is high and variable, with 16.7% of regional endemics insufficiently known in the north,

Table 5.4. The number of Odonata species in each IUCN Red List Category at a regional scale in Africa.

IUCN Red List Category	Number of species	Number of endemic species
Critically Endangered	18	15
Endangered	14	10
Vulnerable	37	32
Near Threatened	25	19
Data Deficient	95	93
Least Concern	516	452
Total species	**705**	**621**

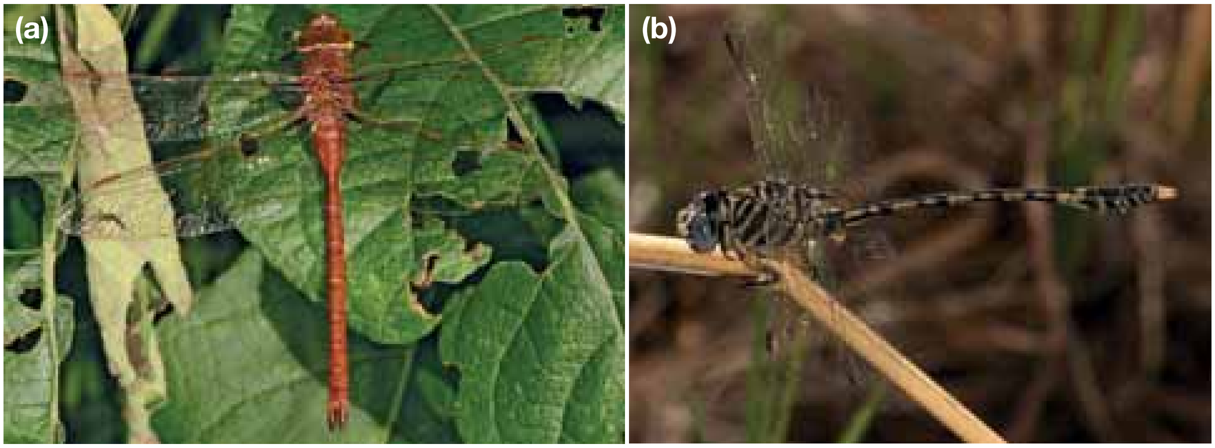
For all species that are endemic to Africa their regional Red List Category represents their global Red List status.



29.6% in the south, 35.2% in the west, and 41.8% in central Africa. Regional endemism is rather uniform in Afrotropical Africa, lying at just above 20% throughout, but with only 7.4% endemic to the northern Africa region with its many Palaearctic species. The main cause of these differences, aside from the lower level of knowledge in central Africa, is the lower human impact there.

5.4.1.2 Distribution of threatened species

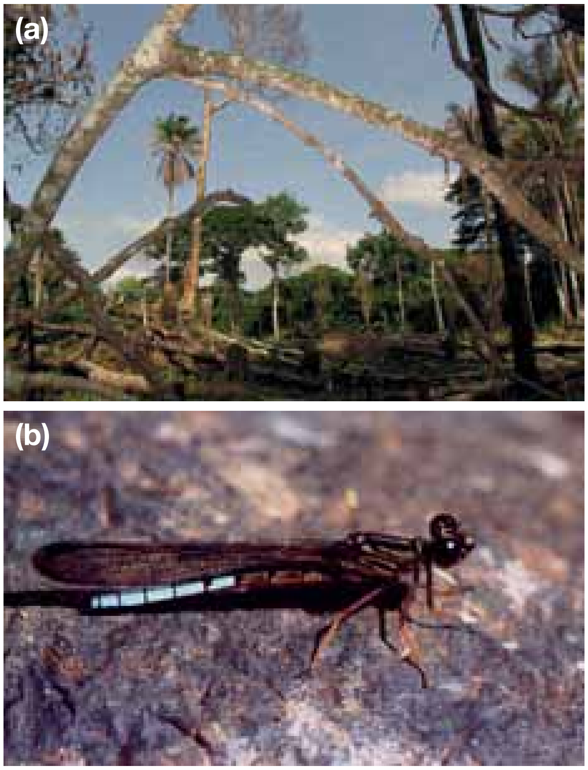
The 79 African species that are globally threatened or Near Threatened (NT) are very localised, the vast majority being associated with highland forest (Figure 5.24a). Seventeen species are found in the mountains and coast stretching from Kenya to the north-east of South Africa. Fourteen occur in South Africa, representing almost half the endemics. Ethiopia completes the eastern trio of sensitive assemblages: nine of 12 endemics are threatened. Towards central Africa, species- and endemic-rich faunas in the highlands along the Albertine Rift (only two threatened but five more NT) and in Angola (one Vulnerable and one NT) seem less sensitive because habitat destruction is less, but regional knowledge is also considerably poorer. The region from Katanga to northern Botswana is known for its swamp endemism. While none of its endemics are threatened, seven are assessed as NT. In the west, most threatened species are also inhabitants of highland forests, in the Lower and Upper Guinea centres of endemism. Eleven threatened and NT species are concentrated in and around the mountains on the Cameroon-Nigeria border, one is endemic to Príncipe, and 11 more are scattered from western Nigeria to Guinea, though concentrated in the far west. Due to high human populations and shortage of water, natural habitats are severely impacted in northern Africa. However, because endemism is low, only three species are globally threatened. The severity of the local situation, however, is expressed by the 17 species



(a) Anax bangweuluensis *(NT) and (b)* Ictinogomphus dundoensis *(LC) are two species known principally from the swamps of Zambia and northern Botswana whose assessment has benefitted from recent fieldwork.* © J. KIPPING

extending from Eurasia whose African populations are threatened, or Near Threatened, with extinction.

The distribution of Data Deficient (DD) species (Figure 5.24b) highlights areas that have been disproportionately well studied: (1) Mount Nimba by Legrand (2003); (2) south-west Cameroon by Vick (1999); (3) north-east Gabon by Legrand (1975); (4) south-west Uganda by Pinhey (1961a); and (5) north-west Zambia by Pinhey (1961b; 1984). Numerous species have been described from these localities, but many of them have not been reported since, although recent fieldwork in south-west Cameroon (Dijkstra, Kipping and Schütte in 2008), south-east Gabon (Mézière and Dijkstra since 2008) and north-west Zambia (Kipping and Günther in 2010) has partially remedied this. New records of *Anax bangweuluensis*, *Ictinogomphus dundoensis* and *Trithemis brydeni* from another such area – north Botswana, north-east Namibia and adjacent Zimbabwe (Pinhey 1976; 1984; Kipping 2000; 2003a,b; unpubl.; Suhling and Martens 2007) further demonstrate how data deficiency can be reduced (cf. Suhling *et al.* 2009a). North-east Angola stands out because several species were described from Dundo (= Chitato), but this may refer to the collection held at this town rather than material obtained there (Dijkstra *et al.* 2011).

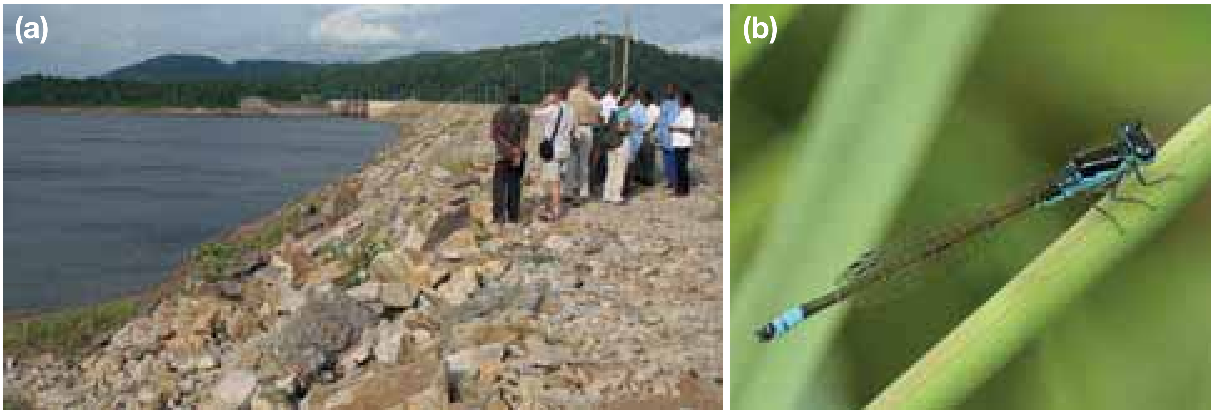


The destruction of forest for agriculture, as here in D.R.C. (a), especially threatens species with restricted spatial and altitudinal occurrence, like (b) Platycypha amboniensis *(CR) on the lower slopes of the Kenya highlands.* © K.-D.B. DIJKSTRA (a) AND V. CLAUSNITZER (b)

5.4.2 Major threats

5.4.2.1 Habitat degradation and deforestation

As human populations grow, transformation of the natural landscape through deforestation, urbanisation and agricultural encroachment, and the subsequent alteration of water bodies by erosion, eutrophication and siltation, is the main threat to Odonata in Africa and the tropics worldwide. This especially concerns species of submontane forests that are fragmentary by nature and lie in fertile and densely populated areas. Examples are *Chlorocypha centripunctata* (VU) in Cameroon's Bamenda Highlands, *Platycypha amboniensis* (CR) in central Kenya, *Amanipodagrion gilliesi* (CR) in Tanzania's east Usambara mountains, *Neodythemis nyungwe* (NT) in Rwanda, and all Ethiopian endemics. Because of their comparatively dry and fire-prone surroundings, human pressure on riparian forests for wood and agriculture is disproportionately high. Few species may be directly threatened by these activities, with the probable exception of *Ceriagrion citrinum* (VU) and *Zygonychidium gracile* (CR) in western Africa, but shaded refuges along rivers are important for many savannah and woodland odonates (e.g., Dijkstra 2009). Wetlands are also economically vital but poorly protected, thus being vulnerable to clearance and overuse, which might endanger a papyrus-endemic such as *Agriocnemis palaeforma* (NT).



While large dams like Akosombo in Ghana (a) can flood great expanses of varied odonate habitats, small dams can create valuable habitat for specialists like the South African endemic (b) Proischnura rotundipennis *(LC).* © K.-D.B. DIJKSTRA (a) AND E.R. NIELSEN (b)

5.4.2.2 Dams

Huge areas of dragonfly habitat have already been inundated following dam construction. For example, Lake Volta in Ghana and Lake Kariba on the Zambezi are the largest reservoirs in the world by surface area (over 8,500km^2) and volume (up to 185km^3), respectively. No data exist from before the Akosombo and Kariba Dams were completed in 1965 and 1958, but O'Neill and Paulson (2001) surveyed the Black Volta in Ghana above the new Bui Dam and Dijkstra (2009) surveyed the Malagarasi in Tanzania above the envisaged Igamba power plant. Even smaller dams can flood critical riverine habitat, such as rapids and gallery forests. *Paragomphus cataractae* (NT) is confined to rapids and waterfalls of large rivers, coming under threat from electric power plants planned at Epupa Falls on the Kunene (cancelled in 2008) and at Popa Falls on the Okavango. Dams also impact downstream flow regimes and sedimentation patterns. Damming in the upper Gambia catchment may flood habitat of *Elattoneura pluotae* (CR) upstream and create erratic water level fluctuations downstream for *Mesocnemis dupuyi* (NT). Not all damming events are harmful to all species, with some endemics in South Africa (e.g., *Africallagma sapphirinum* and *Proischnura rotundipennis*) benefitting from the constructions of trout dams (Samways 1989; Samways *et al.* 1996), and the southern African endemic *Agriocnemis pinheyi* appearing soon after a pond was created for plant conservation (Steytler and Samways 1995).

5.4.2.3 Mining

Africa is renowned for its disproportionate wealth of mineral resources. These are often extracted by open-pit mining, leading to extensive damage of the landscape. This is especially problematic in highlands that are entirely composed of economically valuable deposits, examples being iron ore in Mount Nimba (see 5.3.2.2) and bauxite in Mulanje (5.3.3.4). Exploitation of the latter could wipe out *Oreocnemis phoenix* (CR) completely. Dijkstra (2007f) observed the importance of highlands as freshwater catchments in Ghana's Atewa Range, which has a bauxite cap. Three major rivers in this densely populated region have their headwaters there, of which the Densu supplies one-third of Accra's water. Torrential downpours did not alter stream levels, and while trees were largely removed along the lower Densu, it still hosted typical forest dragonflies. This suggests that the water quality was sufficient despite the extensively damaged surroundings. The steady flow of clean water is determined by the capacity of the soil, swamps and forest on the plateaus and in the valleys to store and filter rainwater, and to buffer for spates and droughts.

Small-scale mining in rainforests, as observed in western Liberia, can be both beneficial and detrimental (Dijkstra 2007e). Partly overgrown pits can create scarce new habitat: emerging individuals of the localised *Tetrathemis godiardi* were found at abandoned diamond pits under a

Mining, such as for gold on the fringes of Ghana's Atewa Forest Reserve (a), may create habitat for well-dispersing dragonfly species of oen habitats, but may also potentially wipe out endangered species, such as (b) Oreocnemis phoenix *(CR) from the bauxite-rich Mt. Mulanje in Malawi.* © K.-D.B. DIJKSTRA

Some threatened South Africa endemics are only known from sites where invasive alien plants have been removed, like (a) Pseudagrion newtoni *(VU) at the Blyde River (b).*

© E.R. NIELSEN (a) AND W. TARBOTON (b)

closed canopy. Open pits, however, are colonised by well-dispersing species that occur throughout Africa (see 5.3.1). Moreover, the drainage of these mines leads to increased turbidity, and probably siltation, of streams. The former reduces visibility for larvae, the latter affects the substrate. Reduced motion and increased sunning of water in open pits also affects the flow, oxygen and temperature regimes of drainage streams. One such stream in western Liberia was suitable for *S. fumosa* (NT), but held low numbers in comparison to a pristine stream.

5.4.2.4 Alien plants and fish

Fish are important predators of odonate larvae. Their introduction to streams and wetlands, particularly of (regionally) alien species like Nile perch (*Lates niloticus*), rainbow trout (*Oncorhynchus mykiss*) or brown trout (*Salmo trutta*), can have a severe impact. There are few studies of such effects in Africa, but *Agriocnemis sania* may have been extirpated in south-west Libya by mosquitofish (*Gambusia* sp.) introduced to combat malaria vectors (Dumont 1991). In South Africa, introducing trout to formerly fish-free headwaters (or those with indigenous specialised fish) is likely to endanger sensitive species like the Cape endemics (see 5.3.3.2), and research on their impact is underway (Shelton, Samways unpubl.).

Similarly, invasive alien trees can be a key threat: riparian Australian wattles (*Acacia* sp.) may overgrow the natural vegetation along streams in South Africa, radically altering natural habitats and affecting many widespread species and all localised endemics (Samways and Taylor 2004; Samways 2006b; Samways and Grant 2006b). However, removal of these aliens results in a rapid recovery of both widespread species (Magoba and Samways 2010) and threatened endemics (Samways and Sharratt 2010). Some, such as *Metacnemis angusta* (VU), *Proischnura polychromatica* (CR) and *Pseudagrion newtoni* (VU) are indeed only known from sites where alien trees have been removed, illustrating the level of threat they pose (Samways *et al.* 2005).

5.4.2.5 Water extraction and pollution

Human populations in many parts of Africa are still low, while industry and chemical-intensive agriculture are under-developed. Chemical and organic pollution is therefore at most a local problem at present. However, with the development of Africa's industrial and agricultural sectors these impacts will increase. River salination due to intensive agriculture in dry regions, as reported in South Africa, may have a strong effect because many Odonata are not salt-tolerant (Suhling *et al.* 2003). Similarly, water abstraction for human consumption, irrigation and industry is at present a local but potentially increasing problem, particularly considering global climate change scenarios. In tandem with pollution arising through development and utilisation of water resources, there is an increasing use of pesticides against human disease vectors. Little is known about the effects of pollutants on Odonata, but aerial spraying of Deltamethrin to control tsetse flies in the Okavango Delta of northern Botswana, tested under semi-artificial conditions, affects both imaginal and larval mortality (Schuran, Kipping unpubl.). Water abstraction and pollution are most critical in dry environments in northern and south-western Africa, transforming rare perennial sources to intermittent, ephemeral or even uninhabitable ones. This may have direct effects by destroying larval habitats, as well as indirect ones by altering well-established patterns of competition between species (cf. Martens *et al.* 2010; Suhling *et al.* 2006). Examples of species of global or African concern in this regard are *Calopteryx exul* (EN), *Gomphus lucasii* (VU), *Paragomphus sinaiticus* (EN^{RG}) and *Cordulegaster princeps* (NT) in northern African, and *Azuragrion granti* (LC; will become NT) on Socotra.

5.4.3 Research actions

5.4.3.1 Field survey

The main priority now is fieldwork, which is still required in most areas despite a recent surge in records (see 5.1.2.2; Figure 5.3). Central Africa stands out in particular, with an almost uninterrupted, understudied swathe from southern Nigeria, through eastern Cameroon, eastern Republic of Congo and central D.R.C. to northern Angola. To give an idea of scale, the 1200 x 800km "empty quarter" that includes much of the Central African Republic and south-west Sudan (Figure 5.2) is almost the size of Belgium, France and Italy combined. Surveys are also needed to confirm the status of (probably) threatened species, for example, in the Ethiopian and east Zimbabwe Highlands. Areas with almost no records but also very few expected

Natural aquatic habitats and their inhabitants are under pressure by increasing human demand for water especially in arid environments, as can be imagined on the Oued Chouf in Morocco (a) and for an endemic of a dry island, like (b) Azuragrion granti *(LC) from Socotra.*

© J.-P. BOUDOT (a) AND R. KETELAAR (b)

species have the lowest research priority, for example, east Kenya and south-west Botswana.

The greatest priorities (ordered north-west to south-east), with the most likely discovery of new and threatened species are:

(1) North-west Upper Guinea: especially the Fouta Djalon in Guinea;
(2) North-west Lower Guinea: especially the Cross River State and Niger Delta in Nigeria;
(3) South-east Lower Guinea: most forest area from south Cameroon to north-west Angola;
(4) West and south Congo Basin: especially the "Cuvette" (e.g., along the Likouala River, Salonga National Park);
(5) West Albertine Slope and Highlands in eastern D.R.C. (e.g., Ituri Forest, Maiko and Kahuzi-Biega National Parks); and
(6) Angolan Escarpment and Highlands.

Of secondary priority are medium-rich regions with open habitats or fragmented (highland) forests, especially:

(7) Guinea, southern Mali and northern Côte d'Ivoire;
(8) Northern Nigeria, through northern Cameroon, southern Chad and the Central African Republic to southern Sudan;
(9) Northern and eastern Tanzania;
(10) Southern Tanzania and northern Mozambique;
(11) Southern Mozambique; and
(12) Eastern Angola and western Zambia.

5.4.3.2 Ecological research

Although, in general, dragonflies and damselflies are well known ecologically (Corbet 1999), knowledge of tropical and particularly African species is often poor. Especially deficient is the knowledge of population ecology. As a result, the IUCN Red List Criteria A, C and D could be applied in only a few cases for the African Odonata assessments. Even where population trends could be estimated, these were inferred indirectly, for instance by rates of habitat loss. This is problematic, as the habitat of most species is not precisely known, being based mostly on sketchy descriptions of observation localities. At most a handful of Maghreb and Cape endemics may have been sufficiently investigated to determine reliable trends. To enable more reliable assessments in the future, population trends and detailed habitat requirements of (at least) selected species should be investigated. Candidates are species for which population decrease has been inferred from habitat destruction, because this may allow for correlations between habitat and population trends. This requires regular monitoring of population size at selected sites, carried out by local researchers.

Life cycles of African Odonata are also poorly known, with the possible exception of some species on the continent's arid northern and southern fringes (e.g., Samraoui *et al.* 1998; Samraoui 2009; Suhling *et al.* 2003, 2004, 2005). The life cycles of forest species in particular must to be explored to understand their sensitivity. For example, tree-hole breeders like *Coryphagrion grandis* (Clausnitzer and Lindeboom 2002) and forest stream species, such as most chlorocyphids and calopterygids, may be impacted if climate change leads to more regular or severe seasonal droughts. A first step is to obtain more phenological data, from which much life cycle information can be inferred. This is possible through regular counts of adults, for example, at monthly intervals, as carried out by Parr (1984) in Malawi. Also more autecological studies would be useful, an excellent example being the study of *Ictinogomphus ferox* by Miller (1964).

5.4.3.3 Understanding change

An understanding of environmental and evolutionary history can aid the conservation of present diversity (see 5.2.2.1; 5.2.2.2). Diversifications can be unravelled by combining ecological, geographic and phylogenetic data from field surveys, GIS analysis and molecular research. Climate change affects the density, size, permanence, flow and vegetation of aquatic habitats. Amphibious insects such as Odonata are affected directly by change and can potentially also respond instantly through dispersal by flight ("range follows change"). Such "freshwater fliers" are honest indicators also because complicating geological, ecological and human factors are limited. For example, patterns are complicated in fish patterns by their confinement to river basins, in many vertebrates by human disturbance, and in many insects by intricate relationships with host biota. Nonetheless, fewer than 2% of phylogenetic studies on African animals are estimated to focus on aquatic groups equipped for flight. Given our reasonable knowledge of their taxonomy, distribution and ecology, Odonata are the most suitable group to fill this scientific gap. Suitable radiations for study, representing overall diversity in species numbers and ecological preferences, are Chlorocyphidae, *Chlorocnemis* (Figure 5.14), *Elattoneura*, *Pseudagrion* (Dijkstra *et al.* 2007b) and *Trithemis* (Damm *et al.* 2010).

This research would firstly provide basic ecological answers (see also 5.4.3.2) to questions such as how sensitive, or tolerant, are species in relation to which environmental factors, and what are their dispersal capacities? We can then better understand how they may respond to disturbance or change. Secondly, historic depth is added to help answer questions about what are species' relative ages, and whether groups show similar responses to similar events? Thirdly, ecology and evolution can be viewed together to help us answer further questions – for example, where (regions, habitats) are older or younger species, where are sensitive or tolerant ones? Where might species originate or survive? Is assemblage change by immigration or local speciation? Which ecologies are ancestral, how frequent are ecological shifts (e.g., forest to savannah), and which shifts are prevalent? Do these rates differ for aquatic (larval) and terrestrial (adult) habitats? Do older species have wider tolerances, because sensitive ones do not survive long? For instance, are species assemblages in forests or streams relatively sensitive and/or recent? What is the influence of ecological interactions? If radiations are explosive and species adaptable, with close relatives overlapping extensively, how is high local diversity possible?

5.4.3.4 Information disclosure

As mankind continues to devastate freshwater ecosystems, now exacerbated by the hydrological impact of climate change, tools to assess impacts are needed. Although attention for aquatic biodiversity conservation has increased, access to relevant knowledge remains poor. Recent developments make it timely and feasible to promote dragonflies as a focal group in freshwater conservation in Africa as:

(1) The taxonomy of the over 700 species has been largely revised (Dijkstra 2007d), with identification literature for nearly 75% of species (becoming) available (Tarboton and Tarboton 2002; 2005; Suhling and Martens 2007; Dijkstra and Clausnitzer in prep.; Samways 2009);

(2) The IUCN Freshwater Biodiversity Assessment (current study) resulted in Red List assessments and a record database for all African species, as summarised in this report;

(3) The Dragonfly Biotic Index (DBI) was developed in South Africa as a rapid environmental assessment tool for habitat integrity (Simaika and Samways 2009a; 2010), and subsequently applied as a site-selection method (Simaika and Samways 2009b) and used in measuring habitat recovery (Simaika and Samways 2008);

(4) Odonata are increasingly employed in environmental impact assessments, especially where aquatic systems are vulnerable, for example, by mining and damming (e.g., Dijkstra 2007b,e,f; 2009). Africa's rich mineral deposits are being increasingly exploited, and also water and energy are becoming prominent resources. For example, the feasibility of the Grand Inga scheme, generating twice the power of China's Three Gorges Dam, and Reduced Emissions from Deforestation and Degradation (REDD) in central Africa depends on the environmental health of the Congo Basin, the world's second-largest rainforest, containing one-quarter of Africa's freshwater; and

(5) Being colourful and conspicuous, dragonflies have gained broad public appeal (e.g., Suh and Samways 2001; 2005; Niba and Samways 2006), as seen in the worldwide boom in popular literature (e.g. Tarboton and Tarboton 2002; 2005; Dijkstra and Lewington

Odonates require diverse and structured habitats for their survival. The Malagarasi in western Tanzania shows how the morphological diversity of a single river's streambed can create different freshwater habitats, like rapids, pools and swamps. Gallery forest provides shelter in the dry season, which has left the surrounding hills dry and inhospitable. © K.-D.B. DIJKSTRA

2006; Suhling and Martens 2007; Samways 2009) and growth of the volunteer workforce.

Furthering their role in freshwater conservation in Africa requires improved identification tools and accessibility to data on status, ecology and distribution, on which DBI is based. It is therefore necessary to assemble, generate and disclose taxonomic and ecological data, identification tools, range maps, specimen scans and field photos for all species. Species diversity is greatest, but knowledge the least, in countries such as Cameroon, Gabon and the Congos (see 5.4.3.1), so the stimulation of dragonfly research in francophone Africa is especially important.

5.4.4 Conservation actions

To conserve Odonata, and the freshwater biodiversity they represent, it is necessary to maintain the structural integrity of both larval and adult habitats, i.e., water bodies and their surrounding landscape. Many measures to avoid erosion, siltation and unnatural flow regimes (both daily and seasonal) are simple. When damming streams or piping springs, sufficient spill-over and regular discharge must be guaranteed to avoid spates and droughts. The impact of drought on freshwater systems is obvious, but irregular water fluctuations may also seriously impact aquatic life cycles, for example, by affecting the micro-climate of breeding habitats and disturbing adult emergence. The impact of dams, at least downstream, can be reduced if a natural water regime with normal seasonal fluctuations is retained (Clark and Samways 1996; Stewart and Samways 1998). Alien fish should generally not be released, and invasive alien trees should be removed from stream banks and flood plains.

In large-scale landscape altering projects like open-cast mining and plantations, damage to the watershed can be minimised by leaving broad buffer zones of natural vegetation around water bodies (rivers, inundation zones, swamps) (Kinvig and Samways 2000). Forest removal should generally be avoided, as many freshwater organisms, including dragonflies, require shade in their adult stages. Where usage perturbs water, such as in irrigation and mining, measures to avoid siltation of streams and rivers from the outflow are needed, the simplest being minimising outflow by recycling water and the use of settling ponds.

Species in the spotlight

A guardian of Kenya's watershed: Maathai's longleg

Clausnitzer, V[1]

The Maathai's longleg (*Notogomphus maathaiae*) was first discovered in 2000 along the Rongai River, in Kenya's Mount Elgon National Park. It is a very striking, bright green dragonfly and only its restricted occurrence in montane forest streams can explain its rather late discovery. Dragonflies have, since the 1950s, been fairly well studied in Kenya; so finding a new species (the first for Kenya in many years) was a rare thrill. Indeed, most new species identified around the world in recent years have turned up, not in the wild, but as the result of sifting painstakingly through old Odonata collections in natural history museums. Following the discovery of this new species in the wild, collections were browsed and more specimens discovered: one male, collected in 1970 by B. Watulege in the Marioshoni Forest (on the Eastern Mau Escarpment between Nakuru and Kericho) turned up in the collection of the National Museums of Kenya (hitherto it had not been recognised as a distinct species) and two other (male) specimens, both collected during the 1950s in the Katamayu Forest (on the lower, southern slopes of the Aberdare Mountains by the pioneering early East African naturalist V.G.L. van Someren) turned up in London's Natural History Museum (both these specimens had been misidentified as a "Kenyan race" of another clubtail species, *Notogomphus flavifrons*).

*The Maathai's longleg (*Notogomphus maathaiae*) (EN).* © VIOLA CLAUSNITZER

The new dragonfly was named in honour of the 2004 Nobel Peace laureate, Wangari Maathai, the first African woman to be honoured with this prize. Wangari Maathai was recognised for her effort to advocate sustainable human development by focusing on the protection of Africa's last remaining and fast shrinking forests. The Nobel Committee's choice for 2004 emphasizes the importance of the protection of the world's natural resources in the fight against poverty. Safeguarding forests, and the rivers that flow from them, benefits mankind and also ensures the survival of unique biodiversity.

The eastern African dragonflies are neither known for having a rich montane fauna nor for the presence of many montane endemics. The discovery of the apparently truly montane *N. maathaiae*, which seems to be restricted to montane forest streams above 2,200m, is therefore surprising. Other notable montane dragonflies in Kenya are *Platycypha amboniensis*, *Pseudagrion bicoerulans* and *Atoconeura kenya*. All three are largely confined to highland forest streams in Kenya and north Tanzania between 1,500 and 3,000m. *P. amboniensis* occurs below 2,000m and is endemic to the western slopes of Mt. Kenya and the eastern slopes of the Aberdares, making it particularly vulnerable to expanding agriculture and deforestation on the mountain slopes. *P. bicoerulans* on the other hand is characteristic of altitudes above 2,500m and is not found below 2,000m.

The Maathai's longleg is assessed as Endangered (EN) on The IUCN Red List of Threatened Species. It is only known from clear streams in three high mountain forests. Such habitats have been widely destroyed in recent decades, and the species must have suffered significant declines. As deforestation continues in the densely populated highlands, this rare dragonfly may become Critically Endangered (CR). It therefore serves as an indicator of healthy streams and as a flagship species for urgent watershed protection. Conserving riverside forests not only helps this dragonfly, but also the people of the foothills, by guaranteeing stable soils and a clean and dependable water source. To this end, dragonflies such as this one are dubbed "guardians of the watershed".

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[1] Senckenberg Museum of Natural History Görlitz, PF 300154, D-02806 Görlitz, Germany

*The globe skimmer (*Pantala flavescens*) (LC).*
© VIOLA CLAUSNITZER

Species in the spotlight

The globe skimmer: on a journey around the world

Clausnitzer, V[1]

The globe skimmer, *Pantala flavescens*, is arguably the most successful dragonfly in the world, with a distribution range extending to all continents except Antarctica. In tropical areas and in North America its numbers often build into large aggregations which become true migratory swarms. In Africa large swarms of the species, which is known locally as the "helicopter insect", are taken by the people to indicate to coming of the rains. It is also known as the "wandering glider", as its wings are large and broad, helping it to glide for exceptionally long distances.

Although the migratory swarms of this species are well known, it was only recently discovered that it regularly migrates over incredible distances. For example, the species has been recorded as travelling thousands of kilometres at an altitude of 1,000m, where it unwittingly provides an important food source for migrating birds taking the same route. It is thought that *P. flavescens* takes advantage of the moving weather systems and monsoon winds to complete a truly epic migration from southern India to east and southern Africa, and back again. This represents a round trip of 14,000 to 18,000km that takes several generations to complete. How each dragonfly knows the migration route remains a mystery, given that no individual completes the full migration, dying on the way and leaving its offspring to complete the journey. This in itself is remarkable, but the migration distance covered is truly impressive, and makes the globe skimmer the strongest migrating insect species known.

The globe skimmer breeds in small, bare, stagnant water bodies, and is commonly found in temporary rain pools. As a strong migrant it is specialised to colonise these temporary habitats as its larvae have evolved to complete their life-cycle in one month, which is shorter than most species. The advantage of colonising temporary rain pools, and of a short development time, is reduced competition and predation, as few other species are able to colonise these pools so quickly. The success of this adaptation is evidenced by the unusually high numbers in which the globe skimmer occurs.

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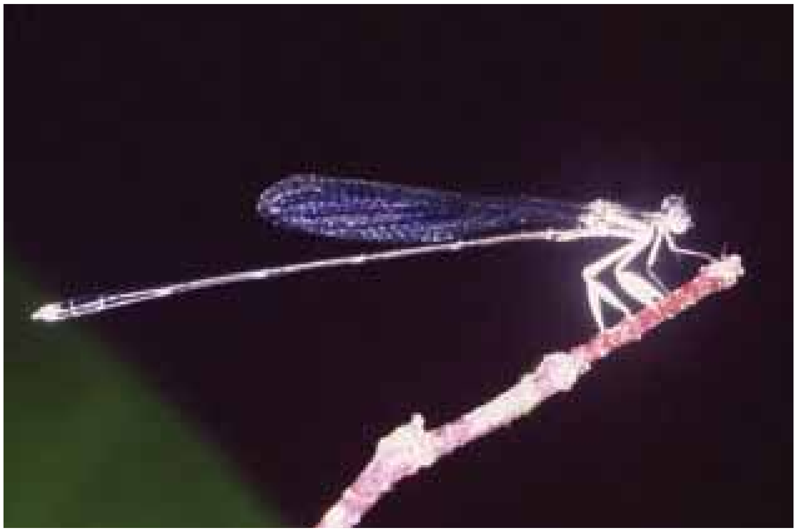
[1] Senckenberg Museum of Natural History Görlitz, PF 300154, D-02806 Görlitz, Germany

Species in the spotlight

The Pemba featherleg: a fragile damselfly in a fragile realm

Clausnitzer, V[1]



*The Pemba featherleg (*Platycnemis pembipes*) (CR).* © VIOLA CLAUSNITZER

> Remarkably, the nearest relatives of *Platycnemis pembipes* are found not on the African mainland as one might assume, but in Madagascar, 1,000km away

The Pemba featherleg (*Platycnemis pembipes*) (CR), named for its white quill-like shins, was only discovered in 2001 and was formally described in 2007. This delicate damselfly was discovered along the only stream in the Ngezi Forest on Pemba Island, a small offshore Island on the northern coast of Tanzania. Ngezi Forest is the only remaining large patch of a tropical moist forest that once covered all of Pemba Island. Forest clearance for cash crop plantations (cloves, cardamom) began in 1830, leaving only a few square kilometres of original forest. This remaining forest patch, the Ngezi Forest, attained Forest Reserve status in 1959, with a gazetted area of around 1,500ha.

The Pemba featherleg dwells in the dark understory of the moist and dense rainforest. Males settle on twigs and leaves above, or close to, the sluggish stream, facing the water while waiting for females to arrive. They approach females carefully, and oviposition (egg laying) takes place on dead plant material lying in the stream.

Remarkably, the nearest relatives of *Platycnemis pembipes* are found not on the African mainland as one might assume, but in Madagascar, 1,000km away. The origin of *P. pembipes* on Pemba is most likely through wind-aided dispersal across the Mozambique Channel from Madagascar. The strong monsoon which follows the East African coast north-westwards from June to September could possibly have carried these damselflies to Pemba. The Madagascan connection of *P. pembipes* has parallels in other Pemban taxa. While many of the island's species are also found in continental Africa, Pemba is, despite its small size (about 1,000km^2) and proximity to the mainland, recognized for its unique combination of species. For instance, the moist forest of Ngezi is peculiar in its floristic composition, with tree species restricted to coastal East African forests, Madagascan links, eastern Indian species and Afromontane elements found in combination. In other respects, Ngezi Forest odonates represent a typical assemblage of species also found in coastal forests on the mainland.

Platycnemis pembipes is assessed as Critically Endangered on The IUCN Red List of Threatened Species because of its very restricted range and ongoing threats, including habitat disturbance such as stream pollution and forest clearance, which are bringing the species to the brink of extinction.

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[1] Senckenberg Museum of Natural History Görlitz, PF 300154, D-02806 Görlitz, Germany

Species in the spotlight

A wonderful water relic with an ancient lineage

Samways, M[1]

The gilded presba, *Syncordulia legator* (VU), is not only a stunning insect but one with great charisma. Until recently nothing was known of the species, with only a couple of broken specimens in museums hinting at its existence. Then one day in October 2006, sitting on a bush in one of the most beautiful settings of the ancient Cape Fold Mountains, this stunning dragonfly was found, freshly emerged, and glistening in the early morning sun. This was not a small insect, and was even declared as being the size of a "young elephant", which although an exaggeration, nevertheless emphasizes how extraordinary it is that such a large and magnificent insect could have been overlooked in the past.

There are two reasons why this species had not been recognized earlier. The first relates to its biology. It emerges early in the summer season, and immediately departs from its natal river and flies high into the rugged mountains, where it cruises swiftly over the bushy fynbos vegetation, unique to the Cape Floristic Region in South Africa. Although a week after the first sighting a visit to the site produced some females, equally beautiful with golden wings, a few weeks later none were to be seen – all having departed for the upper slopes. The second reason why this species had not become known was that its habitat had been threatened by the impact of invasive alien trees. The trees, mostly *Acacia* and native to Australia, thrive along the water courses of the Cape. They shade out the native habitat and render conditions unsuitable for many sun-loving Cape endemic dragonfly species. However, at this site, where the gilded presba was first seen alive, alien trees had been removed as part of the national Working for Water Programme. This was originally proposed to improve hydrology and give jobs but, as it turned out, was also amazingly encouraging for the return of this and other threatened freshwater species.

*The gilded presba (*Syncordulia *legator) (VU).* © MICHAEL SAMWAYS

The cherry on the icing was provided by geneticist Jessica Ware, who examined the DNA of the genus *Syncordulia*, and discovered another new species, the rustic presba (*Syncordulia serendipator*). Jessica found that the species in the genus diverged some 60 million years ago. Although these species had survived the various comings and goings of cold and warm eras, in the geological blink of an eye they were almost rendered extinct by invasive alien trees. They have been given a reprieve by the removal of alien trees through the Working for Water Programme in South Africa. This reprieve came about only because the key threat was identified (alien trees) and dealt with, allowing narrow range endemics, like the gilded presba, to return. This emphasizes that ancient endemics can be surprisingly resilient when they are given the opportunity by removing major human-induced threats. Without habitat restoration such as this, it is quite possible that the gilded presba would have gone extinct without ever being discovered.

> “Although these species had survived the various comings and goings of cold and warm eras, in the geological blink of an eye they were almost rendered extinct by invasive alien trees

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Chapter 6.

Freshwater crabs of Africa: diversity, distribution, and conservation.

Cumberlidge, N.[1]

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An unidentified freshwater crab species within the family Potamonautes. This specimen was collected in central Africa, a region noted for its limited field sampling. © DENIS TWEDDLE

The Purple March Crab Afrithelphusa monodosa *(Endangered) which lives in swamps and year-round wetland habitats in north-western Guinea.* © PIOTR NASKREKI

Potamonautes lirrangensis *(Least Concern), a relatively abundant and widespread species found in large slow flowing rivers in rainforests across central and eastern Africa.* © DENIS TWEDDLE

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6.1 Overview of the African freshwater crab fauna

Freshwater crabs are among the most important invertebrates inhabiting African inland waters, and these large and conspicuous crustaceans are present in almost all freshwater habitats, from mountain streams to large lowland rivers and smaller water bodies (Rathbun 1921; Balss 1936; Bott 1955; Cumberlidge 1999; Yeo *et al*. 2008). The present work focuses on the freshwater crabs of continental Africa, which includes northern Africa in the Palaearctic zoogeographical zone, and the rest of the African continent that lies in the Afrotropical zone. The countries of northern Africa that host freshwater crabs are Morocco, Algeria, Tunisia, and Egypt, where there are three species of freshwater crabs in two genera (*Potamonautes* and *Potamon*) and two families, Potamonautidae Bott, 1970, and Potamidae Ortmann, 1896 (Yeo *et al*. 2008; Cumberlidge 2009a,b; Cumberlidge *et al*. 2009). The part of the Afrotropical zone dealt with here includes all 43 African countries south of the Sahara Desert, but excludes the islands of the western Indian Ocean (Socotra, the Seychelles, and Madagascar) that also lie in the Afrotropical zone. This part of Africa includes 119 species of freshwater crabs in 10 genera that all belong to the Potamonautidae (Cumberlidge 1999, 2009a,b; Daniels *et al*. 2006; Cumberlidge *et al*. 2008; Yeo *et al*. 2008; Cumberlidge and Ng 2009; Cumberlidge *et al*. 2009).

The total taxonomic diversity of continental Africa (11 genera, 120 species, two families) (Table 6.1) is markedly lower than seen in the freshwater crab faunas of the Neotropical (50 genera, 298 species, two families) and Oriental/Palaearctic (154 genera, 849 species, two families) regions (Yeo *et al*. 2008; Cumberlidge *et al*. 2009). Continental Africa's freshwater crab fauna is highly endemic at the family, genus, and species levels with 100% endemicity for the predominant family, the Potamonautidae (Bott 1955; Cumberlidge 1999; Cumberlidge *et al*. 2009). The African continent is, for the purposes of this project, subdivided into the five main regions, and each of these has a distinct freshwater crab faunal composition, with only a few species (14 out of 120) found in more than one region. For example, the most diverse regions are eastern Africa (44 species, three genera), central Africa (33 species, three genera), and western Africa (24 species, six genera), while southern Africa (20 species, one genus) and northern Africa (four species, two genera) each have a less diverse regional fauna (Bott 1955; Cumberlidge 1997, 1998, 1999, 2009a,b; Cumberlidge and Boyko 2000; Corace *et al*. 2001; Cumberlidge *et al*. 2002; Cumberlidge and Vanini 2004; Cumberlidge and Reed 2004, 2006; Cumberlidge and Tavares 2006; Cumberlidge and Dobson 2008; Cumberlidge *et al*. 2009)

The Common Creek Crab Liberonautes latidactylus *(Least Concern) is the most common and most frequently caught freshwater crab in small streams throughout the rainforest and savanna zones of western Africa.* © PIOTR NASKREKI

Table 6.1. Numbers of species, genera, families and subfamilies, and their regions of occurrence, for each of the 43 countries in Africa that has freshwater crabs. N = northern Africa, W = western Africa, C = central Africa, E = eastern Africa, S = southern Africa.”

	Country	No. Species	No. Genera	Region	Family, subfamily
1	Morocco	1	1	N	Potamidae, Potaminae
2	Algeria	1	1	N	Potamidae, Potaminae
3	Tunisia	1	1	N	Potamidae, Potaminae
4	Egypt	1	1	N	Potamidae, Potaminae
		2	1		Potamonautidae, Potamonautinae
5	Nigeria	10	3	W	Potamonautidae, Potamonautinae
6	Liberia	8	1	W	Potamonautidae, Potamonautinae
		1	1		Potamonautidae, Hydrothelphusinae
7	Guinea	5	2	W	Potamonautidae, Potamonautinae
		2	1		Potamonautidae, Hydrothelphusinae
8	Côte d’Ivoire	6	3	W	Potamonautidae, Potamonautinae
9	Ghana	6	3	W	Potamonautidae, Potamonautinae
10	Togo	4	2	W	Potamonautidae, Potamonautinae
11	Sierra Leone	2	2	W	Potamonautidae, Potamonautinae
		1	1		Potamonautidae, Hydrothelphusinae
12	Benin	2	2	W	Potamonautidae, Potamonautinae
13	Chad	2	1	W	Potamonautidae, Potamonautinae
14	Mali	2	2	W	Potamonautidae, Potamonautinae
15	Mauritania	2	1	W	Potamonautidae, Potamonautinae
16	Burkina Faso	1	1	W	Potamonautidae, Potamonautinae
17	Niger	1	1	W	Potamonautidae, Potamonautinae
18	D. R. Congo	24	3	C	Potamonautidae, Potamonautinae
19	Cameroon	13	4	C	Potamonautidae, Potamonautinae
20	Congo	11	3	C	Potamonautidae, Potamonautinae
21	Gabon	8	2	C	Potamonautidae, Potamonautinae
22	Central African Republic	4	2	C	Potamonautidae, Potamonautinae
23	Equatorial Guinea/Bioko	3	1	C	Potamonautidae, Potamonautinae
24	Angola (Cabinda)	1	1	C	Potamonautidae, Potamonautinae
25	Sudan	3	2	E	Potamonautidae, Potamonautinae
26	Somalia	1	1	E	Potamonautidae, Potamonautinae
		1	1		Potamonautidae, Hydrothelphusinae
27	Ethiopia	6	1	E	Potamonautidae, Potamonautinae
28	Kenya	13	1	E	Potamonautidae, Potamonautinae
		2	1		Potamonautidae, Hydrothelphusinae
29	Uganda	12	2	E	Potamonautidae, Potamonautinae
30	Rwanda	4	1	E	Potamonautidae, Potamonautinae
31	Burundi	1	1	E	Potamonautidae, Potamonautinae
32	Tanzania	24	1	E	Potamonautidae, Potamonautinae
		1	1		Potamonautidae, Hydrothelphusinae
33	Malawi	4	1	E	Potamonautidae, Potamonautinae
34	Angola	5	1	S	Potamonautidae, Potamonautinae
35	Botswana	2	1	S	Potamonautidae, Potamonautinae
36	Lesotho	1	1	S	Potamonautidae, Potamonautinae
37	Mozambique	3	1	S	Potamonautidae, Potamonautinae
38	Namibia	4	1	S	Potamonautidae, Potamonautinae
39	South Africa	14	1	S	Potamonautidae, Potamonautinae
40	Swaziland	1	1	S	Potamonautidae, Potamonautinae
41	Zambia	3	2	S	Potamonautidae, Potamonautinae
42	Zimbabwe	3	1	S	Potamonautidae, Potamonautinae

6.1.1 Biogeographic patterns

Freshwater crabs are found in all major habitat types in continental Africa, including floodplains, swamps, lakes, moist forest rivers, Mediterranean systems, highland and mountain systems, large lakes, large river rapids, dry savanna rivers, and even xeric systems where there are freshwater resources above ground. Species diversity is highest in the rivers and streams of the major river basins of Africa, especially those that flow through lowland rainforest and drain forested highlands. Because of their widespread representation in Africa's aquatic ecosystems, freshwater crabs are also represented in most of the continent's freshwater ecoregions (e.g., the North African, Nilo-Sudan, Upper Guinea, West Coast Equatorial, Congo, Great Lakes, Eastern and Coastal, Cuanza, Zambezi, and Southern Temperate freshwater ecoregions) (Thieme *et al*. 2005; Abell *et al*. 2008). However, with only a few exceptions, there is no close correlation between freshwater crab distribution patterns and freshwater ecoregion boundaries found in the African region. The only instances where freshwater crabs distribution coincides with ecoregion boundaries are those species that have a restricted distribution.

The White Volta River as an example of suitable habitat for at least two freshwater crabs species. © KLAAS-DOUWE DIJKSTRA

Table 6.2. The threatened species of freshwater crabs found in continental Africa, with their regions of occurrence, and a summary of their conservation status. C = central Africa, W = western Africa, S = southern Africa, E = eastern Africa, N = northern Africa.

	Species	Regional Distribution	Red List Category	Red List Criteria
1	*Liberonautes grandbassa*	W	CR	B1ab(iii)+2ab(iii)
2	*Liberonautes lugbe*	W	CR	B1ab(iii)
3	*Afrithelphusa monodosa*	W	EN	B1ab(iii)+2ab(iii); C2a(i)
4	*Globonautes macropus*	W	EN	B1ab(iii)+2ab(iii); C2a(i)
5	*Liberonautes nanoides*	W	EN	B1ab(iii)+2ab(iii)
6	*Liberonautes rubigimanus*	W	EN	B2ab(iii)
7	*Louisea balssi*	C	EN	B1ab(i,ii,iii,iv,v)
8	*Louisea edeaensis*	C	EN	B1ab(i,ii,iii,iv,v)
9	*Potamonautes gonocristatus*	C	EN	B1ab(i,ii,iii,v)
10	*Potamonautes idjiwiensis*	C/E	EN	B1ab(i,iii)+2ab(i,iii)
11	*Potamonautes mutandensis*	C/E	EN	B1ab(iii,v)+2ab(iii,v); C1+2a(ii)
12	*Potamonautes platycentron*	E	EN	B1ab(iii)+2ab(iii)
13	*Liberonautes nimba*	W	VU	B1ab(iii)+2ab(iii); D2
14	*Potamonautes choloensis*	E	VU	B1ab(i)
15	*Potamonautes gerdalensis*	E	VU	B1ab(i); D2
16	*Potamonautes ignestii*	E	VU	B1ab(i); D2
17	*Potamonautes infravallatus*	E	VU	B1ab(i); D2
18	*Potamonautes lividus*	S	VU	B1ab(iii)+2ab(iii)
19	*Potamonautes montivagus*	E	VU	B2ab(i)
20	*Potamonautes pilosus*	E	VU	B1ab(i,iii); D2
21	*Potamonautes raybouldi*	E	VU	B2ab(iii)
22	*Potamonautes reidi*	W	VU	B1ab(iii)+2ab(iii)
23	*Potamonautes triangulus*	W	VU	B1ab(iii)+2ab(iii)
24	*Potamonautes unisulcatus*	E	VU	B1ab(i,ii,iii); D2
25	*Potamonautes xiphoidus*	E	VU	B1ab(iii)+2ab(iii); D2
26	*Potamonemus sachsi*	W/C	VU	B1ab(iii)+2ab(iii)

The Purple March Crab Afrithelphusa monodosa *(Endangered) which lives in swamps and year-round wetland habitats in north-western Guinea where it is known from only a few specimens from two localities. This species is clearly a competent air-breather and has a pair of well-developed pseudolungs. It is mainly threatened by habitat loss and degradation.* © PIOTR NASKREKI

6.2 Conservation status

The conservation status of Africa's freshwater crab fauna was assessed by Cumberlidge *et al*. (2009) using the IUCN Red List Categories and Criteria at the global scale (IUCN 2003), and individual species assessments are freely available through the IUCN Red List website (www.iucnredlist.org). Results reveal current high levels of threat with 26 (21%) of the 120 species assessed as globally Threatened (Table 6.2 and 6.3, and Figure 6.1a). There is insufficient information to assess the status of 27 species which were categorised as Data Deficient (DD) due to a lack specimens, and locality and population data (Cumberlidge *et al*. 2009; Table 6.3, and Figure 6.1a). If all Data Deficient (DD) species also proved to be Threatened, the level of threat could be as high as 44%.

Figure 6.1. The proportion (%) of freshwater crab species in each regional IUCN Red List Category in mainland continental Africa (Cumberlidge *et al*. 2009, Appendix 1): a) all 120 species from the region; and b) following removal of the 27 DD species.

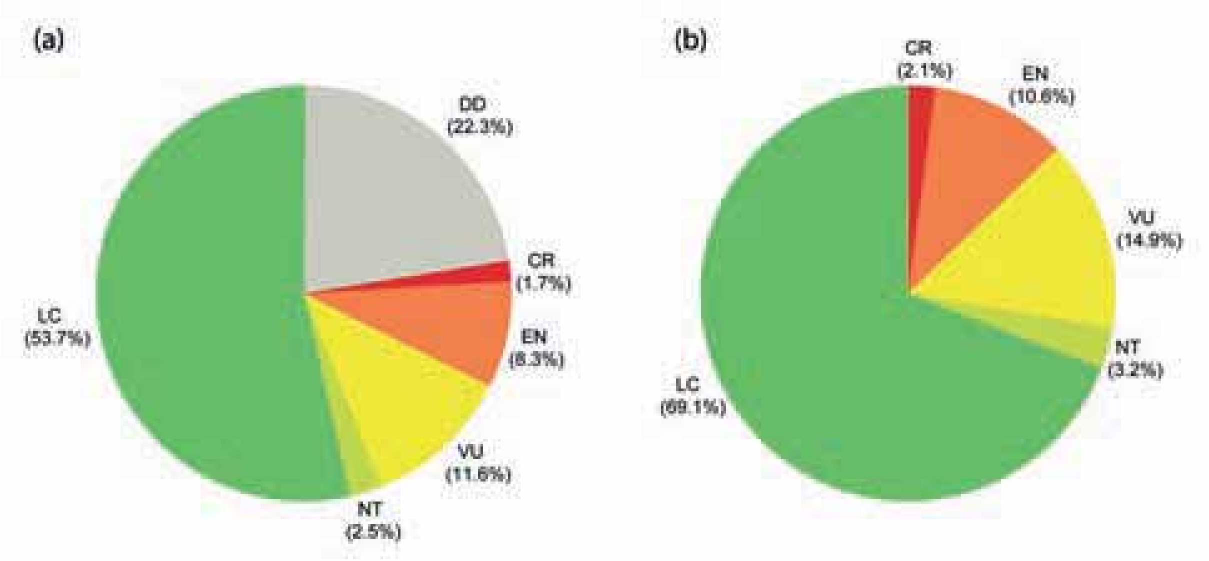


Table 6.3. The number of African crab species in each IUCN Red List category by region (Cumberlidge *et al*. 2009, Appendix 1). The total number of species per Category does not include species found in more than one region. Numbers with an * = total species per region including those species that are found in more than one region. For example, LC includes five species that are found in both W + C, two species that are found in both E + N, and one species each that is found in both E+ C, E + S, and S + C + E); EN includes two species that are found in both C + E); DD includes one species that is found in both C + S). C = central Africa, W = western Africa, S = southern Africa, E = eastern Africa, N = northern Africa.

	REGION					Total species per
IUCN Red List Category	N	W	C	E	S	Red List Category
Critically Endangered	0	2	0	0	0	2
Endangered	0	4	2	4	0	10
Vulnerable	0	3	1	9	1	14
Near Threatened	0	0	0	2	0	2
Least Concern	2	10	16	24	15	64
Data Deficient	0	5	12	5	4	25
Total species per region*	**2***	**24***	**31***	**44***	**20***	**117**

Of the 94 species that could be assessed, the majority (65 species, 69%, Figure 6.1b) belong to seven genera and were judged to be Least Concern (LC), and most of these live in rivers, marshy lowlands, or mountain streams in the forested parts of Africa (Cumberlidge 1999; Cumberlidge *et al*. 2009). Forty-three out of the 76 species of *Potamonautes* are LC, as are one of the three species of *Potamonemus*, eight of the 11 species of *Sudanonautes*, eight of the nine species of *Platythelphusa*, three of the eight species of *Liberonautes*, and one each of the two species of *Erimetopus* and *Potamon*. Twenty-six (28%) of the 94 assessed species were listed in one of three threatened categories, either as Critically Endangered (CR) (two species), Endangered (EN) (10 species) or Vulnerable (VU) (14 species) (Figure 6.1b and Table 6.3). Just three species (3%) were assessed as Near Threatened (NT). No species of freshwater crabs from Africa could be confirmed Extinct (EX) or Extinct in the Wild (EW). However, it should be noted that a species cannot be formally assessed as Extinct until exhaustive surveys have been carried out.

Aubry's Crab Sudanonautes aubryi *(Least Concern) is a widespread species found throughout much of western and Central Africa. This specimen was collected on the western border of the Campo Maan National Park on the border to Equatorial Guinea. This large species inhabits streams, rivers, and ponds, and digs burrows near waterways; at night and during rainstorms it is often found on land because it is capable of breathing air.* © JENS KIPPING

Detailed assessments of species' regional status are also available for eastern Africa (Darwall *et al*. 2005), southern Africa (Cumberlidge and Daniels 2008), western Africa (Smith *et al*. 2009), northern Africa (Garcia *et al*. 2010), and central Africa (Brooks *et al*. 2011).

6.3 Patterns of species richness

Continental Africa has a rich, highly diverse, and distinctly recognisable freshwater crab fauna, with all species endemic to the continent, and distributed over 43 countries (Cumberlidge 1999; Table 6.1). Distribution data used here have been derived from all available specimen records but are still likely to be incomplete. Although a majority of the African species are quite well studied, there are still some that are known only from either the type locality or from just a few records, and in these cases further collections are necessary to ascertain their actual distributions. The available data indicate that the composition of the freshwater crab fauna in Africa is not uniform, changes from region to region, and varies with ecosystem, aquatic drainage basins, and vegetation cover. For example, freshwater crabs are found in all of the major ecosystems in continental Africa, but are noticeably more abundant in the rainforest, especially in highland regions (Cumberlidge 1999). Species diversity appears to depend on vegetation cover and the availability of water, with the highest number of species occurring in rainforest ecosystems, especially in highland areas, and the fewest in savanna ecosystems. One interesting pattern shown by the distribution of species in African forests is areas of high biotic diversity surrounded by apparently identical forest areas that have a gradient of declining species numbers (Cumberlidge 1999). For example, there are three relatively small areas of the African rainforest that stand out as having an unusually high number of species and a higher than normal number of endemic species: the Upper Guinea forest in western Africa, the Lower Guinea forest in Nigeria and Cameroon, and the forests of eastern D. R. Congo (Cumberlidge 1999).

At the genus level the taxonomic diversity is highest in western and central Africa (six genera), lower in eastern Africa (four genera), and lowest in northern Africa (two genera) and southern Africa (one genus) (Table 6.4). Although eastern Africa is the most species rich region (with 44 species in three genera and two subfamilies), western Africa stands out as the most diverse (with 24 species, six genera and two subfamilies) (Table 6.4). Distribution patterns considered at the genus level indicate that each of the five African regions has genera with species that have a wide distribution, and many other species that have a restricted distribution. Five out of eleven genera have a wide distribution in more than one region. For example, *Potamonautes* is found in all five regions, *Sudanonautes* is found in three regions, while *Platythelphusa* and *Potamonemus* occur in two regions. *Potamonautes*, *Sudanonautes*, and *Liberonautes* include some widespread species, and some species that are endemic to a particular region. In contrast, six genera have a relatively restricted range and are endemic to a particular region. For example, *Afrithelphusa, Globonautes* and *Liberonautes* are all endemic to western Africa, *Louisea* and *Erimetopus* are both found only in central Africa, and *Deckenia* is found only in eastern Africa. Although *Potamon* has a number of wide distributional ranges in the Mediterranean and Middle East as far east as the Himalayas (Brandis *et al*. 2000), within Africa this genus is found only in the Palaearctic zone of northern Africa.

Table 6.4. Number of species and genera found in each region in Africa. N = northern Africa, W = western Africa, C = central Africa, E = eastern Africa, S = southern Africa. * = regional endemic.

		REGION				
Genus	# Species	N	W	C	E	S
Potamonautes	76	2	4	23	33	19
Sudanonautes	1 1	0	5	5	1	0
Platythelphusa	9	0	0	9	9	0
*Liberonautes**	8	0	7	0	0	0
*Afrithelphusa**	4	0	4	0	0	0
Potamonemus	3	0	1	2	0	0
*Deckenia**	2	0	0	0	2	0
*Erimetopus**	2	0	0	2	0	0
*Louisea**	2	0	0	2	0	0
Potamon	1	1	0	0	0	0
*Globonautes**	1	0	1	0	0	0
Genera /region		**2**	**6**	**6**	**4**	**1**

Potamonautes lirrangensis *(Least Concern) is a relatively abundant and widespread species found in large slow flowing rivers in rainforests across central and eastern Africa. It is subject to a small commercial fishery in Malawi.* © DENIS TWEDDLE

6.3.1 All freshwater crab species: interpretation of distribution patterns

Potamonautes includes by far the largest number of species in Africa (Bott, 1955, 1959, 1969, 1970; Stewart *et al*. 1995; Cumberlidge 1997, 1998, 1999, 2009a,b; Stewart 1997; Corace *et al*. 2001; Cumberlidge *et al*. 2002; Cumberlidge and Vanini 2004; Reed and Cumberlidge 2004, 2006; Cumberlidge and Boyko 2000; Cumberlidge and Tavares 2006; Cumberlidge and Dobson 2008). The 76 species of this large genus are found in all five regions of Africa, and are distributed throughout sub-Saharan Africa from the Cape to Cairo, and from Senegal to the Horn of Africa (Figure 6.2). The only region where *Potamonautes* does not occur is in the coastal fringe of north-west Africa (the Maghreb) that lies in the Palaearctic zoogeographical region. Some species of *Potamonautes* are widespread and are associated with the major river basins throughout the continent, some have adopted a semi-terrestrial air-breathing habit, while others have a narrow distribution and are endemic to a very restricted area. The largest numbers of species of *Potamonautes* occur in eastern Africa and in the forested Congo River basin. The vast majority of species of *Potamonautes* occur in eastern, central, and southern Africa (33, 24, and 20 species respectively), and there are only four species of *Potamonautes* in western Africa (all endemic), and two in northern Africa (both widespread species found along the Nile River). One species (*Potamonautes ecorssei*) is even found in the Sahara desert in Mali, but only where the Niger River flows through Timbuktu (Cumberlidge 1999).

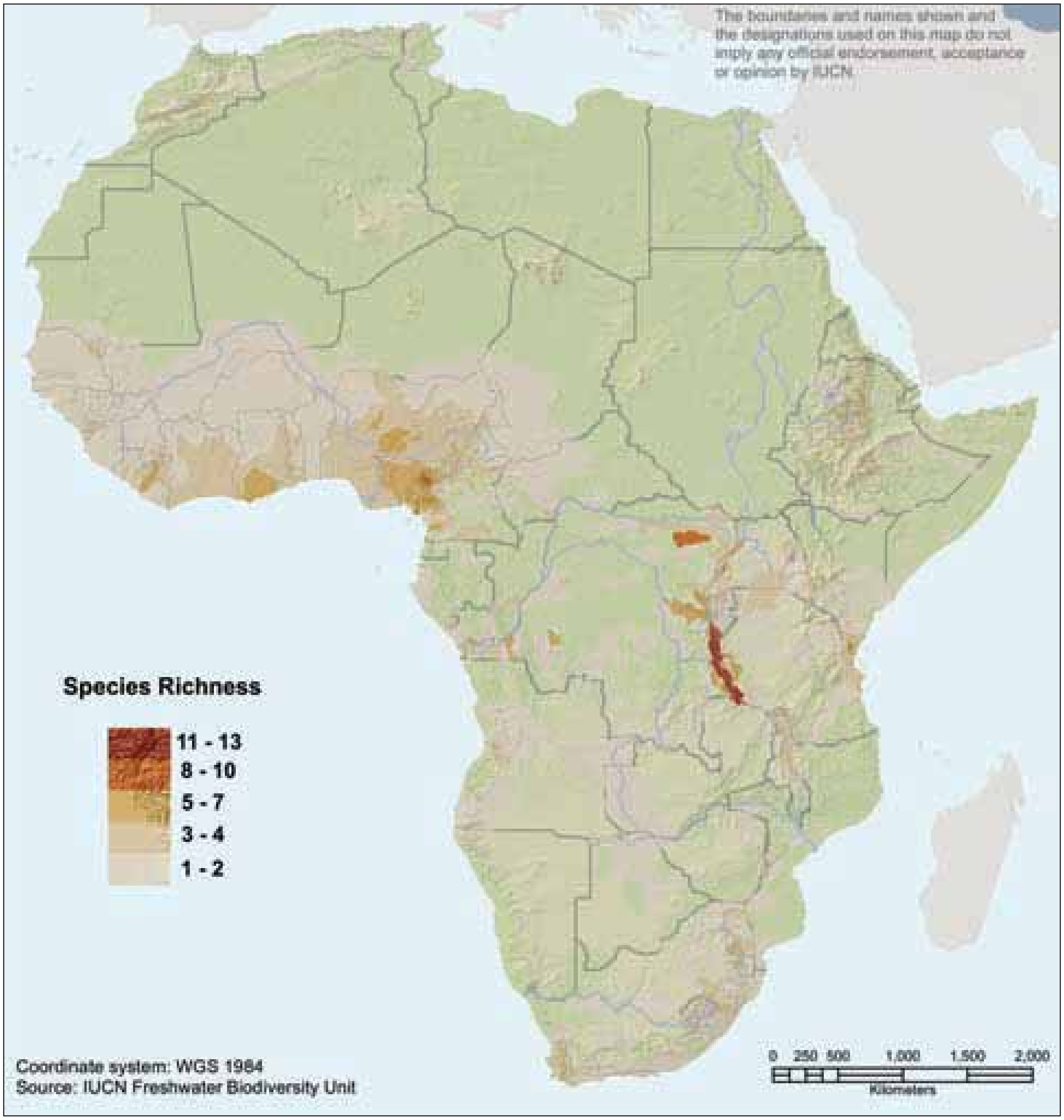
Sudanonautes includes 11 species distributed in western and central Africa, with one species (*S. floweri*) reaching as far east as Uganda and Sudan in eastern Africa (Cumberlidge 1989, 1991, 1993b,c, 1994b, 1995,a,b,c,d, 1999) (Figure 6.2). The largest numbers of *Sudanonautes* species are found in the forested region of south-east Nigeria, south-west Cameroon, and on the island of Bioko. Species of *Sudanonautes* occur in most of the major ecosystems of western and central Africa (tropical rainforest, Guinea and Sudan savanna), and are found in most aquatic habitats (standing water, streams and major rivers) and on land. *Sudanonautes africanus, S. nigeria, S. granulatus, S. orthostylis, S. chavanesii* and *S. faradjensis* occur exclusively in rainforest habitats, while *S. aubryi* and *S. floweri* are found in both rainforest and woodland savanna. *Sudanonautes kagoroensis* occurs only in Guinea savanna in Nigeria, while the semi-terrestrial air-breathing *S. monodi* is the only species found in both Guinea and in dry Sudan savanna. Eight of the 11 species of *Sudanonautes* are widespread throughout western and central Africa, while the other two species, *S. orthostylis* and *S. sangha*, each have a restricted distribution in central Africa (Cumberlidge 1999; Cumberlidge and Boyko 2000).

The freshwater crab Potamon algeriense *(Least Concern) is endemic to the streams and rivers of Morocco, Algeria and Tunisia. It is Least Concern and affected by human induced threats such as habitat loss and degradation linked to population growth and industrial and agrarian development.*
© JEAN-PIERRE BOUDOT

The eight species of *Liberonautes* are all restricted to western Africa; the western limit of the genus is Senegal, the eastern limit is Ghana, and the northern limit is Mali (Cumberlidge 1999; Cumberlidge and Huguet 2003) (Figure 6.2). One species (*L. latidactylus*) is widespread over the entire range of the genus, while the remaining seven species each have a limited distribution in Liberia, Guinea, and Côte d'Ivoire. Species of *Liberonautes* are found mostly in rainforest, although *L. latidactylus* is also found in both Guinea and Sudan savanna zones. Most species are found in aquatic habitats (streams or major rivers) while *L. paludicolis* is more terrestrial and *L. rubigimanus* and *L. nimba* are found at high altitudes, and *L. chaperi* and *L. nanoides* are found exclusively in the major rivers.

The three species of *Potamonemus* occur in only in western and central Africa in the forested highlands of south-east Nigeria, south-west Cameroon, and western Togo (Figure 6.2). These species occur in small streams and probably leave the water at night to feed (Cumberlidge and Clark 1992; Cumberlidge 1993a; 1999). *Globonautes macropus*, the Liberian Tree Hole Crab, occurs only in the western part of the Upper Guinea forest in Liberia and Guinea, and lives in small water reservoirs in tree holes in closed canopy forest (Cumberlidge and Sachs 1991; Cumberlidge 1991, 1996a,b; 1999). The four species of *Afrithelphusa* occur only in the western part of the Upper Guinea forest of western Africa. *Afrithelphusa gerhildae* and *A. monodosa* are both found only in Guinea, while *A. afzelii* and *A. leonensis* are only known from Sierra Leone (Cumberlidge 1987, 1991; 1996a,b; 1999). The two species of *Louisea* are found only in south-west Cameroon in the forested highlands and the moist lowland rainforests (Cumberlidge 1994a, 1999). One of the two species of *Erimetopus* (*E. brazzae)* is relatively widespread in the lower Congo River, while the other species, *E. vandenbrandeni,* is more restricted in its distribution (Cumberlidge and Reed 2004; Cumberlidge *et al*. 2009). All nine species of *Platythelphusa* are endemic to

Figure 6.2. The distribution of freshwater crab species across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.


The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

Lake Tanganyika (Cumberlidge *et al*. 1999; Marijnissen *et al.* 2004), while both species of *Deckenia* are endemic to eastern Africa (Ng *et al*. 1995; Marijnissen *et al.* 2005). One species of *Potamon* (*P. algeriensis*) is found in continental Africa and is endemic to the Mahgreb in northern Africa (Brandis *et al*. 2000; Cumberlidge 2009a).

6.3.2 Threatened species

Some 28% (26 out of 94 species) of African freshwater crabs were assessed as being in one of the three threatened categories (CR, EN, VU) (Cumberlidge *et al*. 2009; Figure 6.1a; Table 6.5). Most of these (20 species) are found in either eastern Africa (11 species) or western Africa (nine species), and there are only three threatened species in central Africa (the most speciose region) and just one in southern Africa (Figure 6.3). There are no threatened species in the northern Africa region. Of the threatened species, 10 were assessed as EN, of which four are from western Africa (*A. monodosa, G. macropus, L. nanoides,* and *L. rubigimanus*), four from eastern Africa (*P. idjwiensis, P. mutandensis, P. platycentron,* and *P. gonocristatus*) and two from central Africa (*L. edeaensis* and *L. balssi*). None of the species from southern Africa was assessed as EN. A further fourteen species were assessed as VU, of which nine are from eastern Africa (*P. choloensis, P. gerdalensis, P. ignestii, P. infravallatus, P. montivagus, P. pilosus, P. raybouldi, P. unisulcatus,* and *P. xiphoidus*), four from western Africa (*P. reidi, P. triangulus, Potamonemus sachsi,* and *L. nimba*), one from southern Africa (*P. lividus*),

Table 6.5. Number of species from each genus in each IUCN Red List Category.

Genus	IUCN RED LIST CATEGORY LC	NT	VU	EN	CR	DD
Potamonautes	4	30	1	24	0	1
Sudanonautes	8	0	0	0	0	3
Platythelphusa	8	0	0	0	0	1
Liberonautes	3	0	1	2	2	0
Afrithelphusa	0	0	0	1	0	3
Potamonemus	1	0	1	0	0	1
Deckenia	0	2	0	0	0	0
Erimetopus	1	0	0	0	0	1
Louisea	0	0	0	2	0	0
Potamon	0	1	0	0	0	0
Globonautes	0	0	0	1	0	0
Total species	**64**	**3**	**14**	**10**	**2**	**27**

and one from central Africa (*P. sachsi*, which is also found in western Africa). Two species (*L. grandbassa* and *L. lugbe*) were assessed as CR, both of which are from western Africa. Just two species, *Deckenia imitatrix* and *D. mitis* (both from eastern Africa) were assessed as NT. The main threats to these species were identified as urban, industrial, and agricultural development and the associated aquatic habitat degradation and pollution.

6.3.3 Restricted range species

Excluding DD species, some 29 species were found to have a restricted range (<20,000km^2) (Table 6.6), and these restricted range species are irregularly distributed throughout Africa (Figure 6.4). The limited distributions of these species are not simply a product of omission errors stemming from a lack of knowledge or under-collection. These species are

Figure 6.3. The distribution of Threatened freshwater crab species across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.

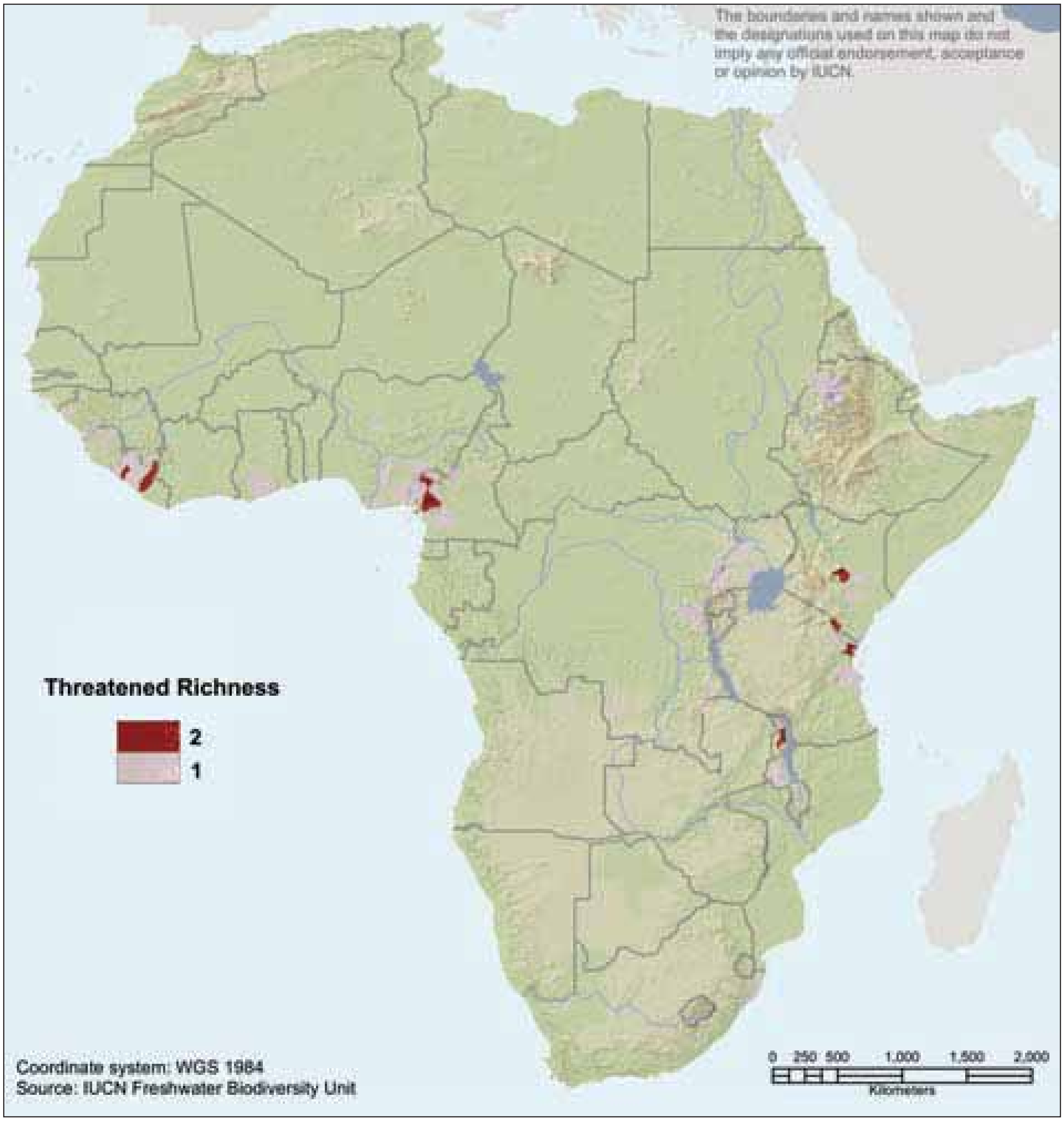


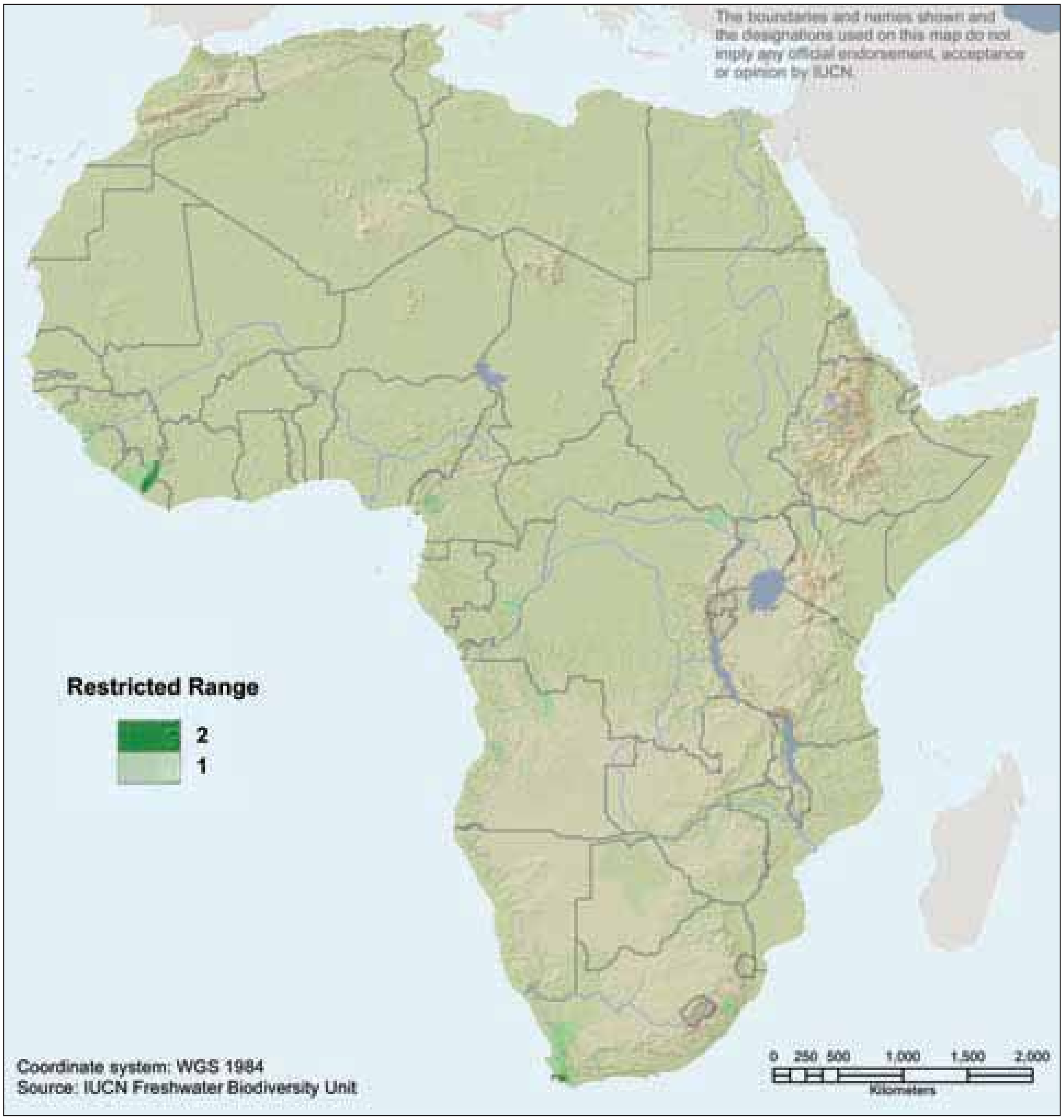
Table 6.6. Species of freshwater crabs of Africa restricted to single river basins, excluding those considered to be Data Deficient. RL = IUCN Red List status; LC = Least Concern; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; Range = an estimation of the species distribution range based on all known specimens; #Loc = Number of discontinuous localities from which the species was collected; PA = found in a protected area; Y = yes, N = no; regions of Africa are noted as N = northern Africa, W = western Africa, C = central Africa, E = eastern Africa, S = southern Africa.

Species	RL Category	Range (km2)	# Loc	PA	Region
Liberonautes grandbassa	CR	~ 100	1	N	W
Liberonautes lugbe	CR	~ 100	1	N	W
Afrithelphusa monodosa	EN	< 5,000	2	N	W
Globonautes macropus	EN	< 5,000	5	N	W
Liberonautes nanoides	EN	< 5,000	1	N	W
Liberonautes rubigimanus	EN	< 20,000	3	Y	W
Louisea edeaensis	EN	< 5,000	2	N	C
Louisea balssi	EN	< 5,000	3	N	C
Potamonautes gonocristatus	EN	< 5,000	<10	N	E
Potamonautes idjiwiensis	EN	< 500	<5	N	E
Potamonautes mutandensis	EN	< 500	<5	N	E
Potamonautes platycentron	EN	< 500	<5	N	E
Erimetopus brazzae	LC	< 20,000	<10	N	C
Potamonautes margaritarius	LC	< 800	<5	N	C
Potamonemus mambilorum	LC	< 20,000	8	N	C
Potamonemus sachsi	VU	< 20,000	<10	N	C
Sudanonautes kagoroensis	LC	< 5,000	7	N	W
Liberonautes nimba	VU	< 20,000	4	Y	W
Potamonautes choloensis	VU	< 20,000	<10	N	E
Potamonautes gerdalensis	VU	< 20,000	<5	N	E
Potamonautes ignestii	VU	< 20,000	<5	N	E
Potamonautes infravallatus	VU	< 20,000	<10	N	E
Potamonautes lividus	VU	< 20,000	<10	Y	S
Potamonautes montivagus	VU	< 20,000	<10	N	E
Potamonautes pilosus	VU	< 20,000	<5	N	E
Potamonautes raybouldi	VU	< 2,000	<10	N	E
Potamonautes reidi	VU	< 20,000	<10	Y	W
Potamonautes triangulus	VU	< 20,000	6	N	W
Potamonautes unisulcatus	VU	< 20,000	<5	N	E
Potamonautes xiphoidus	VU	< 2,000	<5	N	E

specifically recorded, through many surveys conducted over the years, as being absent in localities where they may have been expected to occur. Any disruption to the habitats of these species (either from development, pollution, or political unrest) could have serious consequences, given that 24 of these restricted range species have been assessed as Threatened (Table 6.6). Any species with a restricted range is potentially vulnerable to extreme population fragmentation and could suffer a rapid decline, and even extinction, in a relatively short time should dramatic changes in land-use suddenly affect its habitat. It is therefore of immediate concern that 24 of the 94 crab species that could be assessed are known from distribution ranges of less than 20,000km^2 (and some of these have an estimated range of 5,000km^2 or less). Despite the dangers of population fragmentation, current population levels of stenotopic species assessed as LC or NT were estimated to be stable because they have been

The Blue River Crab Potamonautes lividus *(Vulnerable) is a relatively restricted range species endemic to swamp forests in north-eastern Kwa-Zulu Natal, South Africa.* © WINKS EMMERSON

Figure 6.4. The distribution of freshwater crab species with severely restricted distributional ranges across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

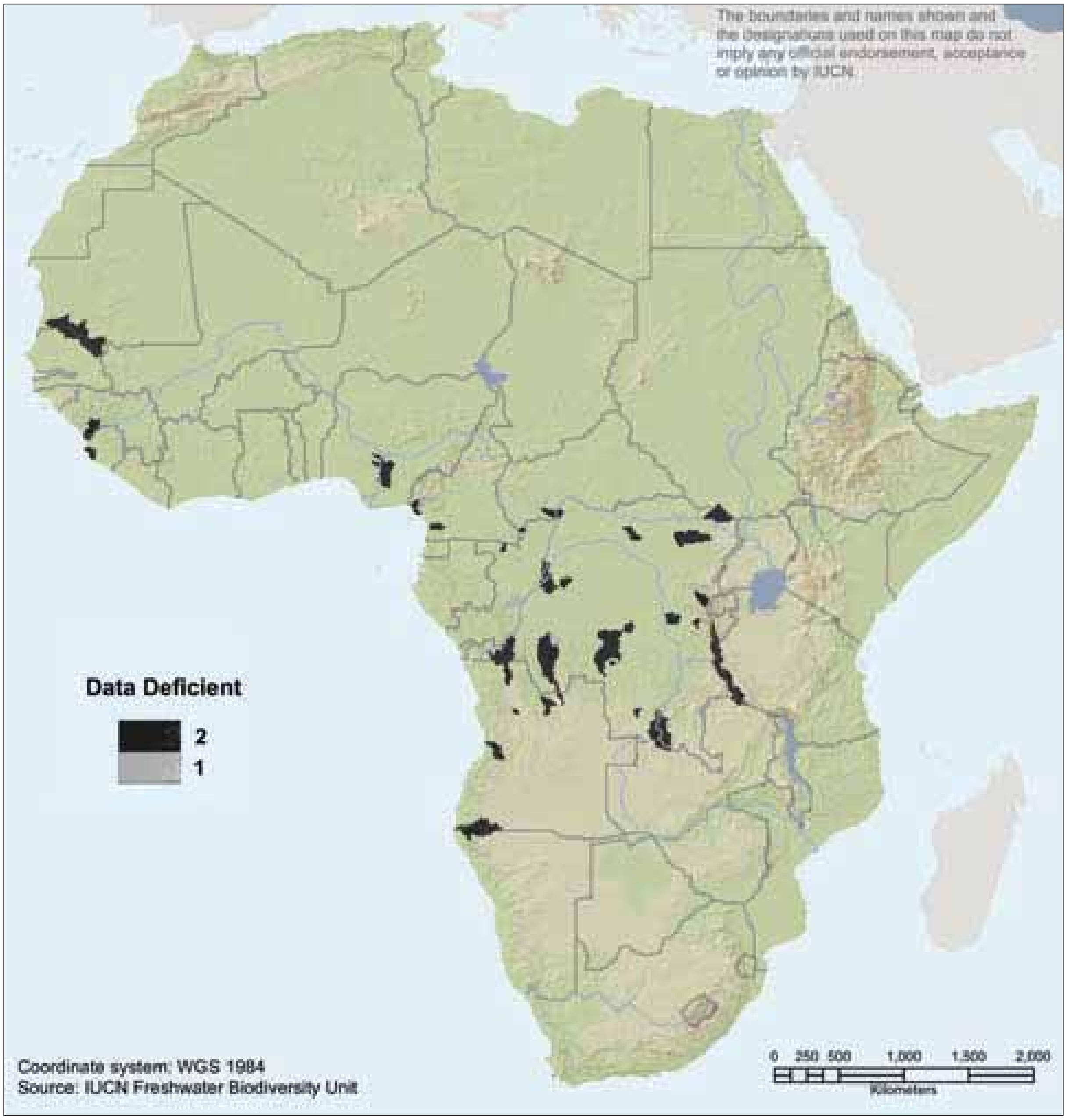
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

collected recently and there are no identifiable immediate threats that would impact the health of those streams and endanger their long-term existence. The reasons for the restricted ranges of the stenotopic species are largely unknown, but it is thought likely that they have speciated relatively recently in response to isolation in a specialised (marginal) habitat or through island colonization, rather than their being the remnant populations of formerly widespread species now in decline (Cumberlidge 2008; Cumberlidge *et al*. 2009).

6.3.4 Data Deficient species

Some 27 of the 94 species (28%) assessed were judged to be DD (Table 6.3, Figure 6.1a). Thirteen of the DD species are from central Africa (*E. vandenbrandeni, P. acristatus, P. adeleae, P. adentatus, P. lueboensis, P. punctatus, P. schubotzi, P. semilunaris, Potamonemus asylos, S. orthostylis* and *S. sangha*), five are from western Africa (*A. afzelii, A. gerhildae, A. leonensis, P. senegalensis,* and *S. nigeria),* six are from eastern Africa (*P. praelongata, P. amalerensis, P. bipartitus, P. didieri, P. rodolphianus,* and *P. rothschildsi*), and three are from southern Africa (*P. kensleyi, P. dubius,* and *P. macrobrachii*) (Figure 6.5). None of the species from northern Africa were found to be DD. The relatively high proportion of DD species reflects the general lack of specimens available, a scarcity that continues to fuel uncertainty about the distribution of these little-known species (Bott 1955; Cumberlidge 1999; Cumberlidge *et al*. 2009). It is of great concern that in many cases these DD species have not been found in recent years. These species have been listed as DD in view of the absence of recent information on their Extent

Figure 6.5. The distribution of Data Deficient freshwater crab species across mainland continental Africa. Species richness = number species per river/lake sub-catchment.



of Occurrence, habitat, ecological requirements, population size, population trends, and long-term threats (Cumberlidge *et al*. 2009). It is also of concern that many of these species are known only from a few individuals collected many years ago, and that no new specimens have been found recently. The DD status is also assigned where there is insufficient information either on their taxonomic distinction (e.g. *E. vandenbrandeni*), or where they are known from either only one or only a few localities (*P. schubotzi, S. orthostylis* and *S. sangha*) and the full range extent is uncertain. It is possible that in some cases the DD status may be due to under-sampling but, as mentioned above, this is not thought to be the case for many of the DD species. Further research is needed on all of these species because, at least, they may prove to be restricted range endemics vulnerable to habitat loss.

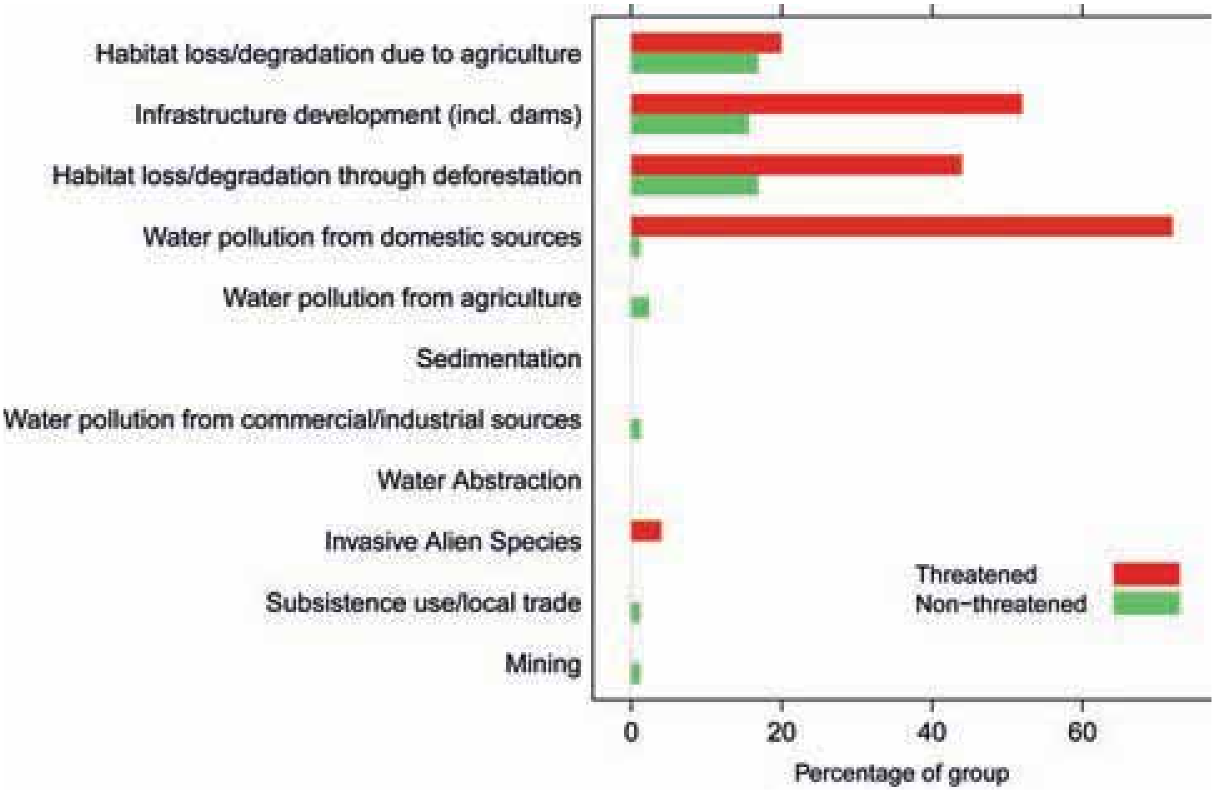
6.4 Major threats

The main threats to African freshwater crabs include water pollution, urban, industrial, and agricultural development, and habitat loss and deforestation resulting from human population and urban and agricultural expansion (Figure 6.6).

6.4.1 Habitat destruction

Threats to the endemic species include habitat destruction in the form of deforestation driven by timber extraction, mining, increasing agriculture, the demands of increasing industrial development, the alteration of fast flowing rivers for the creation of hydroelectric power, and the drainage of wetlands for farming and other uses (Figure

Figure 6.6. Major threats to freshwater crab species in mainland continental Africa.



6.6). Destruction of the forests in many parts of Africa is further exacerbated by logging roads that provide access to remote and previously undisturbed parts of the forest. Other threats that result in deforestation and habitat destruction include political unrest and refugee movements, which are often accompanied by deforestation and soil erosion that contributes environmental damage to freshwater ecosystems. Potential future threats to aquatic communities in rivers associated with cities and towns in Africa include pollution by sewage and industrial and general waste. Some agricultural pesticides used by farmers may prove to be lethal to freshwater crabs, but more research needs to be carried out. All of the above factors combine to increase the overall level of threat to range-restricted endemic species, and the careful management of Africa's forests and water resources in the future will have the biggest impact on their long-term survival.

Deforestation near the village Simpa in western Ghana, in the region of the Upper Guinean Rainforest. © JOHANNES FÖRSTER

6.4.2 Pollution

Pollutants from mining activities for diamonds, gold, bauxite, iron ore, and coltan, and from organic wastes from leaking sewage systems in urban areas in Africa can accumulate in rivers and other freshwater bodies. These pollutants impact freshwater crab populations because they are benthic feeders that ingest other invertebrates and detritus that may contain high levels of contaminants. Immediate attention should be given to the improvement of the water quality in these areas, not least because the bioaccumulation of metals in crabs could pose an increasing problem for the health of people that may eat them.

6.4.3 Natural predators and competition with introduced species

A large number of African predators – including yellow-necked otters, water mongooses, African civets, kites, egrets, herons, giant kingfishers, monitor lizards,

Pollution from urban and domestic sources is a major threat to threatened freshwater crab species. © RANDALL BRUMMETT

and crocodiles – depend on freshwater crabs as vital components of their diet. This is because freshwater crabs are the largest macro-invertebrates in African aquatic ecosystems and form an integral part of the food chain (Cumberlidge *et al*. 2009). The ecological importance of freshwater crabs in food webs in Africa is underlined by the impact of alien North American crayfish (*Procambarus clarkii*) in the rivers of western Kenya, which out-competed and replaced the native crabs. The drop in freshwater crab populations in these systems led to a subsequent decline in clawless otter populations that fed on crabs, most likely due to increased competition with other predators attracted by the abundance of crayfish (Foster and Harper 2006, 2007; Ogada 2006). Recent reports indicate that the highly competitive *Procambarus clarkii* is rapidly spreading elsewhere in Eastern Africa and may even reach Lake Tanganyika, where it could threaten populations of freshwater crabs in the endemic genus *Platythelphusa* (Howard, pers. comm.).

6.4.4 Taxonomic issues

The evolving taxonomy of freshwater crabs may prove to be a challenge for conservation planning in the future because, although a lot of progress has been made recently, some taxa currently assumed to be widespread and common may prove to be complexes of several distinct cryptic taxa, each with specific ecologies and distributions requiring direct conservation action. Three such possibilities are *P. perlatus, P. lirrangensis* and *S. granulatus* that are all currently assessed as LC primarily on account of their wide distributional ranges. However, the distribution patterns of these species consist of many relatively isolated subpopulations that show a great deal of morphological variation, and further investigations may show these species to be species complexes (Daniels *et al*. 2002).

6.5 Research actions required

Significant areas of this vast continent still remain insufficiently explored, and new species of freshwater crabs are sure to be discovered if collection efforts in remote areas are intensified and taxonomic advances become more readily available in the form of identification keys. Although taxonomic knowledge has advanced considerably recently, and museum collections of freshwater crabs have improved, a great deal of work still needs to be done. There is a need for further surveys

The Louisiana Crayfish Procambarus clarkia *has become seriously invasive throughout inland waters in Africa. It is omnivorous and will hunt and compete with the native freshwater crab species.* © GEOFFREY HOWARD to discover new species, refine species distributions, define specific habitat requirements, describe population levels and trends, and identify specific threats to Africa's important and unique freshwater crab fauna. It is vital to the health of these ecosystems that fishery managers consider measures that specifically include the conservation and sustainable use of local populations of river crabs.

6.6. Conservation recommendations

The biology and distribution patterns of the freshwater crabs of Africa are becoming better known, as are the potential threats to their long-term survival. With 27 species (28%) of the 94 non-DD species of freshwater crabs from Africa currently assessed as being at risk of global extinction, the long-term survival of the continent's largely endemic freshwater crab fauna is a concern. Nevertheless, it is hoped that conservation recovery plans for threatened species will be developed for those species identified to be in need of conservation action through this Red List assessment process (Collen *et al*. 2008; Cumberlidge *et al*. 2009).

The conservation of many species of freshwater crabs depends primarily on preservation of areas of natural habitat large enough to maintain water quality. Although it is not yet known exactly how sensitive African freshwater crabs are to polluted or silted waters, there is evidence from Asia that similar crabs are not likely to survive when exposed to these factors (Ng and Yeo 2007). Development, agriculture and exploitation of natural products are necessary realities in developing economies, but compromises may have to be made if freshwater crab species are not to be extirpated in the future. Judicious and careful use of resources is unlikely to cause species extinctions as long as water drainages are not heavily polluted or redirected, some forest and vegetation cover is maintained, and protected areas are respected (Cumberlidge *et al*. 2009).

Common species assessed as LC have a wide distribution in the rivers, wetlands, and mountain streams of the region and, so far, have proved to be relatively tolerant of changes in land-use affecting aquatic ecosystems. It is encouraging that these more adaptable species can persist in the already disturbed and visibly polluted parts of the lowland rivers and streams. The increasing loss of natural vegetation and pollution as a result of land development and agriculture are, however, likely to affect the lowland rivers in the long term, and many of the wholly aquatic species that live there could eventually be vulnerable. Even species assessed as LC could suffer catastrophic declines should there be abrupt changes in land development, hydrology, or pesticide-use regimes. It is not known how the highland taxa will cope with habitat disturbance and pollution but, considering their specialised habitat requirements, it is likely that most of these species will not adapt as readily as the more widespread lowland species. In many countries with a rapid pace of development, often only a fine line separates a species assessed as LC from one assessed as VU, or a VU species from one that is assessed as EN. Development projects could have a dramatic impact on species with specific habitat requirements and a restricted distribution. Conservation activities should therefore be aimed primarily at preserving the integrity of sites and habitats while at the same time closely monitoring key freshwater crab populations.

The 27 species of African freshwater crabs judged to be DD were assigned to this category primarily as the result of insufficient field survey. The scarcity of available specimens is in some parts of the continent due to the long-term poor security situation, and as a result little is known of the habitat needs, population trends, or threats to these species. When more information has been gathered, it is expected that almost all DD species will have a relatively restricted distribution and be endemic to the river basin where they are found.

The conservation assessment of freshwater crabs in Africa (Cumberlidge *et al*. 2009) represents a first step toward the identification of threatened species within the region and toward the development of a conservation strategy for endemic species. The restricted range of many species, together with the on-going human-induced loss of habitat in many parts of the region, are primary causes of concern for the long-term survival of this fauna. Africa's freshwater crabs have a high degree of endemism, with many species living in specialised habitats such as river rapids, lowland marshes, forested highlands, and islands. Additional research is recommended to determine the minimum effective size and design of protected areas for freshwater species such as crabs.

Species in the spotlight

A unique species flock of freshwater crabs in Lake Tanganyika: a model for studies in evolution and extinction

Marijnissen, S.A.E.[1]

Lake Tanganyika is unique among the African Great Lakes in harbouring 10 endemic species of freshwater crabs, including *Potamonautes platynotus* and nine species in the genus *Platythelphusa* which form the only known lacustrine species flock of freshwater crabs in Africa. Platythelphusid crabs have a striking variety of morphological and ecological features making them ideal subjects for studies in adaptive evolution (Cumberlidge *et al.* 1999; Marijnissen *et al.* 2004). For instance, both males and females of *Platythelphusa armata* are armed with one significantly enlarged claw that they use to crush snail shells. *Platythelphusa conculcata* has evolved an extremely flat body that enables it to hide inside narrow crevices underneath rocks and stones. *Platythelphusa maculata*, on the other hand, is a tiny round-bodied species, which is often found taking refuge within empty shells of the large endemic snail *Neothauma tanganyicensis*.

As Africa's oldest (estimated 9-12 million years) and most species diverse lake, Lake Tanganyika is a famed natural laboratory for studying processes of adaptive evolution (e.g. Glor 2010, and references therein). Initially, it was thought that the platythelphusids were a relict group of marine crabs that got trapped in the lake after a recession of the sea and remained unchanged over millions of years (Moore 1903). However, genetic evidence indicates that all Lake Tanganyika crabs are derived from freshwater ancestors.

Potamonautes platynotus *(LC) is primarily aquatic but has been observed to climb out of the water to feed amongst rocks along the lake shore.* © HEINZ BUSCHER

The evolutionary divergence of the platythelpusids coincides with a period of climate change and drought, when the lake levels dropped substantially and Lake Tanganyika was split into separate basins (Cane and Molnar 2001; Marijnissen *et al.* 2006). Other taxa, including several cichlid groups (Duftner *et al.* 2005; Koblmüller *et al.* 2004, 2005, 2007), as well as the *Synodontis* catfish species flock (Day and Wilkinson 2006), diverged during the same period, about 3.3-2.5 million years ago.

The morphological differences between the platythelphusid crabs seem to have evolved within a relatively short period of time. A longstanding hypothesis is that the high levels of species diversity in the African Great Lakes are the result of competition and ecological niche diversification (Schluter 2000). Research on the crabs shows morphological differentiation that could indeed be linked to ecological niche divergence (Marijnissen 2007). However, there is also evidence of considerable ecological versatility among platythelphusid species that coexist in rocky shore areas (Marijnissen *et al.* 2008).

Lake Tanganyika offers a wide diversity of habitats, ranging from cobble beaches, rocky outcrops, and stromatolite reefs, to extensive beds of empty *Neothauma tanganyicensis* shells, sandy beaches and deep layers of mud. Crabs can be found in all these habitats, but the majority of the species are found in the rocky areas. The crabs are important components of the food-web as prey as well as predators. They are included in the diet of numerous endemic fish, such as spiny eels (*Mastacembelus plagiostomus*), bagrid catfish (*Chrysichthys brachynema* and *C. stappersi*), and catfish

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[1] UNDP/GEF Project on Lake Tanganyika, Regional Coordination Unit, c/o Secretariat of the Lake Tanganyika Authority, Route Principale, Kigobe Nord, Bujumura, Burundi

(*Synodontis dhonti*), as well as cichlids (*Boulengerochromis microlepsis* and *Lamprolus lemarii*). The crabs themselves are top invertebrate predators, and their relative abundance can have important implications for organisms lower in the food web, including algae, insect larvae, ostracods, and snails (Marijnissen *et al.* 2008, 2009).

Lake Tanganyika is increasingly under pressure from environmental problems generated by human populations (reviewed in Lowe-McConnell 2003). The majority of species diversity is found in rocky near-shore areas, which are severely impacted by sedimentation resulting from ongoing deforestation in the lake catchment (Cohen *et al.* 2005). Sedimentation can negatively affect aquatic organisms through a range of factors including deterioration of habitat quality and heterogeneity, reduction of food intake, alteration of competitive relationships, decrease of reproductive success, and breakdown of mate recognition systems as water visibility is reduced (Donohue and Molinos 2009). Research in Lake Tanganyika has demonstrated negative impacts of sedimentation on algal productivity as well as on species diversity and densities of ostracods, snails, and fishes (McIntyre *et al.* 2004, and references therein). As crabs are closely linked, either as predators or prey, to many other organisms that are vulnerable to the impacts of increased sedimentation, it is likely that they will respond by shifting their foraging patterns (e.g. McIntyre *et al.* 2004). However, demonstrating and predicting the effects that habitat disruptions will have on the endemic crabs requires taking into account the complexity of the ecosystem. Changes in the species flock may be delayed relative to those of other species as crabs occupy multiple positions within the food web, and a considerable amount of overlap exists among the ecological niches of the different Lake Tanganyika crab species (Marijnissen *et al.* 2008).

“Lake Tanganyika is increasingly under pressure from environmental problems generated by human populations

Lake Tanganyika’s crabs are also threatened by invasion of the non-native Louisiana Crayfish (*Procambarus clarkii*) and the Red Claw Crayfish (*Cherax quadricarinatus*). Both of these crayfish have been introduced to Africa for aquaculture purposes and are spreading rapidly throughout the continent (e.g. Arrignon *et al.* 1990; G. Howard, IUCN, pers. comm.). Considering their current presence in catchments adjacent to Lake Tanganyika, it is likely that these crayfish will move into the lake basin in the near future. Due to their resilience to different environmental circumstances, high dispersal capacity and opportunistic diet, crayfish are capable of causing dramatic biodiversity shifts (e.g. Smart *et al.* 2002; Snyder and Evans 2006; Cruz and Rebelo 2007), and could cause an ecological disaster if they establish themselves in Lake Tanganyika.

Without conservation effort to address environmental threats in the Lake Tanganyika basin, this could lead to the loss of a dynamic endemic species flock that provides unique insight into the evolution and ecological functioning of this unusually diverse lake system.

Platythelphusa armata *(LC) is the largest and most distinctive species in the genus. Juveniles are often found sheltering within the empty shells of the gastropod Neothauma tanganyicense.* © SASKIA MARIJNISSEN

Species in the spotlight

The East African tree hole crab – spectacular adaptation

Bayliss, J[1]

Potamonautes raybouldi, the East African tree hole crab, is a bizarre example of crab evolution. It is exceptionally rare for a crab to live in a tree (an arboreal species), and most of those that do depend on an external water supply – for example, several species of mangrove crab reside in trees for protection but lay their eggs in the sea.

There are over 1,200 species of freshwater crab, out of which only a handful exhibit some kind of arboreal association. The East African tree hole crab is unique in this case. It lives solely in the water filled tree holes formed where a tree branches. When branching occurs it often creates a small hole, or bole, which fills with water. The East African tree hole crab has evolved to occupy this niche, adapting its behaviour and morphology accordingly.

What is remarkable about this species is its natural history. This species has an apparent lack of dependence on any water body, except that collected in tree holes as water run-off from the host tree. What is yet more remarkable is the way in which it obtains the calcium in order to build its exoskeleton (Bayliss 2002). It forages at night or in heavy rain, when it leaves its hole to search for leaf-litter snails. When it find these snails it takes pieces of the snail shell back to its water-filled tree hole and masticates them, which releases the calcium ions into solution. It then ingests the calcium in order to obtain sufficient quantities to build its own exoskeleton. It also eats its old exoskeleton when it moults. As crabs have a hard exoskeleton they need to moult in order to be able to grow and mature. Below the hard exoskeleton is soft tissue that expands over time. Eventually the hard exoskeleton will prevent any further expansion, at which stage the process of moulting (or ecdysis) occurs.

Juvenile crabs in a communal tree hole. © JULIAN BAYLISS

It was first observed and collected by Professor John Raybould in 1966, but it was not until 2004 when it was eventually described under the patronym *Potamonautes raybouldi* (Cumberlidge and Vannini 2004). It is a forest species found in just a few sites in east Africa, such as the East Usambara Mountains in northern Tanzania, and several sites in southern Kenya (e.g. the Shimba Hills).

It has primitive lungs that enable it to spend time outside water, and elongated legs that allow it to climb up and down the tree trunks. The males have one claw that is larger than the other, which is presumably used for display and eventual mating. The females have been found protecting their young (parental care), living in the same tree holes with a brood of juvenile crabs that is presumably their own. These tree holes need cleaning on a regular basis as leaves

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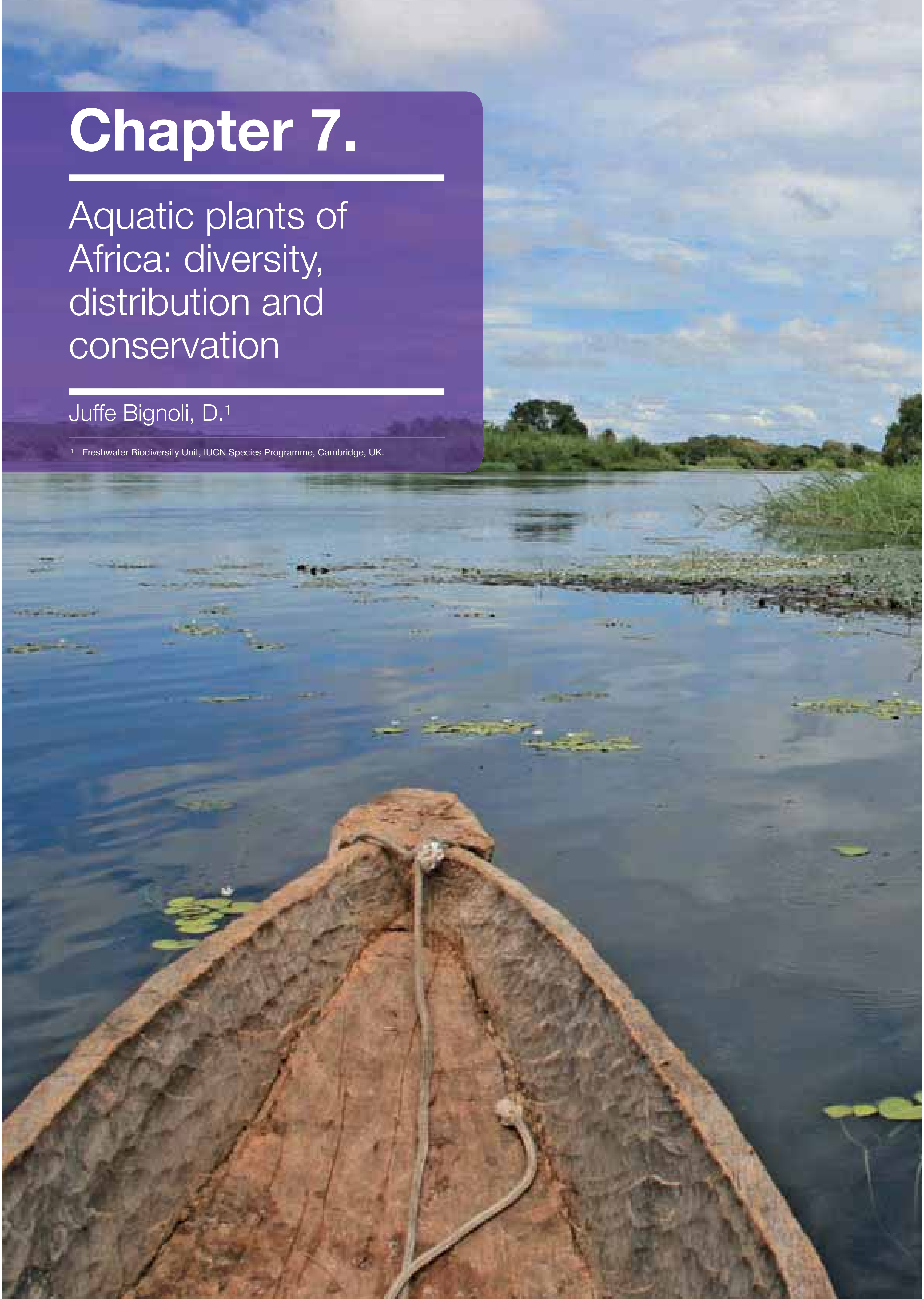
[1] Conservation Science Group, Department of Zoology, University of Cambridge

and other debris accumulate. The juvenile crabs are often too small to cope with moving larger leaves and debris, and would be unable to clean the tree-hole without assistance from the adult female crab. They also need protection from predators, possibly including other crabs.

The local people in the East Usambara Mountains use the water that *Potamonautes raybouldi* lives in as a medicinal potion. They often collect the water, which they call 'Mazi yangodi' (the water from holes with crabs), to give to pregnant women. The water contains calcium, which is required by pregnant women to reduce the risk of pregnancy-induced hypertension (PIH), high blood pressure (pre-eclampsia), and kidney failure, all of which can result in miscarriage. Exactly how and when the connection between the 'crab water' and calcium deficiency in pregnant woman was arrived at is a mystery.

The East African tree hole crab is a spectacular example of adaptation, essentially of an aquatic species not only to a terrestrial environment but also to an arboreal existence. It has lost its dependency on larger water bodies such a streams and rivers, and via the process of natural selection, through trial and error (otherwise known as evolution), it has managed to exploit a niche that crabs have rarely occupied. The further connection between the local population of the East Usambara Mountains and their use of the Mazi Yangodi further highlights this species scenario as an amazing example of natural history and a connection with a human society. However, this story of natural history is not finished. Exactly how the males and females find each other in order to mate in closed canopy, dark forest, when each crab resides in a different tree and they are relatively short-sighted, remains an exciting mystery yet to be solved.

Adult crabs defending their tree hole. © JULIAN BAYLISS



Chapter 7.

Aquatic plants of Africa: diversity, distribution and conservation

Juffe Bignoli, D.[1]

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CONTENTS

MAIN: *Freshwater habitat in the middle Zambezi river near Bovu island.* © JENS KIPPING

RIGHT: Myriophyllum spicatum *(LC^{RG}) is very common in the northern hemisphere and southern Africa.* © SERGE MULLER

RIGHT BELOW: Oxalis dines *(EN) is only known from eight locations in the Western Cape, South Africa. It is found in seasonal pans in clay where it is threatened by heavy grazing and trampling.* © NICK HELME

7.1 Background

Africa's hugely varied climate and diverse geomorphology have led to the evolution of a variety of freshwater ecosystems that include immense coastal and inland river deltas (e.g. the Niger, Nile, and Okavango deltas), globally renowned lakes (e.g., the Great Lakes in eastern Africa, Lake Chad, and the Cameroon crater lakes), and large rivers (e.g., Congo and Zambezi). Freshwater plants play an important role in the creation and maintenance of these habitats. They provide nutrients and structural support to species in the higher trophic levels and, together with phytoplankton, supply the primary production upon which life within these systems depends. Aquatic plants help sustain local livelihoods through direct use (e.g., as foods, fibre, medicines, and structural materials), and provide a wide range of indirect ecosystem services by reducing flood risk, nutrient cycling, removing pollutants and excess nutrients, and trapping sediments (Millennium Ecosystem Assessment 2005).

Although a number of previous studies have examined biogeographic patterns of plant species across continental Africa, the focus has predominantly been on terrestrial groups (e.g., White 1993; Myers *et al.* 2000; Linder 2001; Mutke and Barthlott 2005). No study of aquatic plants has collated information on the conservation status, geographic distribution, and threats for freshwater species. Here we address this information gap by compiling data on the distribution and status of aquatic freshwater plants across the continent. The results of these assessments are available for each of the regions of Africa in a series of reports, each including a chapter on aquatic plants (see Darwall *et al.* 2005; Darwall *et al.* 2009; Smith *et al*. 2009; Garcia *et al*. 2010; Brooks *et al.* 2011). This chapter compiles the findings from these regional assessments and presents a synthesis on the status and distribution of aquatic plants across continental mainland Africa.

A temporary pan in the Kalahari region. © JENS KIPPING

A typical freshwater channel in the Okavango Delta. © JENS KIPPING

Table 7.1. Plant families assessed and the numbers of species assessed within each. Families highlighted in blue are considered to be fully aquatic. The combined data set = 718 species within 65 families.

a) Selected plant families (SPF) = 365 species within 21 families

Family	Species	Family	Species
ACANTHACEAE	45	JUNCACEAE	40
ALISMATACEAE	16	LEMNACEAE	13
APONOGETONACEAE	16	MARSILEACEAE	23
ARACEAE	23	MENYANTHACEAE	11
AZOLLACEAE	2	NYMPHAEACEAE	9
CABOMBACEAE	1	PONTEDERIACEAE	5
CERATOPHYLLACEAE	2	POTAMOGETONACEAE	17
COMPOSITAE	74	SALVINIACEAE	3
HALORAGACEAE	5	TRAPACEAE	1
HYDROCHARITACEAE	35	TYPHACEAE	7
ISOETACEAE	17		

b) Additional plant families = 353 species within 44 families

Family	Species	Family	Species
AMARANTHACEAE	1	LABIATAE	3
AMARYLLIDACEAE	4	LEGUMINOSAE	11
BORAGINACEAE	2	LENTIBULARIACEAE	5
CALLITRICHACEAE	4	LYTHRACEAE	7
CAMPANULACEAE	6	ONAGRACEAE	3
CARYOPHYLLACEAE	4	ORCHIDACEAE	2
COMMELINACEAE	3	OXALIDACEAE	6
CONVOLVULACEAE	1	PALMAE	2
CRASSULACEAE	8	PLANTAGINACEAE	2
CRUCIFERAE	8	PLUMBAGINACEAE	5
CUCURBITACEAE	1	PODOSTEMACEAE	44
CYPERACEAE	129	POLYGONACEAE	3
DROSERACEAE	4	PRIMULACEAE	4
ELATINACEAE	1	RANUNCULACEAE	4
ERIOCAULACEAE	7	RESEDACEAE	1
EUPHORBIACEAE	2	ROSACEAE	1
GENTIANACEAE	1	SCROPHULARIACEAE	16
GRAMINEAE	15	SELAGINELLACEAE	1
GUTTIFERAE	1	TECOPHILAEACEAE	1
HAEMODORACEAE	1	UMBELLIFERAE	9
HYPOXIDACEAE	1	VIOLACEAE	1
IRIDACEAE	5	XYRIDACEAE	13

It was not possible to assess all described aquatic plants in Africa, so the focus was on those families identified by Cook (2004) in his publication *Aquatic and Wetland Plants of Southern Africa*. Two data sets were analysed. First, in order to eliminate any unintended bias in the selection of species within families, we assessed all known aquatic species within each of 21 families. The criteria for selecting these families are explained in Chapter 2. This was called the selected plant families (SPF) data set, which includes 365 species. An additional 353 species from other plant families were also assessed but in these cases it was not possible to assess all species within each family, leaving potential for bias in species selection. Once it became clear that there was no apparent bias in the selection of species, the SPF data set was merged with the 353 additional species, resulting in a combined data set of 718 species. The similarities between findings from the two data sets are presented and discussed below. The compositions of the two data sets are summarised in Table 7.1. All species assessments and distribution maps included in this analysis have been published and are freely available through the IUCN Red List website (www.iucnredlist.org).

Few plant families can be described as being exclusively aquatic, and many apparently aquatic species are somewhat drought-tolerant, being able to survive extended periods of exposure. For this study we follow Cook's (1996) definition of aquatic plants as "vascular plants whose photosynthetically active parts are permanently or, at least, for several months each year, submerged in water or float on the surface of the water". This definition is particularly difficult to apply to families such as Compositae or Cyperaceae, which include species occurring in freshwater systems which can also survive in temporarily dry areas. For this reason all species included in this study may not be considered by some authors as true aquatics.

Problems relating to taxonomy arise as there is currently no single globally accepted classification scheme. Although most institutions agree to follow the taxonomy proposed by the Angiosperm Phylogeny Group (APG) there are still many publications and Herbaria that use, or have used, other systems. This creates problems, particularly when trying to compare studies at higher taxonomic levels (i.e., family). For example, depending on the classification system used, *Trapa natans* is considered to belong to the Trapaceae or Araceae familiy. As the taxonomy of plants is undergoing major revisions at the time of writing, this study follows the taxonomy applied within the IUCN Red List, which will be updated as and when a single taxonomy is agreed.

Global figures for the number of described aquatic vascular plants (angiosperms, gymnosperms, and ferns and allies) vary depending on the author and the definition used for an aquatic plant. Cook (1996) estimated that 1 to 2% of vascular plants may be truly aquatic. On the assumption of a maximum of 315,903 described vascular plants (Chapman 2009), Cook's estimate means that there are between 3,319 and 6,638 aquatic vascular plants globally. Chambers *et al.* (2008) estimate there to be 2,614 species of vascular aquatic macrophytes globally, although their definition of an aquatic plant is more restrictive. The 484 endemic aquatic plants assessed in this study therefore account for between 7 and 18% of all vascular aquatic plants found globally, depending on which global estimate is used. Although not a complete inventory, the information presented here provides the most comprehensive assessment to date of the distribution and conservation status of aquatic plants across mainland continental Africa.

7.2 Overview of the freshwater flora of mainland continental Africa

Continental Africa is known to have one of the most diverse and fascinating floras with more than 40,000 plants described and probably more than 49,000 species in total (Beentje pers. comm. 2010.). Knowledge of Africa's plants is still inconsistent and is yet to benefit from completed floras (Beentje and Smith 2001; Brooks *et al.* 2011). Some regions have been poorly surveyed (e.g. Congo and Central African Republic) while others, such as the Cape Floristic region, are well studied.

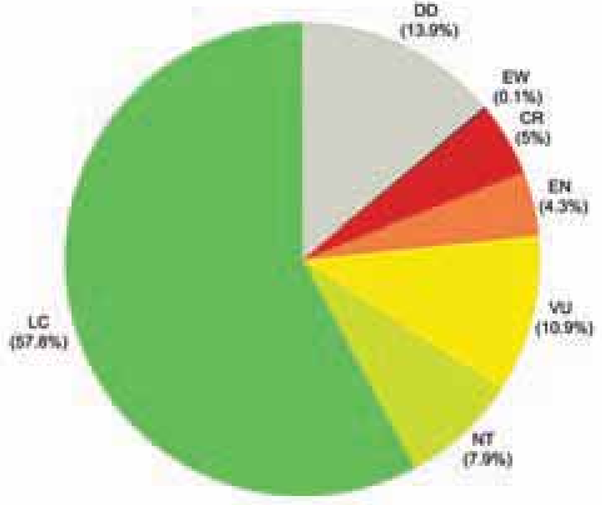
Although a common approach to plant surveys is to systematically describe all species within a specific region, a few studies focus specifically on aquatic plants. For example, Cook (2004), described the aquatic and wetland plants of southern Africa, and this work formed a central basis for IUCN's southern Africa regional report (Darwall *et al*. 2009). Similarly, much work on aquatic plants has been conducted in the Zambezi basin (e.g., Timberlake *et. al* 2000*)*. Chambers *et al.* (2008) reviewed the number and distribution of aquatic vascular plants at the global scale, but their analysis is restricted to large bio-geographic realms and so lacks the spatial resolution required for identifying patterns of distribution within Africa.

Aquatic plants do not tend to form discrete taxonomic groups, with many families including both aquatic and terrestrial species, but it is accepted that aquatic angiosperms have evolved from ancestors within terrestrial angiosperms (Cook 1996). Whether or not we should therefore expect to see a similarity between terrestrial and aquatic species distributions is not clear. We should not, however, assume aquatic plants will, by default, be

The Makoge lake in Tanzania. © GITA KASTHALA.

effectively captured within conservation plans based purely on knowledge of terrestrial species distributions. Nevertheless, it is a useful exercise to examine what is known for terrestrial species. There are many studies from which we can extract information on terrestrial plant distribution patterns and vegetation types across Africa (e.g., White 1983; White 1993; Linder 2001; Kuper *et al.* 2004; Kier *et al.* 2005; Beentje *et al.* 1994). Myers *et al.* (2000) also used plant distributions as a key component within the process for delineating 21 global Biodiversity Hotspots. Linder (2001) studied patterns of plant diversity and endemism for a total of 1,818 species in sub-Saharan tropical Africa and concluded that, while overall species richness patterns are related to precipitation levels, patterns of endemism are more closely related to paleoclimatic fluctuations (changes in climate throughout Africa's evolutionary history). Some examples of species rich areas identified include: the mountain ranges of Morocco, Algeria and Tunisia (High Atlas and Middle Atlas mountain ranges); Upper Guinea (Sierra Leone to Ghana), Lower Guinea (Nigeria, Cameroon, Equatorial Guinea and Gabon); the East African coastal strip (Tanzania and Kenya); the Zambezi-Congo catchment; the Lake Kivu catchment in eastern Congo, Rwanda and Burundi; the eastern highlands of Zimbabwe and the adjacent mountains of Mozambique; and the Cape Floristic Region. Commonly cited centres of endemism include the High Atlas and Middle Atlas mountain ranges; Upper Guinea and Lower Guinea; the Zambezi-Congo catchment; the East African coastal strip; the Lake Kivu catchment; Cape Floristic Region; and Huilla in southern Angola (White 1993; Beentje *et al.* 1994; Linder 2001).

Figure 7.1. The proportion (%) of aquatic plant species in each regional IUCN Red List Category in mainland continental Africa.



7.3 Conservation Status

Assessments of species extinction risk were conducted following the IUCN Guidelines on application of the IUCN Red List Categories and Criteria at national or regional levels (IUCN 2003), noting that the regional Red List status of any species endemic to mainland continental Africa will correspond to its global Red List Status. Those species not native to the region, or with less than 5% of their global distribution within Africa, were not included within the analyses. Section 7.3.1 presents results for all species assessed, whereas Section 7.3.2 shows the results for only those species endemic to continental Africa.

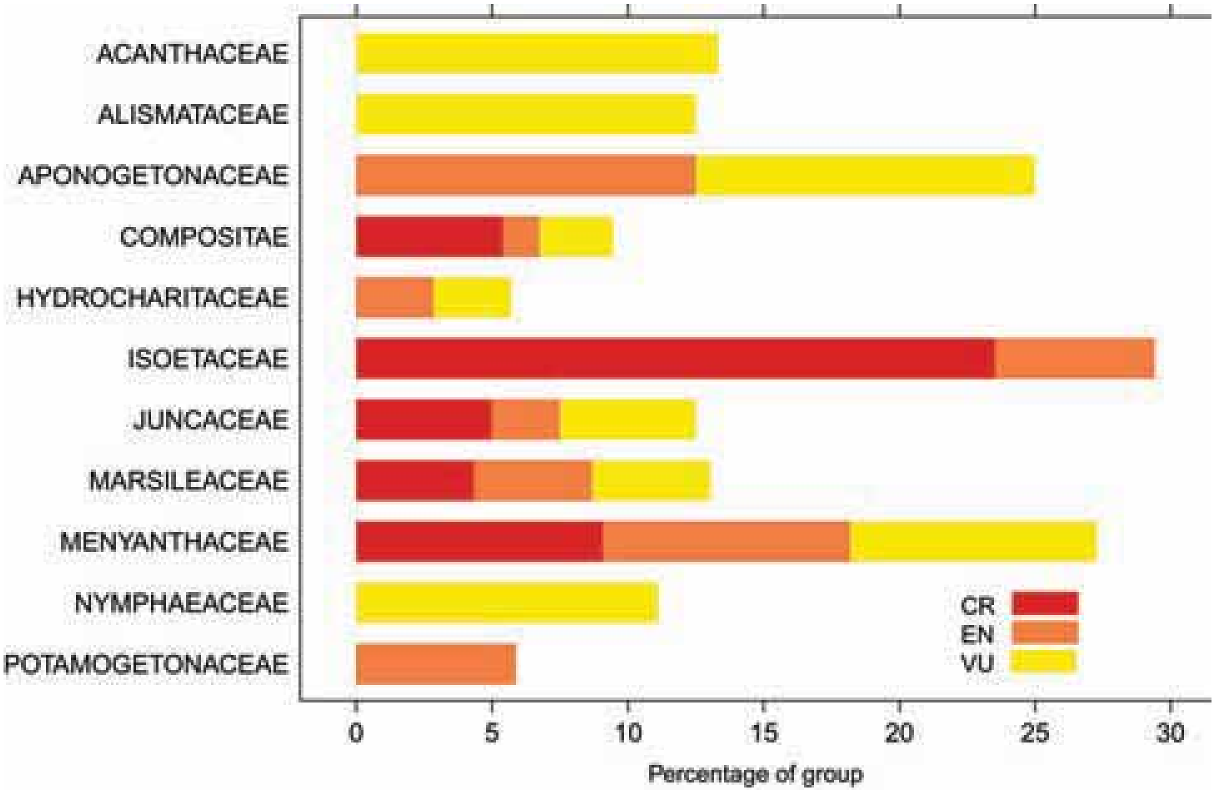
7.3.1 All species

Fifty eight percent of all species were assessed as Least Concern (Figure 7.1 and Table 7.2), being relatively common and widespread with no major threats identified as likely to impact their overall population viability. This represents a positive finding given the importance of plant species to the function and stability of freshwater ecosystems. Some species, such as *Prionium serratum*, assessed as Least Concern, are noted for their importance as ecosystem engineers creating new habitat for many other species (see Species in the spotlight – **the habitat creator**, this volume).

Table 7.2. Numbers of species in each regional IUCN Red List Category, as applied to mainland continental Africa.

	IUCN Regional Red List Category	Number of species	Number of regional endemics
Threatened Categories	Extinct In The Wild	1	1
	Critically Endangered (CR)	36	32
	Endangered (EN)	31	23
	Vulnerable (VU)	78	69
	Near Threatened (NT)	57	41
	Least Concern (LC)	415	238
	Data Deficient (DD)	100	80
Total		**718**	**484**

Figure 7.2. The proportion (%) of aquatic plant species within the fully assessed families in each regional IUCN Red List Category in mainland continental Africa.



One in five species (20%) are assigned to one of the IUCN Red List threatened categories (Table 7.2), with large regional differences in the level of threat. In southern Africa, for example, only 5% of species are considered threatened. By contrast, 24% of species in northern Africa are considered to be regionally threatened.

In the global context this level of threat is consistent with other findings. In Ecuador, for example, Valencia *et al.* (2000) concluded that 72% of endemic species and 19% of the total native flora are threatened. Globally, less than 3% of known plant species have been assessed using the IUCN Red List Categories and Criteria. Of these, 70% are threatened (Vie *et al.* 2008), but it has been suggested that this high level of threat is a reflection of bias amongst the

Macropodiella pellucida *(VU) is endemic to Cameroon and is restricted to rivers in the coastal area of the south-west provinces. It has been assessed as Vulnerable due to its restricted distribution and threats from water pollution.* © JEAN-PAUL GHOGUE

Winklerella dichotoma *(CR) is a Cameroon endemic. It is known from only one site where it is threatened by an existing dam.* © JEAN-PAUL GHOGUE

Dicraeanthus africanus *(LC) is endemic to central Africa. This plant is very specialized in term of ecology as it is only found in fast flowing waters such as rapids and waterfalls.* © JEAN-PAUL GHOGUE

botanical community to focus primarily on species that were *a priori* expected to be threatened (Vie *et al*. 2008). A recent report carried out by Royal Botanical Gardens Kew, the Natural History Museum of London, and IUCN, using a sampled approach, provides a more balanced picture concluding that 22% of plants are globally threatened (for more information see RBG 2010).

There are significant differences in the numbers of threatened species within those plant families where all aquatic species were assessed. High numbers of threatened species are found within the families Aponogetonaceae, Menyanthaceae, and Isoetaceae (Figure 7.2). Aponogetonaceae is a family of fully aquatic species, mainly endemic to Africa, found in seasonal and temporal marshes and pools. They are valued locally for food and for decorative purposes. As an example, *Aponogeton azureus* (VU) is a threatened species only known from a single locality in northern Namibia, where it is threatened due to harvesting and grazing pressures. Species of Menyanthaceae are found in still waters and have an important economic value through their use as ornamental species, mainly in aquariums and water gardens (e.g. *Nymphoides* spp.). Finally, the Isoetaceae, commonly referred to as quillworts, can grow submerged, emergent or seasonally submerged. On the basis of a number of unusual features, quillworts are considered by some botanists to be the last remnants of ancient trees from the early Triassic. Some species of quillwort are useful indicators of declining water quality being highly intolerant to nutrient enrichment (Cook 2004).

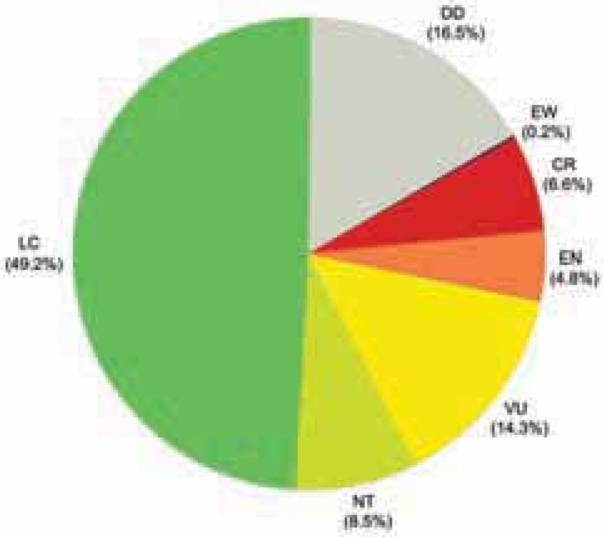
Although all aquatic species within the family Podostemaceae have not yet been assessed, it has the highest number of threatened species with 27 of the 44 assessed species threatened. With 86 species of Podostemaceae in continental Africa (Rutishauser *et al.* 2007), this means at least 31% of species within this family are at risk of extinction. Podostemaceae is the largest exclusively aquatic family of angiosperms (Chambers *et al* 2008), requiring seasonal inundation, clean water, and high light intensity (Philbrick 2004). Globally, most of the Podostemaceae are endemic to small geographic areas. Across Africa, species are restricted to the centre and west of the continent and often have a limited distribution occurring in a single cataract or river (Cook 1996). Such localised distributions make these species more vulnerable to habitat degradation and alterations to river hydrology caused by water abstraction, impoundment and sedimentation. *Ledermanniella keayi*, for example, has only been found at a single site on Mount Oku and the Ijim Ridge area in Cameroon. It has been listed as Critically Endangered as a result of habitat degradation associated with water abstraction, modifications to the river's flow regime, and upstream agricultural development. Other examples of restricted range threatened species in this family include *Winklerella dichotoma* (CR), *Macropodiella pellucida* (EN), and *Ledermanniella kamerunensis* (VU).

Fourteen percent of all species assessed are listed as Data Deficient (DD). The DD category is assigned when there is insufficient information to assess the conservation status of the species and, as such, does not indicate that

Aponogeton dystachyos *(LC), known as Cape-pondweed is endemic to South Africa. The buds and flowers of this plant are widely used for human consumption. For example, the recipe of Waterblommetjiebredie, a renowned local dish, includes Cape-pondweed.* © CRAIG HILTON-TAYLOR

the species is not at risk. Many of these species may prove to be threatened when these gaps in knowledge are resolved. Most of the plants listed as DD are rare species for which the distribution range is unclear or which suffer from taxonomic uncertainty.

Figure 7.3. The proportion (%) of endemic aquatic plant species in each regional IUCN Red List Category in mainland continental Africa.



7.3.2 Endemic species

Four hundred and eighty four of the 718 species assessed are endemic to mainland continental Africa. It is important to reiterate that in the case of these endemic species, their risk of extinction within Africa is equivalent to their global risk of extinction. Some have very restricted ranges, often being confined to a single area or site, such as *Isoetes nigroreticulata* (CR)*,* which is currently only known from one seasonal pool in southern Kenya. Others, such as *Lagarosiphon cordofanus* (LC), are widespread throughout Africa. Historically, most conservation efforts and studies have focused on endemic species that represent local uniqueness and in some cases are linked to regional traditions (see Section 7.6.).

Of the endemic species assessed, 49% are listed as Least Concern, while a quarter fall into one of the threatened categories (CR, EN, VU), and 17% were considered Date Deficient (Figure 7.3). The proportion of threatened endemic species (26%) is higher than that for all species assessed (20%). This means that one in four aquatic plants native to Africa are at risk of becoming globally extinct. Species such as *Cadiscus aquaticus* (endemic to South Africa), *Drosera insolita* (endemic to D. R. Congo), *Cyperus microumbellatus* (endemic to Kenya), and *Ledermanniella batangesis* (endemic to a single site in Cameroon) are all listed as Critically Endangered, and are just a few examples of very restricted range species in need of targeted conservation actions if they are to survive in the long-term.

Data Deficient species are a priority for further research, as those later found to be threatened can be identified and action taken to ensure their survival. For example, *Ottelia brachyphylla* (Hydrocharitaceae) has only been recorded once in Sudan and there is no reliable information on current threats or its distribution. Further research will confirm if the species is at risk of extinction or whether other sub-populations exist. With such high levels of data deficiency, the true proportion of threatened species could rise to 40% if all DD species are later found to be threatened.

7.4 Extirpated species

For a species to be assessed as Extinct (or Regionally Extinct) there must be no reasonable doubt that the last individual has died. Until extinction can be confirmed species may be listed Data Deficient or Critically Endangered (Possibly Extinct). Taking this into account, only one aquatic plant from the selected families has been listed as Extinct in the Wild. Originally found in a single site in Rwanda, *Nymphaea thermarum* (Nymphaceae) (EW) now only survives due to *ex-situ* conservation efforts – its story is given in **Species in the spotlight – A small wonder of nature saved from extinction**, this volume.

7.5 Patterns of species richness

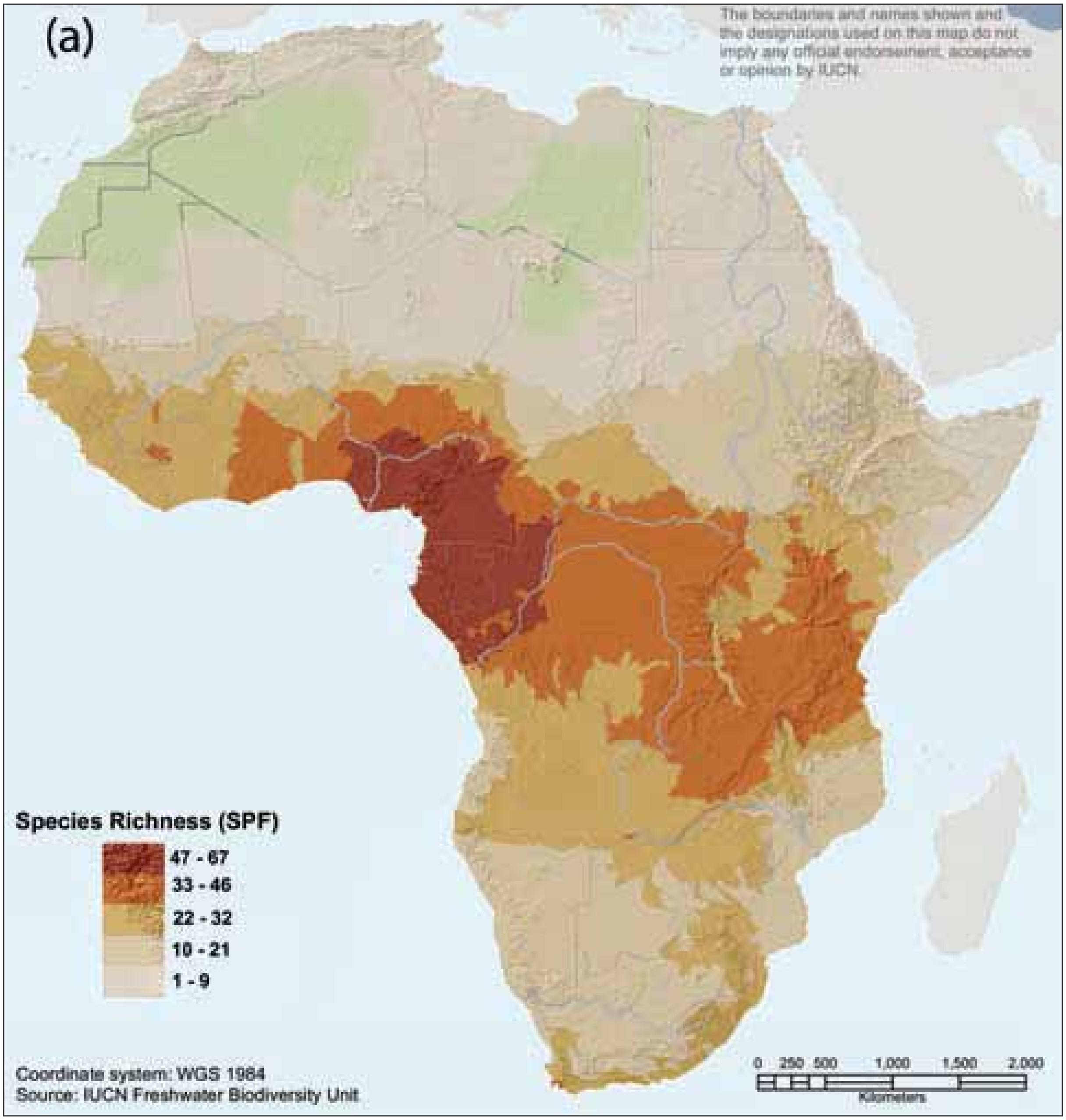
Species distributions are mapped where possible to river sub-catchments. However, in particular for widespread Least Concern and Data Deficient species, distribution data were unavailable at the catchment scale, and in these case species were mapped to country boundaries. This relatively course resolution of spatial data is the best information that could be obtained for countries such as Angola, D. R. Congo, and Congo where data are often scarce and unspecific. With this limitation in mind, the spatial overview presented below provides the most complete picture to date of the distribution of aquatic plant species throughout continental Africa. It is, however, also clear that further research is required to close the information gap for many species.

7.5.1 All assessed species

Species richness patterns for species within the selected plants families (SPF) (Figure 7.4a) and the complete data set for all assessed species (Figure 7.4b) reveal minimal differences between the overall patterns of species richness. This confirms that little, if any, bias is introduced through inclusion of species from families for which not all aquatic species have yet been mapped and assessed. The pooling of all species within the analysis therefore seems justified. The only notable difference between the two richness maps lies in the mountain ranges adjacent

Nymphaea and Nymphoides spp. in the Okavango Delta. © WILLIAM DARWALL

Figure 7.4. The distribution of aquatic plant species across mainland continental Africa for: a) Selected plant families (SPF); and b) all species. Species richness = number of species per river/lake sub-catchment.

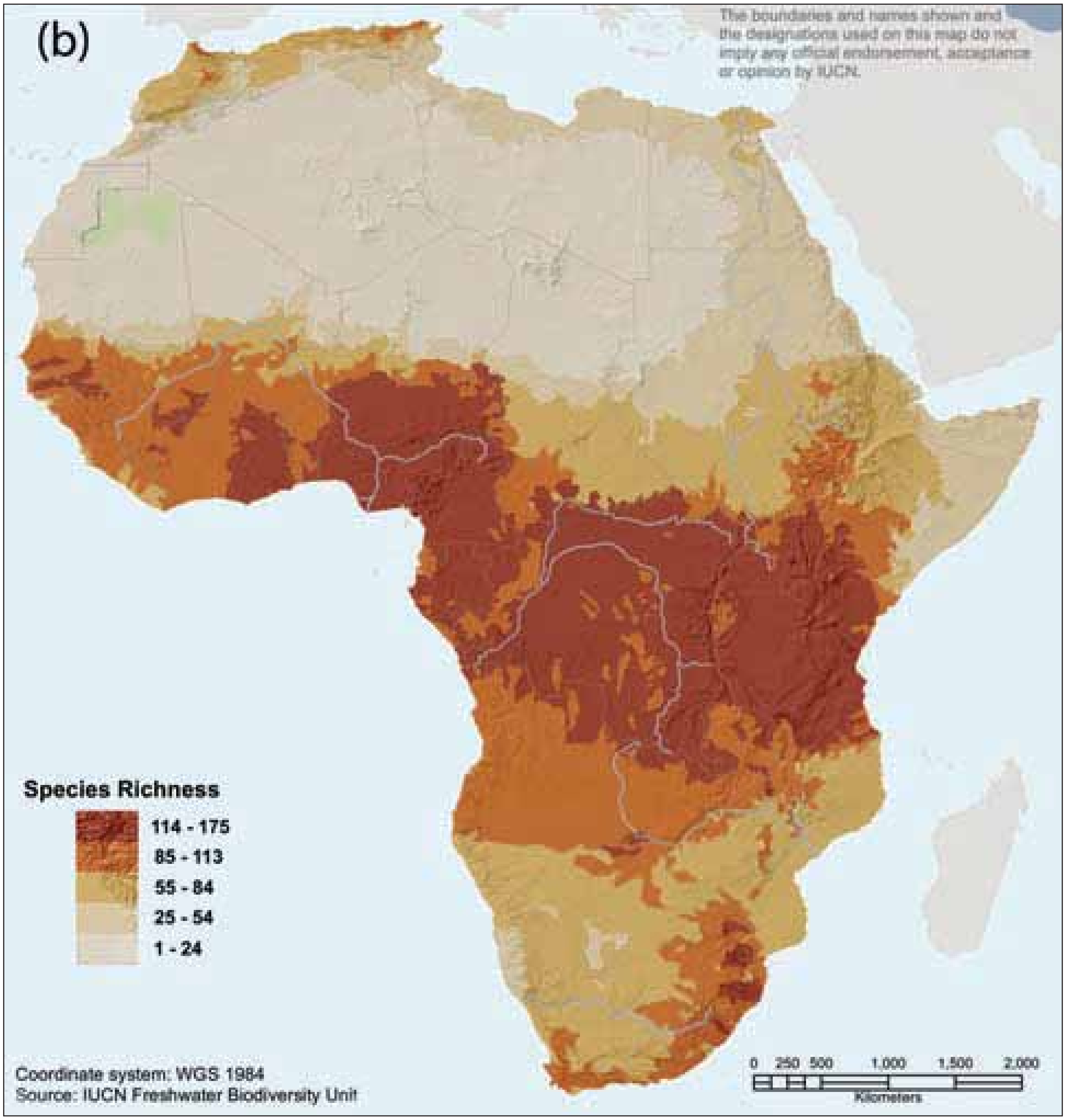


Trapa Natans *(LC), also known as water chestnut, is widespread throughout many countries across Africa.* © WILLIAM DARWALL

to the rift lakes in western D. R. Congo, including Burundi and Rwanda, which show an area of significant richness that is only revealed when all species are pooled (Figure 7.4b). This area has been highlighted by Linder (2001) as the Kivu centre due to its high species diversity and high levels of endemism.

The greatest density of species follows a broad band across the tropics, with high numbers of species observed in the Lower Guinea and eastern Africa in particular. A similar pattern has been pointed out by Linder (2001), who argues that precipitation patterns provide a good indicator for plant species richness.

The highest density of species is seen within an area extending from Mount Cameroon to the western equatorial



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

crater lakes, where individual sub-catchments are recorded to contain up to 175 species. Other notable regions of high species richness include the Lower Niger Delta in Nigeria, Equatorial Guinea, Gabon and Congo. In eastern Africa an area of high species richness extends across the great rift lakes and river systems. Finally, the Lake Bangweulu basin, Lake Mweru basin and southern D. R. Congo are also species rich. A number of these regions were also highlighted by Linder (2001).

Although less diverse than the equatorial regions, the Cape fold area in South Africa, KwaZulu-Natal, Mpumalanga and Limpopo, also support notably high numbers of species. In northern Africa, the Atlantic and Mediterranean coasts of Morocco, Algeria and Tunisia, and the Nile represent a globally renowned centre of biodiversity known as the Mediterranean Biodiversity Hotspot (Myers *et al.* 2000), where the intersection of Eurasian and African flora and fauna has created an area of exceptionally high biodiversity.

Species richness in the Upper Guinea area, which includes Liberia, Sierra Leone, Guinea, and Congo, and northern Angola, especially on the borders with D. R. Congo and Zambia, was lower than expected. This most likely reflects data deficiency rather than a true biogeographic pattern.

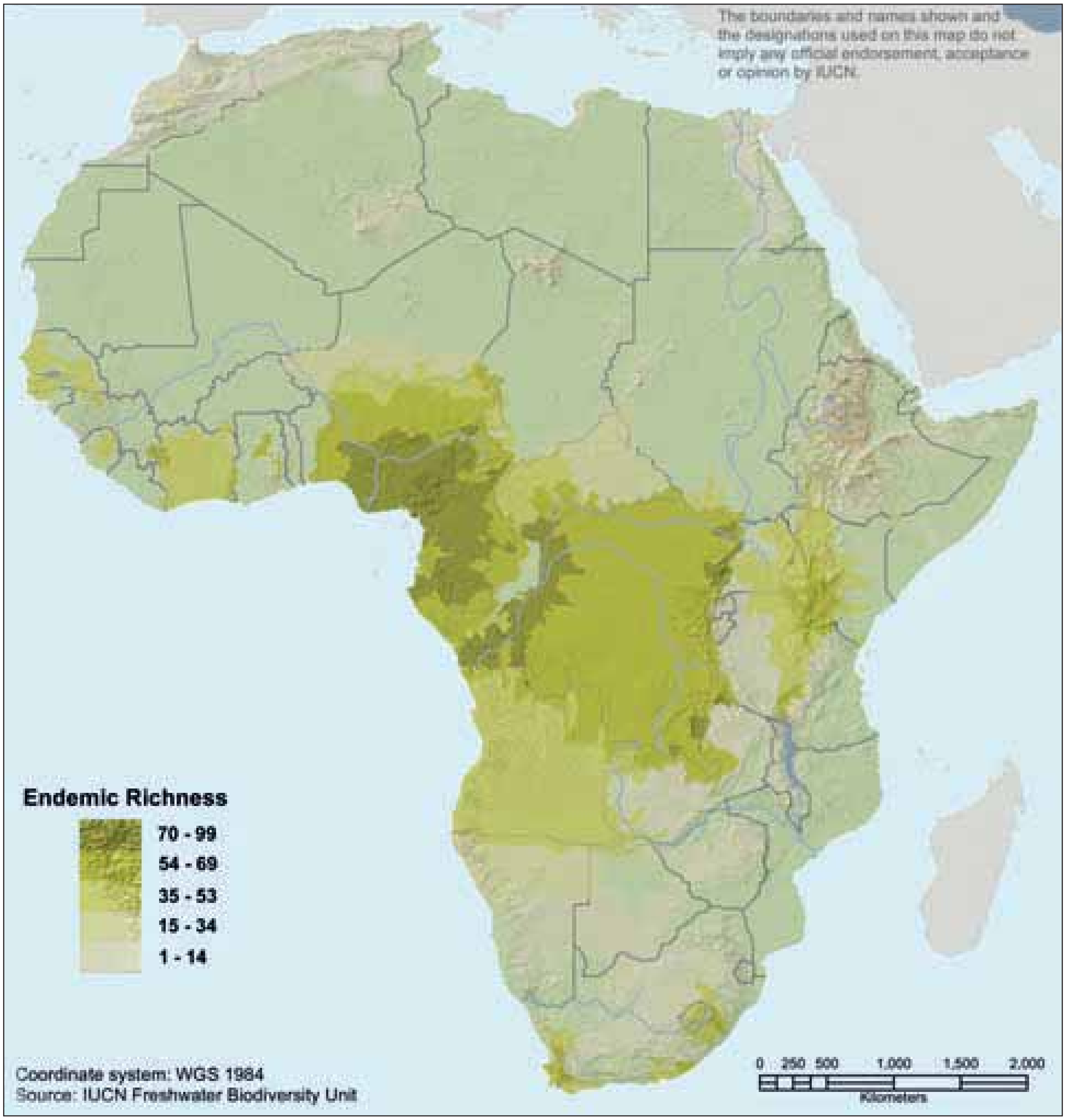
7.5.2 Continental endemic species

Centres of species endemism are, as for overall species richness, in the southern Gulf of Guinea drainages (Mount Cameroon, western Cameroon highlands) and the Lower

Cadiscus aquaticus *(CR) is endemic to the Western Cape between Groenekloof and Saldanha Bay. It is restricted to vernal pools where it is threatened through overgrazing by livestock, infilling of wetlands, invasion by alien grasses and eutrophication.* © NICK HELME

Cotula myriophylloides *(CR) is endemic to the Cape Peninsula in the Western Cape, South Africa. This species had not been collected for the past 30 years and was thought possibly extinct until this population was discovered at Kleinmond in October 2008. Its main threats are urbanisation and invasive alien species.* © NICK HELME

Figure 7.5. The distribution of aquatic plant species endemic to mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

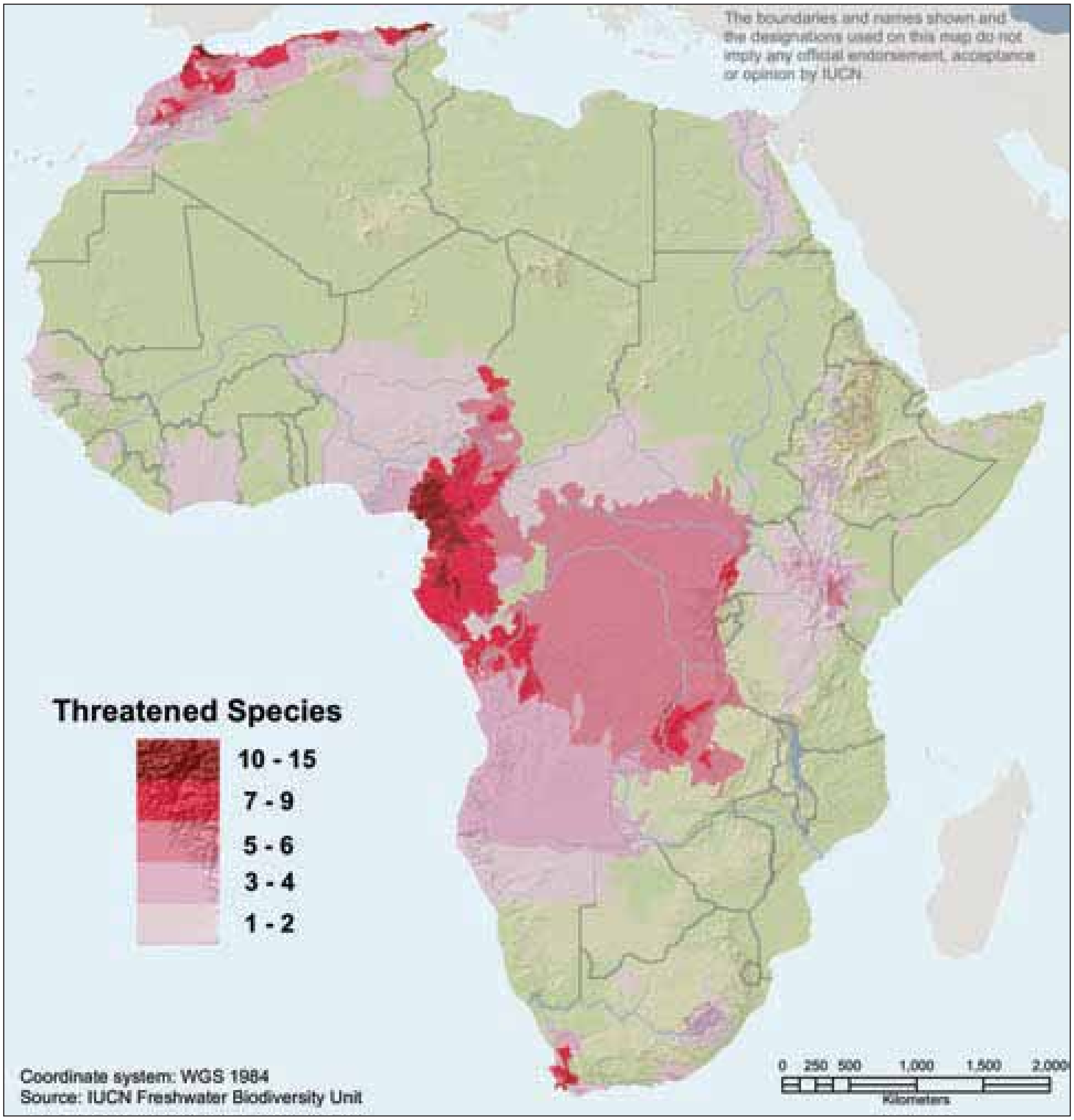
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

Niger Delta (Figure 7.5). Species of Podostemaceae, such as *Ledermanniella cristata* (VU), *Macropodiella pellucida* (EN) and *Saxicolella laciniata* (VU) are found in this area, where they face threats from tourism and water pollution. The overall pattern of endemism agrees with that reported by Linder (2001) and White (1993), who identified centres of endemism corresponding well with those shown in Figure 7.5. Examples of these are the Lower and Upper Guinea Centres, the Cape Floristic Region (Linder 2001) and the Mediterranean and the Guineo-Congolian Regional Centres of endemism (White 1983).

As mentioned above, northern Africa is an important regional centre of endemism (White 1993) and is part of the Mediterranean Biodiversity Hotspot (Myers *et al.* 2000). High numbers of endemic aquatic plants are found across the High Atlas and Middle Atlas mountain ranges, and within the upper Nile Delta. Examples of species endemic to the area include *Juncus maroccanus* (CR), *Pulicaria filaginoides* (CR), *Epilobium numidicum* (CR), and the orchid *Serapias stenopetala* (CR), all of which are threatened by habitat loss and fragmentation. This is a common threat to species in northern Africa, representing an unfortunate by-product of human development that has left less than 5% of the hotspot area intact today.

Another important area of species endemism extends from north-east of Lake Victoria across the southern lakes of Kenya and the Eastern Rift to Lake Tanganyika. This area coincides with part of the Somali-Massai and Afromontane centres of plant endemism also described by White (1993). The Okavango delta, highlands of Lesotho,

Figure 7.6. The distribution of threatened species of aquatic plants across mainland continental Africa. Species richness = number of species per river/lake sub-catchment.



and the border zone of north Angola and south-west D. R. Congo also hold important numbers of endemic species.

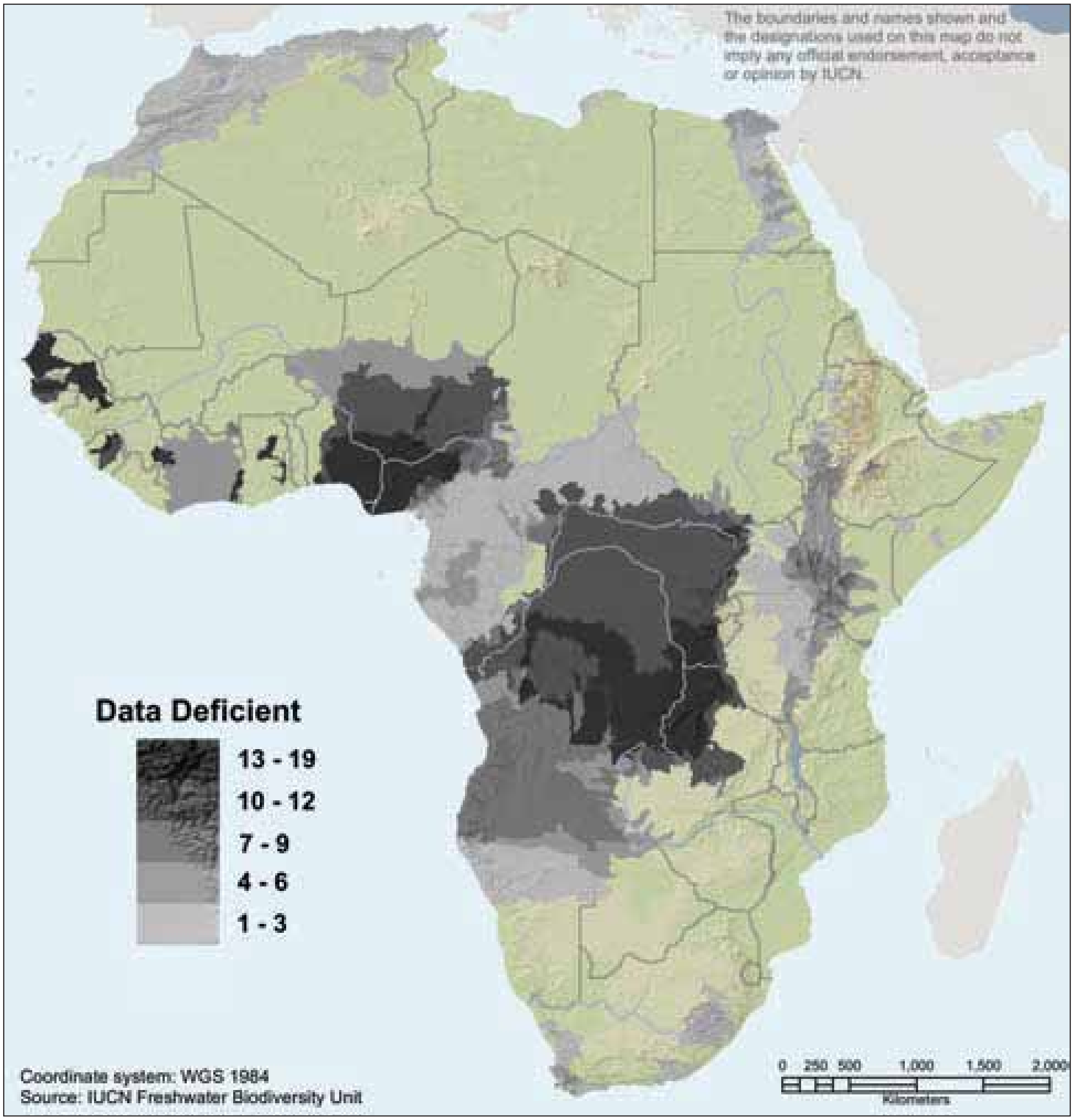
Apparent low numbers of species in the Congo River system and south of Lake Victoria may be an artefact of the lack of information for these areas. Linder also identified the Congo-Zambezi watershed as a regional centre of endemism, but this was not confirmed by the available data in this current project.

7.5.3 Threatened species

Areas with highest numbers of threatened species largely coincide with those already identified as centres of species richness and endemism. High numbers of threatened species are found in the western equatorial crater lakes, Mount Cameroon, southern Gulf of Guinea drainages, the Ogooue-Nyanga-Kouilou-Niari and Lower Niger-Beune ecoregions (Figure 7.6). Although there are many protected areas in this region, major threats to freshwater systems and aquatic plants, such as deforestation leading to siltation and changes in flow regimes, and pollution from mining are still prevalent. Such impacts are of concern for species such as *Acanthus latisepalus* (VU) and *Dicraeanthus zehnderi* (CR), both of which are restricted to these areas.

In northern Africa the highest numbers of threatened species are found in those areas where drainage of wetlands for agriculture and coastal development are most intense (Rhazi and Grillas 2010). These include the coastal

Figure 7.7. The distribution of Data Deficient species of aquatic plants across mainland continental Africa. Species richness = number of species per river/lake sub-catchment. Note: not all species could be mapped due to lack of information on their geographic ranges.



Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

plain and the Rif, Tell Atlas and Middle Atlas mountain ranges in Morocco and Algeria, and the Mediterranean coast of Tunisia and Algeria. *Pulicaria filaginoides* (CR) is only known from one location on the Mediterranean coast of Algeria, where it is threatened by urbanization.

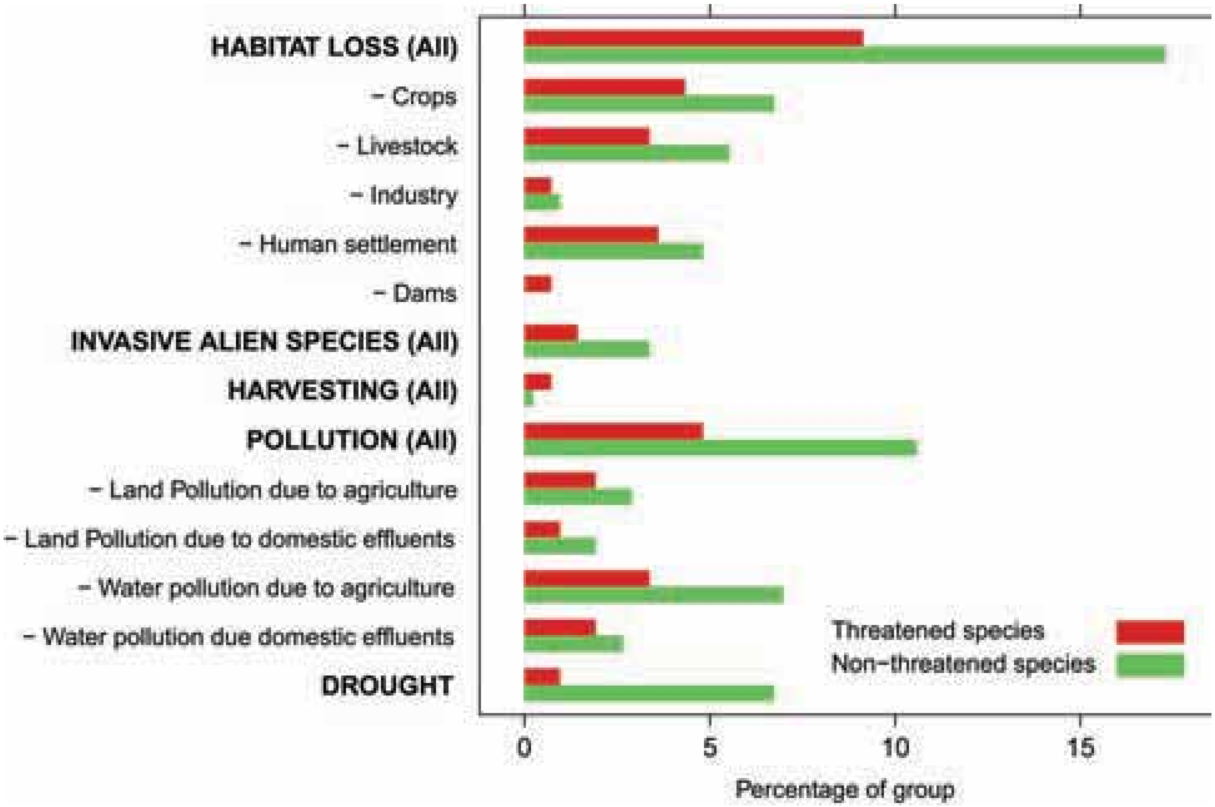
In eastern Africa many threatened species occur in south-east Kenya, especially near Nairobi, where infrastructure development and agriculture pose important threats to freshwater plant habitats. *Ethulia scheffleri* (EN), for example, is endemic to eastern Africa and is threatened by severe land conversion near Nairobi.

In southern Africa there is an important concentration of threatened species in the Cape Fold area, especially in the Cape Peninsula. This is an area where agriculture, urbanization and invasive species are threatening many aquatic species (Sieben 2009). The Cape Fold area holds many endemic and rare species such as *Aponogeton angustifolius* (VU), *Oxalis natans* (CR) and *Cadiscus aquaticus* (CR).

7.5.4 Data Deficient species

A proportion of species are assessed as Data Deficient (see section 3.1) reflecting the often-poor state of knowledge on the distribution and threats to aquatic plants (Figure 7.7). Most Data Deficient (DD) species are located in the northern Upper Guinea centre of endemism extending across the Senegal and Gambia River basins. Other areas with significant numbers of DD species include the lower

Figure 7. 8. Percentages of aquatic plant species affected by the major categories of threat across mainland continental Africa. Only those species in the plant families comprehensively assessed (SFP) are included in the analysis. Note that many species have more than one threat listed.



and upper Niger Delta, the Lake Chad drainage, and the Bright Drainages ecoregion (Thieme *et al.* 2005), which incorporates important freshwater systems such as the Ogun and Oshun rivers in Nigeria. D.R. Congo also contains a high number of DD species, particularly along the border region with Angola and Zambia. Angola itself has significant numbers of DD species, particularly in the south part of the country where the so-called Zambezian regional centre of endemism lies (White 1993). In eastern Africa, the Lake Victoria basin and the north-eastern rift are areas for which information on many aquatic species is limited.

Although the high concentration of DD species can be attributed to low sampling intensity in areas such as the Mediterranean coast of Morocco, Algeria and Tunisia, other areas such as the Cape Fold, which are relatively well surveyed, also contain relatively high numbers of DD species. In these better studied areas the main issue is taxonomic uncertainty.

7.6 Major threats to aquatic plants

The most significant threat to aquatic species in the inland waters of Africa is the loss and degradation of habitat. Globally, expansion of agriculture and the manufacturing industry during the last decade has increased the demand for water, contributed to the pollution of surface and ground water, and has degraded or destroyed many wetland habitats, and Africa is no exception (Millennium Ecosystem Assessment 2005). While only 60% of the population in Africa is served with safe drinking water and adequate sanitation (UN DESA 2010), the level of sewage treatment remains even lower (around 30% in sub-Saharan Africa), and probably represents a significant factor contributing to the high proportion (28%) of lakes and reservoirs in Africa subject to eutrophication (Nyenje *et al*. 2009). These, and the many other activities which threaten Africa's aquatic plants, are dealt with in more detail below.

Due to matters of scale, some localised threats may not be detected through this synthesis at the continental scale but more detailed information on threats to aquatic plants at a regional scale is provided through a series of regional reports (see Darwall *et al.* 2005; Darwall *et al.* 2009; Smith *et al.* 2009; Garcia *et al.* 2010; Brooks *et al.* 2011).

The major threats to aquatic plants are shown in Figure 7.8. Results presented are absolute values where the percentage values represent the proportion of all species subject to a particular threat.

7.6.1 General threats

Globally, Africa has seen the largest regional population rise over the period 1990 to 2000. Furthermore, an additional

The extensive Mweke swamp at Kapikili in the Upper Zambezi catchment in Zambia. © D. TWEDDLE

65 percent increase in the population is expected between 2000 and 2025 (WHO/UNICEF 2000). As the population rises, this is closely followed by expansion of urban areas, agriculture, industry and infrastructure, putting ever-increasing pressure on wetland ecosystems. The extent and impacts of such developments are examined below.

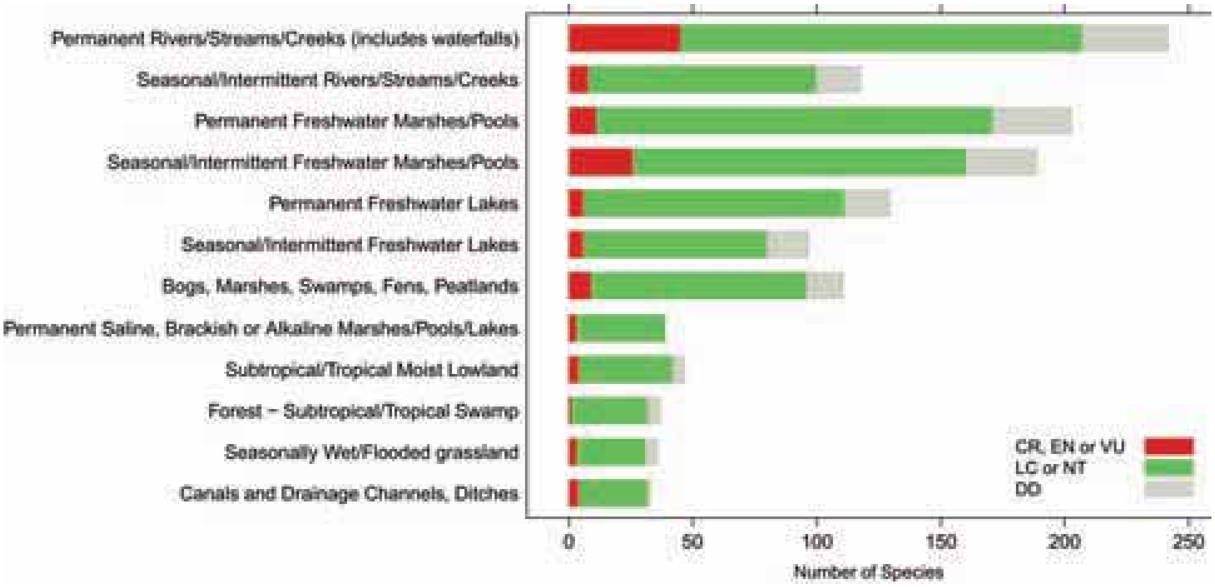
Although 58% of the species assessed were not considered to be at risk of extinction, this does not mean they face no threats. Species listed as Least Concern (LC) or Data Deficient (DD) may also be impacted by threats which, if not halted or minimized, could lead to the species becoming threatened in the future. DD species may already be threatened, but we currently lack sufficient information to make this assessment. Threats recorded for all LC and DD species are therefore included in the analysis.

Habitat loss or degradation is the major threat to aquatic plants, impacting 26% of the species assessed. The main cause of habitat destruction is agricultural expansion through irrigation, reclamation of land (through draining wetland areas), and livestock farming. Infrastructure development, such as urban expansion, industrial development and dam construction, are identified as the other major causes of habitat loss. Pollution is identified as the second largest major threat, affecting 15% of the species assessed. This is mostly attributed to water pollution by agricultural, industrial and domestic effluents. Finally, drought and invasive alien species impact 8 and 5% of species, respectively.

For threatened species alone (Figure 7.8) habitat loss and pollution are also the major causes of species decline, with 34% of species affected by habitat loss due to agriculture and 36% by habitat loss due to infrastructure development. Water pollution is a major threat to 25% of threatened species.

The clover fern Marsilea strigosa *(EN^{RG}) grows in poorly mineralized temporary pools of Tunisia, Algeria and Morocco. It faces a number of threats, such as overgrazing, water extraction, and habitat loss due to changes in land-use related to agriculture and the construction of road infrastructures.* © SERGE MULLER

Figure 7.9. Numbers of aquatic plant species associated with each of the main habitat types across mainland continental Africa.



The numbers of species recorded against each major habitat type are presented in Figure 7.9. The chart illustrates that the highest numbers of threatened species are found in habitats such as permanent rivers, creeks and waterfalls, followed by seasonal and intermittent marshes and pools. Permanent rivers, especially rapid waters and waterfalls, are a potential source of hydropower, water for agriculture, urban and industrial use, and provide many other important resources such as food fish, fibre, and building materials. Consequently, despite their great value in terms of the ecosystem services provided, they are more often subject to the pressures associated with development than are other habitats. Intermittent and seasonal pools and marshes are at risk from drainage or conversion for associated agricultural activities.

7.6.2 Habitat loss due to agriculture

Agricultural expansion is responsible not only for the loss of physical space for species to grow but also the degradation of many habitats. Conversion (clearing or transformation) or drainage for agricultural development have been the principal causes of inland wetland loss worldwide (Millennium Ecosystem Assessment 2005). Across Africa commercial farmers drain wetlands for planting crops such as Amadumbe (*Colocasia esculenta*) or sugar cane (*Saccharum officinale*). Subsistence farmers may also pose a threat to species and their habitats where they are restricted to limited areas (Sieben 2009).

As the population rises in Africa it becomes increasingly evident that the intensification and efficiency of agricultural production has to increase too. The main challenge is to combine intensification with conservation of the underlying environmental services provided by wetlands. There are many initiatives that seek to increase productivity in order to help African people produce the food they need. One of the most important initiatives of the past years is The Alliance for a Green Revolution in Africa (AGRA). AGRA is an African-led partnership whose main goal is "…to achieve a food secure and prosperous Africa through the promotion of rapid, sustainable agricultural growth based on smallholder farmers" (AGRA 2010). AGRA's strategy includes increasing two- or three-fold crop yields to address food shortages. This will be achieved through improving soil fertility using organic and inorganic

Pilularia minuta *(CR^{RG}) is a small amphibious fern found in Algeria, Morocco and Tunisia. Its population is in decline in northern Africa as a result of its very small and fragmented area of distribution, combined with anthropogenic threats to its habitat of temporary pools.* © SERGE MULLER

Aponogeton angustifolius *(VU) is restricted to Cape Province in South Africa where it is threatened by habitat loss due to urbanization.* © NICK HELME

fertilizer, using "high quality local adapted varieties" through breeding programmes, increasing research and capacity building, and promoting policies that provide comprehensive support to farmers (AGRA 2010).

If initiatives such as that mentioned above are to be successful, environmental sustainability must be included as a key component within planning processes. Services provided by wetland ecosystems, which are in turn dependent upon aquatic plants as the primary producers and habitat builders, underpin the success of these future development ambitions. Reliable information on aquatic species, such as provided through this current study, must therefore be fully integrated within these initiatives if we are to ensure they move forward, as pledged, in an environmentally sustainable way. Without the effective integration of such information, wetlands and their wildlife may be impacted in ways that might have been avoided if the necessary information had been accessed.

7.6.3 Habitat loss due to infrastructure development

Impacts from infrastructure development have been recorded throughout the whole continent. In northern Africa development related to tourism in coastal areas is extremely high, affecting availability of water and suitable habitats for many plant species (Rhazi and Grillas 2010). In South Africa urbanization in coastal areas is a serious threat for many species, as it not only reduces areas of suitable habitat but also increases pollution in adjacent wetlands (Sieben 2009). Increasing infrastructure development, which includes urbanization, construction of dams, or irrigation structures, has also been described as one of the major threats to aquatic plants in central Africa (Ghogue 2010). Species such as *Acanthus latisepalus* (VU), *Aponogeton angustifolius* (VU), *Juncus maroccanus* (CR) and *Isoetes capensis* (EN) are all threatened by infrastructure development.

7.6.4 Water pollution

Eutrophication presents a serious ongoing problem for African water bodies (Nyenje *et al*. 2009). The main cause is an increased input of mainly nitrogen (N) and phosphorus (P) into the aquatic system resulting in "blooms" of phytoplankton or other plant species that are able to quickly utilize the excess nutrients. Eutrophication leads to increased species mortality, changes in species assemblages, and an overall loss of aquatic diversity. In the case of native aquatic flora, eutrophication leads to plant assemblages becoming simplified, with only a few dominant species remaining, commonly at a cost to habitat

A water body in Morocco affected by over-abstraction of water. © JP-BOUDOT

specialists and endemic species (Sieben 2009). In addition, eutrophication may favour the proliferation of invasive species that can take advantage of their more competitive reproduction strategies. A healthy community of aquatic plants in freshwater systems is able to retain excess nutrients (N and P) and can therefore act as a buffer to eutrophication. However, in many cases the rapid rates of encroachment on freshwater habitats, and increased wastewater production in urban areas, have increased nutrient loading beyond the buffering capacity of the wetland. Pollutants that cause eutrophication may come from wastewater, pesticides, or mining activities. Of the total amounts of wastewater produced by cities in sub-Saharan Africa, at present, less than 30% is treated in sewage treatment plants, while the remainder is disposed of via onsite sanitation systems, eventually discharging wastewater into river and lakes. Examples of African lakes affected by eutrophication are numerous and include Lake Victoria, Lake Chivero in Zimbabwe, Lake Albert, the Zeekoevlei in South Africa, and the rift lakes in Ethiopia (Nyenje *et al.* 2009).

Although eutrophication has a major impact on plant species, pollutants from a range of other sources have also been recorded as threats to plant species. For example, pesticides used in agriculture and against human pest vectors (e.g., the tsetse fly) are an emerging problem for species survival and water quality in wetland areas. Pollutants from mining activities (such as lead, cadmium, iron, and copper) and organic wastes from leaking sewage systems can accumulate in rivers and other freshwater bodies, affecting water quality and species survival. For example, *Limonium duriaei* (Plumbaginaceae) (CR) is a plant native to Algeria and Morocco that is directly impacted by pesticides used in agriculture. Other species affected by water pollution due to agricultural or mining activities include *Cadiscus aquaticus* (CR), *Aponogeton bogneri* (EN), and *Drosera bequaertii* (VU).

7.6.5 Water use: extraction and transfers

Water resources are unevenly distributed across the African continent, with about 50% of the total surface water on the continent contained within the Congo River basin, and 75% of total water resources concentrated within eight major river basins – the Congo, Niger, Ogooue (Gabon), Zambezi, Nile, Sanga, Chari-Logone and Volta (Donkor and Wolde 1998). This has led to an increase in water transfers from water-rich catchments to those where water is limited, with major implications for channel integrity and ecological functioning, leading to a frequent loss of biodiversity. More specifically, water transfers lead to flow reduction in donor rivers and increased flow in the recipient rivers, along with changes in the physical and chemical status of the river's water, introduction of fine sediments from one river to another with the subsequent loss of benthic habitats (such as gravel spawning beds for fishes), and the spread of alien fish species, floating aquatic plants, and animal diseases and their vectors.

By sector, the highest water use is for agriculture through irrigation followed by domestic use and industrial use. As discussed above, irrigation is predicted to increase enormously in the future in response to growing demands for a more productive agriculture. However, the need to expand irrigated areas as the immediate solution has been challenged for the sub-Saharan region, through reported ongoing deficiencies in the production process that could be solved through more efficient use of existing irrigated areas (Riddell *et al*. 2006). Whatever the outcome, an Integrated Water Resource Management strategy is necessary if we are to protect freshwater biodiversity while increasing water use for irrigation.

7.6.6 Invasive species

Alien invasive plants pose an important threat to native species, either through direct competition for resources or through indirectly changing vegetation dynamics ultimately leading to habitat degradation or loss of plant diversity (see also Chapter 8). Species such as *Pistia striatiodes (*water lettuce*)*, *Eichornia crassipes* (water hyacinth), *Salvinia molesta* (kariba weed), *Typha australis, Azolla pinnata*, *Azolla filiculiodes* or *Ludwigia stolonifera* are well-known invasive species. Their harm to native habitats has been widely documented, and the cost associated with their control has proven to be high. For example, the control of water hyacinth is an important problem to many wetlands throughout Africa. Alimini and Akinyeminju (1990) calculated the annual cost of clearing 1km2 of water hyacinth in Nigeria ranged from USD 9,500 for manual control to USD 4,400 for chemical control. Calculated costs will be even higher if the environmental costs of using chemicals to eradicate weeds from wetlands are included. Water hyacinth has been reported as invasive in the Nile Delta, Niger Delta, Lake Victoria, and the Middle and Lower Zambezi River (Thieme *et al.* 2005). The issues around the spread and control of water hyacinth are examined in Species in the spotlight – **Water hyacinth, a threat to the freshwater biodiversity of western Africa**.

7.6.7 Climate change

Although droughts are reported to affect 8% of the species assessed, the impact of climate change was not specifically considered as a threat. The potential impacts of climate change to freshwater species throughout Africa are, however, discussed in a dedicated section within Chapter 8, this volume.

7.7 Conservation recommendations

7.7.1 Planning and Policy

Conservation of aquatic plants can be facilitated through effective policies and systematic planning processes that identify, value and protect important areas for plant conservation. Having identified important sites, the most important policy requirement is for management actions to be targeted at the catchment scale, employing such methods as Environmental Flows and Integrated River Basin Management. Such an approach is often required, as many threats to aquatic plants, such as pollution and invasive species, will spread rapidly throughout a catchment, impacting species sometime distant from the initial source of the threat.

7.7.2 Alien species removal

Effective measures to control and eradicate invasive species are needed if we are to enable native species to successfully re-colonize former habitats taken over by non-native species. In many cases the only way of controlling invasive freshwater plants is periodic physical removal or chemical control. The first option is expensive and time consuming and the second may be harmful for non-target species and overall ecosystem health. A third option is biological control, for which there has been some reported success through use of plant feeding insects and pathogens, but this technique is not completely risk free and needs careful consideration (Moran *et al.* 2005*).*

7.7.3 Catchment-scale actions (also see Chapter 9, this volume)

Although site based conservation has proved to be effective and remains a key tool for protecting threatened species in the short and medium term, in many cases the best way to achieve conservation targets is to combine both catchment and site scale approaches (Boyd *et al*. 2008). The importance of riparian ecological corridors for maintaining biodiversity and natural patterns is well known (Forman 1995; Bunn and Arthington 2002; Bennet 2003).

One example of the landscape scale approach comes from ongoing work in the Miombo-Mupane woodlands. This vast area of savanna is irrigated by rivers, pools and pans across Angola, Zambia, Namibia, Botswana and Zimbabwe. It is a diverse area where local communities are highly dependent on water-related resources. Several large-scale conservation initiatives seek to manage healthy ecosystems within this ecosystem while benefiting human well-being and conserving nature. Conservation International is working towards the establishment of ecological corridors across this unique landscape, specifically to "…identify the most important freshwater areas within Miombo-Mopane, to describe and understand what are the key factors driving and maintaining such systems, and to develop programs that will ensure that the essential services that these freshwater systems provide will remain viable into the future" (Conservation International 2010).

7.7.4 Species or site based actions (also see Chapter 9, this volume)

Site based actions also have their place within the portfolio of options available to managers. The Alliance for Zero

Rufiji Floodplain in Tanzania. © DAVID ALLEN

Extinction (AZE) provides a good example for the relevance of site based conservation actions. AZE sites are specific places that harbour a critical proportion of the populations of species in imminent danger of global Extinction (Ricketts *et al.* 2005*).* Currently, 140 species present in 82 different sites have been identified in Africa and Madagascar (AZE 2010) but see Chapter 8, this volume. An example of a species which might benefit from site based conservation is *Nympahea thermarum* which is Extinct in the Wild and is being recovered *ex situ* and can hopefully be re-introduced to the wild following site based restoration actions (see Species in the spotlight – **A small wonder of nature saved from extinction**, this volume)**.** Another example is *Aponogeton ranunculiflorus* (EN), which is endemic to southern Africa where it is restricted to only three locations in Lesotho and KwaZulu-Natal province in South Africa. Site based conservation at any of these locations will benefit this species.

7.7.5 Restoration

The importance of vegetation as natural infrastructure, which, among other things, serves to prevent or alleviate flood events and to purify polluted waters, is now well established (e.g., Millennium Ecosystem Assessment 2005 TEEB 2009). This increased recognition of the value of wetlands is supporting an increasing momentum for the restoration of degraded wetland ecosystems. For example, a recent assessment by the United Nations Environmental Programme encourages restoration as a tool for sustainable development, and specifically points out the importance of restoring wetlands for this purpose. Indeed, one its main recommendations is to "apply ecosystem restoration as an active policy option for addressing challenges of health, water supply and quality and wastewater management by improving watersheds and wetlands, enhancing natural filtration" (Nellemann and Corcoran 2010).

Restoration is financially viable in many cases (TEEB 2009) and provides multiple benefits for wildlife and local communities. For example, in South Africa a government-funded programme, Working for Water (WfW), carried out a project to restore the Manalana wetland in Mpumalanga in 2006. The site, which was degraded by erosion, was considered to offer important services to the local communities, with at least 70% of the people benefiting in some way. After the restoration was completed, an economic study concluded that the livelihood benefits recovered through restoration were valued at more than twice the cost of undertaking the restoration project. Furthermore, the provisioning services that the wetland now provides are estimated at EUR 315 per year in an area where 50% of households survive on an income of less than EUR 520 per year (Pollard *et al.* 2008).

7.7.6 Further research

The availability of information on aquatic plants is relatively low, with considerable gaps remaining in some of the African floras, and there are some countries for which floras are yet to be completed (Beentje and Smith 2001; Ghogue 2010). There are many aquatic plants for which the taxonomic status, distribution, population size and trends remain unknown. Additional taxonomic study, field survey and long-term monitoring will help to fill these gaps. Data Deficient species might be the primary targets for such research, as guided by the concentrations of DD species identified in Figure 7.7.

7.8 Key messages

❶ Aquatic plants play a major role in the provision of many ecosystem services including flood alleviation, bio-remediation of polluted waters and nutrient cycling. They are also essential to wetland ecosystems as the source of primary production at the base of the food-web. Their conservation is therefore of great importance.

❷ The extinction risk of 718 aquatic macrophytes across mainland continental Africa has been assessed, including 365 species representing 21 comprehensively assessed families, and an additional 353 species from another 44 families.

❸ One in five of all species assessed face risk of global extinction.

❹ One in four of all species endemic to continental Africa are threatened with extinction.

❺ Central Africa, the Mediterranean and Atlantic coasts of Morocco, Algeria and Tunisia, and the Cape Fold area, are the regions with the highest numbers of threatened species.

❻ Habitat loss due to agriculture and human expansion (settlements and infrastructure) is the main threat to aquatic plants.

❼ Water pollution is a major threat to aquatic plants mainly due to agricultural and domestic run-off.

❽ Development planning policy must include adequate consideration for the conservation of aquatic plants to ensure development moves forward in an environmentally sustainable way, with minimal impact to wetland ecosystems wherever possible. A combination of catchment and site scale actions is recommended.

❾ Additional research is needed to increase our knowledge for the 14% of species for which extinction risk assessments could not be completed due to lack of knowledge on their distributions, population status, and taxonomic status.

Species in the spotlight

A small wonder of nature saved from extinction

Magdalena, C[1] and Juffe Bignoli, D[2]

Nymphaea thermarum, listed as Extinct in the Wild, is unique. It is the smallest water lily in the world, endemic to one single site in Rwanda, and has not been recorded elsewhere, despite extensive searches. The intriguing story about this scientific rarity seems more like a drama screenplay than a true scientific achievement.

It was discovered in 1987 by Professor Dr. Eberhard Fischer at Mashyzuza near Nyakabuye in Rwanda. Its specific habitat requirements seem improbable; it is known only from a muddy site flooded by a series of hot springs that flow at 80°C, where the waters have cooled to approximately 24-26°C (Fischer 1993).

A few specimens were airlifted from its only known location soon after its discovery and were kept at Bonn University Botanic Gardens, where botanists were hoping to propagate the species. All attempts failed. While growing mature specimens seemed to be relatively easy and seeds easily germinated, the seedlings were impossible to grow to maturity and died shortly after they germinated. The urgency for understanding its growing requirements became increasingly evident as repeated searches in numerous hot springs across central Africa failed to find another single population (Fischer, pers. comm. 2010). In 2008, a pump was installed in the only hot spring where *N. thermarum* used to grow, sequestering the water before it reached the surface. The whole habitat dried out in the sun, and the last 50 specimens growing in the wild died. Probably millions of years of evolution in stable conditions were wiped out in one single human action.

The minute flower of Nympheae thermarum, *listed as Extinct in the Wild.* © C MAGDALENA

In 2009, Carlos Magdalena, a senior horticulturist from the Royal Botanic Gardens, Kew in London, unveiled the secret. While the seeds of all other Nymphaea species are traditionally grown deep, submerged in water, this species was again different. Growing the seedlings in pots filled with loam totally damp but so shallow that the surface of the compost (and therefore the seedlings) was exposed to the air, was the simple change that made all the difference and was all that was needed to save the species. Once its *ex-situ* growing requirements were met and fully understood the species was easy to propagate. Hundreds of plants are currently being grown at the Royal Botanic Gardens, Kew, while not a single one has survived in the wild.

If Professor Fischer had missed the ”unusual” little plants while he was looking at the area, the species would never have been discovered and its extinction would have gone unnoticed. If Fischer had considered that his duty as a botanist ended just as he described the species instead of also trying to figure out the conservation status, then the plants would have reached Germany only as dried (and therefore dead) specimens and there would have been no material from which to propagate. In addition, had the Bonn Botanic Gardens failed to provide facilities and horticultural skills over a long period of time, it would have also been lost forever. If Bonn had decided to keep these little gems for themselves instead of sharing them with other institutions, then the mystery about how to propagate this species may have never been solved at Kew.

All the above highlights the importance of knowing what species we have, where they grow and which ones are really in peril. Once those are identified, we can spare the resources and the skilled staff able achieve the goal of keeping them going. This particular species has a huge potential for a reintroduction programme, and its story is fascinating enough to raise awareness about the wonders and singularities of nature and, sometimes, its compelling fragility. *N. thermarum* illustrates a success story for which its last chapter is yet to be written.

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[1] Royal Botanic Gardens, Kew.

[2] Freshwater Biodiversity Unit, IUCN.

Species in the spotlight

Sailing flowers

Cook, C.D.K

Lagarosiphon is a genus with nine species that are confined to Africa and Madagascar. One species (*Lagarosiphon major*) has become naturalized in Europe and New Zealand. It has been in Europe since, at least, 1910. Occasionally it flares up in pools and lakes where it may interfere with sport fishing. In New Zealand it has become a serious pest; large populations can choke dams and rivers, interfering with the generation of electricity and irrigation. It has, therefore, been gazetted as a class B noxious plant. Following this, it was declared to be a pest in Australia (one can be fined up to AUS 80,000 for introducing it to Queensland) and also in the USA, despite the fact that it is not naturalized in either of these countries. It is probably this information that led to the species being declared a noxious weed in South Africa although it is in fact, endemic to southern Africa, confined to an area extending from southern Zimbabwe to South Africa, where it leads a modest and blameless existence!

Although most species of *Lagarosiphon* are common, they have not merited presentable vernacular names – they are just called oxygen weeds or babergrass. Even the Latin name, which is in fact Greek, is boringly technical: *Lagarosiphon* is derived from the Greek words *lagarós*, meaning thin or weak, and *siphon*, tube - which refers to the long tube joining the "flower" with the ovary. From a distance the plants do not look exciting, and perhaps deserve their lack of interesting common names. On top of it all, they are not particularly good at producing oxygen.

When they flower a real wonder takes place. The flower buds of the male plants become detached from the mother plant; they are liberated under water and come to float on the surface of the water. Then, relatively quickly and in front of your eyes, they open. At first the sepals and petals bend back on themselves. Their outer surfaces are wettable, so they stick to the water surface, which stabilizes the flower so that it cannot capsize. The inside parts of the flower are unwettable and remain dry. Three fertile stamens then stretch horizontally, parallel to the water surface. Three sterile stamens become feather-like and elongate, eventually reaching upwards to form a sail. The male flower is a perfectly engineered tiny sailing boat that skims over the water surface with the slightest breeze. This is something unique in the plant kingdom

The stamen is also very special. Only one pollen mother cell from each of the four pollen sacs divides. Each stamen thus develops only 16 pollen grains. This is the minimum possible number of pollen grains for a complete anther. The anthers take a vertical position at right angles to the stamen filament. The pollen grains are abnormally large; they are presented on the outer surface of the anther, just in the right position to deposit their grains on the upright stigmas of the female flowers, which they hit while skimming over the water surface.

Just because *Lagarosiphon major* leads a modest life in southern Africa today, it does not mean that it must stay so. Perhaps major alterations to the environment could encourage its ability for very fast growth, and it could become a serious threat.

Lagarosiphon major *flowers.* © C.D.K. COOK

Species in the spotlight

The habitat creator

Sieben, E[1]

Palmiet (*Prionium serratum*) is the only African representative of the family Thurniaceae, but up to the recent past it has been allocated either to the family Juncaceae or given its own family Prioniaceae. Even though palmiet in itself is not a threatened species (listed as Least Concern), the unique ecosystems that it forms are becoming increasingly rare.

Palmiet is a special type of plant in that it is an ecosystem engineer. It creates wetlands by growing in dense stands that block the flow of rivers. These wetlands are subsequently colonized by many other plant species that would otherwise not find suitable habitats. In that sense, *P. serratum* forms the basal structure for a complete ecosystem, and is responsible for creating the most extensive peatlands of the Cape Floristic Region. Pools that come into existence when river flows are blocked by Palmiet also provide valuable habitats for animals such as fish. For example, the Clanwilliam Yellowfish (*Labeobarbus capensis*) is a threatened species (Vulnerable) endemic to the Olifants River System on the West Coast of South Africa, where deep permanent pools with good cover provided by palmiet beds are important refuges for the species in seasonal rivers during the hot dry summers.

Palmiet's distribution is limited to Table Mountain Sandstone (TMS). It only grows on this extremely nutrient-poor substrate so does not occur away from the Cape Mountains. The nutrient-poor conditions in which palmiet grows are in sharp contrast with the luxurious growth form that it exhibits. A single ramet of the plant consists of a light woody stem covered in old leaf sheaths, which protect the living tissues against fire. On top of the stem it carries a crown of stiff greyish serrated leaves with sharp edges, making it difficult to move around in an area dominated by palmiet. Underground, the palmiet plant has a dense network of fibrous roots that extend far deeper than any other wetland plant occurring in its habitat, sometimes reaching five metres deep. This root network extends deep into the peatland and, since palmiet grows in dense, widespread, stands, it is assumed that this underlying fibrous root system has a considerable impact on ecosystem functioning.

The palmiet (Prionium serratum) *(LC) is endemic to South Africa. It is common in the Western Cape province in South Africa.* © E. SIEBEN

Palmiet occurs in two very distinct habitats: mountain streams and peatlands. In the first habitat, small plants of palmiet can be found lining Cape mountain streams or even headwater seepages. The second habitat is created entirely by autogenous succession (where the stimulus for change is internal) of the palmiet plants themselves. In the foothill zone of rivers the species can form dense stands that slow down the water flow. Since palmiet is able to grow in flowing water it can choke the river leading to inundation of large areas of the valley. In this situation, peat will start to form and the palmiet itself will then be able to further expand the area that it occupies. In these situations, palmiet will create a habitat for many other riverine and wetland species that grow between the palmiet plants.

The species occurs in two disjunct populations on two different strata of quartizitic sandstone. The Table Mountain group sandstones are found in the Western Cape Mountains. Here Palmiet occurs together with plants such as *Wachendorfia thyrsiflora*, *Cliffortia strobilifera* and *Calopsis paniculata*. On the Natal Group sandstones, extending from the Eastern Cape into southern KwaZulu-Natal, palmiet is also found, often occurring together with Pondoland endemic species such as *Leucadendron pondoense* and *Syzygium pondoense*. The palmiet here has slightly narrower leaves with less of the greyish shine as seen in the Table Mountain populations, so it has been suggested that this may represent a second species. The name ”Palmiet Valley” that can be found on maps of the city of Durban in southern KwaZulu-Natal, suggests that the distribution range of this second form of palmiet historically must have extended further north than it does today.

Most farmers in the area have a paradoxical relationship with palmiet. They use water found in the peatlands to irrigate their land, but simultaneously cut away the palmiet plants themselves in effort to limit encroachment into their land. In the past, the leaves of the palmiet have been used as fibres, but this use is not very extensive nowadays. The fibre, called palmite, is the original source of the name for this plant.

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[1] University of the Free State, South Africa

Species in the spotlight

Water hyacinth, a threat to the freshwater biodiversity of western Africa

Ouédraogo, R.L.[1]

Eichnornia crassipes, or water hyacinth, is an aquatic plant within the family Pontederiaceae and is native to the Amazon basin. This species, which is now widespread throughout much of Africa, was first recorded in western Africa in 1985 where it was recognised as a problem species within a few years (Ouédraogo *et al.* 2004). The adverse impacts of the species in Africa have led to it being called the "Tiger of Bengal" (NAS 1976) or "Green peril of Congo" (Lebrun 1959). The rapid spread of water hyacinth poses a significant threat to water supplies and the use of inland water bodies, such as for fishing or transport, throughout the western Africa region. The Inter-State Committee for the Fight Against Drought in the Sahel (CILSS) prioritises water storage and its sensible management as a key component in their food self-sufficiency policy and the fight against poverty (ECOWAS 1994). The control of water hyacinth infestation throughout the region has, therefore, become an imperative (Ouédraogo 1996).

Water hyacinth in Burkina Faso. © R.L. OUEDRAOGO

The harmful effects of this plant are demonstrated through the following specific examples from various water bodies in western Africa. For example, in some key fishing areas in the west of Burkina Faso, the rapid spread of water hyacinth and its subsequent impacts on the free movement of fishing boats effectively paralyzed all related human activities across 15 kilometres of the Son River. This resulted in an estimated loss of earnings amounting to EUR 27,500 a year (Ouédraogo *et al.* 2004). In other places, increases in biomass and the associated high rates of evapotranspiration due to water hyacinth proliferation have reduced the capacity of water bodies to meet the needs of men and animals. For example, in the Ouagadougou dams (Burkina Faso), annual water loss due to infestation of nine hectares by water hyacinth amounted to 292,329m3 with an estimated associated cost of EUR 80,000, according to the National Water and Sanitation provider (ONEA). The biomass of water hyacinth covering the area was estimated to be 3,500tonnes, representing a major obstruction to free movement across the water body and posing a serious threat to the functional ecology of such freshwater systems that represent an important resource for many people across the region.

The water hyacinth is highly adaptive and has proved resistant to the many varied efforts to eradicate it from the region. It has a cyclical growth pattern within the two distinctive seasons typical to western Africa. Plants behave as hemicryptophyes as the rizome and vegetative parts become dormant during the unfavourable dry season, but rapidly activate when conditions become more favourable in the humid season, at which time the plant spreads rapidly. There is also a significant germination of seeds in the late wet season. Hence, the water hyacinth shows a perfect adaptation to the Sahel environment, being able to withstand water shortage and droughts and to ensure its survival and rapid expansion through massive production of seeds and vegetative growth (Ouédraogo *et al.* 2004). These factors are of major importance when considering new strategies and methods for controlling these plants in the Sahelian countries.

The control of water hyacinth and other invasive plants through integrated strategies is already underway. Technologies generated in the field do, however, need to be constantly adapted to meet local peculiarities and to take account of climatic differences. Despite clear successes, current methods for controlling this plant need to be improved through further research in order to make strategies more efficient and cost-effective. An integrated approach including reduction of nutrient loading of inland waters, and biological and chemical control is recommended.

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Chapter 8.

Synthesis for all taxa

Holland, R.A.[1], Garcia, N.[1], Brooks, E.G.E.[1] and Juffe, D.[1], with contributions from: Howard, G.[2] (Section 8.2.3); Foster, M.N.[3] (Section 8.3.4); Harrison, I.[3], Upgren, A.[3], Alonso, L.E.[3] (Section 8.5); Matthews, J.H.[4], Wickel, A.J.[5], Freeman, S.[5] and Thieme, M.L.[5] (Section 8.6)

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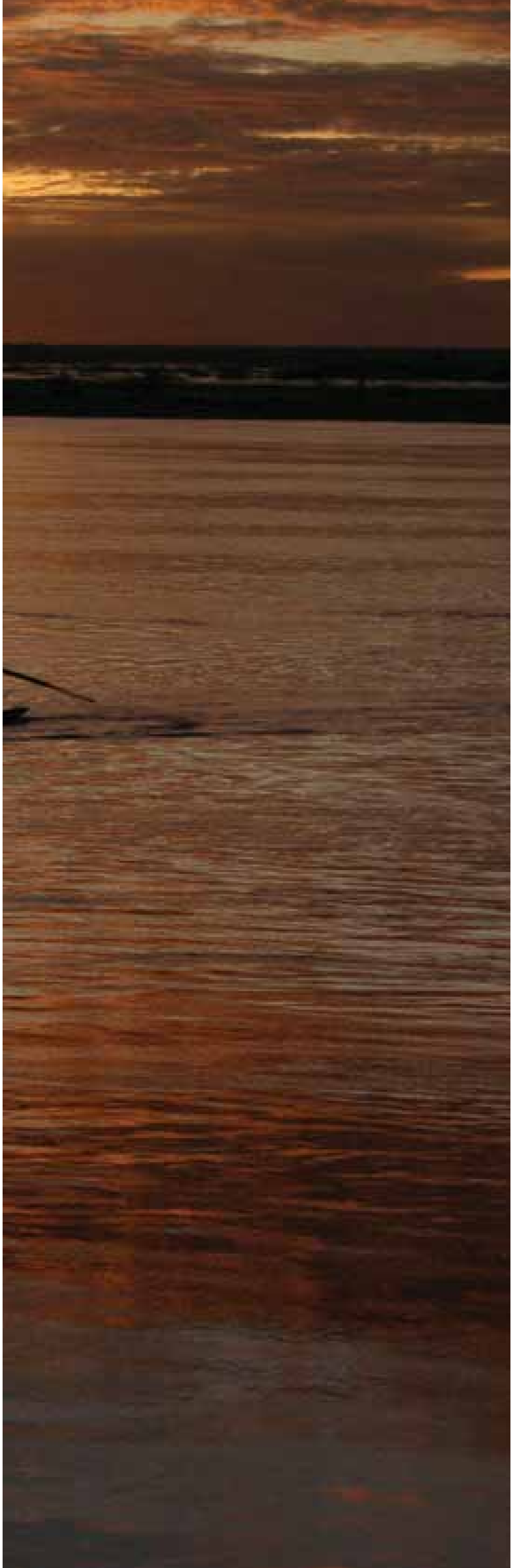
MAIN: Fishers return to Senanga on the Zambezi River, at the southern end of the Barotse floodplain.
© JENS KIPPING

RIGHT: High species diversity in a fish catch at Ilagala market, Lake Tanganyika, Tanzania.
© KLAAS-DOUWE DIJKSTRA



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Platythelphusa maculate *(LC), a small crab endemic to Lake Tanganyika, hides in empty* Neothauma *shells.* © SASKIA MARIJNISSEN

8.1 Introduction

In this synthesis chapter, we combine information presented in chapters 3 to 7 and consider the status and distribution of freshwater biodiversity across mainland continental Africa. We present a combined analysis for all fish, molluscs, crabs, odonates and plants, to illustrate patterns of richness and threat across African countries and consider what drives these patterns. We discuss the role that existing protected areas have in conserving freshwater biodiversity and identify the location of Key Biodiversity Areas and Alliance for Zero Extinction sites, as these represent important focal areas for conservation effort. Finally, we examine the future of African freshwaters and consider one of the most significant threats that they face. Africa is home to a significant proportion of the world's species that are dependent on freshwater habitats (Table 8.1) and, as such, understanding the distribution and status of this biodiversity, the threats which it faces and the actions that need to be taken is key to ensuring its continued survival and provision of benefits to people.

8.2 Freshwater biodiversity across Africa

8.2.1 Patterns of richness and main threats

In previous chapters, analysis has been conducted at the sub-catchment scale, as this represent the logical mapping unit for freshwater species. Here, we firstly consider patterns at the country level to highlight important patterns relevant for policy makers.

Figure 8.1. Richness of species across continental Africa based on occurrence in countries.

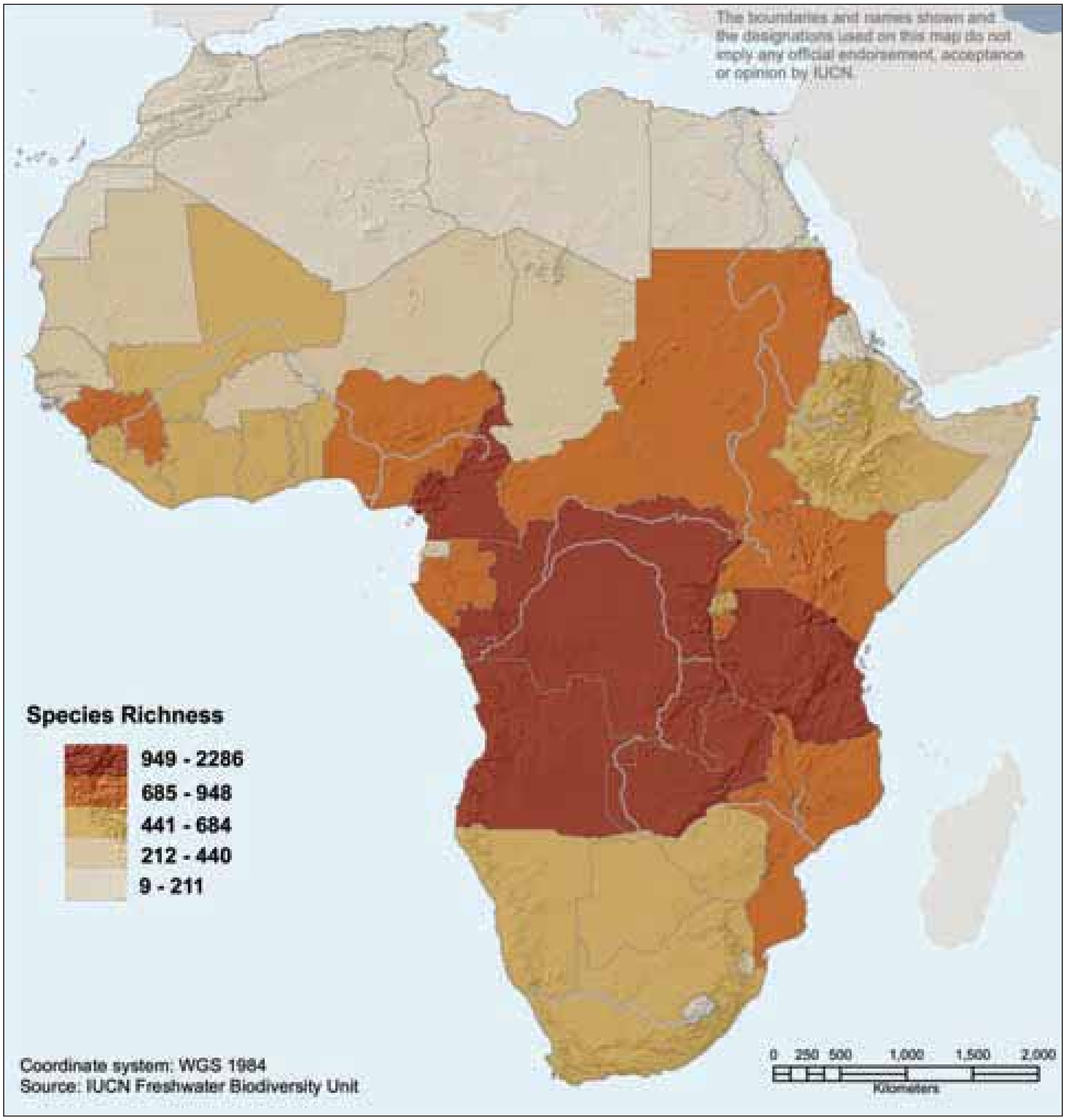


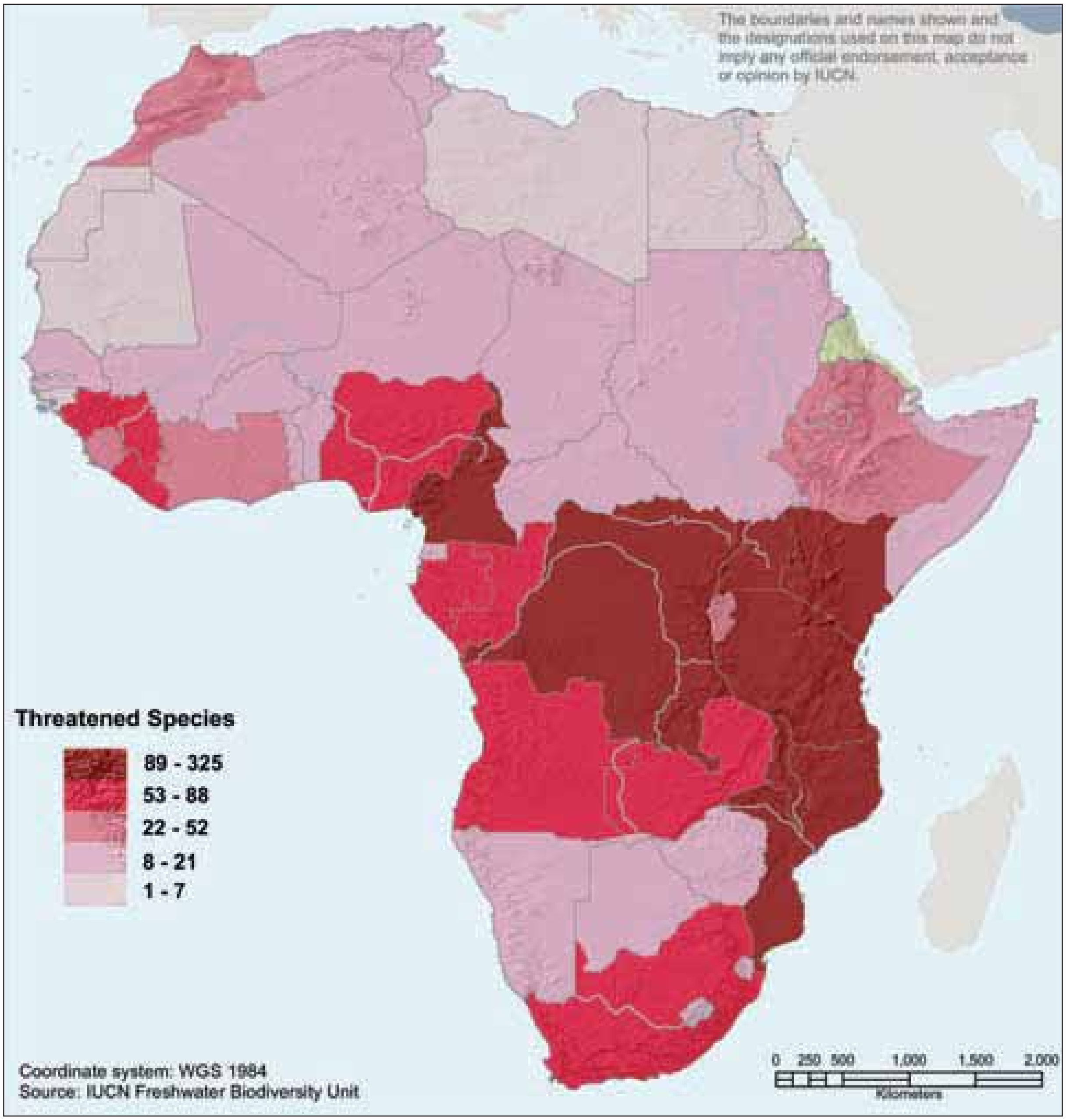
Table 8.1. Estimated number of inland water dependent species by major taxonomic group. Data from the IUCN Red List of Threatened Species - September 2010.

Taxon Group	Number of described species	Number of species assessed in Africa	% of global total found in Africa
Crabs	1280	120	9%
Fish	>15000	2836	*c.* 19%
Molluscs	>5000	624	*c.* 12%
Odonates	5680	705	12%
Amphibians	4251	624	15%
Waterbirds	868	279	32%
Mammals	145	32	22%

At the country scale, richness for all freshwater groups in Table 8.1 decreases from the equator. Such a pattern has been suggested to represent a general rule in ecology named after Eduardo H. Rapoport, who first described it for mammals. Although Rapoport's Rule has been called into question in recent years (Gaston 1998), patterns shown in Figure 8.1 demonstrate that, at this course scale, richness of freshwater taxa is highest in equatorial countries and decreases with latitude.

Equatorial countries also contain significant numbers of species classified as being of conservation concern according to the IUCN Red List (Figure 8.2), with the highest concentrations occurring in a band across the centre of the continent through Tanzania, D. R. Congo, Uganda and Kenya. However, high numbers of threatened species are

Figure 8.2. Richness of threatened species across continental Africa based on occurrence in countries.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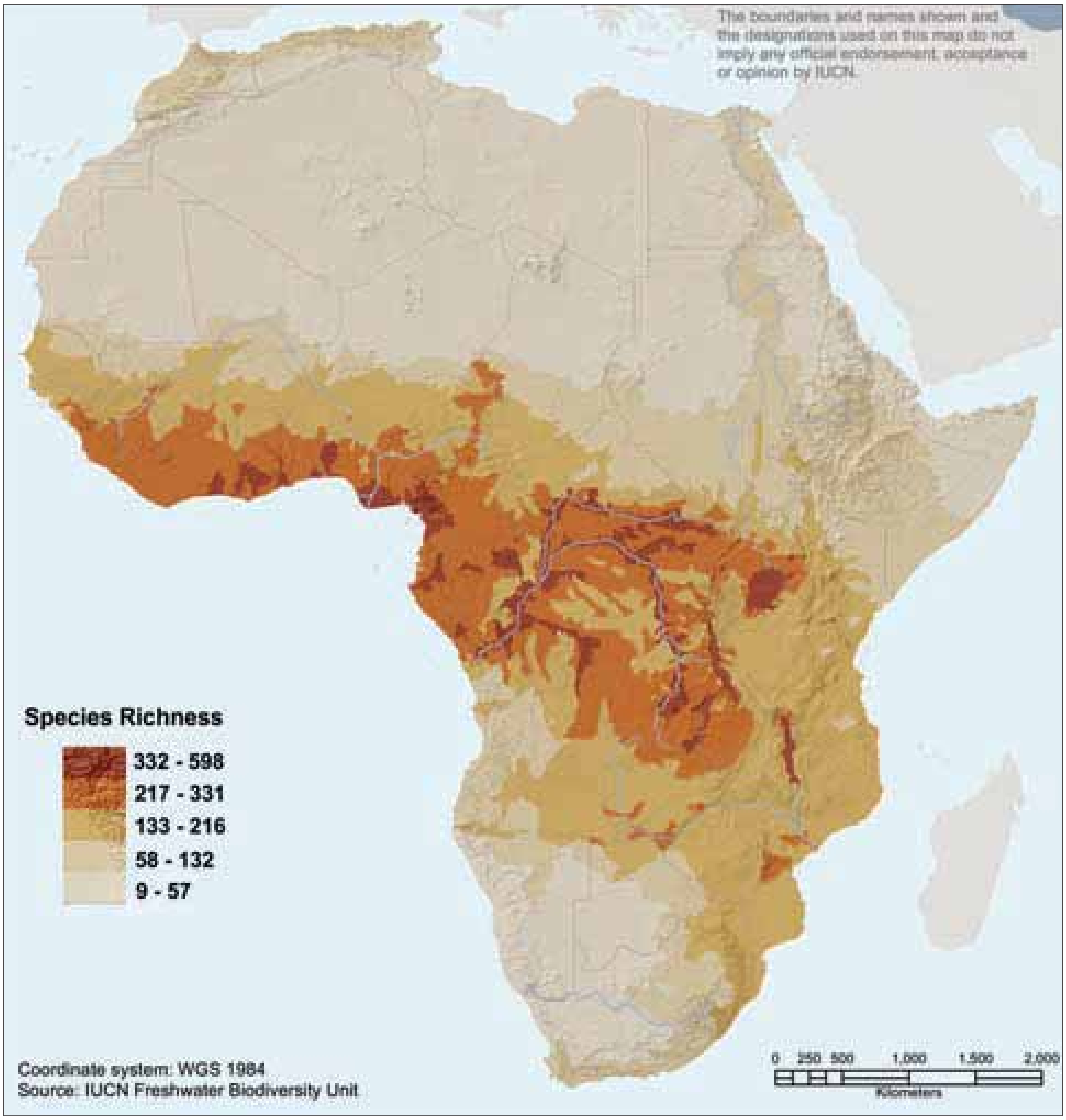
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

also found in countries extending down the east coast (Mozambique, Malawi) and up the west coast (Cameroon, Nigeria). To the far north of the continent, Morocco also has high numbers of threatened species, mainly due to over-abstraction of water associated with agricultural production in this comparatively arid landscape. Moving south of the equator, development of South Africa's water resources and the spread of invasive species has led to high numbers of threatened species in this country.

By combining information on fish, odonates, crabs, molluscs and plants at the sub-catchment scale, a clearer picture of the drivers of biodiversity patterns within and between countries emerges. Across equatorial countries, areas of highest richness are driven by the diversity of species in the Great Lakes of eastern Africa, rivers in coastal sub-catchments in western Africa, and sub-catchments that trace the course of major rivers through the centre of the continent, primarily in D. R. Congo (Figure 8.3). Areas of lowest richness correspond with arid regions, such as the Sahara, Namib, and Kalahari deserts, where there are few suitable habitats for freshwater species.

Africa is home to some species with remarkable adaptations that enable them to cope with ever changing habitats that arise through flooding or seasonal rainfall patterns. Perhaps the most famous such adaption is found in the Lungfish (*Protopterus annectens* (LC)), which is able to cocoon itself in mud when its floodplain habitat dries up. Less well known are the annual Killifish (e.g., *Nothobranchius* spp.) that exploit temporary pools or even puddles in roads as habitats. When these temporary water bodies dry up, the

Figure 8.3. Combined richness of five freshwater groups at the sub-catchment scale. ***Species richness = number of species per river/lake sub-catchment.***



eggs of the fish can remain buried in the mud for years until water once again returns to awaken them.

In the most arid regions, where freshwater species coexist with human populations, there is often intense pressure on water resources, creating areas of high concentrations of threatened species. For example, in Morocco and Algeria sub-catchments containing high numbers of threatened species are situated along the coastline where the majority of the human population is found. Across the continent a similar pattern is often found with threat richness corresponding to areas of high human population density (Figure 8.4). Although a range of different drivers of threat are identified, broadly speaking, results confirmed findings from other studies that activities associated with agricultural production

*The African lungfish (*Protopterus annectens*) (LC) normally lives on flood plains, and when these dry up it survives by secreting a thin slime around itself, which dries into a protective cocoon.*

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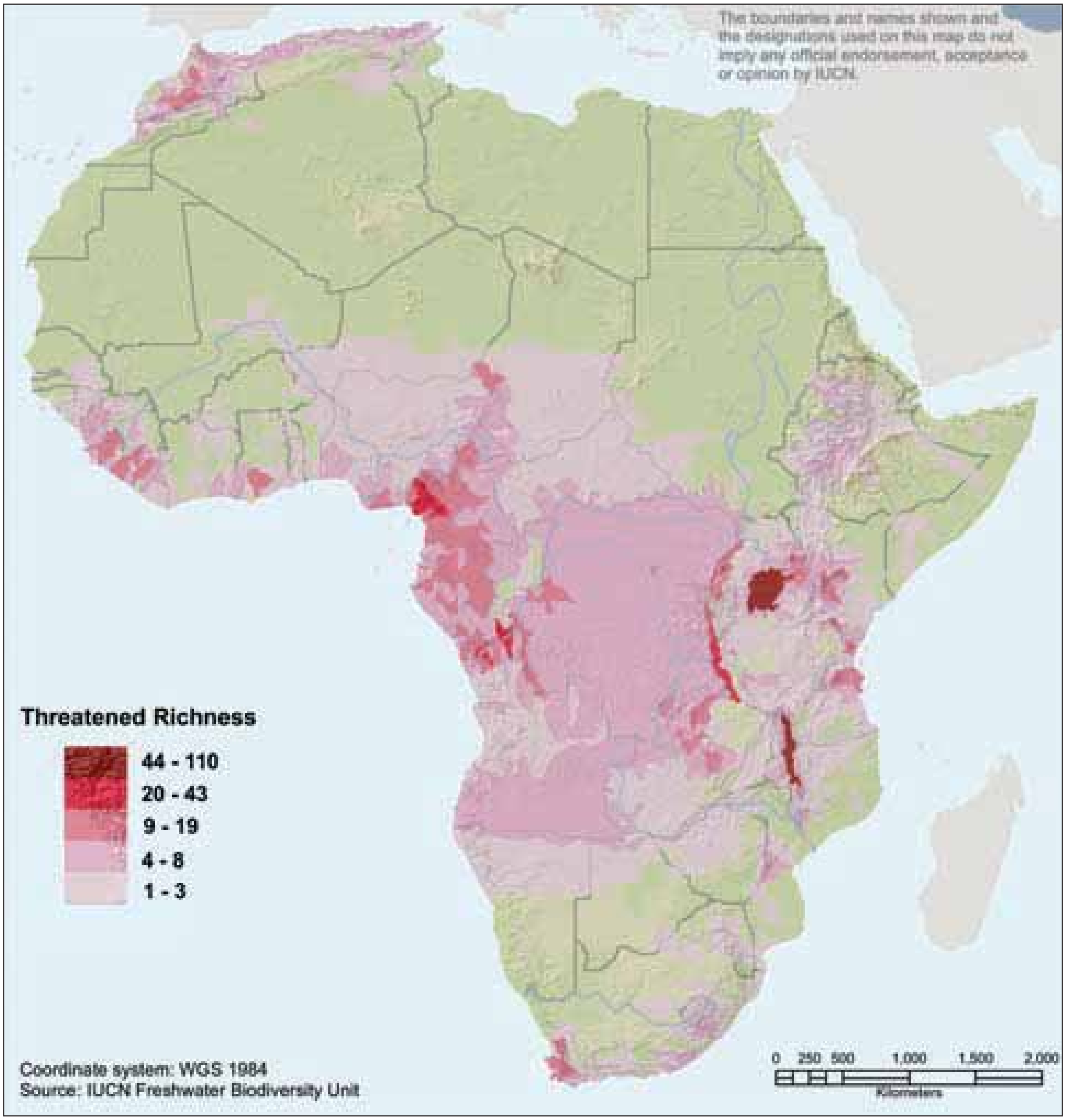
Figure 8.4. Combined richness of threatened species based on the five freshwater groups at the sub-catchment scale. ***Threatened richness = number of threatened species per river/lake sub-catchment.***



Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

and urbanisation within catchments represent the most pervasive threat to species and the health of the world's freshwaters (Allan 2004).

Based on sub-catchment analysis, the high concentration of threatened species recorded for Tanzania (Figure 8.2) arises as the country borders Lakes Victoria, Tanganyika and Malawi. As discussed in previous chapters, pressures, such as overfishing, invasive species and eutrophication, have significantly impacted the rich endemic fauna of these lakes, threatening many species. The problems faced by species in these lakes highlight one of the most difficult issues surrounding the management of freshwater systems, where activities in one part of a lake or river catchment have the potential to propagate widely throughout lakes or river networks, often crossing international boundaries and management zones. The transmission of threats in this way requires a co-ordinated approach to management between countries. However, there is a long history of disputes arising due to such transboundary issues, principally relating to use of water resources. Realisation that the connected nature of freshwater systems means all stakeholders need to be jointly involved in management actions has the added benefit of fostering co-operation to protect shared resources. This has been demonstrated in a number of instances, for example, the UNESCO initiative 'From Potential Conflict to Co-operation Potential' fosters co-operation between countries to address problems relating to water resources that could not be addressed by countries acting on their own. The case of the Great Lakes highlighted here represents just one example where countries must work with their neighbours to protect aquatic biodiversity.

Erosion and sedimentation, as seen here, pose a major threat to many freshwater species. © SASKIA MARIJNISSEN

While the high number of threatened species in the Great Lakes is of concern, a more positive picture emerges for central Africa, where the rich fauna of rivers through the Congo contain relatively few globally threatened species in relation to their overall biodiversity. As highlighted in previous chapters, this area presented a quite different challenge during the course of the assessment, due to the relative lack of information. The high number of DD species in this region reflects this difficulty. With the development of rich mineral deposits to the east of the region, and the associated threat to freshwater species, the establishment of a baseline for species current status, against which to measure impact, should be an urgent priority.

8.2.2 Distribution of threats to African freshwater species

Across the five newly assessed freshwater groups, 21% of species were classified as threatened, according to IUCN Red List Categories and Criteria. The level of threat is highest for mollusc species (29% threatened) and lowest for odonates (9% threatened) (Table 8.2).

Documenting threats is important for the Red List, not just for assessing species' status, but also for guiding appropriate conservation action. Previous chapters provide a detailed discussion of threats to the five taxonomic groups assessed. Currently, spatially explicit data on the location of threats is not collected as part of the Red List assessment. By examining the distribution of species that are threatened, and identifying where high numbers of species or a high proportion of the total species are threatened, we attempt to identify priority areas for further research and conservation action. For each sub-catchment, analysis was limited to the main threats identified for African freshwater species, these include water pollution through agriculture, logging, water extraction, habitat loss due to agriculture, harvesting for food at subsistence level, infrastructure development, mining, sedimentation, and invasive alien species. The importance of threats varies between taxa, so in some instances we describe patterns based on a subset of species in order to highlight areas of particular concern, whereas in other instances our analysis is based on combined data for all groups.

Table 8.2. Summary of the IUCN Red List Category classifications at the global scale by taxonomic groupings. Data current from the IUCN Red List September 2010. Subsequent revisions may lead to changes in the status of species which will be refelcted by changes in these statistics.

Taxonomic group	EX	EW	CR	EN	VU	NT	LC	DD	% Threatened
Crabs	0	0	2%	9%	12%	2%	55%	20%	23%
Fishes	0.1%	0%	4%	5%	13%	3%	57%	19%	22%
Molluscs	3%	0%	9%	12%	7%	6%	34%	30%	29%
Odonates	0	0	2%	9%	12%	2%	55%	20%	9%
Plants	0	0.2%	6%	5%	13%	8%	49%	18%	25%

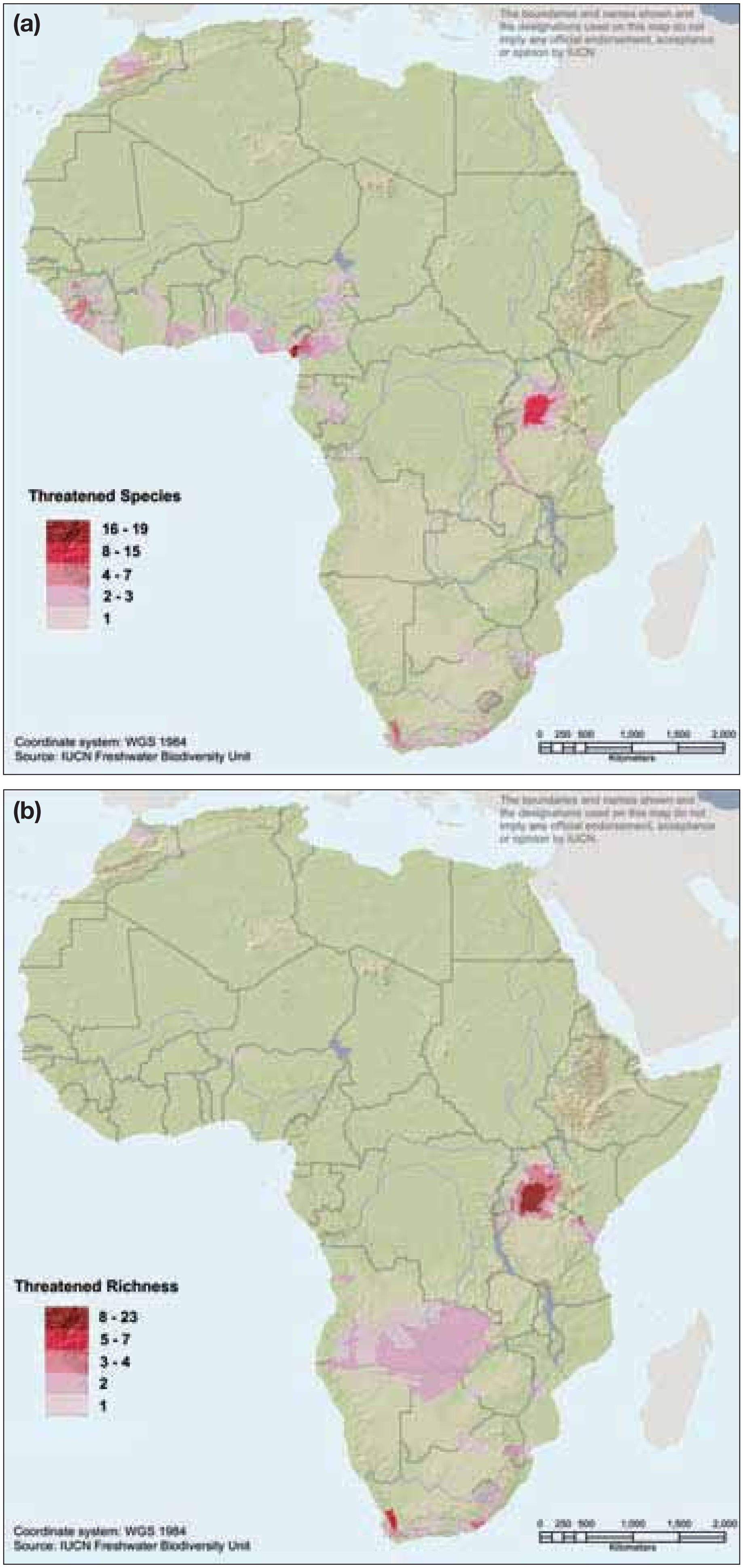
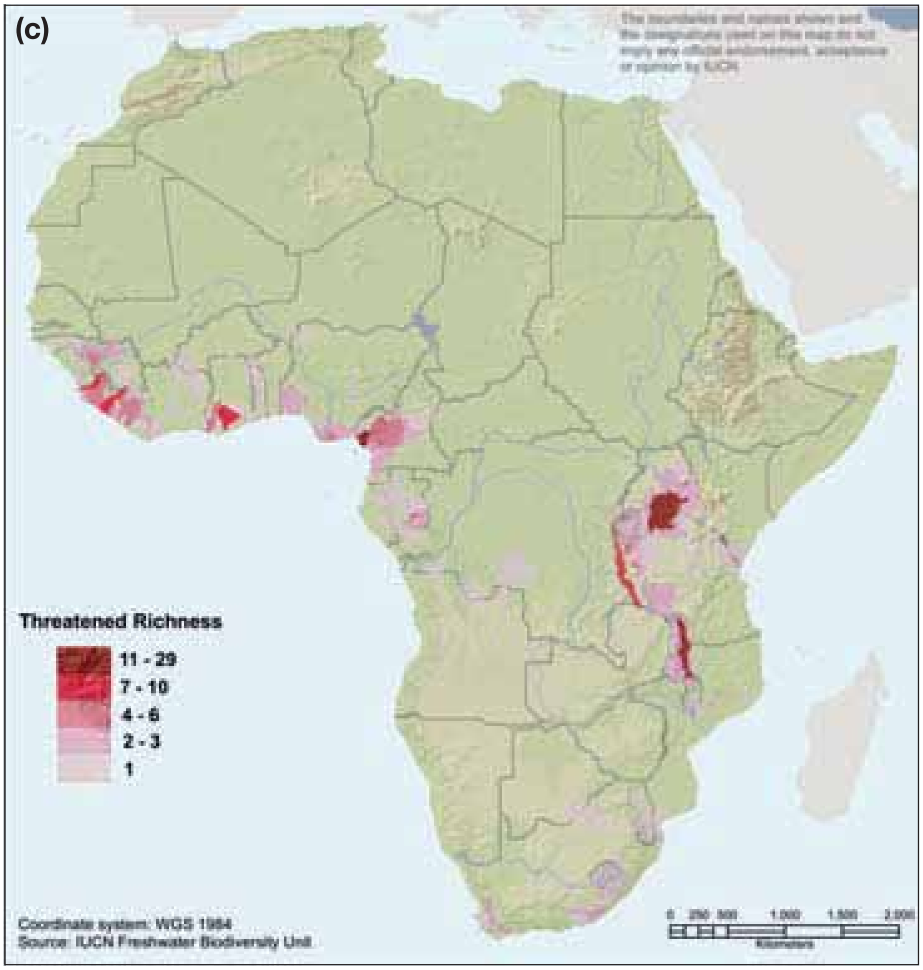


Figure 8.5. The number of fish species classified as threatened due to: (a) agriculture; (b) invasive species; and (c) sedimentation. ***Threatened richness = number of threatened species per river/lake sub-catchment.***

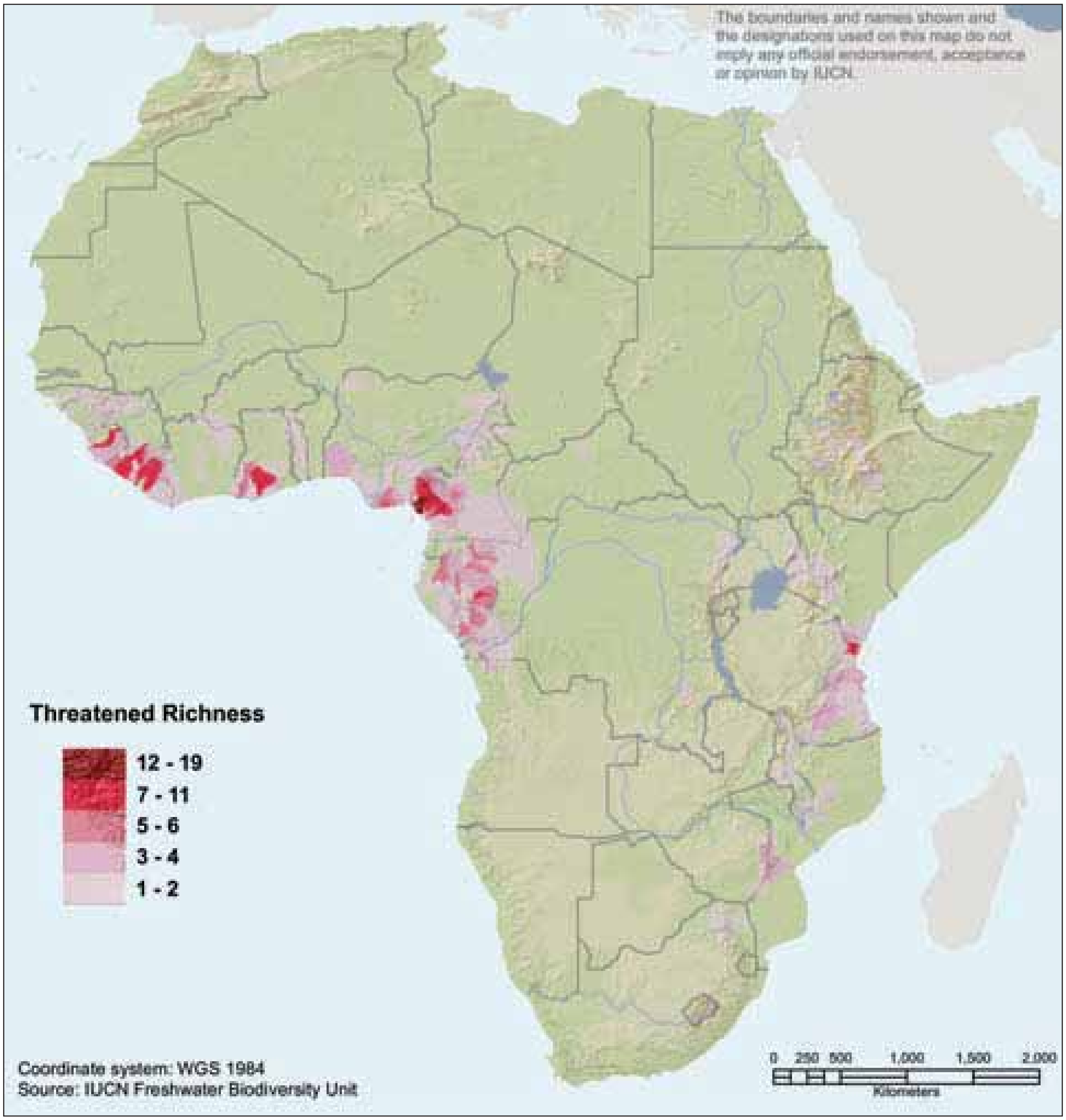


Results of the analysis show that major concentrations of threatened freshwater species occur along the Mediterranean and Atlantic coasts of Morocco, Algeria and Tunisia, the Upper and Lower Guinea, southern and eastern South Africa and the Great Lakes in eastern Africa. As such, these areas represent priority regions for conservation. Lake Victoria stands out as hosting a remarkably high number of threatened species with its unique fish fauna being of particular concern. Lake Victoria has been dubbed 'Darwin's dreampond' as it represents the world's most spectacular demonstration of evolution, as just a handful of fish have diversified into many hundreds of species, possibly over a period of just 15,000 years, meaning that a new species arises on average every 30 years (Spinney 2010).

Thirteen species, representing 2% of the total fish diversity across the continent, are threatened due to water pollution from agriculture (Figure 8.5a), 23 species (4% of the continent's total fish diversity) are under risk of extinction due to invasive species (Figure 8.5b; but see Chapter 1, Box 1.1 Is Nile perch a scapegoat?), and 29 species (5% of the continent's total) are threatened due to sedimentation (Figure 8.5c). The changes seen in Lake Victoria over the past decades are of particular concern, due to the importance of inland fisheries for the people of Africa. Freshwater fish form a vital component of the diet of many people in sub-Saharan Africa. There is growing evidence of a decline in the health of some of the largest fisheries across Africa (Dugan *et al*. 2010). Our analysis indicates significant pressures on species in the Great Lakes region, with many fish from Lake Victoria and Malawi threatened by over-harvesting. Lake Kivu holds a high richness of restricted range freshwater fish known to be threatened by harvesting for subsistence, including seven *Haplochromis* species: *Haplochromis crebidens, H. occultidens, H. olivaceus, H. paucidens, H. rubescens, H. scheffersi* and *H. vittatus*.

Agriculture represents one of the most significant threats to aquatic systems globally. This represents an interesting trade-off for management of catchments, as increasing land based food production by the application of fertilisers and pesticides can have a negative impact on the harvest of food species from freshwaters within the catchment. In the Lower Guinea, species are particularly threatened by the negative impact of activities such as intensive land use and pollution from rubber, banana, and palm oil plantations. Up to 29 species are recorded to be impacted by habitat loss from agriculture (21 threatened), and all the threatened species are affected by water pollution arising from agricultural activities. The eastern slopes of Mount Cameroon (Upper and Middle Mungo River) is an area where high numbers of threatened and restricted range

Figure 8.6. The total number of species for the five groups classified as threatened by deforestation. ***Threatened richness = number of threatened species per river/lake sub-catchment.***



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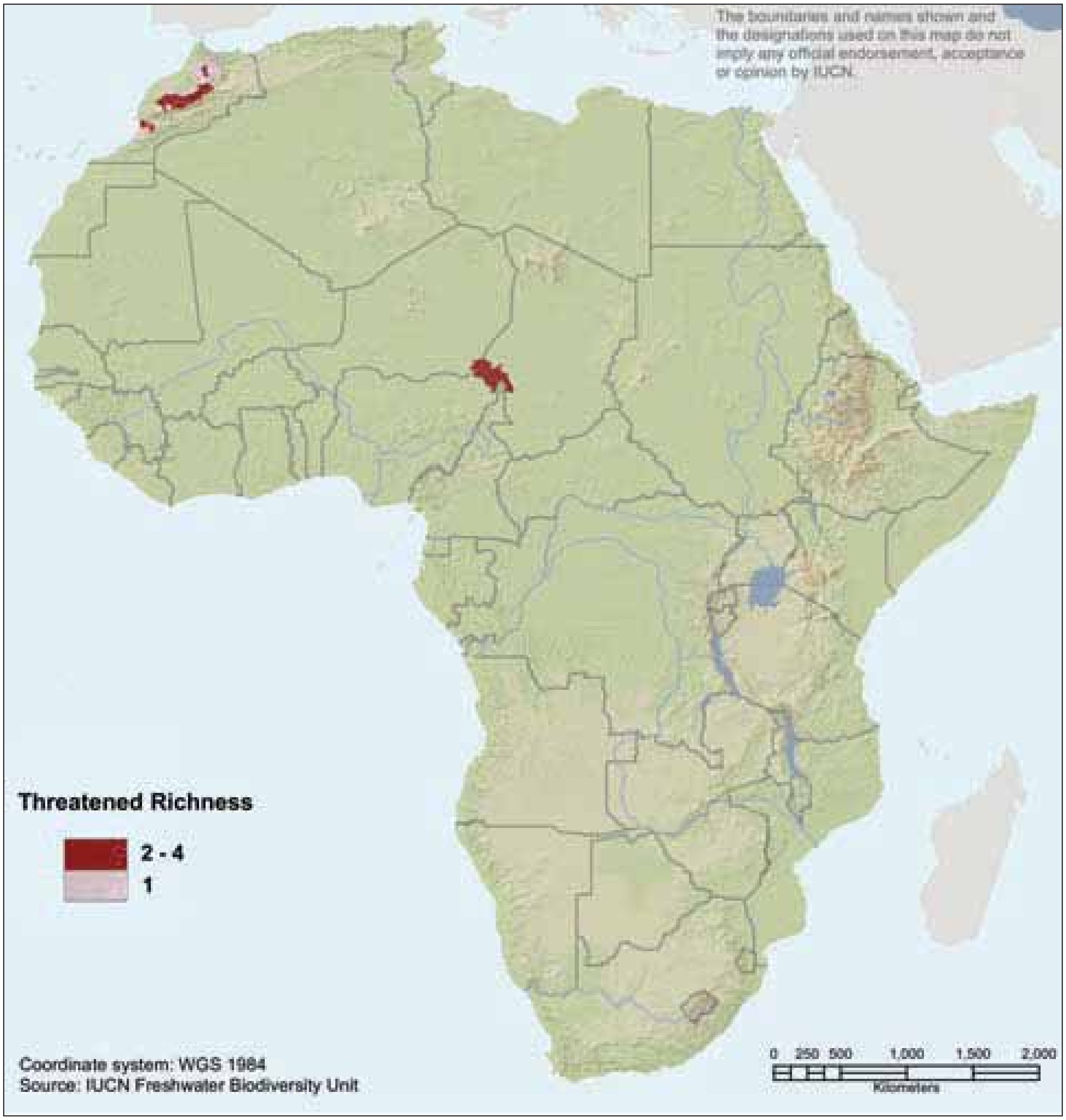
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

species can be found, including up to 21 restricted range and threatened freshwater fish impacted by habitat loss due to agriculture. The Olifants River basin in Western Cape region also holds particularly high numbers of restricted range fish and odonata threatened by intense agricultural activities, including citrus, deciduous fruit and vineyard development.

One of the most complex threats to species, both freshwater and terrestrial, arises through deforestation. Rates of deforestation across Africa are amongst the highest in the world, driven by the interplay of economic, institutional, technological and demographic factors (Geist and Lambin 2002). The loss of tree cover and associated disturbance of the catchment can have profound affects on the functioning of freshwater systems, including changes to biogeochemical processes, hydrology and thermal regimes (Allan 2004). As illustrated in Figure 8.6, deforestation threatens high numbers of species in coastal western Africa and along the eastern coast of Mozambique and Tanzania. In western Africa, deforestation, as a result of agriculture expansion, is widespread along the banks of the Volta River at Akosombo in Ghana and in Niger. This is considered to be the region in tropical Africa where forests are disappearing at the fastest rate (FAO 1997). Deforestation associated with agriculture was identified as a principal threat to crabs and odonates in Upper Guinea and Mount Cameroon.

Figure 8.7. The total number of mollusc species classified as threatened due to water abstraction. ***Threatened richness = number of threatened species per river/lake sub-catchment.***

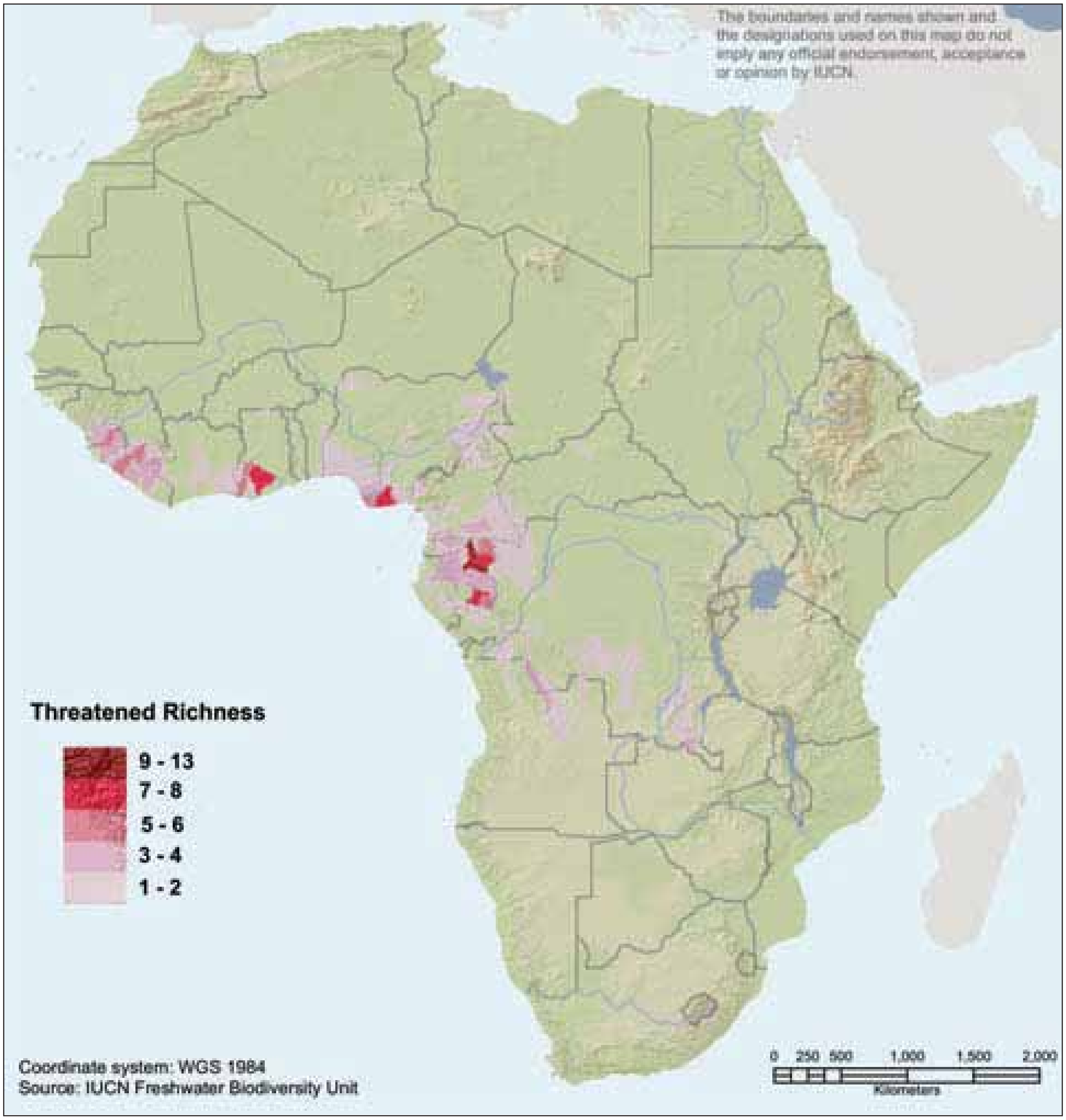


Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

Competition for water resources has become an increasingly prominent issue in recent decades and has, in some instances, resulted in armed conflict. Within such disagreements, the allocation of water for maintenance of aquatic biodiversity is rarely considered (Dudgeon 2006). Threats to biodiversity attributable to competition for water resources vary considerably across the continent (Vörösmarty *et al*. 2010). As illustrated using freshwater molluscs (Figure 8.7), water abstraction represents a major threat in the Atlantic Plains of Morocco, where many wells, which are the sole known habitat of some species, are at risk of drying out. Perhaps the most vivid example of pressure placed on water resources arises from Lake Chad, which has shrunk by an estimated 95% since

Rates of deforestation across Africa are amongst the highest in the world. Loss of tree cover from within a catchment can have a significant impact on downstream freshwater ecosystems. © JANE BOLES

Figure 8.8. The total number of species for the five groups classified as threatened due to mining. ***Threatened richness = number of threatened species per river/lake sub-catchment.***



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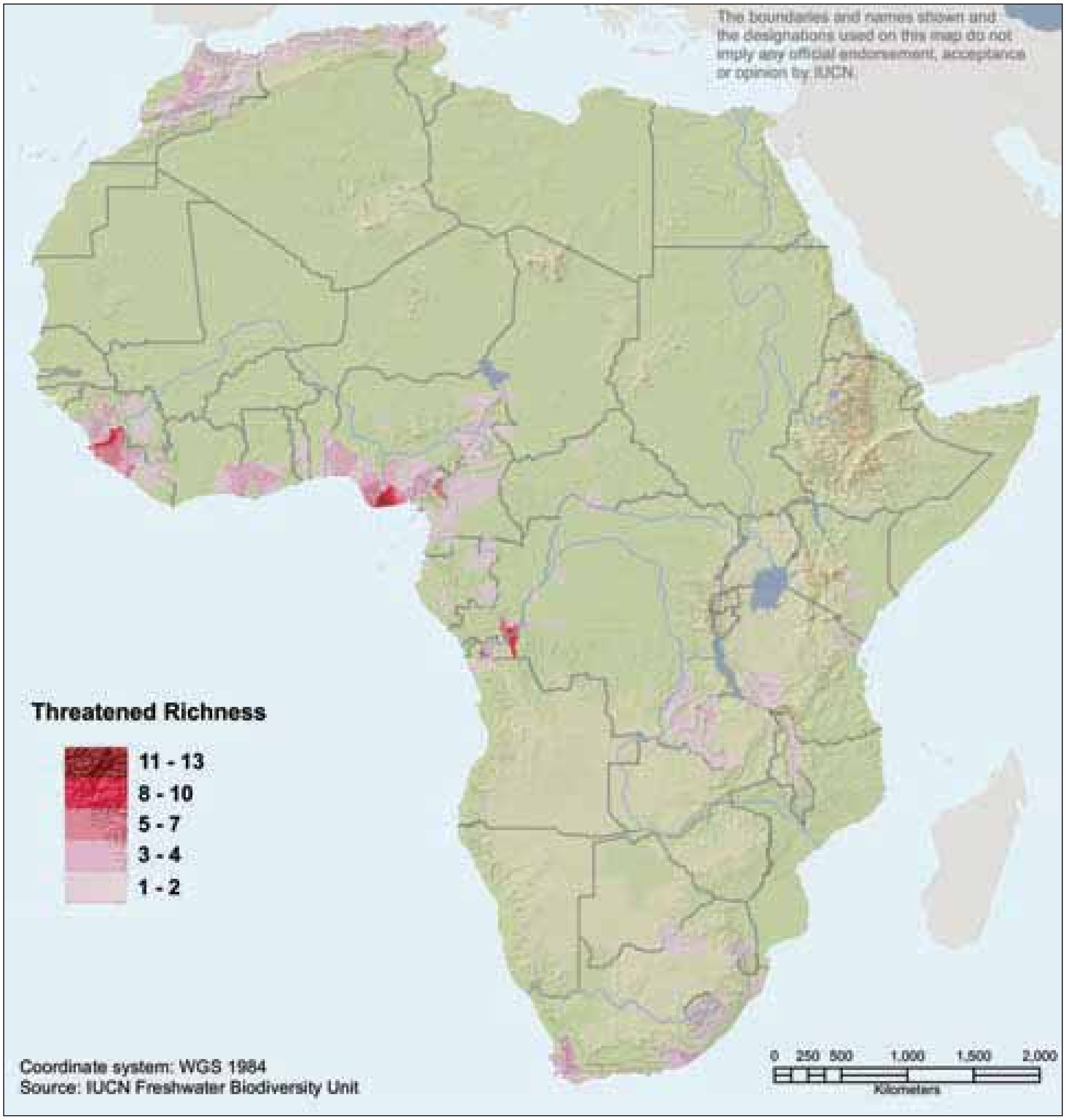
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

the mid 1960s due to water extraction for irrigation and changing rainfall patterns (Chapter 1).

In western Africa, exploitation of areas rich in mineral deposits has resulted in a concentration of threatened species within the Guinea Basin**.** In Nigeria, Ghana and Cameroon, open-pit mining activities for oil, aluminium (bauxite), gold and diamonds pose a threat to a number of species. Molluscs are particularly impacted in the highlands of the Nimba region, where the landscape has been intensely modified as a result of the economic value of the deposits. The impact that exploitation of mineral resources can have on species is reflected in the remarkably high numbers of freshwater species threatened in the Niger Delta (Figure 8.8). Oil exploration in the Niger Delta, together with water pollution from pesticides used in agriculture, is a major cause of threat for many restricted range species.

Construction of dams and other infrastructure development is a major threat to African species (Figure 8.9). Globally, river systems have been heavily fragmented by over 1 million dams, which act as barriers to migration for freshwater species and profoundly alter the characteristics of the river systems (Richter *et al*. 2010). Similarly, urbanisation profoundly influences the hydrology of catchments and can increase the level of pollutants that reach freshwater systems (Allan 2004). The rapid growth of large cities,

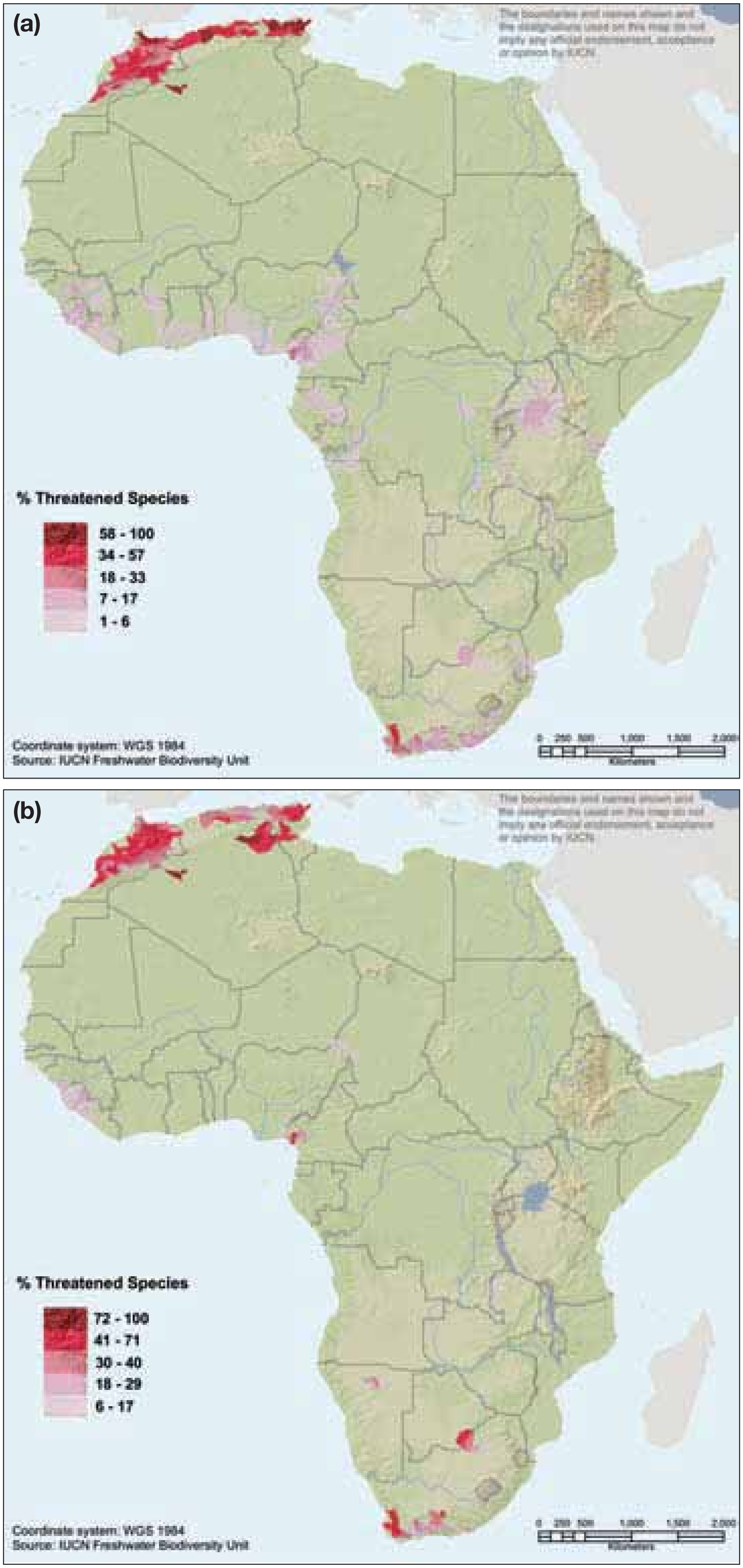
Figure 8.9. The total number of species for the five groups classified as threatened due to infrastructure development. *Threatened richness = number of threatened species per river/lake sub-catchment.*



such as Freetown and Monrovia, in the coastal zones of western Africa, and increasing urbanisation along the Niger Delta and the coastal plains of Sierra Leone and western Liberia, has created a hotspot of species threatened by infrastructure development. Similarly, urbanisation at the Pool Malebo, upstream of Kinshasa in D. R. Congo, threatens a number of freshwater fish species through sewage discharge and lead toxicity (Brooks *et al*. 2011).

In addition to consideration of the total number of species impacted by a specific threat, analysis of the proportion of species within sub-catchments that are threatened can provide useful insights into areas that are a high priority for conservation action, as illustrated in Figure 8.10. Based on this approach, the Maghreb region in northern Africa emerges as the area with the highest proportion of species currently threatened. This is a result of intensive agriculture activity, infrastructure development and water extraction impacting a comparatively limited fauna. Similarly, the impact of invasive alien species is seen to be particularly significant in the Cunene basin in Angola, the Atlantic plains of northern Morocco, the Lower Rufiji and Kilombero Rivers in Tanzania and the Niger in Mali, where a high proportion of the overall biodiversity is threatened. In those areas where overall biodiversity is low, the loss of a single species can have a significant impact on function within the ecosystem and so impact the goods and services provided by the regions freshwaters (McIntyre *et al.* 2007).

Figure 8.10. The proportion of species from all taxonomic groups threatened by: (a) water pollution; (b) water abstraction; (c) habitat loss due to agriculture; and (d) invasive species.



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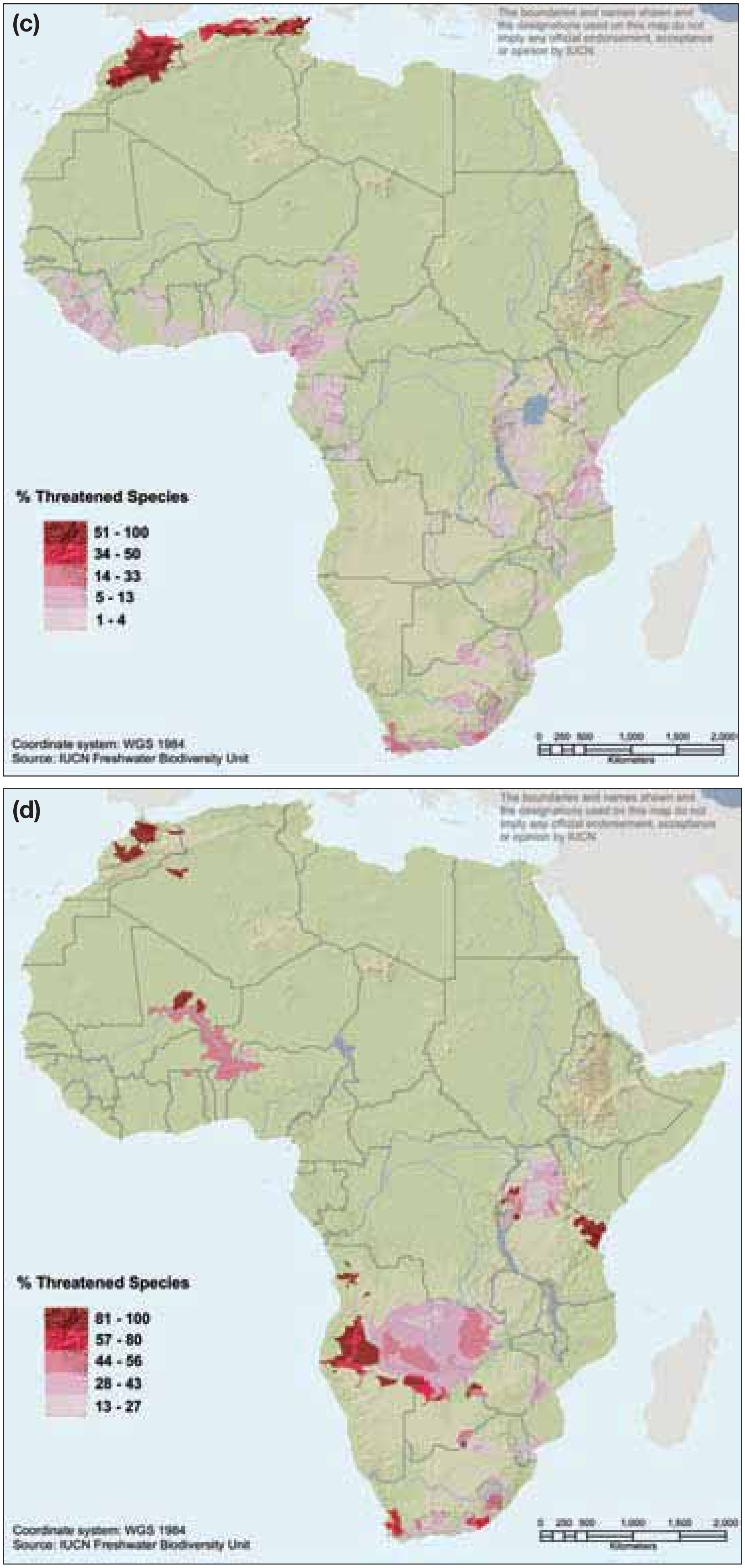
Source: IUCN Freshwater Biodiversity Unit


(c)
The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN
% Threatened Species
51 - 100
34 - 50
14 - 33
5 - 13
1 - 4
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit
0 250 500 1,000 1,500 2,000
Kilometers
(d)
The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN
% Threatened Species
81 - 100
57 - 80
44 - 56
28 - 43
13 - 27
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit
0 250 500 1,000 1,500 2,000
Kilometers

Roadside sale of Oreochromis *species, possibly* O. niloticus*, which has been widely introduced to systems outside its native range throughout Africa. The high commercial value of such species makes their control especially difficult.*

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8.2.3 Biological invasions affecting freshwater species in Africa

During the African freshwater assessments, invasive species emerged as one of the key threats to freshwater biodiversity. Invasive alien species are considered to be the one of the main causes of biodiversity loss globally. To illustrate the damage that such species can have on freshwater systems, we consider some of the most notorious examples from across Africa. However, before examining these cases in detail it is important to define what we mean by an invasive species.

Biological invasions are caused by alien (or exotic) species being introduced to a new habitat, where they become established, spread and cause damage to biodiversity (CBD Decision VI/23 2002). Biological invasion is always the result of an interaction between the incoming species and the habitat concerned – so it does not make sense to refer to species as an 'invasive' unless that interaction is causing damage of some kind to the recipient habitat, its species and its functions. It is particularly important when considering freshwater biodiversity in Africa to ensure that this definition refers to presence or absence in a *habitat* rather than the usual understanding of 'alien' or 'exotic', meaning not native to a *country*. This is because many African freshwater species are restricted to a single river system or a distinct habitat within a lake, and as such, are not native to many parts of the country in which they are found. Species can therefore become invasive within their country of origin if barriers to movement within the country are removed, for example, by linking water bodies or through the translocation of species to new areas; the species then colonises new areas, where it may damage the habitat and impact biodiversity.

Across Africa there are a variety of routes through which invasive species have entered freshwater habitats. Freshwater fish native to Africa, together with several non-African species, have been intentionally introduced to rivers, lakes and wetlands in order to enhance local fishery yields or to provide enhanced sport-fishing opportunities. More recently, as the aquaculture trade has expanded into almost every river and lake basin across the continent, escapes from fish farms have begun to represent a route for the entry of species into new habitats.

One of the most notorious examples found in African freshwaters is the Nile tilapia, *Oreochromis niloticus* (with at least two recognised sub-species and many genetically manipulated types and strains), which is still being promoted in its many forms as a highly productive aquaculture species: see Species in the spotlight – **Tilapia in eastern Africa – a friend and foe**. As an omnivore, the Nile tilapia is capable of causing serious damage to populations of essential aquatic plants, other species of fish and a range of freshwater invertebrates. It has hybridised with other (indigenous) *Oreochromis* species, further expanding its different forms and resulting in hybrids that are reportedly even more damaging than their invasive parent. Although it is argued by some that this species does not always become invasive (serious impacts to native biodiversity have been recorded in many cases), it is especially difficult to manage its spread in the wild, as it is such a highly-desired fishery and aquaculture species. Nile tilapia is the preferred food item in many parts of Africa (fresh, frozen, smoked or dried) and is the basis of an export industry in some countries and, as such, has some commercial value.

Another category of food item that has become a serious problem in the freshwater habitats of Africa is alien freshwater crayfish. Four species were introduced (intentionally and legally) to the continent several decades ago by fish farmers, and two of those (the Australian red claw crayfish, *Cherax quadricarinatus* and the American Louisiana crayfish, *Procambarus clarkii*) were then moved to other aquaculture farms, dams and lakes in southern and eastern Africa, where they have caused damage locally and escaped and infested river and lake basins. These two species have invaded some of the major lakes and rivers of Africa (for example, Lakes Victoria and Edward, the Semliki River, and the Nile and the Zambezi basins), and indications are that they will move to other areas, putting pressure on many endemic and threatened freshwater species. Both species are capable of omnivory and will hunt larval fish and fingerlings, other crustaceans, molluscs and insects, and devour aquatic vegetation. The Louisiana crayfish has altered the vegetation and invertebrate fauna of Lake Naivasha in Kenya (Clearwater *et al.* 2008) – assisted by a number of exotic fish, including bigmouth bass (*Micropterus salmoides*) and common carp (*Cyprinus carpio*). Both crayfish species are capable of travelling between watersheds, so their impacts may be much greater in the future unless their spread and invasion are curtailed. The principal reason for the success of these two species is the lack of endemic crayfish, meaning that they face no competition from within their own group, and only limited competition from native crabs.

Lack of competition has similarly contributed to the success of the tropical water hyacinth (*Eichhornia crassipes*) (Hill *et al*. 1998) that has been introduced into a continent that does not have any other species of large, free-floating aquatic plants. The species was introduced to Africa several times during the early 19th century as an attractive water plant, for its flowers, and because it gave a green covering to water bodies that early foreign settlers liked to see and imagined was reducing evaporation/water loss. This extremely invasive species has benefited from a lack of competition and absence of controlling pests and diseases, and has now infested most rivers and wetlands and almost every large water body in tropical Africa. Water hyacinth covers the water surface, leading to diminution of light and oxygen beneath, and consequently impacts local biodiversity from plankton to the largest fish and water plants. The presence of water hyacinth has the potential to alter freshwater habitats such that the balance of component plants changes significantly (Howard and Harley 1998). This, in turn, affects other freshwater organisms, which are now dominated by new complexes of vegetation and environmental conditions. A classic example is the ability of water hyacinth to form floating mats which can support riparian vegetation, such that a floating complex of sedges, grasses and other aquatic and semi-aquatic species forms ‘floating islands’ (different from the classic ‘sudd’ formations) which transport species to new localities, contain different invertebrates, create new refuges and niches for a range of aquatic organisms and, inevitably, disadvantage some endemic and threatened species. Water hyacinth was joined during the early to mid 20th century by three other free-floating alien aquatic plants from the American tropics – *Salvinia molesta, Pistia stratiotes* (which has been in some parts of Africa for much longer, but is not especially invasive) and *Azolla filiculoides*. These are also capable of forming floating mats, sometimes separately, sometimes in combinations of the three species, with similar (but not quite so severe) impacts as water hyacinth. There are many other examples of invasive aquatic plants, including submerged species, emergent species, floating-leaved species and riparian or semi-aquatic species. These plants can be effective competitors (for light, nutrients, space, and so on) in particular habitats and regions of Africa, and can affect native species of both freshwater flora and fauna through direct as well as indirect impacts, such as changed habitats and opportunities for new herbivores, diseases, and changes in water physical and chemical parameters.

*Introduced in the 19th century, water hyacinth (*Eichhornia crassipes*) has been able to occupy an apparently vacant niche (as a free-floating species), and has since become invasive throughout much of Africa.* © GEOFFREY HOWARD

*Freshwater crayfish, such as the Louisiana crayfish (*Procambarus clarkia*) (pictured here) have become invasive in many freshwater systems across Africa; in part due to lack of competition. These species are omnivorous and significantly alter the flora and fauna of areas that they colonise.* © G. HOWARD

Occasionally inundated floodplains and lake-edge and riverbank habitats are also susceptible to invasion by both semi-aquatic and terrestrial plants affecting native freshwater species. The invasive Australian black wattle (*Acacia mearnsii*) has altered the riparian vegetation of several streams in southern Africa so that the perching sites for several Odonata are no longer available. The Australian black wattle and other Australian acacias are now widespread in Africa and aggressively invade woodlands and other vegetation types in both production and conservation habitats and ecosystems. Subtle changes in habitats of many species can result in population declines or even extirpation, and this is especially so in the riparian zone, which often has a complex flora and fauna that is compressed into a narrow area close to the water. Across Africa there is one species of riparian and floodplain leguminous shrub in particular that has become invasive in many areas that affect freshwater biota. *Mimosa pigra*, sometimes called the giant sensitive plant, is a species of spiny shrub that probably originated in the tropical New World but has been recorded in Africa for several centuries. This species has become invasive in the last three decades in small and large floodplains and seasonally-inundated wetlands across the continent (Shanungu 2009). *M. pigra* can change from being a sparsely distributed riparian species to a dense, monoculture of tightly-packed tall shrubs (up to 5m high) sometimes covering several thousand hectares. It excludes all other plants from these thickets and prevents entry of most terrestrial and aquatic vertebrates, while supporting very few invertebrates as herbivores (a reason for assuming that it is indeed an alien species). Such a drastic change of aquatic and semi-aquatic habitat has already had deleterious impacts on a range of species, from semi-aquatic antelopes to floodplain fish and water birds, and is associated with an almost complete dearth of other species of plants. A closely related (and definitely alien) species of spiny shrub, *Mimosa diplotricha* (sometimes erroneously called *Mimosa invisa*), is also spreading in some riparian and floodplain areas and similarly becoming invasive – in at least two countries, the two mimosa species are competing for space on floodplains and other occasionally-inundated habitats. This New World species is already a serious problem in parts of Australia and Asia and could become an increasing threat to freshwater species of animals and plants in Africa. It is already threatening swamp and riparian reeds and sedges by growing over them, and is quite tolerant of extended periods of inundation.

Several species of alien molluscs (both bivalves and gastropods) have been recorded in African freshwaters and are probably having impacts on native species. But detailed information on the precise introduced species that may be affecting threatened and endemic species is rarely available (across most taxa), although there are a number of named examples within the project's regional reports. Even for well-studied invasive species, it is difficult to pinpoint the exact nature of negative impacts. But where threatened species are concerned, it is essential to make the connections more precise in order to gather enough information to predict and so prevent or manage future invasions, and so reduce the threat to native African species. This is the purpose of 'Invasion Biology', a young science that is slowly developing in a number of centres around the world. Finding solutions to freshwater invasions by alien species – especially those that are mainly submerged – is extremely difficult at present (Howard and Matindi 2003). Clearly, in aquatic situations it is extremely unwise to use chemical methods of control, and mechanical means are often unsatisfactory. Management of invasive species through utilization is tempting, but the simple process of using such species gives them an economic value and so reduces the chances of effective control. For alien plants, there are usually possibilities for biocontrol using agents (specific pests and diseases from where the invasive originates), and a number have been used and proven to be effective (Wilson and Garcia 1992). However, there is often official resistance to the introduction of yet more organisms, as there is often a fear that they will not be specific to the species they are designed to control. New ideas are slowly emerging for control using genetic manipulation and developmental and reproductive hormones for some aquatic animals (Kapuscinski and Patronshi 2005) – but this will take time. It is important, therefore, to understand the invasions that are presently affecting African biodiversity, to reduce the chances of spread, and to actively prevent further introductions to freshwater habitats without the requisite risk assessments and other checks and balances. Failure to do so may result in increased pressure on already threatened species and may lead to a deterioration of the conservation status of other species, as invasive species impact their habitat.

Mimosa species have become invasive throughout many wetlands systems in Africa, often forming dense monocultures which support few other species of plants or animals. © GEOFFREY HOWARD

8.3 Conservation action

8.3.1 Congruence between taxonomic groups

So far, we have considered patterns in species richness and the threats to freshwater biodiversity across the continent. We now consider how the rich freshwater biodiversity of Africa can be safeguarded and how current conservation strategies might be applied.

A central question in conservation biology is how well data collected for one taxonomic group represents patterns in another. High surrogacy between groups allows the most efficient allocation of resource for practical conservation work, and means that conservation planning for general biodiversity can be based on information collected for a single taxonomic group. Surrogacy for globally assessed taxonomic groups (for example, birds, mammals and amphibians) is generally reported to be high, meaning that conservation action based on the distribution of one of these taxonomic groups will confer benefits for others.

Overall patterns of species richness for fish, molluscs, odonates and plants exhibit reasonably strong correlations (Table 8.3), suggesting some surrogacy between these taxonomic groups. This is driven by broad scale geographic patterns (i.e., higher richness in the tropics) but is lower than has been reported between other taxonomic groups. The correlation between crabs and all other freshwater groups is low. From a practical perspective the strength of the relationships indicates that although differing taxonomic groups exhibit broadly similar large-scale patterns, they are not effective enough surrogates for each other to reduce the need for separate assessments.

The need for separate assessments is highlighted by weak relationships between richness of species classified as threatened according to the IUCN Red List (Table 8.3) for all five taxonomic groups. This lack of congruence presents a considerable challenge for conservation practitioners, as it indicates that investment in conservation for one group may not confer co-benefits for others.

Table 8.3. Spearman's Rank Correlation between total species richness and threatened species richness. Significance at the 5% level was assessed using Dutieuls correction to account for spatial autocorrelation.

		All species	Threatened species
Crabs	Fish	0.55***	0.18***
Crabs	Molluscs	0.48*	0.12***
Crabs	Odonates	0.35	0.19***
Crabs	Plants	0.48	0.09
Fish	Molluscs	0.71***	0.14***
Fish	Odonates	0.67***	0.16***
Fish	Plants	0.68	0.24
Molluscs	Odonates	0.67*	0.13***
Molluscs	Plants	0.72	0.08
Odonates	Plants	0.86	-0.03

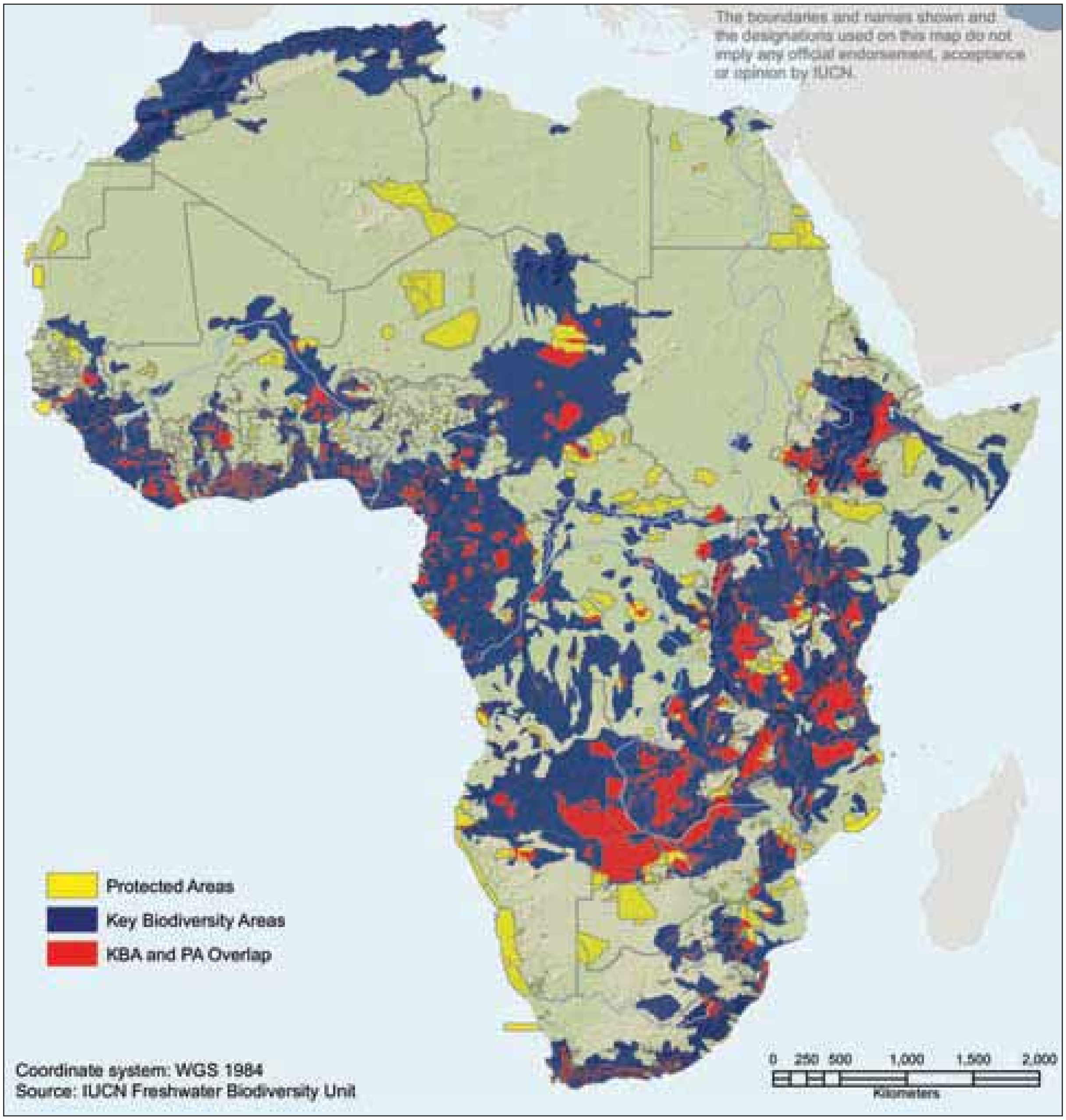
8.3.2 Protected areas for freshwater ecosystems

Faced with threats to biodiversity from broad scale drivers, such as habitat loss and degradation, the emphasis of conservation action has shifted in recent years from one based on targeting individual species towards the establishment of protected areas that address broad scale threats by managing areas of land for multiple species (Langhammer *et al.* 2007; Gaston 2008). With the exception of Ramsar Wetlands of International Importance, the designation of protected areas has rarely been targeted towards freshwater species such as fish or invertebrates. Most commonly, sites are identified based on our knowledge of the conservation status of better-known groups, such as bird, mammals and amphibians (Brooks 2004). There is also a bias in the location of protected areas towards sites that are at high altitude and are far from population centres, as protection of these areas is easier, given the limited societal demands upon them (Joppa 2009). For these reasons, two important questions arise for freshwater species. Firstly, how inclusive is the current protected area network for inland waters of Africa, and secondly, are there significant gaps in its coverage for freshwater species?

Analysis based on data from the World Database on Protected Areas (IUCN and WCMC 2010) suggests that 10.21% of the river network across continental Africa falls within an existing protected area. This is below the 13.95% of the total land area within the protected area network, and does not take into account the fact that rivers are often used as boundary markers to delineate the borders of reserves. Similarly, this figure does not provide an indication of whether management within protected areas includes a consideration of freshwater habitats. Nel (2008) found that in South African National Parks, 50% of river systems within the parks were considered to be in a poor state. However, 72% of rivers outside parks were considered impacted, suggesting some benefit of parks to freshwater systems. These results indicate that, although some benefit may come to freshwater habitats, management of protected areas most often focuses primarily on the terrestrial environment.

Using the distribution of species classified as threatened, results show that protected areas are congruent with freshwater species of conservation concern across only 4.90% of the total river network. We found that 13.8% of freshwater species fall entirely outside the protected area network, including 188 species classified as threatened

Figure 8.11. Distribution of protected areas, areas identified as potential freshwater Key Biodiversity Areas, and the overlap between the two.



(Table 8.4). This is particularly worrying for the 30 species classified as Critically Endangered where, in addition to falling outside a protected area, in many cases no known conservation measures are in place.

Table 8.4. Shortfall in conservation planning for freshwater species. Number of species in each Red List category falling outside existing protected areas.

Taxa	CR	EN	VU	NT	LC	DD
Crab	1	3	0	0	1	5
Fish	7	16	124	1	215	147
Mollusc	22	12	3	0	1	24
Odonata	0	0	0	0	5	8

8.3.3 Key Biodiversity Areas for freshwater species

Key Biodiversity Areas (KBAs) are one of the primary tools developed to detect and close gaps in the existing protected area network (Langhammer *et al.* 2007). KBAs are sites of global significance for conservation, identified using globally standard criteria and thresholds based on the 'vulnerability' and 'irreplaceability' of species. Here, vulnerability refers to the likelihood that a site's biodiversity values will be lost in the future, and irreplaceability refers to the spatial options for conservation that will be lost (Langhammer *et al*. 2007). The methodology for the identification of KBAs has been developed and successfully applied to identify the most important sites for the conservation of other taxonomic groups, such as birds and plants.

Based on data collected during this assessment, the IUCN Species Programme's Freshwater Biodiversity Unit has developed site selection criteria and thresholds for the identification of freshwater KBAs. Some 2,305 sub-catchments across continental Africa meet the selection criteria as potential freshwater KBAs. The number of sites qualifying is a clear reflection of the conservation status of the continent's freshwater habitats and associated species.

Freshwater KBAs are delineated based on sub-catchment boundaries. As previously discussed, freshwater systems are unique in that they occupy the lowest point in the landscape, so to protect biodiversity it is essential to consider management in this broader context. The form that this management takes may vary considerably, dependent on both the vulnerability and irreplaceability of species present, and the wider societal context. At the most basic level, all sites qualifying as freshwater KBAs would benefit from an ecosystem management approach (Christensen 1996) that legitimises freshwater species as users of the water resource and manages the catchment in a sustainable way. For areas containing species of the highest conservation concern, more strict protection can be applied in line the IUCN Protected Area criteria (Dudley 2008).

Analysis of congruence between existing protected areas and sub-catchments identified as potential freshwater KBAs found that 21.30% of the total area of these priority sub-catchments falls within the protected area network (Figure 8.11). Uneven sizes and distributions of existing protected areas mean that coverage in some regions is far more comprehensive than in others. For example, existing large protected areas in northern Botswana, across Zambia and in south-east Angola provide good coverage of the Okavango Delta. This contrasts with areas such as the Central African Republic and Senegal, where there is little overlap between existing protected areas and potential freshwater KBAs, and countries in western Africa, where a highly fragmented network of protected areas makes understanding the relationship complex. In all cases, however, for freshwater species to gain maximum benefit from inclusion within a protected area, management must include a greater focus on the requirements of freshwater ecosystems, with adequate consideration of longitudinal and lateral connectivity (see Chapter 9).

8.3.4 Alliance for Zero Extinction – AZE sites

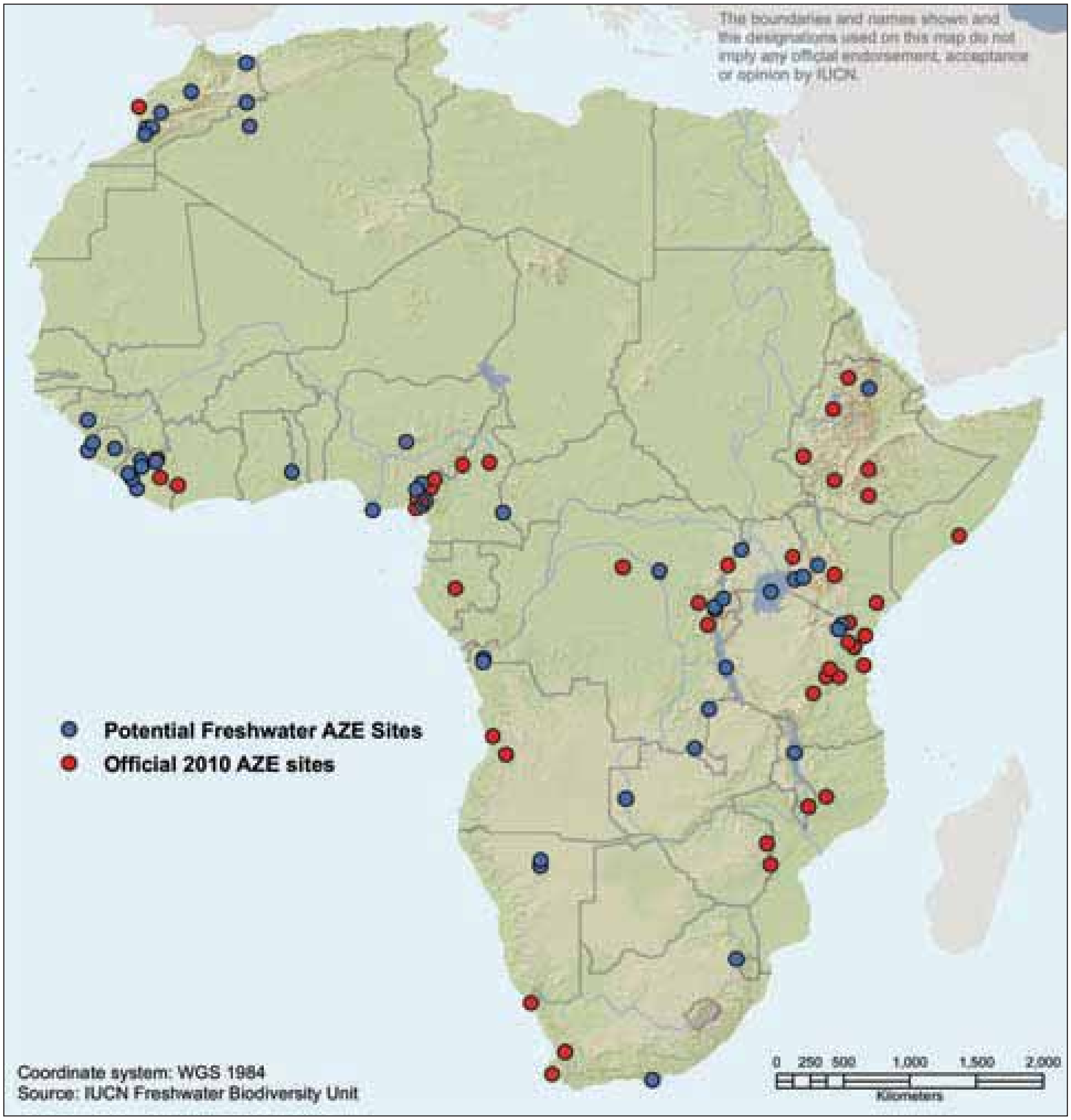
The Alliance for Zero Extinction (AZE) includes membership of 70 non-governmental organizations around the world dedicated to the prevention of human-caused extinctions. In 2005, AZE first identified 561 sites around the world that deserved immediate conservation action in order to prevent the extinction of 779 species. These sites hold the last remaining population of a Critically Endangered (CR) or Endangered (EN) species, according to the IUCN Red List, and if not safeguarded, the loss of these sites would lead to the global extinction of one or more species. In 2010, the analysis was updated based on new species assessments and improved information, resulting in 587 sites that hold the last remaining populations of 920 CR or EN species. Eighty two of these sites, associated with 141 of these species, are located in the African continent.

AZE sites can be seen as subsets of KBAs, where qualification is based on three strict criteria. Firstly, the site must contain at least one Endangered or Critically Endangered species. Secondly, the site is irreplaceable, as the species either occurs nowhere else on earth or a significant proportion of the species population occurs there, either permanently or at some point in its life history. Thirdly, the site must have a definable boundary within which the character of the habitats, biological communities, and/or management issues have more in common with each other than they do with those in adjacent areas.

To date, the AZE analysis has focused on species groups that have been globally assessed in entirety: mammals, birds, amphibians, turtles and tortoises, iguanas, crocodilians, corals, and conifers. The completion of this assessment of many of Africa's freshwater species provides AZE with an interesting and exciting opportunity to analyze at least the African species that may qualify for AZE status, and identify AZE sites for those species.

For freshwater species, especially those in rivers, the third criterion makes designation of AZE sites difficult, as river systems by their very nature are connected with the surrounding landscape. In a preliminary analysis, we identified sites qualifying for designation under the AZE criteria based on the occurrence of Critically Endangered or Endangered species within a single sub-catchment. Using these criteria, 134 fish, five odonates, 39 mollusc and seven crabs would trigger AZE site designation. In a number of cases the justification for site designation is clear. For example, the Critically Endangered cave catfish (*Clarias cavernicola*) is known from a single pool in Angola measuring 18m by 2.5m, where ground water abstraction and collection for the aquarium trade threatens the species. Similarly, in northern Africa a number of molluscs such as *Iglica soussensis* (CR) and *Giustia saidai* (CR) are known from single wells, where water abstraction is leading to population decline. Species such as these are restricted to incredibly small areas that would benefit from immediate conservation action. The situation becomes more complicated for species where the area occupied is not as easily defined, for example, *Austroglanis barnardi* (EN) is a fish endemic to three tributaries of the Olifants river whose range has extended at certain times into the main river channel. Unsustainable water abstraction has, in recent years, caused this area to dry up, leading to fluctuations in the distribution of the species.

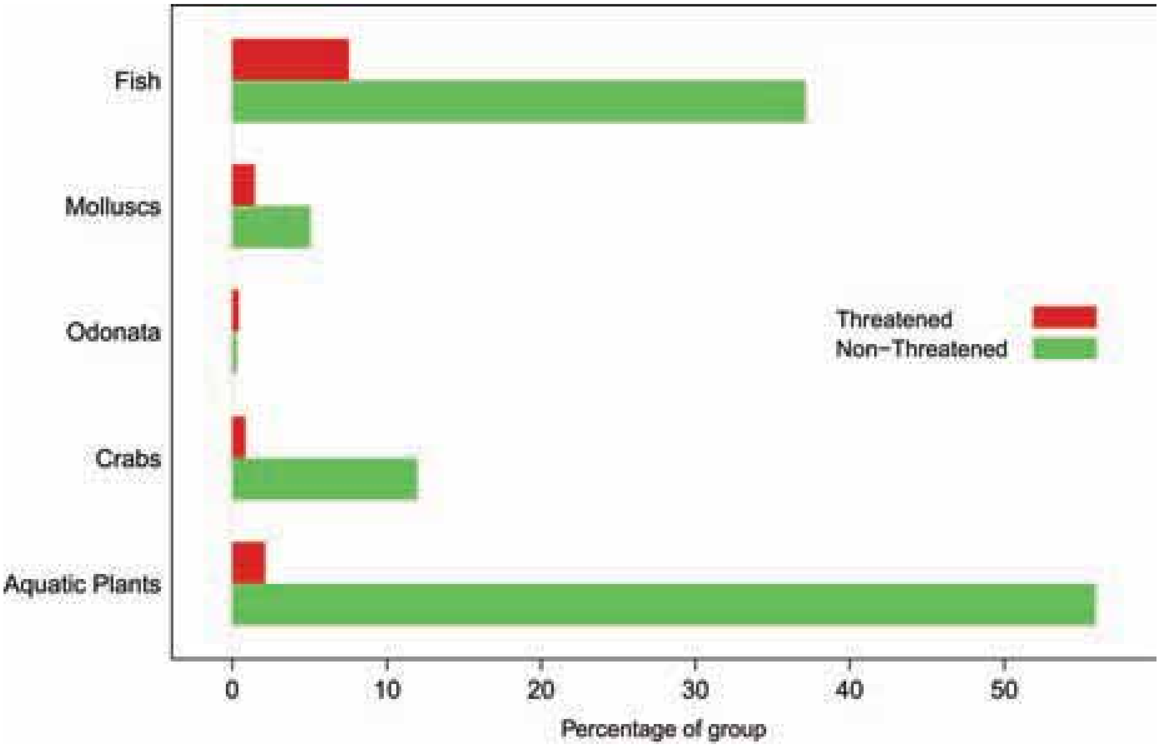
Figure 8.12. Existing Alliance for Zero Extinction sites and those proposed as a result of the freshwater assessment.



While not yet officially approved, given the need for review by external experts during the next AZE update, the freshwater species data suggest that the network of AZE sites in Africa would be expanded significantly upon their incorporation. Figure 8.12 shows the 82 official 2010 AZE sites in Africa in red, with an additional 48 potential AZE sites identified for freshwater species in blue. Only one potential freshwater AZE trigger species fell within an already designated 2010 AZE site (at Bakossi Mountains), and this is shown in red with a blue outline.

If we as a global community are serious about achieving Target 11 of the Convention on Biological Diversity, which in part aims to prevent the extinction of species through 2020, then we need to focus conservation actions urgently on these sites that, if lost, would result in extinctions. Additionally, safeguarding these urgent sites for freshwater biodiversity conservation will not only benefit the target species, but also provide a range of other benefits. Even when only considering AZE sites for terrestrial species, Larsen *et al*. (in prep) have shown that protecting these sites would provide disproportionate benefits to human well-being, e.g. in terms of contribution of freshwater services to humans. Given that inclusion of freshwater biodiversity in a provisional draft analysis of AZE qualification results in at least 136 additional species and 48 additional sites (nearly doubling the number of trigger species in Africa and increasing the number of sites by 50%) in Africa alone, it is an urgent priority for AZE to incorporate these new data into new assessments.

Figure 8.13. Percentage of assessed African freshwater species utilized by people.



8.4 Livelihoods dependence on freshwater species

Freshwater species have been utilized by people throughout history, and continue to form an integral component in the livelihoods of millions of people in Africa (see Chapter 1, Section 1.3). Species are relied upon directly for subsistence, as well as providing income and trade. Overall, the most heavily utilized taxa are the freshwater fishes and aquatic plants, with a total of 45% and 58% of all known species harvested, respectively (Figure 8.13). Within the harvested species, 72% are exploited for human consumption; however, the proportion of species that are consumed is highly variable between taxonomic groups (Figure 8.14).

Figure 8.14. Use of freshwater species by people in Africa

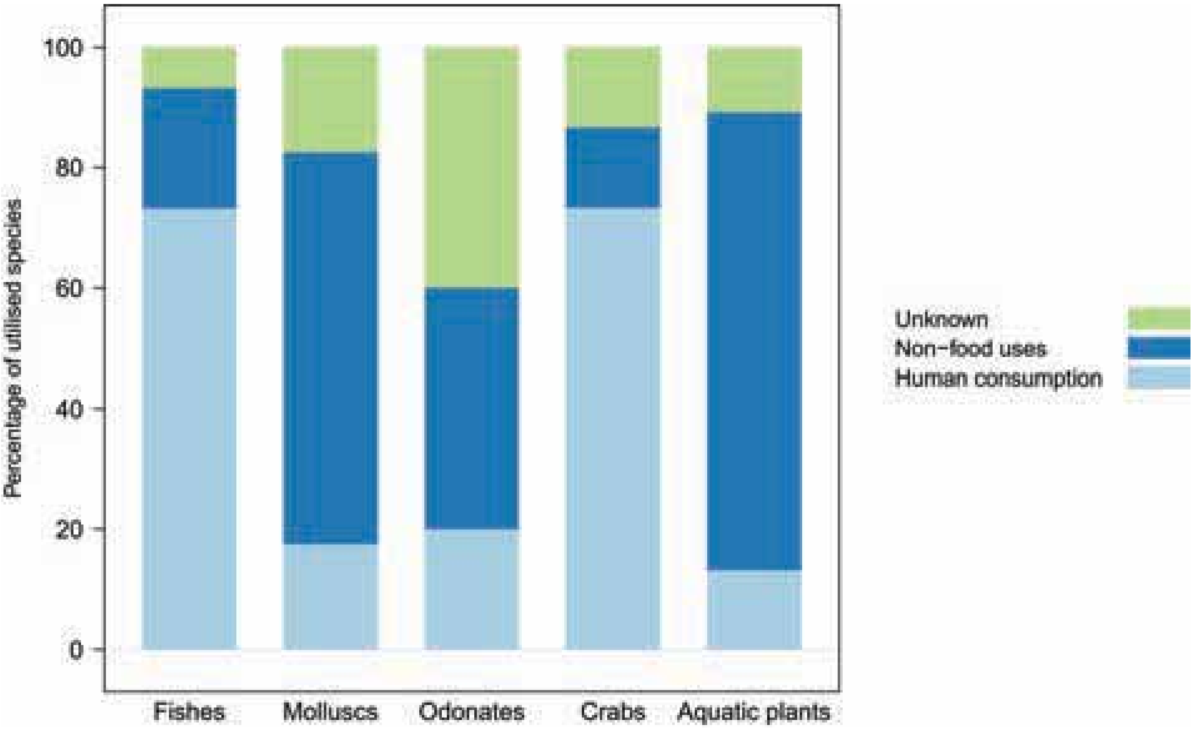
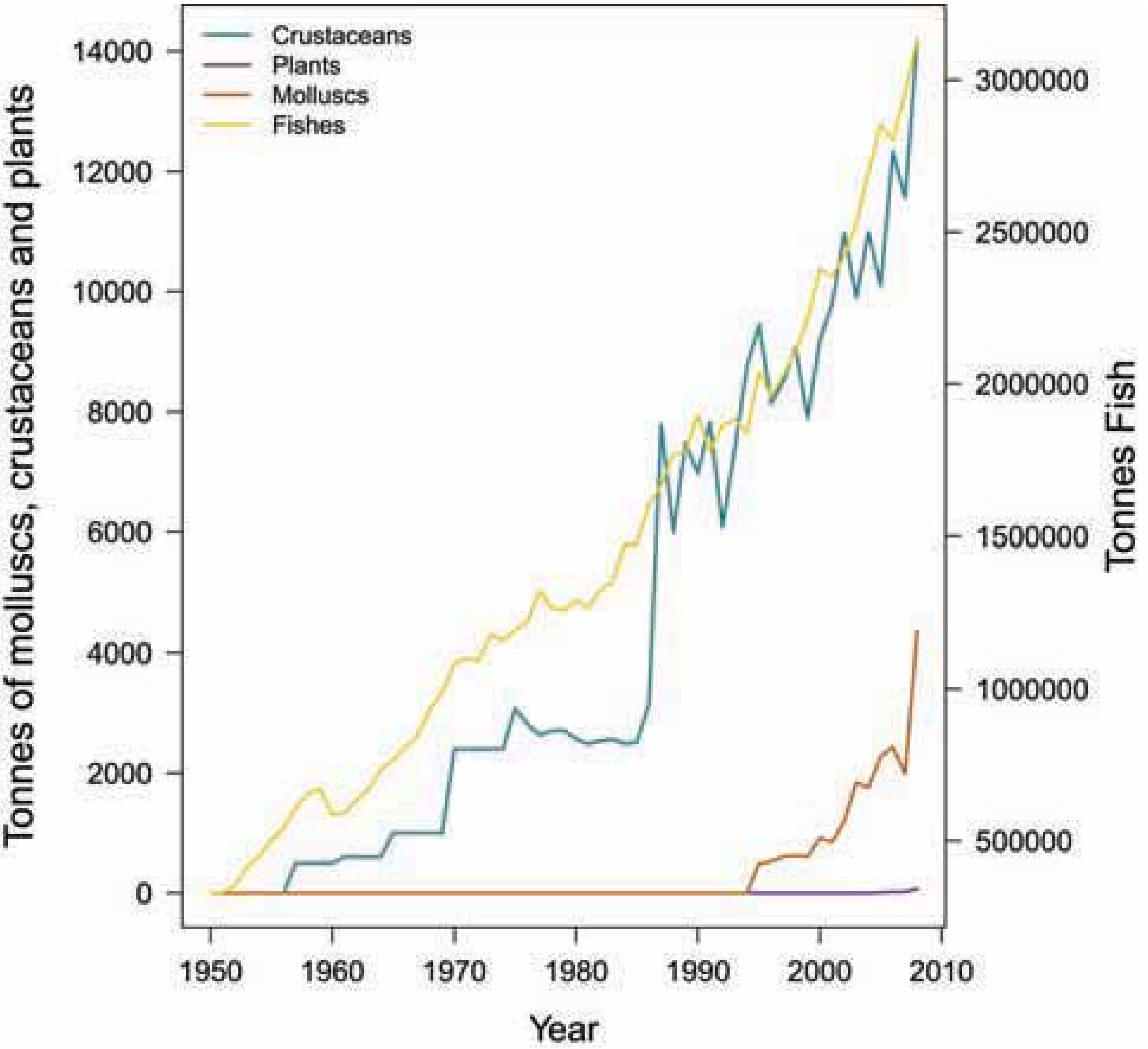


Figure 8.15. Total reported harvest (in tonnes) of freshwater species in Africa over last 60 years. Freshwater crustaceans, molluscs and plants plotted on left hand axis, fishes on the right. Source: FishStat 2010.



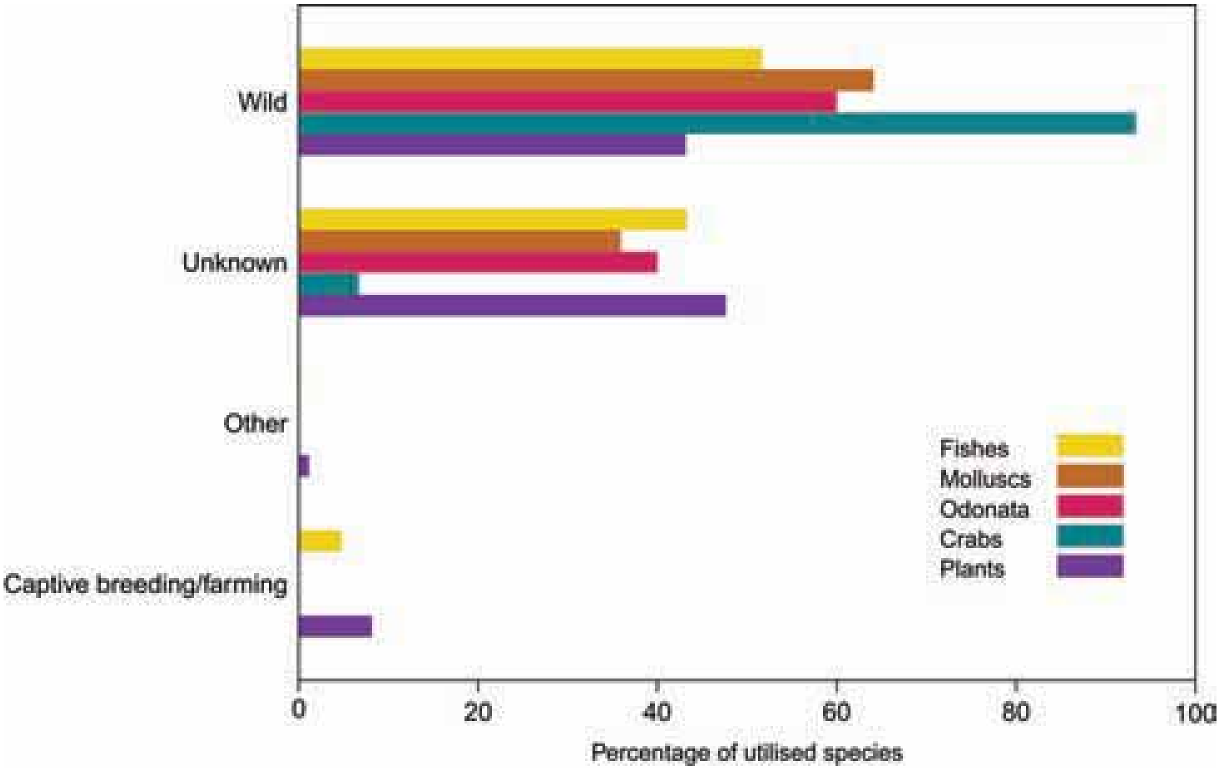
Fishing contributes greatly to many people's livelihoods in Africa. Here a fisherman repairs his nets in Mozambique.

© WORLD BANK PHOTO COLLECTION

Despite advances in, and expansion of, agriculture, inland waters are as important today as they ever have been for supporting livelihoods. In Africa, the total annual fishery production for freshwater fishes, molluscs, crustaceans and aquatic plants is more than 3.4 million tonnes, accounting for 25% of the world's inland waters capture fisheries (FishStat 2010). Whilst aquaculture of fishes has been steadily increasing for decades, expansion of this trade has been more recent for molluscs and crustaceans, and floral aquaculture production was recorded for the first time in 2005 (Figure 8.15). Aquaculture is, in fact, now seen as the fastest growing food production sector globally (Kura *et al.* 2004).

These statistics emphasise the importance of freshwater species as a resource for millions of people within Africa, where they are often the only source of protein available to rural communities in developing countries (Kura *et al.* 2004). In Malawi, for example, inland fisheries account for about 70% to 75% of the total animal protein for low-income families (Millennium Ecosystem Assessment 2005). Although fishery production per person is comparatively low in Africa, at 2.1 tonnes per year, compared to 21.4

Figure 8.16. Source of utilized freshwater species in Africa.



tonnes in Europe and a global average of 3.3 tonnes (FAO 2008), this indicates the low level of industrialisation of the trade and the key role played by small-scale fisheries. The majority of inland water catches across the continent come from subsistence and recreational fisheries and, as such, go largely unreported, with the FAO estimating that actual catches are likely to be two to four times as great as recorded (Kura *et al*. 2004). By underestimating the scale of utilization of freshwater species, these resources are greatly under-valued. The great danger that this poses is that small-scale needs are likely to be marginalised when conflicting interests compete over use of water resources (Kura *et al*. 2004). Ready access to freshwater fisheries provides a real lifeline to many rural communities, acting as a 'bank in the water', where local populations can harvest species for rapid income needs, as well as acting as a 'safety net' for communities in times of agricultural hardship (Béné *et al.* 2009; Dugan *et al*. 2010).

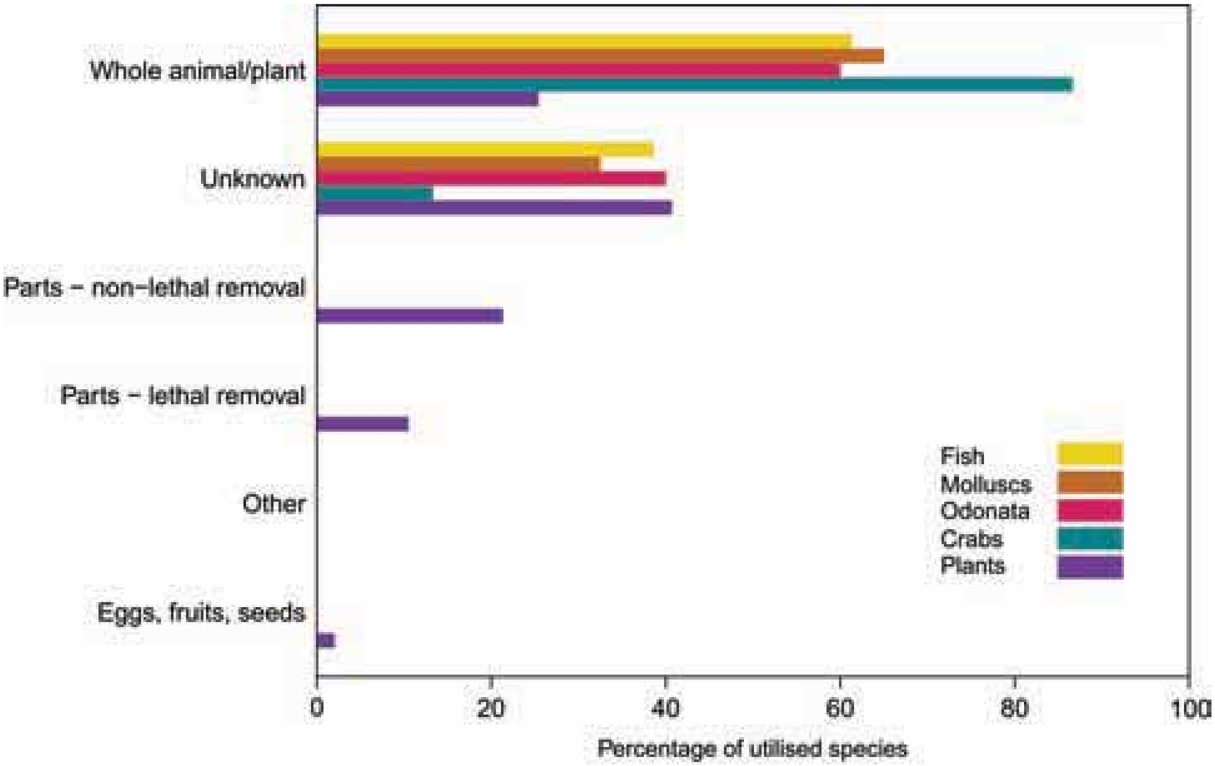
In addition to the direct benefits to fishers themselves, freshwater fisheries employ approximately double that number of people in the post-harvest sector. The fisheries industry provides employment to the rural poor and poorly educated, and to women, with 55% of small-scale fisheries workers in developing countries being female (Dugan *et al*. 2010).

The vast majority of freshwater species utilized in Africa are taken from the wild, or are of unknown origin (Figure 8.16). Use is predominantly lethal, as the whole organism is harvested (Figure 8.17); this includes species removed live for the aquarium trade, as they are no longer contributing to the wild gene pool. Currently, use of freshwater species is having a direct impact on the long-term sustainability of many wild populations in Africa. The requirement for sustainable management of these species is critical to their survival and for the continued provision of benefits to many dependent people.

Monitoring of species use within management units (that is, at the catchment and sub-catchment level) is important, not only to identify potential threats to the species concerned. In many cases, the Red List assessments could be improved with provision of catch data, such as has been used for some Lake Victoria fish species and for many species of sturgeon where fisheries statistics help to identify population trends.

Fishes: Fishes are not only the most speciose of the freshwater groups assessed here, but also the most utilized and depended upon. They provide a means of direct sustenance, as well as a means of income, particularly for the rural poor. Within Africa, 40% of known freshwater fishes are harvested, of which 81% are for human consumption. Three African countries are in the top 10 for global capture production in inland waters – Uganda, Nigeria and Tanzania. This highlights the particular importance of the large lakes for inland fisheries, with both Lakes Victoria and Chad being ranked among the highest for freshwater fish production in Africa. Uganda is among

Figure 8.17. Form of removal of utilized freshwater species in Africa.



the smallest of Africa's nations, yet currently claims the highest freshwater fish catch on the continent. These catches are largely from natural systems, but aquaculture is becoming a growing industry, and between 1970 and 2006, Africa showed the third largest growth in aquaculture globally (after Latin America and the Near East; FAO 2008). The five most cultivated species in Africa are: flathead grey mullet (*Mugil cephalus*), Nile tilapia (*Oreochromis niloticus niloticus*), 'torpedo-shaped' catfishes (*Clarias* spp.), Kafue pike (*Hepsetus odoe*) and North African catfish (*Clarias gariepinus*). By far the largest aquaculture production is in Nigeria (Table 8.5).

Although the industry is increasing and overall catches are getting larger, this is not an indication of healthy fish stocks; indeed the majority of Africa's fisheries are either fully- or over-exploited (Brainerd 1995). The effects are sometimes easy to see, as illustrated by the crash in fishery production in Lake Chad in the 1980s. Where species have been introduced, the overall impacts on the ecosystem may be masked by an overall increase in catch while dramatic declines of native species go un-noticed. In Lake Victoria for example, the introduction of Nile perch has created a multi-million dollar industry. However, 64 out of the 74 threatened cichlids are threatened by Nile perch, and 73% of these are now Critically Endangered and even Possibly Extinct (such as *Haplochromis dentex* and *H. flavipinnis*). With massive declines in traditionally fished species in Lake Victoria, and a more recent decline in Nile perch catches, other native species are escalating in importance (for example, *Haplochromis laparogramma*) particularly for local subsistence. These shifts in reliance

Table 8.5. Top five African countries ranked by inland aquaculture production in 2008 (source: FishStat 2010).

Country	2008 Aquaculture production (t)	Top cultured species
Nigeria	143,207	Kafue Pike, North African catfish, Cyprinids (nei), Torpedo-shaped catfishes (nei), Nile Perch (Lates niloticus)
Egypt	98,833	Flathead Grey Mullet, Nile Tilapia, Common Carp (Cyprinus carpio carpio), Torpedo-shaped catfishes (nei), European seabass
Uganda	52,250	Torpedo-shaped catfishes (nei), Nile Tilapia, Red-bellied Tilapia (Tilapia zillii), Common Carp, Nile Perch
Zambia	5,640	Nile Tilapia, Three spotted tilapia (Oreochromis andersonii), Longfin tilapia (Oreochromis macrochir), Redbreast tilapia (Tilapia rendalli), Common carp
Ghana	5,594	Nile Tilapia, North African catfish, African bonytongue

**nei – Not Elsewhere Included – Species groups where individual catch data was not collected at the species level.*

Oreochromis karongae *(EN), a heavily overfished, and highly valued, species endemic to Lake Malawi.* © GEORGE TURNER

between different species highlight the importance of maintaining a rich diversity of species that can adapt to changing pressures. The ability of ecosystems throughout Africa to adapt is becoming increasingly important as more become modified for human uses, and long-term changes are projected due to climate change (see section 8.6).

In Lake Malawi, 'chambo' (*Oreochromis* spp.) are the most valuable food fishes and, as a result, some species are being overexploited to the point where they have become threatened. *Oreochromis karongae* is one of three chambo species endemic to Lake Malawi, which is targeted for local subsistence as well as commerce. Populations of this species collapsed in the 1990s as a result of overfishing, with as much as a 70% decline in catches within a 10-year period, and it is now assessed as Endangered.

Other species are threatened through non-targeted fishing activities, particularly through the use of nets with small mesh sizes (for example, mosquito nets). These indiscriminate methods of fishing result in high by-catch, especially of fry, and may have a severe impact on some species, particularly in smaller lakes. Examples include *Alestopetersius nigropterus* (EN) in Lake Mai-N'dombe, *Garra regressus* (VU) in Lake Tana, and *Lamprologus tumbanus* (EN) in Lake Tumba. Some fishing practises still used in parts of Africa have an even wider reaching impact, such as the widely illegal practise of using poisons. Such methods are indiscriminate and may even degrade the underlying habitat itself.

Overfishing has been demonstrated to result in the process of 'fishing down the food web' (Pauly *et al*. 1997), whereby species occupying lower trophic levels are exploited as

Fishing provides an important food source for many people living in the Okavango Delta. © WILLIAM DARWALL

*The yellow-belly bream (*Serranochromis robustus jallae*) (LC), forms part of the fishing catch in the Okavango Delta.*

© WILLIAM DARWALL

those species at the apex are lost, or become commercially unprofitable as their numbers decline. This leads to an initial increase in the total catch, followed by stagnation and, in some cases, collapse of the fishery (Pauly *et al*. 1997; Allan *et al*. 2005). The resulting change in the food web structure can have a profound influence on the functioning of the system. For example, fish play an important role in nutrient cycling such that the loss of species can have a significant impact on primary productivity (Allan *et al.* 2005). Loss of species also reduces genetic diversity, so reducing the options for adaptation to a changing environment. Such impacts can have profound social consequences, as illustrated by recent archaeological evidence suggesting that collapses in freshwater fish stocks across Europe around a thousand years ago led to the shift from reliance on freshwater species towards exploitation of marine species, as we see today (Barrett, Locker and Robert 2004).

The second most common utilization of fish is for the aquarium trade, with 8% of freshwater fishes in Africa being collected. It is believed that over 90% of ornamental freshwater fishes can be bred successfully in captivity (Tlusty 2002), yet large numbers are still harvested from the wild. Eighty two per cent of species noted as being targeted for the aquarium trade in Africa are threatened, although over-harvesting for the aquarium trade is not currently thought a major threat. These species are more usually threatened due to their restricted range and local habitat degradation. Establishing a sustainable scheme for wild-harvested aquarium species has been proven to serve as a direct incentive for habitat preservation and conservation (for instance in Guyana), as well as providing local livelihoods (Bicknell and Chin 2007).

Molluscs: Mollusc collection has traditionally been a source of livelihood throughout Africa. For millennia, both bivalves and gastropods have been exploited for a number of reasons, predominantly for food, or as adornments. As well as being an important form of sustenance to some rural communities, molluscs often fetch high market prices in comparison to fishes, and even more so as items of decoration or jewellery. It is a particularly important industry for women, as the majority of mollusc collection in inland waters is by women and children and can be one of the few income-generating options open to women in rural communities.

Based on volume, the primary use of molluscs is for food (e.g., *Pila occidentalis* or *Mutela zambesiensi*). Molluscs are also commonly collected for animal feed, or as fishing bait (e.g., *Chambardia wahlbergi)*. Molluscs are not only harvested from the wild, but are also farmed. For example *Egeria radiata* is a freshwater clam endemic to western Africa, where it is found in the lower reaches of the Volta, Cross, Itu and Sanaga Rivers. It is easy to maintain, and in the Volta River alone it is believed that young clams have been transported into upstream fisheries for centuries, bringing in an annual harvest of 4,000 to 7,000 tonnes by the 1960s (Pople 1966). These fisheries (and populations of *E. radiata*) have diminished due to the construction in the 1960s of Lake Volta, the largest reservoir by area in the world. However, farming of this species continues elsewhere within its natural range, providing a locally important source of meat, producing up to 112kg/ha/yr (Pople 1966).

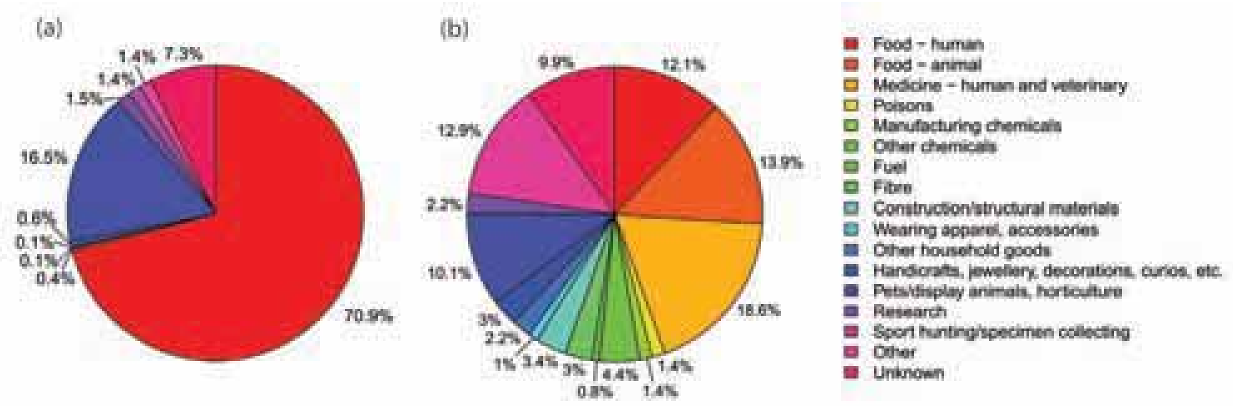
The form of use common to the greatest number of species is specimen collection. Rarer shells may be greatly sought after and can fetch a high price, particularly among enthusiasts. However, this market remains relatively small, and such activities are not thought to be having a major impact on species survival.

Mollusc shells and pearls are frequently harvested for use as jewellery and decoration. Although this is a common practise for many species, for some that are restricted in range this harvesting represents a major threat. Threats from this activity are particularly high in northern Africa, where species directly impacted by collecting include *Melanopsis letourneuxi* (EN), *M. magnifica* (EN), *M. mourebeyensis* (EN), *M. saharica* (CR), *M. scalaris* (EN) and *M. subgraëllsiana* (VU).

Odonata: Odonates are the only freshwater taxa assessed that are not regularly used by people. It is known that dragonfly nymphs are used as fishing bait, and in India they are specifically used as pest-control to reduce the numbers of mosquitoes in domestic water tanks. In Africa, only three species were recorded as being collected (*Aethiothemis bequaerti*, *Aciagrion africanum* and *Aeshna affinis*), but it is not known for what purpose.

Crabs: The importance of crabs as a source of food is often overlooked, as official fisheries statistics may tend to focus primarily on freshwater fish species. However,

Figure 8.18. Utilization of freshwater species in Africa: a) Freshwater fishes, molluscs, odonates and crabs; and b) Aquatic plants.



indirect evidence from infection rates of paragonimiasis (a food borne zoonosis) and other diseases for which crabs are intermediate hosts suggests that consumption of freshwater crabs is widespread throughout the world (Cumberlidge *et al*. 2009). Due to their size and biomass, crabs can represent an important source of protein, with research suggesting that for poor people living far from water resources there may be a heavier reliance on crabs and other aquatic animals than on fish (Neiland and Bene 2008).

Aquatic plants: Plants are commonly utilized throughout the world. As with other freshwater taxa, there is a rapidly growing market for plants in aquaculture and, in 2006, global aquatic plant production was 15.1 million tonnes with a value of USD 7.2 billion (FAO 2008). However, virtually all of this comes from Asian markets (FAO 2008), and very little is known about aquaculture of plants in Africa. Data collated here for Africa indicates that utilized plants are still predominantly harvested from the wild, with only 8% of used species known to be cultivated (see Figure 8.16).

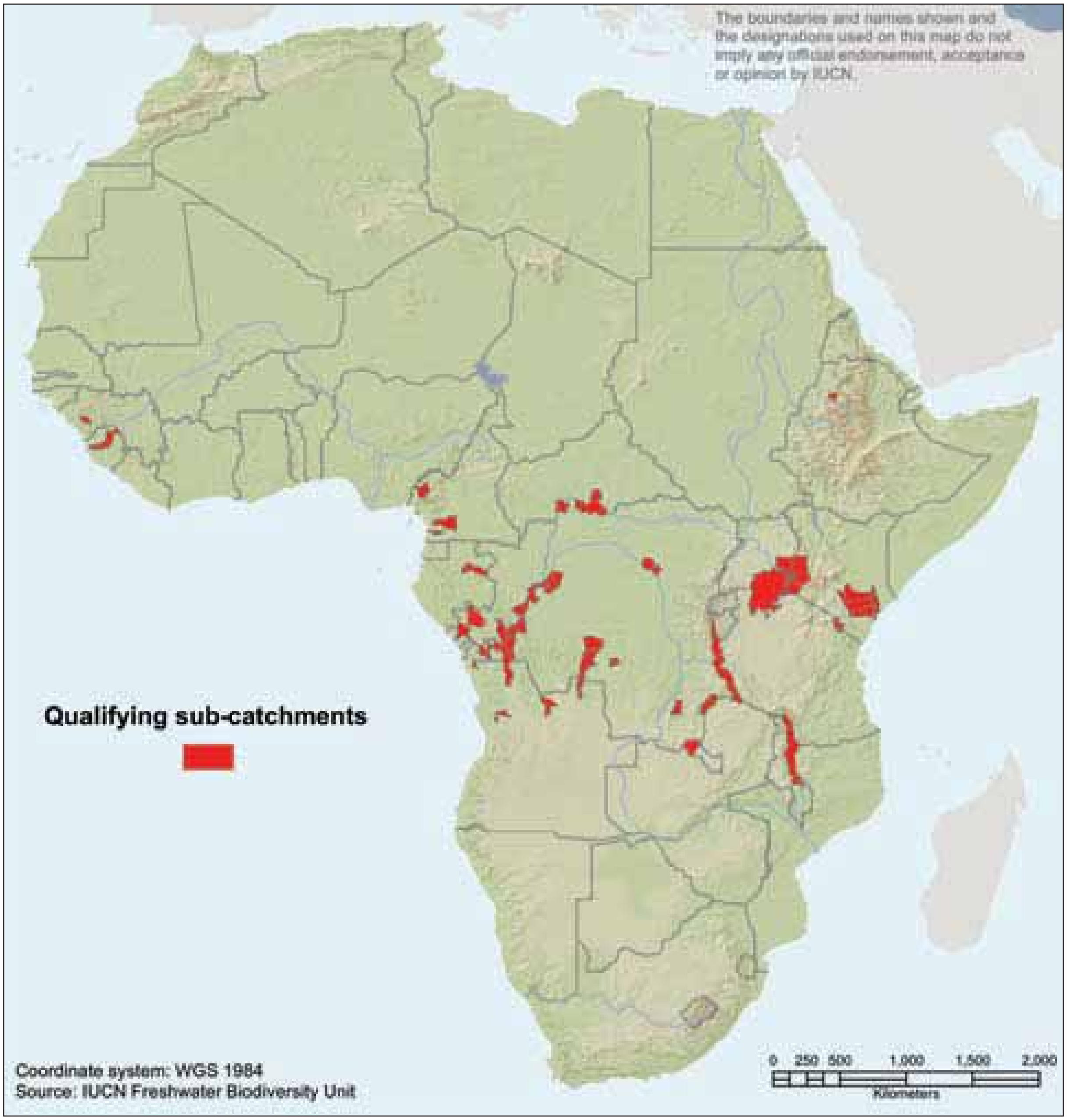
In contrast to the fauna, aquatic plants are collected for a wide range of reasons (Figure 8.18). The uses recorded are numerous and varied and include: structural materials (e.g., *Juncus spp*, *Phragmites australis*, *Typha spp., Cyperus papyrus*); decoration (e.g., *Ceratophyllum demersum* for use in aquaria, *Nympahea* species for water gardens, *Typa latifola* as an ornament); food (e.g., *Butomus umbellatus, Aponogeton* spp*.,* some *Nymphaea* spp.); medicinal purposes (e.g., *Gratiola officinalis*, *Persicaria bistorta*, *Mentha cervina*, *Bacopa monnieri*); or for cultural reasons (e.g., *Trapa natans*, *Genista ancistrocarpa*). In many cases, species have multiple uses. For example, *Juncus rigidus* is used medicinally to treat swellings and gout, has edible shoots, is used for ornamentation and crafting household items, and in Tibesti, Niger, the stems are used to make brushes. In central Africa, the most heavily used freshwater plants are *Lasimorpha senegalensis* (LC), *Cyperus papyrus* (LC) and *Xyris anceps* (LC) (Ghogue 2011). Uses in this region are varied, with *Lasimorpha senegalensis* used for human consumption and decoration, *Cyperus papyrus* as a structural material and a source of fibre, and *Xyris anceps* for food or as a medicine.

The most widespread use of plants is for medicinal purposes, for people and livestock. Plants have a vital role as medicines, particularly in rural communities where access to other forms of healthcare may be extremely limited. For example, *Ambrosia maritime*, is used in traditional medicine to expel kidney stones and to remedy renal troubles, asthma, and even bilharzia.

Aquatic plants represent the only freshwater group reported to have non-lethal harvesting (Figure 8.17). Plants also have the highest level of captive cultivation (see Figure 8.16). For the most part, therefore, wild populations are not threatened by overharvesting, although there are exceptions for scarce and restricted

Collecting water lilies in Mozambique for human consumption. © ROGER BILLS/SAIAB

Figure 8.19. Sub-catchments with five or more DD fish species and at least one threatened species.



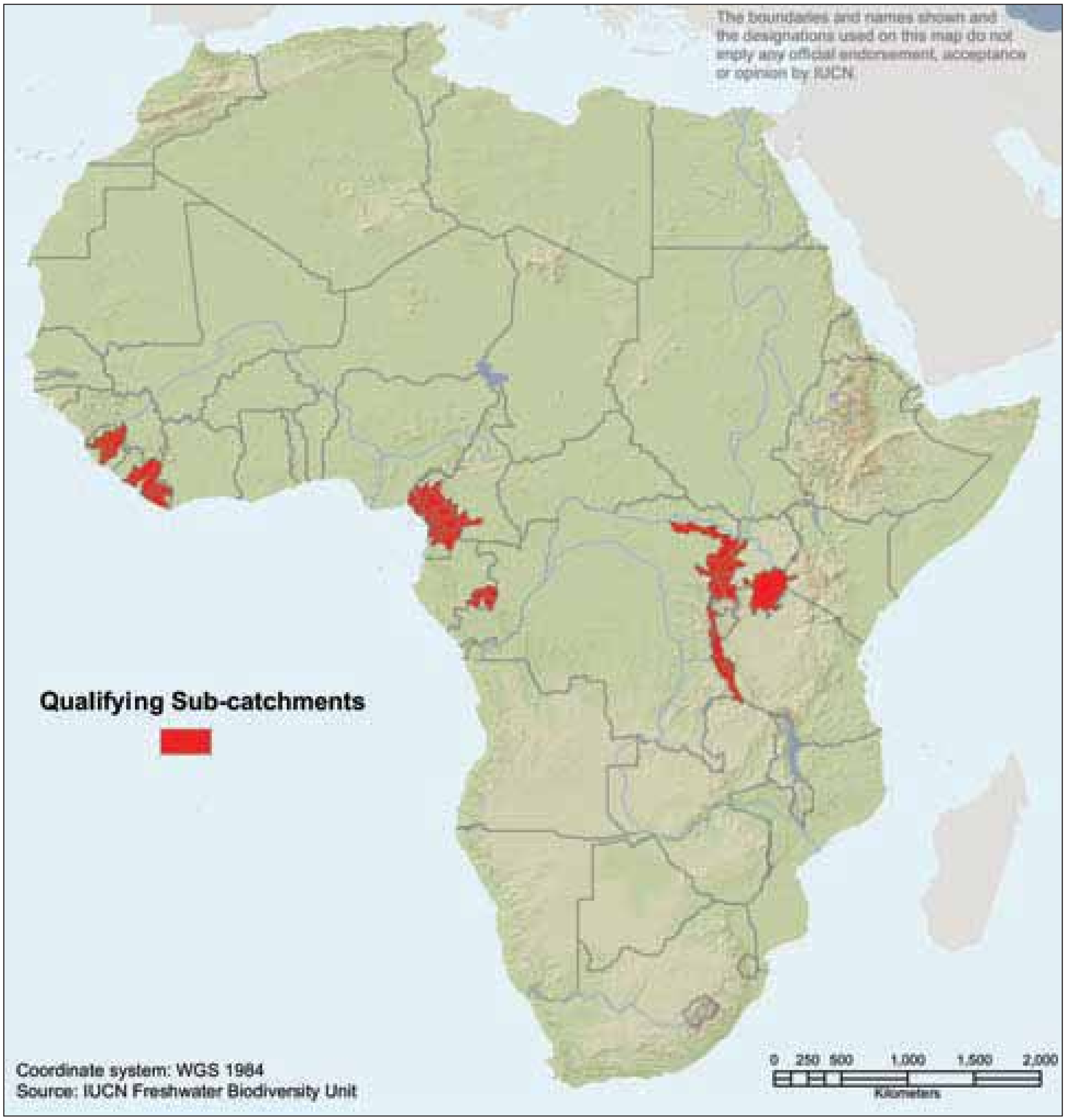
populations. For example, *Mentha gattefossei*, a perennial endemic to Morocco, is threatened by overharvesting due to its medicinal properties. *Aponogeton spp*. are well known for their edible tubers and are consumed in southern Africa. *Aponogeton distachyo*, commonly known as Cape pondweed, is endemic to the western Cape in South Africa. Its flowers are eaten and cultivated for commercial purposes (Sieben 2009), and the traditional Cape dish 'waterblommetjiebredie' has Cape pondweed flowers as its main constituent. Although the Cape pondweed is not threatened through over-exploitation, a number of species from the family, including *Aponogeton azureus* (VU) and *Aponogeton bogneri* (EN) are similarly used by humans and, through the combined pressures of collection and heavy grazing pressure by livestock, are considered threatened.

8.5 Areas for further work

8.5.1 Regions of Data Deficient and threatened species

Species are often recorded as Data Deficient (DD) when there is insufficient information on their distributions and the impact of potential threats within the sub-catchments where found. Several regions with high numbers of DD species have been highlighted in chapters 3 to 7. The lack of knowledge for species in these particular groups, selected to represent a wide range of trophic levels within freshwater ecosystems, infers a significant paucity of knowledge on the broader ecology of the region being examined. This lack of information can, in many cases, be filled through field survey. Sub-catchments where high numbers of DD species coincide with areas thought to be threatened might

Figure 8.20. Sub-catchments with both high levels of DD odonate species and at least one threatened species



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN

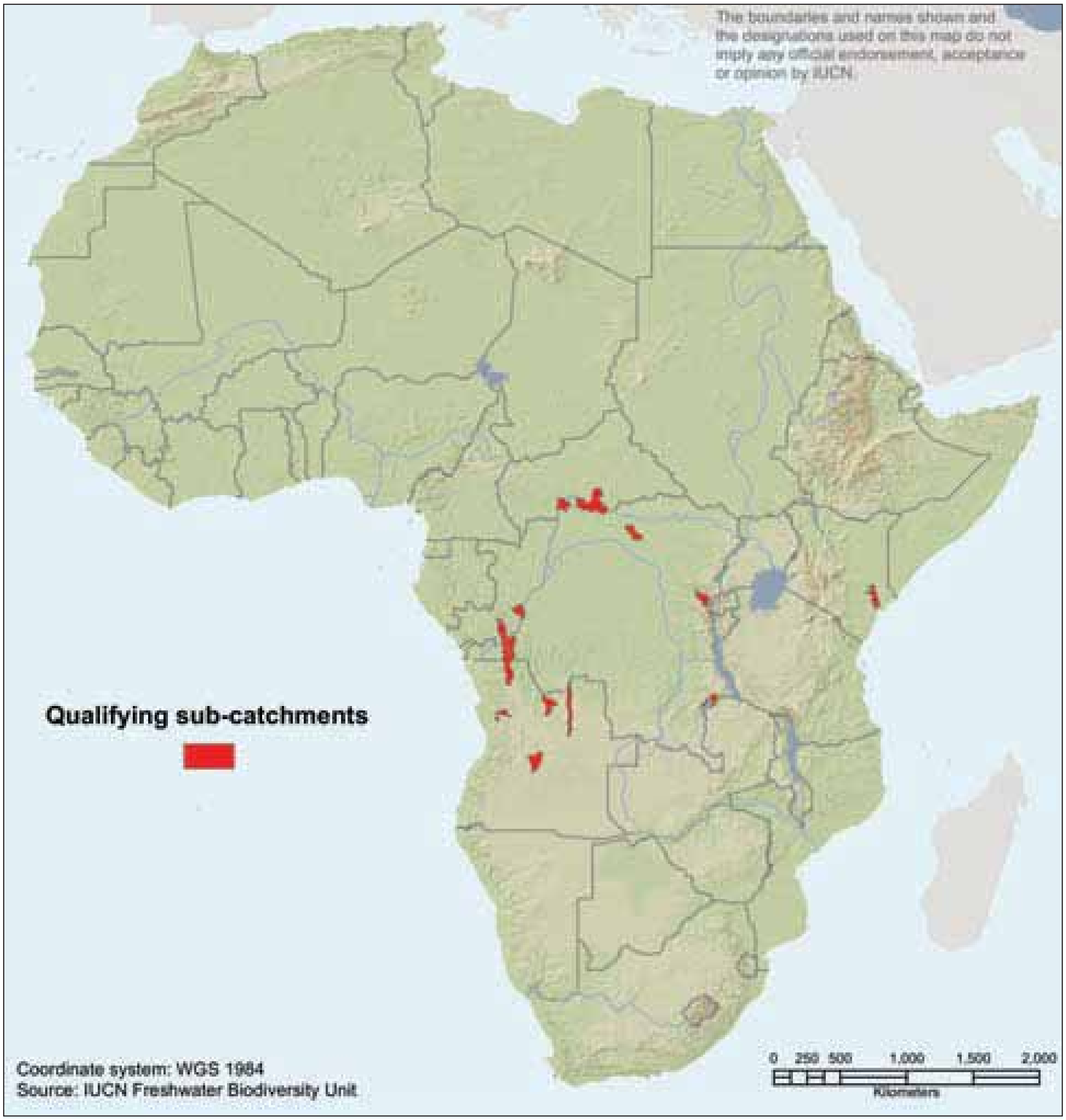
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

be considered high priorities for field survey. An analysis of the patterns of data deficiency for two taxonomic groups, fishes and odonates, identifies a number of such priority areas. The results presented here are preliminary, serving as a test of concept where patterns of data deficiency are used to identify priority areas for future field survey.

For fishes, five or more DD species in a single sub-catchment represents a high level of data deficiency relative to other catchments. Sub-catchments with a high percentage of DD species (e.g., > 25% of the total number of species present) were also taken to represent high levels of data deficiency, with the exception of those sub-catchments with very low total numbers of species. Sub-catchments with five or more DD fish species, where at least one species was known to be threatened (Figure 8.19), include: the Konkoure and Rokel basins in the Upper Guinea province; the upper part of the Cross River; the Nyong, Kribi, Ivindo, Kouilou/Niari in the Lower Guinea Province; much of the lower and middle Congo up to the tributary of the Ruki River at Mbandaka; the Ubangi between Bangui and the affluent of the Kotto River upstream from Moboye; the Upper Congo Rapids; the Lufira River in the Upper Lualaba ecoregion; Lake Mweru and the Kafubu River in the Bwengulu-Mweru ecoregions; parts of the Lovua, Lulua and upper Kasai basins in the Kasai ecoregion; the Cuanza River in Angola; Lake Tana in Ethiopia; and Lakes Victoria (and basins immediately to the north-east of the lake), Tanganyika, and Malawi.

For odonates, sub-catchments with both high levels of DD species and at least one threatened species (Figure 8.20)

Figure 8.21. Sub-catchments with high numbers of DD fish species adjacent to regions with low overall species richness.



The boundaries and names shown and the designations used on this map do not imply any official endorsement, acceptance or opinion by IUCN.

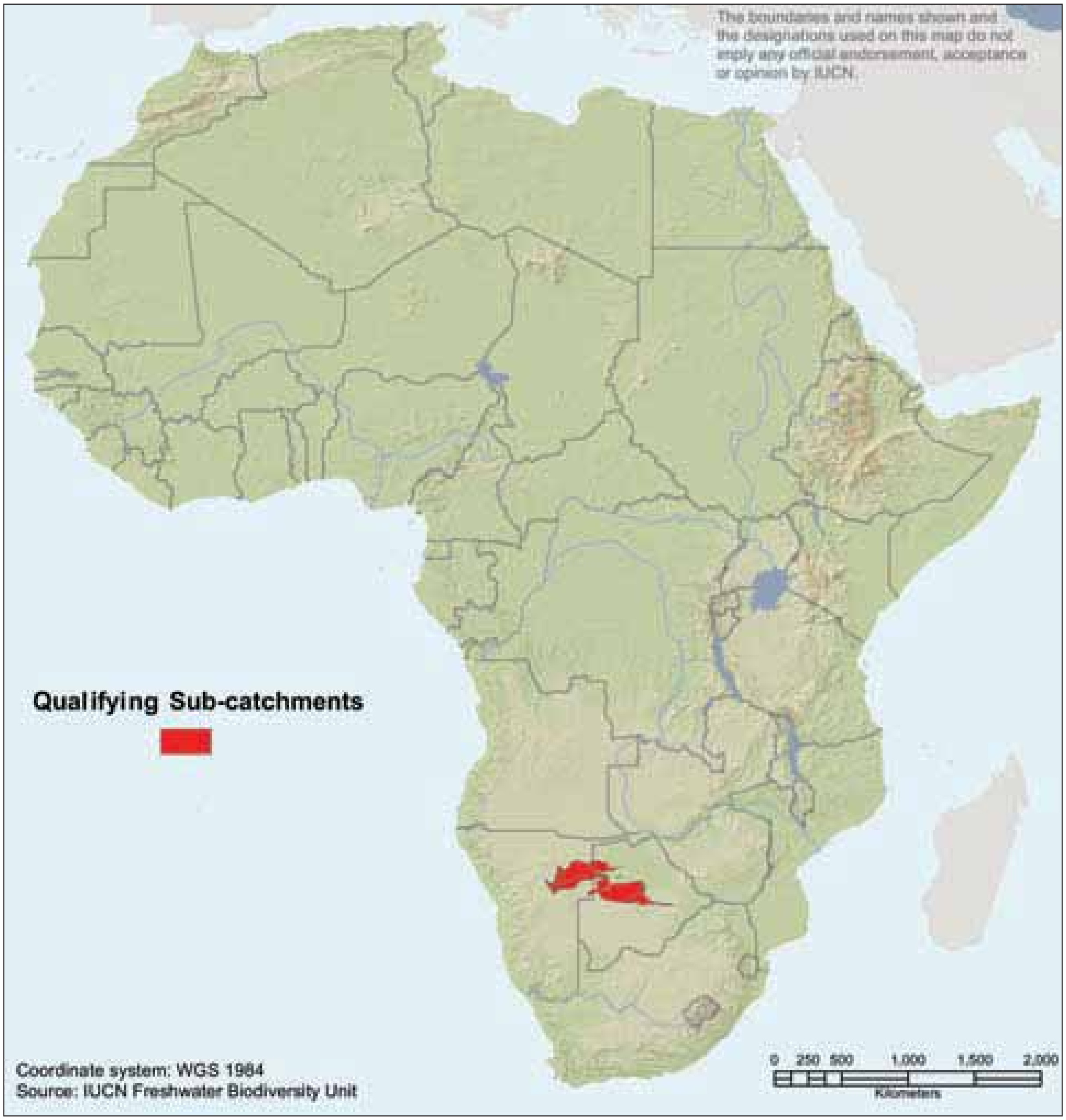
Coordinate system: WGS 1984
Source: IUCN Freshwater Biodiversity Unit

include: the Mabole, Seli, Pampana, Rokel, Taia, Sewa, and Bagbe sub-catchments in Sierra Leone; the Faliko sub-catchment in Guinea; the Du, Nianda, Saint John, Nuon, Cestos, Dugbe, and Sehnkwehn sub-catchments in Liberia; much of southern Cameroon, including all coastal basins to the cities of Bamenda, Yaounde, and Bafia in the east; south-eastern Gabon from Dienga in the west to Lac Tsolo in the north and along the border with Congo; the sub-catchments extending from Lake Albert in the north to Lake Tanganyika in the south; and Lake Victoria. Several of these sub-catchments, such as those around Lakes Victoria and Tanganyika, coincided with those also identified for fishes.

The regions identified represent places there are known threats to at least one species, yet there is a lack of the basic ecological information for a high proportion of the other species present. The presence of high numbers of DD species in Lake Tana and the African Great Lakes is particularly disturbing, not just because these habitats are threatened, but also because most of the species are endemic to these lakes. Areas such as these must be a priority for future field survey.

Several sub-catchments with high numbers of DD species are adjacent to regions with relatively low overall numbers of species (i.e., less than four species per sub-

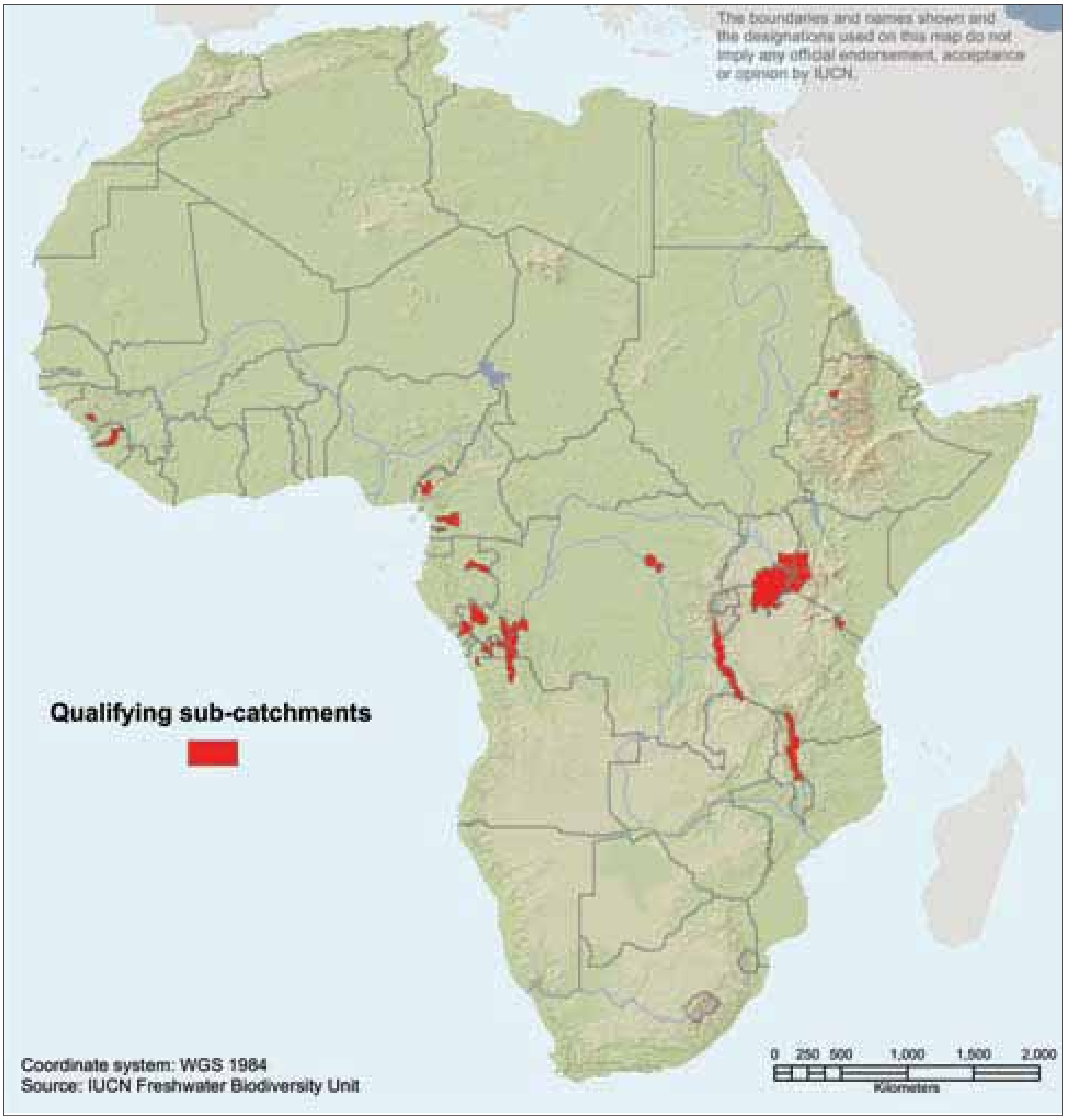
Figure 8.22. Sub-catchments with high numbers of DD odonate species adjacent to regions with low overall species richness.



catchment for fishes, which is the median value for all the sub-catchments in Africa) and no threatened species (e.g., parts of the lower Congo and upper Ubangi in central Africa; the Tana basin in eastern Africa) Figure 8.21. Similarly, for odonates, are sub-catchments in north-eastern Namibia and north-western Botswana (Figure 8.22). The low recorded numbers of species in these neighbouring catchments may, of course, be an artefact of limited sampling. If this is the case, then it is possible that the species present in the data deficient catchments are also found in these adjacent catchments where threats are apparently lower and may represent safe havens. Conversely, if the DD species are not found following additional field survey, this would imply that the species are truly restricted to the zones where there are known threats.

Finally, DD species within sub-catchments surrounded by sub-catchments with high numbers of threatened species (Figure 8.23) might be considered as likely threatened. For example, the Nyong and Kribi basins in Cameroon, and the Ivindo and Bouniandje basins in Gabon have high numbers of DD fish species and are almost completely surrounded by sub-catchments with high numbers of threatened fish species. One might, therefore, reasonably predict that the fishes in the

Figure 8.23. Sub-catchments with high numbers of DD fish species surrounded by sub-catchments with high numbers of threatened species.



Nyong, Kribi, Ivindo and Bouniandje are significantly threatened themselves; these species should be further investigated as a priority. Similarly, sub-catchments located in western coastal Cameroon and extending slightly into Nigeria, including the Mungo, Wouri, Nita, Nkam, Woun, Dibamba, Noun, and the Cross sub-catchments, as well as the sub-catchments surrounding Lac de Bamendjing, have high numbers of DD odonate species adjacent to basins with high numbers of threatened odonate species.

8.5.2 Rapid Assessment Programs (RAPs)

Information on patterns of data deficiency, as discussed above, will be especially relevant and useful for Conservation International's Rapid Assessment Program (RAP) and its partners in the various countries where the field programs are implemented. RAP was created in 1990 to address the lack of biological information needed to make quick but sound conservation decisions. RAP assembles teams of international and host-country expert scientists to conduct first-cut assessments of the biological value of little-known and unexplored areas. RAP field surveys generally last three to four weeks, focused on taxonomic groups that can give an indication of the health of the ecosystem and its conservation value. This technique of rapid biodiversity assessment ensures that biodiversity data are collected quickly so that the data can be available to meet the needs of urgent conservation challenges.

Field survey in the Okavango Delta channel. © JENS KIPPING

'AquaRAP' surveys specifically target freshwater ecosystems, focusing on the entire catchment when possible, to include all the habitats that aquatic organisms use during their life cycles. AquaRAP teams typically include scientists from international and local institutions who are experts on the taxonomy of aquatic plants, fishes, aquatic invertebrates (molluscs, crustaceans and insects), and plankton. Specialists in water quality are also a key part of the team, to provide data on the relevant physical parameters (e.g., dissolved oxygen, turbidity, flow, and nutrient levels) to help explain patterns in the species data. The overarching goal of AquaRAP is to assess the biological and conservation value of a catchment, based on: (1) the heterogeneity of the habitats; (2) a preliminary survey of the organisms that characterize each of these habitats; and (3) the overall intactness of habitats, and their capacity to support important biological resources and ecological processes. Field collections are made to identify the organisms, but the collections are minimized. Specimens are identified to the most appropriate taxonomic level (genus or species) to obtain a first-cut assessment of diversity and species composition.

AquaRAP surveys have provided critical data employed in many cases for assessments of species Red List status in this study of Africa's freshwater biodiversity. It is, therefore, hoped that the priority survey areas identified above might stimulate further surveys throughout Africa. The value of AquaRAP surveys as input to the species assessments is demonstrated through an overview of the assessments conducted in Africa to date.

Since 1990, Conservation International has conducted 13 AquaRAP surveys that have focused on the aquatic ecosystems through the entire catchment. Several other RAP surveys that had a terrestrial focus also included aquatic taxa. Eight RAP surveys conducted in Africa surveyed aquatic taxa. The RAP data have been used in many ways to further conservation efforts and to advance our scientific understanding of species distributions, habitats, and biology. RAP surveys have provided information to update species distribution data for the IUCN's Red List, have discovered species new to science, have re-discovered species not seen in a long time, and have recorded range extensions and new country records for many species.

AquaRAP carried out two surveys of the Okavango delta in Botswana, one in high water in 2000 and the second during low water in 2003. One fish species and one aquatic Heteroptera (Belastomatidae) new to science were recorded during the 2000 survey, along with several new records for the Okavango delta (Appleton *et al*. 2003; Tweddle *et al*. 2003). These AquaRAP surveys provided essential freshwater diversity data for management and monitoring of the Okavango Delta and catalyzed a process for resolving conflicts between local fishermen and sport fishermen in the delta. Data on the shrimp fauna from the 2000 survey are being used to assess health risks in the delta (Appleton *et al.* 2008). The AquaRAP data are currently being used to support a proposal to nominate the Okavango delta as a World Heritage Site.

Freshwater diversity was also surveyed along with terrestrial taxa during RAP surveys in Côte d'Ivoire, Liberia, Guinea, and Ghana in West Africa, and in D. R. Congo in Central Africa. In Haute Dodo and Cavally Classified Forests in Côte d'Ivoire, 33 fish species were recorded, including nine species recorded for the first time in these areas, and one species (Chromidotilapia cavalliensis) endemic to the Cavally River (listed as Vulnerable by IUCN) (Gourène *et al.* 2005).

In the Boké Prefecture of western Guinea, the RAP team recorded the Endangered purple marsh crab, *Afrithelphusa monodosus*, which was recorded for the first time since its original record in 1947 (Cumberlidge 2006). This species was collected from cultivated land, so little is still known about its natural habitat and biology. One species of freshwater shrimp was also recorded in Boké for the first time in Guinea, extending its known range westward from Sierra Leone (Cumberlidge 2006).

Odonata were sampled during the RAP survey of Lokutu in D. R. Congo. A total of 86 species were recorded, with 62 (72%) Guineo-Congolian species, 13 of which have not been found outside of the Congo Basin, and three species likely new to science (Dijkstra 2007a). Odonata were also sampled in three national forests in Liberia in 2005. RAP results documented 93 species, with one species new to science (*Eluthemis* sp. nov.; Dijkstra 2007b).

Two RAP surveys in Ghana included assessment of freshwater taxa. Freshwater macroinvertebrates and fishes were surveyed in the Ajenjua Bepo and Mamang River

Forest Reserves in 2006. Many species of both groups were typical of disturbed or deforested areas (Abban 2008; Samman and Amakye 2008). One fish species, *Barbus pobeguini* (LC), at Mamang River was recorded for the first time in Ghana.

Also in 2006, a RAP team surveyed Odonata and fishes in the Atewa Forest Reserve, in Ghana. Nineteen fish species were documented, including one previously known only from Côte d'Ivoire (Abban 2007). Among the 72 species of dragonflies and damselflies recorded, the record of *Atoconeura luxata* (LC) was especially significant because it had not been described at the time, so the RAP data were used in the species description (Dijkstra 2007c). In addition, this species is a regionally threatened dragonfly (regionally classified as vulnerable), found usually in montane environments (Dijkstra 2007c).

In conclusion, it is hoped that the findings presented in this report will encourage a new series of AquaRAP assessments across Africa to fill the many information gaps identified.

8.6 The future of African freshwaters

In this chapter, we have considered the rich diversity of life in African freshwaters, the threats that this diversity faces, and some practical steps that can be taken to conserve and improve our knowledge of species. Although the conservation of species should be a goal in its own right, what has emerged through this study is the importance that freshwater species have for livelihoods of people across the continent. This makes a compelling case for greater investment in understanding and managing these habitats for future generations. In this final section, we look ahead and consider one of the most serious threats to freshwater species – climate change.

8.6.1 Climate change and African freshwater conservation: seeing the future through the past

African ecosystems have experienced climate change for as long as the African continent has existed. By itself, climate change is not necessarily a source of negative impacts on species and ecosystems, particularly over evolutionary timescales. However, the current period of climate change is novel, not in its pace of change but in that (a) humans are the primary driver of current climate shifts, and (b) the set of ecological responses available to species (such as changes in range, behaviour, and phenology) to new conditions has become reduced as a result of intensifying human modification of ecosystems (Parmesan 2006). Freshwater ecosystems in particular have seen dramatic population and species losses in recent decades (Dudgeon *et al.* 2005; Vörösmarty *et al.* 2010). Economic development for the past two centuries has increasingly involved the development of water infrastructure, direct modification of channels, intensifying water use, and (often) limited treatment of agricultural, industrial, and urban inflows. A consensus is emerging that many of these modifications reduce the inherent ability of ecosystems and species to adjust to climate change induced eco-hydrological impacts (Le Quesne *et al.* 2010).

Fishermen returning at sunset, Yaekela, D. R. Congo. The Congo basin carries about 30% of Africa's surface water flow. © KLAAS-DOUWE DIJKSTRA

This section will briefly describe: the recent climatic history of African freshwater systems; observed, emerging, and projected impacts related to anthropogenic climate change; and how past and current ecosystem and species responses may be useful guides to future freshwater management that will be sustainable for Africa's developing economies and freshwater species. Conservation efforts for African freshwater species and ecosystems must take account of ongoing climatic shifts – and in some cases, climate-informed conservation of African freshwater ecosystems may represent a break with current practices under a so-called 'climate change adaptation' framework (Matthews and Wickel 2009; Wilby *et al.* 2010)[1]. However, Africa's recent climate history suggests that ecosystems and species have shown resilience in the face of dramatic eco-hydrological changes, and conservation efforts should probably focus on enabling or restoring these climate-adaptive capacities as a new climate regime begins to emerge.

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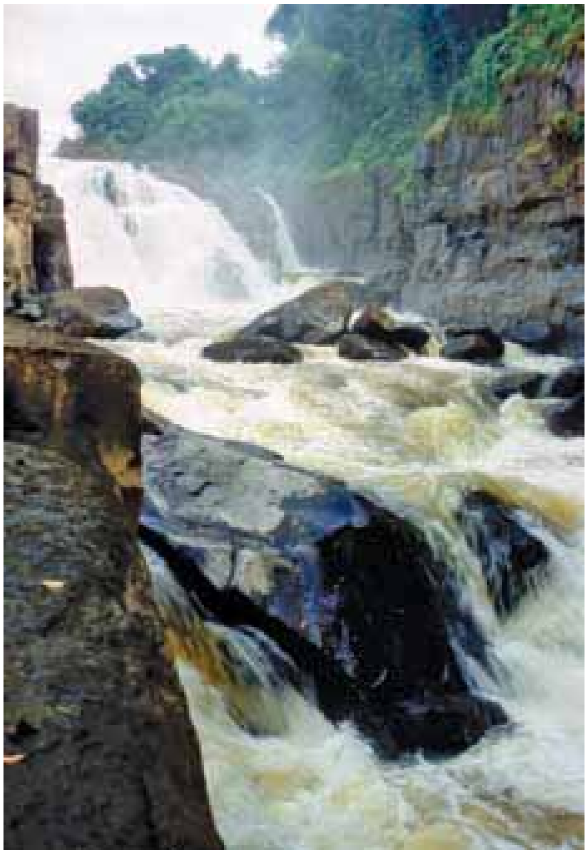
[1] Climate change adaptation (CCA) is a term dating back to about 1990, borrowed from the climate change policy community to describe efforts to respond to realized and anticipated climate change impacts; 'adaptation' in this usage is not directly connected to standard ecological and evolutionary uses of the term, and adaptation in this section will refer to CCA.

8.6.2 African waters: special qualities and challenges

Extant African freshwater ecosystems possess a number of macro-hydrological and ecological characteristics distinct from freshwater systems on other continents (Cushing *et al*. 1995; Thieme *et al*. 2005; Abell *et al*. 2008). Africa's river and lake basins are among the oldest in the world, with most basins originating before the Miocene (approximately 24 million years BP; Beadle 1981).

Currently, at least five climatic zones exist across the continent: equatorial, tropical, subtropical, Mediterranean, and mountain. The general precipitation pattern is one of highest rainfall near the equator in the Congo Basin and along the Gulf of Guinea, with progressively less at higher latitudes. Due to its high rainfall and low evaporation, the Congo Basin carries about 30% of Africa's surface flow, though accounting for only about 13% of the surface area of the continent (FAO 1995). Arid, semi-arid, and dry sub-humid areas cover about 43% of Africa's surface area and include large deserts in the north and south (Bjørke 2002). More than 90 percent of Africa's rivers are less than 9km long, with many flowing only seasonally (Lundberg *et al*. 2000). Another distinctive characteristic of African rivers is that they generally have many more rapids and waterfalls than other rivers in the world because of tectonic activity over the last 20 million years, and none flow unimpeded to the interior of the continent (Lévêque 1997). African lakes tend to show relatively synchronous but large fluctuations in level. Over the 20th century, many large lakes have varied by 5 to 10m (Nicholson 2000).



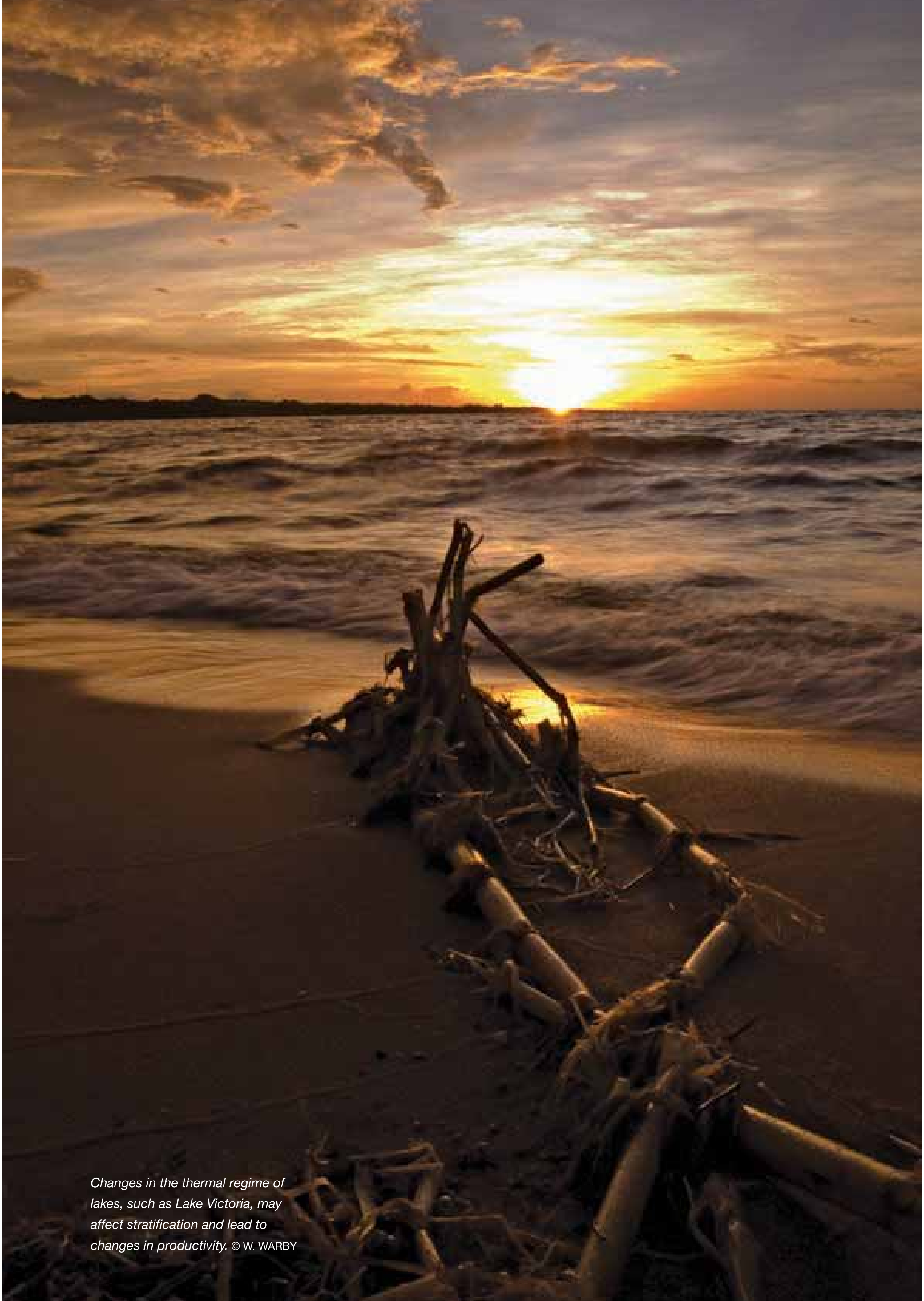
Foulakari Falls, D. R. Congo. African rivers generally have more rapids and waterfalls than other rivers in the world, due to the history of tectonic activity across the continent over the last 20 million years. © ROBERT SCHELLY

Additionally, more than 70% of Africa is dominated by 'green water', or atmospheric-water fluxes from precipitation and evapotranspiration, as opposed to 'blue', or terrestrial surface and aquifer water fluxes (Freeman 2007). In combination with highly seasonal precipitation patterns, many freshwater ecosystems are regularly exposed to weather extremes. Across most of the continent, high interannual, and even interdecadal, variability is not uncommon, with variations of 20 to 40% from mean annual precipitation often found in the instrumental record (Nicholson 2000; Conway *et al*. 2008).

8.6.3 A short history of African eco-hydrological dynamism: the past 100,000 years

The eco-hydrological characteristics of Africa's freshwater systems have undergone extensive shifts over the past 100,000 years, and even since the onset of the Holocene (around 12,000 years BP; Gasse 2000; Issar 2003). Given that ecosystems and species are deeply influenced by their evolutionary and ecological history, the influence of recent eco-hydrological conditions may serve as a useful guide to future impacts.

Recent reviews of trends in African climate and hydrology over the past 100,000 years suggest that current conditions in Africa are relatively dry, compared to the rest of the Holocene (e.g., Gasse 2000; Holmgren *et al*. 2003; Marchant and Hooghiemstra 2004; Kiage and Liu 2006; Weijers *et al*. 2007; Conway *et al*. 2008; Dupont *et al*. 2008). Kröpelin *et al*. (2008), for instance, document the gradual shift in northern Africa over the past 10,000 years, from a relatively wet 'green Sahara' to its current arid state within the past 3,000 years, with freshwater ecosystems evolving from large, permanent freshwater lacustrine and wetland systems to temporary and/or saline (or hypersaline) systems (Nicholson 2000; Marchant and Hooghiemstra 2004). Similar patterns are seen to the south in Lake Malawi, where paleoecological studies document rapid transitions between 'dilute' states comparable to the contemporary system to highly alkaline and saline conditions as a result of increases or drops in water level of dozens to hundreds of metres (Stone *in press*). Other African Rift valley lakes have also expanded and contracted dramatically in recent millennia, responding directly to shifting precipitation regimes (Gasse 2000). Several studies show that shifts in monsoon seasonality have been associated with changes in lake stratification processes (Marchant and Hooghiemstra 2004; Marshall *et al*. 2009). Water quality has varied accordingly, with major shifts in productivity and species assemblages (e.g., Cohen *et al*. 2006). Deposition records show that rivers such as the Nile and Congo are



Changes in the thermal regime of lakes, such as Lake Victoria, may affect stratification and lead to changes in productivity. © W. WARBY orders of magnitude smaller today by the standards of as recently as 7,000 years BP (Issar 2003).

By extension, we can infer that many freshwater systems now classified as temporary or ephemeral have been both permanent and completely dry over relatively recent ecological timescales. Given that most freshwater species are highly sensitive to even minor shifts in the hydrological cycle, the ecological resilience and flexibility of extant African species are remarkable, particularly for endorheic lake fauna. Genetic and paleolimnological studies have not yet fully resolved the relative roles of evolutionary (e.g., rapid evolution and adaptive radiation) and ecological (e.g., refugial) responses by taxa, such as Lake Victoria's cichlids, to these pressures (Stager and Johnson 2008; Elmer *et al*. 2009).

Also significant is the observation that many of the oscillations between wet and dry periods in Africa have occurred relatively rapidly, often on decadal or century rather than millennial timescales (Nicholson 2000; Issar 2003), including the most recent extreme drying event that occurred across large parts of Africa about 4,000 years ago (Marchant and Hooghiemstra 2004).

8.6.4 Signs of anthropogenic climate change in Africa

The colonial and postcolonial periods in Africa have seen increasingly large and widespread modification of terrestrial and freshwater ecosystems from irrigation, deforestation, mining and other types of intensive resource extraction, groundwater pumping, agriculture, hydropower, urban development, disease control, and industrial and manufacturing activities. These modifications are altering hydrological conditions in many parts of the region, reducing connectivity, changing water quality, and altering flow regime and hydroperiod. Agricultural water demand dominates water use on the continent. Vörösmarty (2005) found that a significant portion of agricultural land in Africa is located in areas of high hydrologic variability and low runoff. Ambitious plans exist for additional modification of freshwater resources, particularly for the energy sector. For instance, D. R. Congo's Grand Inga project, which is estimated to be able to generate twice as much electricity as the Yangtze's Three Gorges dam, and other planned large dams have the potential to profoundly alter large swathes of their basins.

The rate of economic development and social change in the past century confounds many of the freshwater records that do exist, as dramatic shifts in water use and management, urbanization, and changes in agriculture have altered the intensity of human impacts on freshwater ecosystems. Detecting the signal of anthropogenic climate change among so many drivers is difficult, particularly given that many African freshwaters have had little or no direct monitoring until well into the 20th century (Le Quesne 2010). Much research into the role of climate change in driving African freshwater ecosystems, therefore, comes from a mix of direct measurements and paleolimnological and proxy studies (Verschuren 2003).

Despite these challenges, the fingerprints of climate change are detectable in African freshwaters using both direct and indirect measures. The UN Intergovernmental Panel on Climate Change (IPCC) has recently reviewed African climate change impacts generally (IPCC 2007) and for African freshwaters (IPCC 2008). Several studies have detailed regional or ecotype impacts, such as the Hecky *et al*. (2006) analysis of climate impacts on large African Rift lakes or the Eggermont *et al*. (2010) analysis of high-altitude mountain lakes. Compared to North American, Australian, or Eurasian studies, the African freshwater impacts literature remains thin.

The most convincing African climate change studies document hydrological rather than ecological impacts. The physics of climate impacts on Lakes Tanganyika and Victoria link shifts in air temperature and precipitation to changes in stratification, altering lake productivity (Verburg and Hecky 2009; O'Reilly *et al*. 2003; Marshall *et al*. 2009). Vollmer (2002) has linked recent climate shifts to changes in water temperature in Lake Malawi, and Hecky *et al*. (2010) have documented similar patterns in Lake Victoria; in some cases, these temperature shifts are occurring in deep waters, which are more buffered from air temperature increases (Matthews 2010). More recently, Lake Chad has shrunk significantly since the 1950s, in part as a result of multi-decadal declining annual precipitation (Nihoul *et al*. 2004).

Does the limited literature mean that few impacts from anthropogenic climate change are occurring in African freshwaters? This conclusion would be dangerous to infer. While the paleolimnological literature in Africa is strong, the limited number of monitoring stations and amount of baseline hydrological, ecosystem, and species data pose major challenges that may take decades to correct.

8.6.5 Projecting trends and responses

The 21st century should witness the resurgence of climate change as a more important change-agent for African freshwater ecosystems (IPCC 2007). Trends in Africa and elsewhere suggest that eco-hydrological conditions will continue to shift, but Africa's recent climate history suggests that there is resilience in African freshwater systems that may help with the coming changes. Specific high-confidence projections have proven difficult to produce. The output of global circulation models (GCMs) for Africa show low levels of confidence for precipitation patterns across most of the tropical and subtropical latitudes of Africa, with the exception of the north African–Mediterranean and southern African regions, where all GCMs show declining levels of annual precipitation over this century (Le Quesne *et al*. 2010). For the rest of Africa, GCM precipitation projections are variable and inconsistent at intra-annual/seasonal and annual resolutions (Wilby *et al*. 2009). It is difficult to know how to interpret these projections and what level of confidence to place in them as the basis for guiding resource management and infrastructure design decisions, especially for infrastructure lasting multiple decades into the future (IPCC 2008; Le Quesne *et al*. 2010).

Several recent studies have attempted to model different scenarios for large-scale shifts in mean annual conditions of freshwater systems across the continent. De Wit and Stankiewicz (2006) suggest that even modest declines in annual rainfall (around 10%) could have inordinate effects on much of Africa, resulting in drops in surface drainage of 50% for regions that now receive between 400 and 1,000mm in annual precipitation. These sensitivities reveal the importance of green (atmospheric) over blue (surface-aquifer) water to African ecosystems and economies (Freeman 2010). Thieme *et al*. (2010) used a climate-hydrological modelling approach to identify regions projected to experience larger shifts in annual precipitation. They conclude that regions now containing more than 80% of African freshwater fish diversity and several outstanding ecological and evolutionary phenomena may experience shifts of at least 10% mean annual runoff or discharge by the 2050s, which will likely alter eco-hydrological conditions in significant ways.

Attempts to estimate changes in the frequency and severity of extreme weather events (in contrast to mean climate), such as droughts and floods, as a result of anthropogenic climate shifts, have had inconsistent results, and very rare extreme events may not be well captured using existing GCM approaches (e.g., Shanahan *et al*. 2008). Climate variability attributable to the ENSO (El Nino–Southern Oscillation), for instance, has been increasing over the past 500 years, especially extreme ENSO events, and particularly over the last century (Gergis and Fowler 2009). Interannual precipitation variability may thus increase. Several recent studies have documented severe multi-decade 'megadroughts' across major regions of Africa (Scholz *et al*. 2007), with some of these episodes marked by relatively abrupt transitions (Shanahan *et al*. 2008). Many of these megadroughts appear correlated with past shifts in global climate engines, so it is not unreasonable to infer that such droughts are more likely to appear this century.

Human responses to anthropogenic climate change are likely to have important conservation consequences. Given that climate variability may be increasing, the risks of competition between human and ecosystem water requirements are high. Grey and Sadoff (2007) provide evidence for a correlation between 'difficult hydrologies' — characterized by seasonal precipitation, high variability in precipitation and flows, and/or frequent extreme weather events — and high poverty/low development levels. Data from Ethiopia show how single drought events can significantly lower national GDP for many years following the end of the event (Sadoff and Mueller 2009).

As a result, climate change will be interacting with economic development in complex, often unpredictable ways, and water management in Africa is likely to be a major target for development aid. For instance, many observers have noted the low level of water infrastructure development relative to potential that exists across a variety of sectors in Africa. Water storage is a widespread response to climate variability, but per capita African storage levels are generally quite low — 28m^3 in Ethiopia and 687m^3 in South Africa, compared to 5,961m^3 in the USA (Grey and Sadoff 2007). Much investment to date has focused on water supply and sanitation needs, but there is also growing focus on the low level of hydropower (approximately 5%) and irrigation (about 30%) relative to potential. These figures suggest that water infrastructure development will be an important part of Africa's near-term future. Unfortunately, even current methods of 'sustainable' water infrastructure operations and design rarely consider climate-driven shifts in hydrological conditions; the assumption of a fixed climate — usually termed 'stationarity' (Milly *et al*. 2008) — can lead to climate-infrastructure mismatches that degrade ecosystems, increase species vulnerability, and ultimately lead to growing 'maladaptations' to shifting climate conditions (Poff 2009; Le Quesne *et al*. 2010). Avoiding these risks will be a major challenge for African policymakers.

These challenges are not limited to individual pieces of infrastructure. Both national and transboundary environmental and resource governance are weak in many regions of the continent. Some 64% of Africa's basins cross international boundaries (UNEP 2005), every country in Africa has at least one transnational river, and about half of these rivers are shared by three or more countries (Sadoff *et al*. 2003).

8.6.6 Implications for facilitating healthy responses to freshwater change

Africa's freshwater ecosystems and species have successfully faced dramatic swings in climate in recent millennia. However, emerging anthropogenic climate change impacts are likely to interact with existing and future water resource management approaches in ways that could hasten rather than buffer negative impacts on African species. The risk for African freshwater resources is that rapid infrastructure development may lock in freshwater management regimes for decades that do not match emerging climate conditions. Given that the global climate system is committed to decades or centuries of additional human-induced change, are there actions we can pursue that might enable positive ecological change?

Several authors have suggested that the assumptions of 'stationarity' exhibited by infrastructure and water managers

Climate driven shifts in hydrological conditions are rarely considered when planning large-scale infrastructure developments that are designed to last many decades. Edea Dam in Cameroon. © JEAN-PAUL GHOGUE

are often widely shared by conservationists as well. Climate change adaptation, in contrast, must focus on facilitating healthy change rather than trying to manage species and ecosystems for fixed or rigidly defined eco-hydrological conditions (Matthews and Wickel 2009; Poff 2009).

What might a climate-informed approach to managing African freshwater resources look like? A full review is beyond the scope of this chapter, but a new vision of sustainability has been developing among some researchers and policymakers. One approach to climate adaptation and climate-informed sustainability is to focus on ecosystem qualities that have enabled adaptation through past climate shifts. Le Quesne *et al*. (2010) defined four aspects of ecosystems that assist climate adaptation: the level of detrimental non-climate pressures that are influencing ecosystems, such as high levels of agricultural runoff; the degree of ecological connectivity, such as dams that impede species movement through a lotic system; the degree of modification to the disturbance regime that the system is ecologically adapted to (flow regime in lotic systems and hydroperiod in lentic systems); and the presence or absence of a climatically complex landscape (i.e., climate refugia are available to buffer extreme weather events). Evaluation of these elements through a climate vulnerability assessment process can provide a clear climate adaptation plan. The protection and restoration of these qualities among African resource managers would mark a significant shift in strategy for many existing conservation plans.

The presence of an adaptation plan assumes that institutional capacity exists for implementation. Conway *et al*. (2005) describe a set of strategies to enable climate institution-based coping options for East African livelihoods. They emphasize better forecasting and information distribution (e.g., for ENSO), the development of flexible resource management regimes that can address managing for variability and extreme events, and preparation by policymakers and governance institutions for long-term impacts from climate change. Their suggestions emphasize the importance of institutional resilience to environmental change.

The challenges facing African freshwater species are daunting, but the continent's climate history suggests that significant resilience exists. With thoughtful development and management, African freshwaters can see a new century with different but not unhealthy qualities.

Once forming the floor of Lake Chad, the Bodelo Depression is slowly being transformed into a desert landscape.

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Chapter 9.

Conservation of freshwater ecosystems

Linke, S.[1] and Hermoso, V.[1] (Section 9.1); Swartz, E.[2] and Tweddle, D.[2] (Section 9.2); Linke, S.[1], Hermoso, V.[1], Turak, E.[3] and Nel, J.[4] (Sections 9.3 and 9.4)[1]

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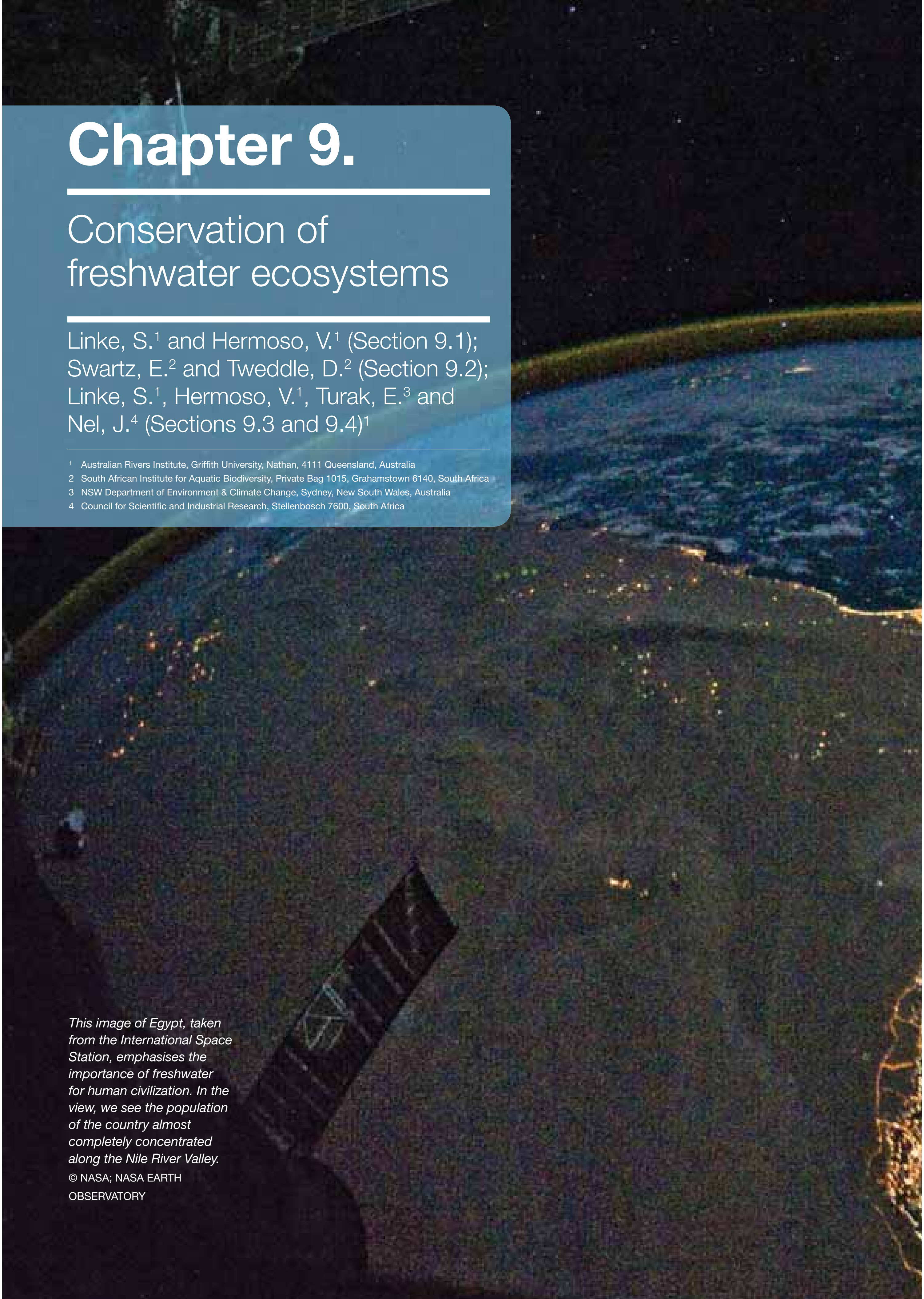
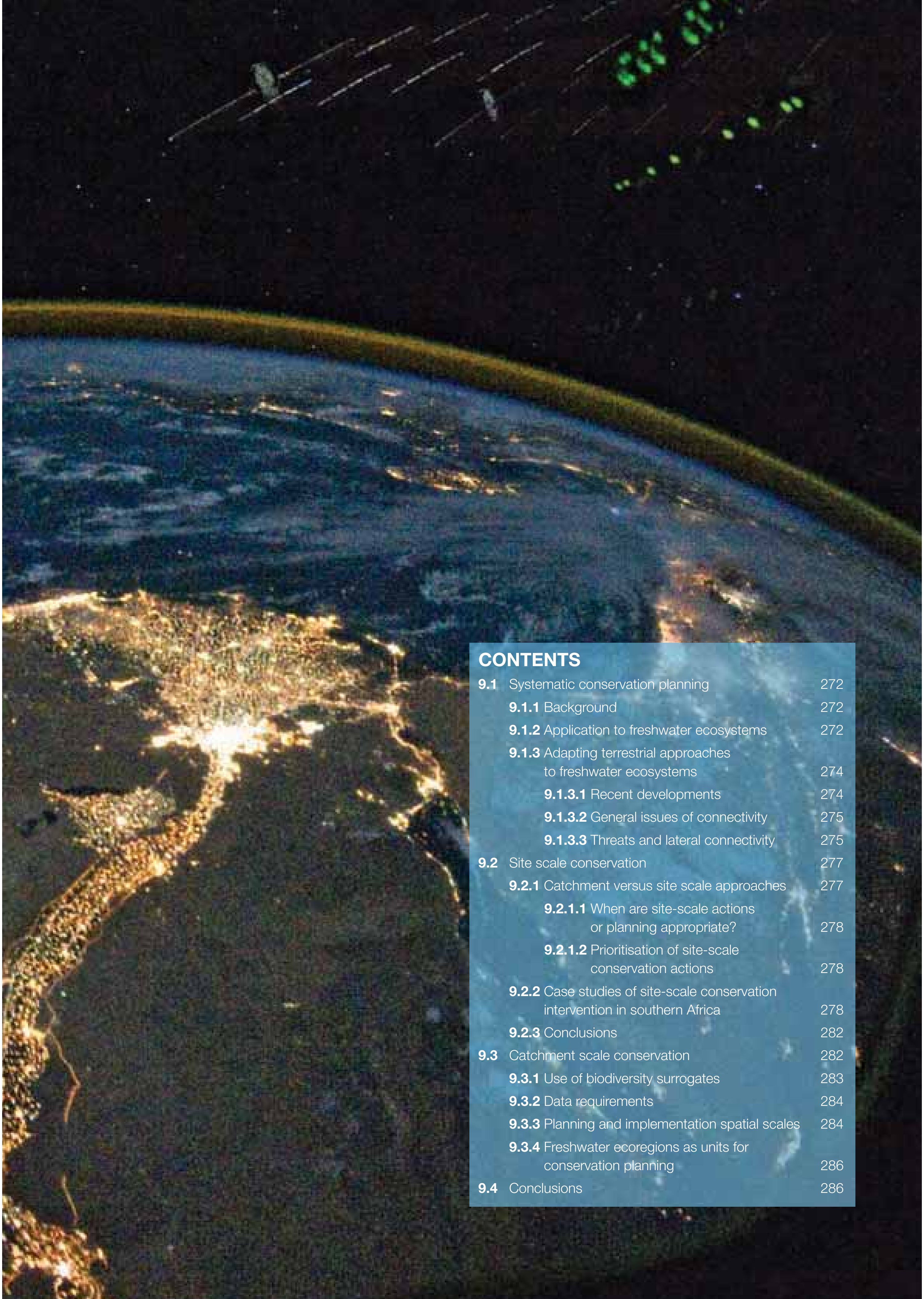


This image of Egypt, taken from the International Space Station, emphasises the importance of freshwater for human civilization. In the view, we see the population of the country almost completely concentrated along the Nile River Valley.

© NASA; NASA EARTH OBSERVATORY



CONTENTS

9.1 Systematic conservation planning

9.1.1 Background

The diversity of life on Earth is rapidly declining under the current biodiversity crisis (Olson *et al*. 2002). Extinction rates are 100 to 1,000 times higher than pre-human levels in many different taxonomic groups and across a wide range of environments (Pimm *et al*. 1995), with species in the freshwater realm heavily impacted (Dudgeon *et al*. 2006). This situation requires identification and focussed management of particular areas that support, or have the capacity to support, important biodiversity values (for example, areas containing threatened or rare species, habitat refugia, or areas important for the maintenance of ecological processes). The most common strategy is to declare these areas as reserves, with varying degrees of protection. Once established, reserves should promote the long term survival of the biodiversity they contain through maintaining natural processes and viable populations, and by mitigating at least some of the proximate threats to their biodiversity (Margules and Pressey 2000; Margules *et al*. 2002). However, protection of biodiversity is not an easy task. Conservation of biodiversity values usually competes with other human interests and activities (Margules *et al*. 2002), often making protection of areas contributing to the persistence of those values unfeasible from a socio-economic perspective. Given these constraints, prioritization of areas in terms of their biodiversity, or contributions to that biodiversity, is a key step.

While it is an accepted fact that conservation planning is targeted towards conserving biodiversity features or representative surrogates, one must remember that this has not always been the case. Only 20 years ago, biodiversity conservation was attempted by *ad hoc* decisions for siting conservation areas based on selection criteria such as scenic value, remoteness, low agricultural production potential or simply availability (Margules *et al.* 1988; Pressey *et al.* 1996; Sarkar 1999). These methods are based either on subjective judgments of biodiversity value, or on other criteria extraneous to biodiversity conservation. Such *ad hoc* conservation strategies tend to focus conservation efforts on those areas that are easy to protect, but that often have little urgent need for protection (Pressey 1994; Knight 1999; Pressey *et al.* 2000). Other methods identify areas of high conservation value using criteria such as richness or rarity (Williams *et al.* 1996; Myers *et al.* 2000). However, they fail to ensure adequate representation of all biodiversity needing protection (Williams *et al.* 1996).

To address the lack of representation and efficiency of previous conservation planning approaches, alternative methodologies have been developed and applied over the last two decades – ‘systematic conservation planning’ is the most widely used. Systematic conservation planning (Margules and Pressey 2000) aims to identify an optimum set of areas that cost-efficiently represent the desired conservation features, using complementarity-based approaches and incorporating cost in the selection process. Complementarity is defined as the gain in representation of biodiversity when a site is added to an existing set of areas (Possingham *et al*. 2000). Methods that incorporate complementarity lead to more effective representations of biodiversity features and more cost-efficient solutions than *ad hoc* (Pressey and Tully 1994), scoring, or ranking strategies (Margules *et al.* 2002; Pressey and Nicholls 1989).

Although not always explicitly acknowledged, most systematic conservation plans address three key principles: comprehensiveness, adequacy and representativeness (CAR). An optimal conservation plan protects biodiversity comprehensively, while selecting areas that ensure adequacy and representativeness under financial and often social constraints. The best plan is one that costs the least and has the least impact on other stakeholders. Efficiency is best addressed in a decision-theoretic framework. The following key steps in the frameworks developed by Shea (1998), and Possingham *et al.* (2001) form the centre of the systematic conservation planning framework developed by Margules and Pressey (2000):

- After collecting data on biodiversity attributes, state clear objectives about desired conservation outcomes. This is a crucial step that is often neglected.
- List the management options, their costs, and the impacts on stakeholders.
- Set constraints (maximum cost or impact on stakeholders), and try to maximise representation of biodiversity features under these constraints.

The last step — maximising outcomes — is commonly performed with complementarity-based algorithms. These algorithms are based on the initial work of Jamie Kirkpatrick, a Tasmanian botanist, who, when prioritising to fill gaps in reserve coverage of plant species, noticed that many of the high scoring areas were home to the same species (Kirkpatrick 1983; Pressey 2002). If all of these areas were recommended for prioritisation, then conservation efforts for individual species would be spatially duplicated. At the same time, areas with few, yet important, species were not assigned high priority. He solved this by removing from the data set those areas that were already prioritised and recalculating priorities, so the areas selected in each subsequent planning step would complement previously chosen or already protected areas. Following this approach, it is, for example, possible to optimize representation of species while minimising the area of land required.

9.1.2 Application to freshwater ecosystems

Freshwater ecosystems contain a disproportionately high amount of the Earth´s global biodiversity (Allan and Flecker 1993), and are submitted to higher pressures and threats than adjacent terrestrial ecosystems (Malmqvist

Figure 9.1. Niasse Game Reserve, in the Rovuma River catchment, Mozambique, demonstrating the use of river channels as boundary markers for the protected area, with no protection of the upper catchment or the river channel itself.

and Rundle 2002; Nel *et al*. 2007), yet they have received little attention from the conservation community (Abell 2002). While assessment of river condition has thrived in the last two decades and, some would argue, has superseded terrestrial efforts, river conservation science is still lagging behind terrestrial and marine assessments of conservation value (Daniels *et al.* 1991; Freitag *et al.* 1997; Root *et al.* 2003). Systematic conservation planning methods have been extensively applied to conservation problems in marine and terrestrial environments (e.g., Carwardine *et al*. 2008; Klein *et al.* 2008). Most conservation planning approaches have, however, overlooked freshwater biodiversity, because incorporating freshwater species and habitats adds several layers of complexity to an already complicated task (Abell 2002). There has been little emphasis on declaring protected areas for the primary purpose of conserving freshwater ecosystems and biodiversity (Saunders *et al*. 2002). Rivers have generally been inadequately dealt with in most assessments of terrestrial ecosystems unless they were considered important for terrestrial biodiversity patterns and processes (Nel *et al*. 2007). Indeed, one of the primary uses of rivers in terrestrial reserves is to define reserve boundaries (Figure 9.1). As a consequence, reserves are usually targeted towards terrestrial features (Lake 1980; Maitland 1985; Nilsson and Gotmark 1992; Skelton *et al.* 1995), with a few notable exceptions (Bayley *et al.* 1991; Saunders *et al.* 2002).

When prioritising for freshwater conservation value, most studies are either geared towards single species/taxonomic groups or use index-based measures. Most of the index-based measures are richness metrics (Clavero *et al*. 2004), measures of rarity (Filipe *et al*. 2004) or compound richness/rarity/diversity indices (Williams *et al*. 2004). A more sophisticated approach used an 'Index of Centres of Density' (Angermeier and Winston 1997), which identifies regionally rare fish taxa and assesses relevance of sites as sources for potential recolonisation. In the last few years, however, an increasing number of conservation planning projects in the freshwater realm are starting to adopt the principles of systematic conservation planning (Nel *et al.* 2007; Linke *et al.* 2007a; Moilanen *et al.* 2008; Hermoso *et al.* 2011).

This gap in freshwater conservation planning might be, in part, due to the complexity that freshwater systems pose to conservation practitioners. The connected and complex nature of rivers imposes clear constraints when planning for conservation in riverine environments. This, combined with a lack of accessible and reliable knowledge on the distributions and status of freshwater species, and the ecological processes required to maintain ecosystem functions, are some of the drawbacks that could have impeded or delayed the planning and implementation of effective conservation practices in the freshwater realm. It is also clear that many of the values of freshwater species are not yet fully appreciated.

9.1.3 Adapting terrestrial approaches to freshwater ecosystems

9.1.3.1 Recent developments

The most fundamental difference between terrestrial and riverine conservation planning is the required spatial configuration of potential protected areas. River networks are connected systems, both laterally and longitudinally. While terrestrial conservation planning is increasingly addressing issues of connectivity when dealing with metapopulations (Cabeza 2003; Fischer and Church 2003), the nature and scale of connectivity are different in freshwater systems. Sections of a river can be affected by activities hundreds or even thousands of kilometres upstream or downstream. Therefore, in accordance with Hynes' (1975) paradigm that 'the valley rules the stream', upstream areas must be considered when estimating conservation value or developing a system of protected areas (Moyle and Sato 1991; Puth and Wilson 2001; Crivelli 2002; Collares-Pereira and Cowx 2004). Some authors acknowledge that exceptions have to be made for very large streams because whole catchment protection is too difficult to achieve (Saunders *et al.* 2002; Collares-Pereira and Cowx 2004). We consider the absence of both theory and tools to resolve this in a systematic conservation planning framework as one of the key factors that impeded the earlier uptake of systematic tools in the freshwater realm.

However, in the last decade a handful of authors have dealt with the topic in both theoretical and applied studies since Abell *et al.* (2000) laid the groundwork with their classification of North America's freshwater ecosystems. The first publication that showed the two distinctive features of a systematic approach — clear objectives and a complementarity algorithm to derive an efficient solution — was a South African study focussed on conserving both river types and processes (Roux *et al.* 2002). It was followed by a few studies that highlighted the use of freshwater

A satellite image of the Congo River, demonstrating the complexity of river networks. The smaller city is Brazzaville on the north side of the river, with Kinshasa on the south side. The cities lie at the downstream end of an almost circular widening in the river known as Stanley Pool. The international boundary follows the south shore of the pool (approximately 30km in diameter). The Congo River exits the pool through a markedly narrowed channel at a series of whitewater rapids that can be seen in this view from space. © NASA/COURTESY OF NASAIMAGES.ORG ecosystem classification in systematic frameworks (Fitzsimons and Robertson 2005; Higgins *et al.* 2005). The year 2007 became a breakthrough year for systematic conservation planning in freshwater systems, starting with a new framework for freshwater reserves (Abell, *et al*. 2007) and an important study in a very data poor area – the Madre de Dios basin in the Amazon (Thieme *et al.* 2007). Two procedures were developed for classifying rivers using multiple attributes: Snelder *et al*. (2007) used freshwater fish species to inform input variables in the environmental classification of rivers, whilst Turak and Koop (2008) used fish, invertebrate and abiotic data to develop a procedure for generating a bottom-up multi-attribute typology for rivers. In the same year, levels of endangerment and protection were described for river types in South Africa using quantitative conservation targets as a basis (Nel *et al.* 2007), and Abellán *et al.* (2007) used C-Plan (Pressey *et al*. 2008) to identify priority areas for the conservation of aquatic Coleoptera on the Iberian Peninsula. Addressing the bias toward river ecosystems, an example appeared suggesting conservation planning approaches that can be applied in to wetlands (Ausseil *et al*. 2007). In addition, three complementarity-based algorithms were modified for use in river systems in conservation planning for: (1) 400 macroinvertebrate taxa in the Australian state of Victoria (Linke *et al*. 2007a,b); (2) large-scale ecosystem processes in all of Australia (Klein *et al.* in press a); and (3) 18 migratory fish species in New Zealand (Moilanen *et al*. 2008).

9.1.3.2 General issues of connectivity

The most obvious difference between planning in the terrestrial and freshwater realms is, as mentioned above, the connected nature of rivers and wetlands (Pringle 2001). It is nonsensical to design freshwater conservation areas without considering the upstream and downstream areas, as well as catchment ecosystems and land use. The success of conservation actions in any part of a river catchment will be greatly influenced by longitudinal connectivity within the catchment. Perturbations upstream or downstream of the boundaries of a freshwater reserve will have clear consequences to the processes within it and its ability to ensure the long-term persistence of its biodiversity. Presence of dams and deterioration of water quality due to wastewater disposals in a basin are just two examples where freshwater communities apparently protected within reserves can be seriously threatened by processes operating far away. The consideration of connectivity, and its importance in maintaining natural ecological processes and biodiversity in fresh waters, is key for systematic conservation planning in these systems (Fausch *et al*. 2002; Ward *et al*. 2004).

Over the last few years, scientists and planners have started to address connectivity issues. Higgins *et al.* (2005) and Thieme *et al.* (2007) first selected 'focal' areas for protection and evaluated the connectedness to existing reserves or headwater streams. These focal areas represent portions of the sub-catchment where management is most restrictive owing to their importance for freshwater biodiversity. Similarly, Sowa *et al.* (2007) set rules to select conservation-opportunity areas as fully connected systems. Since 2007, a number of publications focussed on incorporating longitudinal connectivity into complementarity-based algorithms. Others modified a complementarity-based algorithm similar to the one used in C-Plan (Linke *et al.* 2007a; Linke *et al*. in press), setting static rules to ensure inclusion of the entire upstream catchment in a conservation plan. Shortly after, riverine modifications to two generic conservation planning software tools were developed: Moilanen *et al.* (2008) modified the boundary quality indicator in ZONATION to deal with longitudinal connectivity, while a number of studies have applied MARXAN (Ball *et al*. 2009) to plan conservation along river networks by only considering the boundaries between connected sub-catchments (Klein *et al.* 2009; Hermoso *et al.* 2011; Nel *et al.* 2011; Rivers-Moore *et al.* 2011). An alternative solution has been used by Turak *et al.* (2011) and Esselman and Allan (submitted), whose aggregations of upstream disturbances are used to drive connectivity (see more detailed discussion in Section 9.1.3.3).

While the above examples show that planning tools can be modified for a freshwater setting, an optimal solution has not yet been achieved. Strict rules to conserve the entire upstream catchments (Linke *et al.* 2007a) are often unrealistic (and sometimes unnecessary), but only selecting adjacent catchments (Klein *et al.* 2009) does not automatically guarantee adequate protection (Linke *et al.* 2007b). The most promising approaches to date are the inclusion of different rules of connectivity for each species (Moilanen *et al.* 2008) and a decreasing penalty for planning units that are higher up in the catchment (Hermoso *et al.* 2011). To date, modifications have only tackled longitudinal connectivity – developing conservation planning tools that consider both longitudinal and lateral linkages in the context of planning for rivers and wetlands will be a significant future advance.

9.1.3.3 Threats and lateral connectivity

Lateral connectivity has, in contrast with longitudinal connectivity, been considered by freshwater planners from the start: almost every freshwater conservation plan operates on sub-catchments. Conservation planners have quantified the extent of present condition and future threats from land-use GIS layers (Linke *et al.* 2007a; Nel *et al.* 2007), assuming that land use in the surrounding catchments is a good proxy for threats to biodiversity (see also Stein *et al*. 2002; Norris *et al.* 2007). Turak *et al.* (2011) integrate lateral and longitudinal connectivity by deriving accumulated land use impacts at every point in the drainage network, and use a multiple regression model to quantitatively account for the relative contribution of

The Northern Macquarie Marshes Nature Reserve, NSW, Australia. As with many wetlands, effective conservation of this Ramsar site requires a mix of landscape and site-scale measures, including restoration of the natural flow regime and protection of key habitats. © TOM RAYNER

local and upstream disturbances. Esselman and Allan (2011) created a cost-surface out of aggregated upstream threats that makes degraded sites less attractive in a complementarity-based algorithm.

The interaction between longitudinal connectivity and lateral mediation of threats poses the biggest challenge to conservation efforts, as it is seldom feasible to conserve entire catchments when trying to protect significant downstream ecosystems. One example is the Macquarie Marshes in Australia. This Ramsar listed wetland is downstream from major agricultural development, which increases erosion and sedimentation threats, and reduces flow through water extraction for irrigation. Although this is an internationally significant wetland, the entire catchment cannot be protected, and, in this instance, mixed site and landscape scale protection schemes need to be devised.

The introduction of stressor- and target-specific connectivity and zoning rules would be an approach similar to critical management zones (see Section 9.3 for definition) directed at specific processes, but which addresses the problem of scale explicitly. For example, mild nutrient enrichment will be metabolised within 10km or less (Storey and Cowley 1997). Hence, the sphere of influence of this particular stressor is small, and upstream protection beyond this radius might be unnecessary. Another example would be targeted stressor remediation efforts. If sedimentation is the only threat on a suite of targets in a downstream planning unit, even simple remediation measures, such as riparian restoration or sediment reduction ponds, would be effective conservation measures.

While there has been a lot of scientific progress in including riverine connectivity into systematic conservation planning frameworks, the idea of mixed use zones and stressor-specific connectivity rules has only partially been addressed in freshwater planning frameworks. In one of the few studies applying these principles, Thieme *et al.* (2007) select for the focal areas in a systematic way, and allocated corridors connecting these focal areas *a posteriori*. In an ideal planning scenario, freshwater focal areas, critical management zones and catchment management zones (see Section 9.3 for definitions) would be considered together, as only simultaneous consideration ensures maximum efficiency. In the marine environment, the software package MARXAN has been modified to accommodate the allocation of mixed zones that contribute to conservation targets. After the philosophical background has been set by Abell *et al.* (2007), a similar adaptation for freshwaters that includes connectivity between the zones seems an obvious research priority.

9.2 Site scale conservation

9.2.1 Catchment versus site scale approaches

Conservation planning at the catchment scale, as described above, may be the ideal approach in most cases. There are, however, situations where a catchment scale approach, aimed primarily at ensuring the maintenance of ecosystem functions, may overlook the specific needs of individual species. The principle that conservation of ecosystem processes and functions will ensure the component species and populations also remain healthy (Simberloff 1998) is not always fulfilled. In some cases, management aimed at maintaining ecosystem goods and services may appear to be successful, but evolutionary history and adaptive potential is substantially reduced through a loss of component species. Given the level of current and future threats to freshwater species from impacts such as climate change (see Section 8.6), invasive species (see Section 8.2.3) and human induced ecosystem degradation, it is now critical that we conserve species diversity in order to maximise options for the future.

Maintaining the evolutionary potential of component species while society is primarily interested in the more immediate benefits of goods and services from the environment is perhaps the biggest challenge facing global conservation programmes. Apparently ‘less important’ species should be valued not only for their intrinsic rights to exist, but also for their future opportunity values as important genetic resources. Such species may also act as effective surrogates for the conservation of many other non-target species (e.g., Lawler *et al.* 2003). In the Olifants River system on the west coast of South Africa, for example, conservation actions planned for the Critically Endangered Twee River redfin (*Barbus erubescens*) (Impson *et al*. 2007) will benefit an undescribed *Galaxias* species with a similar distribution and conservation status. Prioritising conservation of populations of the Critically Endangered Barnard’s rock catfish (*Austroglanis barnardi*) will similarly benefit the Endangered Olifants River lineage of fiery redfin (*Pseudobarbus phlegethon*) and other threatened species. The link between conserving one target species and the subsequent benefits to other non-target species or ecosystem functions is, however, not always clear (Simberloff 1998), and care must be taken to account for indirect impacts on other species. For example, it is possible that well-intentioned interventions to conserve one species could inadvertently harm another (Simberloff 1998). In the Olifants River system, for example, large cyprinids such as Clanwilliam sandfish (*Labeo seeberi*), Clanwilliam yellowfish (*Labeobarbus capensis*), and Clanwilliam sawfish (*Barbus serra*) may benefit from removing barriers to migration, such as weirs, and through stopping the temporary desiccation of lower reaches of tributaries due to over-abstraction of water for irrigation. Restoring these corridors will, however, allow alien fish species, such as smallmouth bass (*Micropterus dolomieu*), spotted bass (*Micropterus punctulatus*), bluegill sunfish (*Lepomis macrochirus*) and banded tilapia (*Tilapia sparrmanii*), already present in the lower catchment, to move upstream and invade tributary streams where they may cause the extinction of populations of smaller indigenous fish species.

The spotted bass (Micropterus punctulatus) *is one of four alien and invasive bass species in South Africa that has caused widespread extinction of indigenous fish populations.*
© SAIAB/ERNST SWARTZ

Ideally, conservation planning for freshwater species should cover whole catchments (see Section 9.3), using keystone species to learn more about ecosystem functioning and for monitoring the success of management actions at the catchment scale. In reality, however, many species are restricted to single sites or have few remaining sub-populations – in these cases single species conservation programmes are also essential. In the Cape Floristic Region (CFR) of South Africa, for example, 79% of the 43 genetic lineages of primary freshwater fishes (many undescribed) are threatened with extinction (Linder *et al*. 2010). Several species have been reduced to only one or two sub-populations or sites (e.g., *Barbus erubescens* and several undescribed *Pseudobarbus, Galaxias* and *Sandelia* species across the CFR). If the results of Lawler *et al.* (2003) hold true for most regions, conservation planning strategies for aquatic ecosystems should include single species and site-specific actions. South African scientists have been working on a biodiversity layer for freshwater fishes in the National Freshwater Ecosystem Priority Areas (NFEPA) project (Nel *et al*. 2009). This layer identifies an upper limit of 10 fish sanctuaries (sites or populations) for Critically Endangered, Endangered and Vulnerable species as irreplaceable biodiversity features. Site-specific actions can also achieve conservation targets in, for example, weakly protected catchments, often in conjunction with other uses of the catchment. Smaller planning units usually outperform large planning units, and, similarly, site-specific plans can outperform broader regional plans that might not have clear local goals.

9.2.1.1 When are site-scale actions or planning appropriate?

Site-specific planning and actions are needed when species are highly threatened (usually those species assessed as Critically Endangered or Endangered, according to the IUCN Categories and Criteria) or restricted to one or very few sites that can be clearly defined. When the status of a species or ecosystem is critical, there are usually no options for protection elsewhere. The other option, translocation, can itself create problems, such as affecting genetic integrity of populations (Dowling and Childs 1992; Leary *et al*. 1993; Quattro *et al*. 1996; Avise *et al*. 1997), translocation of parasites (Kennedy 1993), direct or indirect threats to other biodiversity, and loss of a region's evolutionary history. Solutions must, therefore, be found on-site. The advantage of site-specific interventions is that understandable and easily obtainable targets can be set for local scale actions. Such targets can often be met cost effectively, are achievable in areas where capacity is low, and will often benefit other species.

The disadvantage of site-specific interventions is that high biodiversity areas may be neglected, as may lower priority threatened species for which conservation action may be more effective (for example, because of more extant populations). Catchment-wide planning has the further advantage of highlighting areas of overlap between threatened taxa, although these areas are not necessarily the best places to protect specific taxa because their healthiest populations may not be within the area of overlap. Therefore, where planning is on a catchment scale, high priority threatened species may not always be protected in the optimal sites for their survival. An overall strategy should, therefore, combine catchment-wide planning (prioritisation of ecosystems) with site-specific actions (critical species conservation). In many cases, small changes in land use or water management can result in significant conservation success, but in other cases expensive interventions may be the only option.

9.2.1.2 Prioritisation of site-scale conservation actions

Site-specific conservation actions should be prioritised in two steps: 1) where a failure to meet the target will lead to the extinction or unacceptable loss of local biodiversity features or processes; and 2) through prioritisation between site-specific actions within overall catchment plans. In areas where capacity and resources are not available for more extensive intervention, the simpler and cheaper conservation actions for threatened species should be the priority.

Choosing sites for site-specific intervention and incorporation as part of a wider catchment management plan can be relatively simple once the necessary information is available. Obtaining that information can, however, be difficult, time consuming and expensive, since it requires field survey, knowledge of known and projected species distributions, and studies of genetic diversity to understand evolutionary patterns and processes. Evolutionary uniqueness should be a major consideration when prioritising species for conservation. Once sites have been identified, actions can be prioritised according to species conservation status. Species should be ranked from the most threatened to least threatened and a cost-benefit analysis conducted to prioritise actions.

The Rondegat Waterfall, which prevents the invasive smallmouth bass from spreading upstream.

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9.2.2 Case studies of site-scale conservation intervention in southern Africa

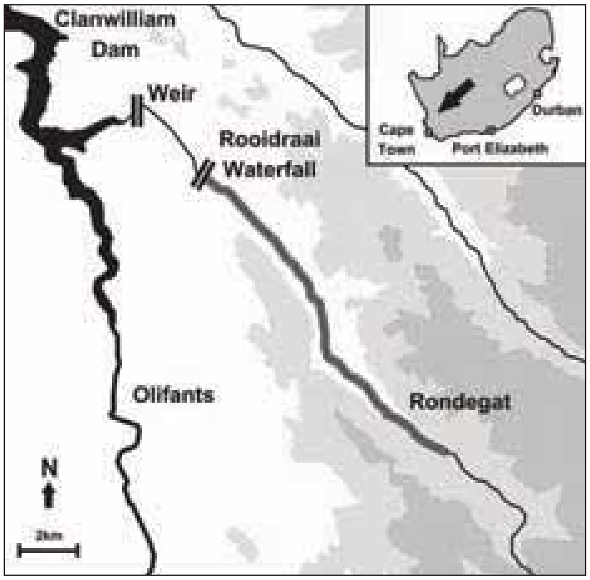
1. C.A.P.E. Biodiversity Conservation and Sustainable Development Project: Eradication of invasive alien fishes from river sections in the Cape Floristic Region of South Africa

The Cape Action People Environment (CAPE) Biodiversity Conservation and Sustainable Development project provides a good example of site-specific conservation targets set within a broader ecosystem conservation framework, where eradication of invasive alien fishes will greatly benefit the indigenous fish fauna of the CFR. Almost all fish species in this region are threatened, according to the IUCN Red List (http://www.iucnredlist.org; Tweddle *et al*. 2009), with invasive alien fishes introduced from the late 1800s to mid 1900s highlighted as having a major impact in almost all cases.

Cederberg tributaries of the Olifants River system in the CFR have some of the most extreme examples of invasive alien fishes impacting populations of indigenous fishes. In a typical scenario, five to six indigenous species are found above a small natural barrier, with no indigenous species surviving below the barrier where the invasive alien smallmouth bass is found. In the Rondegat River ( ), for example, the indigenous fiery redfin, Clanwilliam redfin (*Barbus calidus*), Clanwilliam yellowfish, Clanwilliam rock catfish (*Austroglanis gilli*) and an undescribed *Galaxias* species, survive above a small waterfall that prevents smallmouth bass from spreading upstream. Only a few large Clanwilliam yellowfish are able to survive with the bass, but without successful recruitment.

The stretch of the Rondegat River that is to be treated with piscicide to eradicate alien species of fish. © SAIAB/ERNST SWARTZ

Figure 9.2. The Rondegat River and Clanwilliam Dam, showing the distribution of most of the indigenous fishes (thick grey line). The area between the Rooidraai Waterfall and the downstream weir will be targeted for rehabilitation (eradication of alien fishes) to expand the indigenous fish populations.

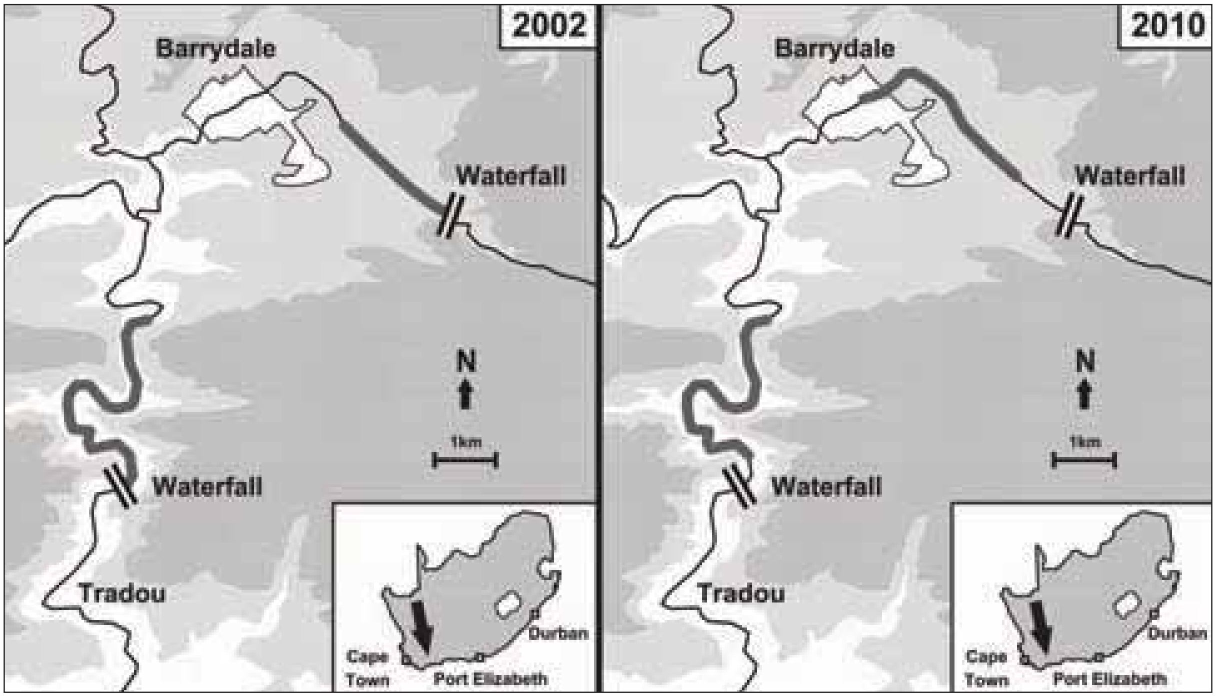


The need for a programme to protect the indigenous fauna of the CFR was clear, and was subsequently initiated in the form of an alien fish eradication strategy. A selection process, involving all conservation scientists with knowledge of the CFR, identified four river sections for a pilot project where: (a) alien invasive fishes constituted a significant threat to the indigenous species; (b) eradication of invasive alien fishes was feasible; (c) the rivers would still provide healthy habitats for the indigenous fishes once the invasive aliens were removed; and (d) the rivers were not of major importance for angling, often targeting alien invasive species.

A proposal to eradicate the invasive alien fishes in these river sections, with the piscicide rotenone as the main eradication method, underwent a rigorous Environmental Impact Assessment (EFA 2009). This recommended that the project go ahead, with very strict environmental safeguards. The EIA recommended that the Rondegat River should be treated first because of the ease of treatment and the minimal risks to the environment, with the lessons learned applied in future eradication programmes. The recommendations of the EIA have been accepted by all relevant environmental authorities, and the project is being implemented.

The pilot project on the Rondogat River involves strengthening an existing farm weir that prevents upstream migration of alien fishes from the Clanwilliam Reservoir on the main stem of the Olifants River immediately downstream of the targeted stretch of river (Figure 9.2). Eradication

Figure 9.3. The Tradou catchment, showing the change in distribution of the Barrydale redfin (*Pseduobarbus* sp.) (thick grey line), due to changes in water management and alien fish distributions.



of aliens from the 4km stretch of river between the weir and the small waterfall upstream will allow subsequent recolonisation by the five indigenous threatened fish species from their current restricted habitat upstream. The outcome will be the extended distribution of indigenous species, and a buffer zone between the alien colonised Clanwilliam Reservoir below the weir and the very small existing natural barrier upstream.

2. Conservation actions for the Barrydale redfin (Pseudobarbus sp.) *in the Cape Floristic Region of South Africa*

This undescribed Barrydale redfin is restricted to a single site in the Tradou catchment of the Breede River system in the Western Cape Province of South Africa (Swartz 2005). The restricted range of this species, which is the only indigenous fish species in the catchment, has been further fragmented by water abstraction, mainly for the town of Barrydale. The species suffers most of the threats common to indigenous fishes of the CFR. Alien largemouth bass (*Micropterus salmoides*), bluegill sunfish (*Lepomis macrochirus*) and banded tilapia (*Tilapia sparrmanii*) have invaded most of the species' indigenous range. Excessive water abstraction stops the river flow above the natural range of the species, and only pools remain in the upper reaches. Some return flow and small tributaries restore habitat in the lower reaches of its range.

The Critically Endangered Barrydale redfin (Pseudobarbus sp.)*. Many other redfin species like this one are being threatened by mainly alien fish species.* © SAIAB/ERNST SWARTZ

The Tradou River Gorge has been invaded by alien fish species, resulting in the complete extirpation of the Barrydale redfin in the lower sections of the gorge (as seen in the picture) and some upstream areas. © SAIAB/ERNST SWARTZ

In this case, simple interventions could greatly improve the situation for the Barrydale redfin. Water is currently removed from upstream and diverted through a canal system that delivers water to the town and farms (Figure 9.3). Water for the farmers is released back into the river from where it is again diverted into canals lower down. If the water allocated to farmers could bypass the first canal and remain in the river until abstraction lower downstream, at least 1km of habitat for the Barrydale redfin could be restored. Largemouth bass occur in the upper reaches of the catchment, but will probably disappear from the river if removed from dams in the upper catchment. There are also opportunities to involve the local community in cleaning up their river, where children formerly played. Water abstraction will, however, remain a contentious issue. Even though all water in the river is currently being used, the population of Barrydale is increasing, and there are already severe water restrictions. The site-based actions recommended above will provide some respite, but a lasting solution is needed to allow restoration of the river flows required under South African legislation.

3. Lesotho Highlands Development Authority project to conserve the Maloti redfin **(Pseudobarbus quathlambae)** *in Lesotho*

The Maloti redfin is a Critically Endangered species (Skelton *et al*. 2001) that has evolved without fish predators in the headwaters of the Orange River in the highlands of Lesotho. Mohale Dam has been built within the system as part of a water transfer scheme to deliver water to Gauteng Province in South Africa. The dam was unfortunately built on an important catchment with regards to the future survival of the largest extant population of the Maloti redfin. The Mohale population is genetically different to the other four populations, with a genetic distance similar to species level differences in other *Pseudobarbus* species (Swartz 2005; Swartz *et al.* unpublished). Predatory fish species can now invade the Mohale Dam through the water transfer tunnel, with potential impact on the Maloti redfin, and, in addition, it is possible that the redfin may not be able to adapt to the new lacustrine habitat (Skelton *et al*. 2001). As a mitigation measure, a dual approach was adopted to: 1) secure that part of the natural range of the Mohale population above the dam with an artificial barrier; and 2) translocate individuals to neighbouring catchments free from alien invasions and habitat alteration (Skelton *et al*. 2001; Rall *et al*. 2002). Recognising that the Maloti redfins themselves could pose a threat to the other aquatic fauna of the translocation sites, an invertebrate study was conducted. The study predicted only minor impacts, as no invertebrates of conservation concern, and no endemic species, were found (Rall *et al*. 2002). Two of the four translocations seem to have been successful. Unfortunately, the proposed barrier to protect the native Mohale population was not built, leaving the natural range of this unique lineage still vulnerable to invasion by alien species. Had the research recommendations (Skelton *et al*. 2001; Rall *et al*. 2002) been implemented in full, the Maloti redfin's Red List status might well have been down-graded, but this is not yet possible, due to the remaining threats.

The banded Neolebias (Neolebias lozii)*, a Critically Endangered species from the Kataba River and its tributary, the Sianda, a small tributary system of the Upper Zambezi, which it joins on the eastern side of the Barotse Floodplain.* © DENIS TWEDDLE

4. Conservation plans for Banded Neolebias **(Neolebias lozii)** *in Zambia*

In the Upper Zambezi River system, one fish species, the banded Neolebias, is Critically Endangered. This species is apparently restricted to the Kataba River and its tributary, the Sianda stream, as intensive sampling in apparently suitable habitats throughout the rest of the Upper Zambezi system has failed to yield any other populations. These two streams form a very small tributary system of the Upper Zambezi, which joins on the eastern side of the Barotse Floodplain (Tweddle *et al.* 2004). The streams inhabited by the banded Neolebias are small and associated with seasonally flooded plains (also called dambos) bordered by open woodland. The species occurs in and under dense floating mats of vegetation adjacent to the stream margin and in dense emergent vegetation (Winemiller and Kelso-Winemiller 1993; Tweddle *et al.* 2004).

In contrast to the previous examples of site-specific conservation in southern Africa, where degradation of the aquatic environment as a result of human activities has necessitated urgent localised interventions, the banded Neolebias does not need immediate action to reverse degradation, or artificial barriers to protect it from threats such as alien species. Instead, site-specific action is needed to promote awareness of the threats posed to the species' survival, and to prevent unintentional degradation of the habitat. The human population in the area is low but increasing, and agriculture in the dambos poses the greatest threat. Part of the Kataba River upstream from the known location of the species has been canalised, and no banded Neolebias were found in this section of the river, as the dense mats of peripheral vegetation were removed when the canal was dug. Canalisation of the streams also accelerates run-off from the floodplain in the dry season. Increasing human population leading to intensification of

Sampling a dense mat of vegetation in the Kataba River using a robust D-net. This mat yielded several specimens of the banded Neolebias (N. lozii). © DENIS TWEDDLE

agriculture, together with deforestation of the woodland bordering the dambos, and possible pollution by fertiliser and herbicides, is likely to threaten the habitat further. A large headwater swamp sustains the Kataba stream, such that any reduction in flow due to groundwater abstraction is also a potential threat. In this tiny sub-catchment of the Zambezi River, therefore, site-specific intervention is recommended to raise awareness among the local communities, who may not know that this rare species lives in their river. Hopefully, people might then be encouraged to maintain the diverse stream habitat and avoid digging canals or clearing the swamp vegetation.

9.2.3 Conclusions

Site-scale conservation has its place within the broader framework of catchment scale interventions, in particular for the targeted conservation of range-restricted species. Simple actions at the site-scale can provide rapid benefits to species that might otherwise not gain from large scale management actions. Among many potential beneficiaries of site-scale action are those species that may appear to provide little benefit through provision of ecosystem services but may often hold significant genetic diversity that is at great risk of being lost forever.

No southern African freshwater fishes have yet been removed from a threatened category on the IUCN Red List as a direct result of conservation actions. Some species have been down-graded, although these do not reflect genuine changes in status but are instead mainly due to provision of better information (Tweddle *et al*. 2009). In conservation planning, it is, therefore, important to include critical sites for aquatic biodiversity to which clear conservation actions can be linked. Catchment-wide conservation planning will always be preferable, but with many species restricted to only one or two sites, it is essential to include them as irreplaceable features. Site-specific conservation actions to protect threatened aquatic species are in their infancy in southern Africa, but there are opportunities for such actions to have a major benefit for threatened species. Local success stories, in particular where limited capacity and funding are available, have the potential to inspire larger interventions.

9.3 Catchment scale conservation

Planning and implementing conservation at the catchment scale — in line with the principles of systematic conservation planning described above (Section 9.1) — poses some on-ground issues. The most basic, and most discussed in scientific literature, is the need for information on the spatial distribution of conservation features. Conservation planning is usually a spatially-explicit exercise, so the spatial distribution of biodiversity features and conservation costs is required to identify the most cost-effective combination of areas that represent all the targeted biodiversity. A range of approaches are being used in conservation planning to represent the spatial distribution of conservation features. Secondly, and no less important, it is crucial to define the spatial scale at which the conservation exercise will be carried out. Selection of the most appropriate scale is essential for integration of planning and implementation stages. In this section, we will discuss the available alternatives for tackling these problems.

The increasing availability of spatial data sets for freshwater species (see Darwall *et al*. 2010), such as presented here for Africa, are opening the door for application of systematic conservation planning approaches in freshwater systems.

9.3.1 Use of biodiversity surrogates

Surrogates need to be used, as we never have a complete quantification of biodiversity in a planning unit – in this case, a sub-catchment. Sarkar (2002) describes a useful dichotomy between 'true surrogates' and 'estimator surrogates'. True surrogates are the target species or processes themselves and are hence ideal 'direct' targets in a planning framework. However, as every researcher or practitioner knows, it is almost impossible to get a complete coverage of true surrogates across all planning units. Therefore, in most real life situations, we need an informed selection of estimator surrogates – features that represent the true target species or processes.

To evaluate the best selection of surrogates, we need to keep in mind the objectives: the surrogates should help us design a conservation plan based on principles of Comprehensiveness, Adequacy, Representativeness and Efficiency (CARE). Therefore, any surrogates used in conservation planning need to relate to the features we want to protect, at the relevant spatial and temporal scales. Linke *et al*. (2011) suggest the following taxonomy of surrogates:

1 **Surrogates based on biological survey data.** This category includes species, species assemblage types, or observed processes. Biological survey data are usually fraught with data gaps (false absences). Direct use of inconsistent survey data in conservation planning will bias selections to well-surveyed areas of the planning region, and ignore un-surveyed areas that may, in reality, be important. To address this bias and obtain a more continuous geographic coverage, many practical applications have modelled species distributions (Linke *et al.* 2007b; Moilanen *et al.* 2008; Hermoso *et al*. 2011) or communities (Turak and Koop 2008; Turak *et al.* 2011) based on environmental attributes. While this alleviates the problem of false absences, it brings with it a different challenge – that of false presences. In conservation planning, false presences, or commission errors, are a problem in that they lead to the false assumption that by capturing a site where a species is falsely present you have it conserved (Loiselle *et al.* 2003; Wilson *et al.* 2005).

2 **Biologically-informed physical surrogates.** These are environmental surrogates that have been stratified by relating them directly to biological survey data. However, unlike in the above category, no biological attributes are directly predicted. Instead, a statistical model links environmental surrogates to the landscape patterns of biological attributes. Freshwater examples are provided by Snelder *et al.* (2007) and the study by Leathwick (submitted). Given the lack of freshwater-specific data (Abell 2002; but see Darwall *et al*. 2010), the technique by Leathwick (submitted) is a particularly exciting new development, as it fits a single environmental model to multiple species and is robust to poor input data. This technique is similar to Generalised Dissimilarity Modelling (GDM), which has been used in the context of terrestrial conservation planning (Ferrier *et al.* 2007) as a technique which models species turnover along environmental gradients instead of actual species. By identifying the variables responsible for the turnover, even very rare features that would not otherwise be modelled are considered in the conservation plan.

3 **Ecoregional surrogates.** These are types of ecosystems or landscapes defined on the basis of a wide range of biological and physical attributes. These ecosystem classifications are usually hierarchical and constrain abiotic classification to within the boundaries of coarsely-defined biological attributes, for example, zoogeographic zones or freshwater ecoregions that are frequently (but not exclusively) expert-derived. Examples of such approaches include Roux *et al.* (2002), Higgins *et al.* (2005), Thieme *et al.* (2007), Ausseil *et al.* (2011), Heiner *et al.* (submitted), Khoury *et al*. (2011), Nel *et al.* (2011) and Rivers-Moore *et al.* (2011).

4 **Pure physical surrogates.** These use abiotic information only and are commonly applied in data-poor planning regions with severely limited biological data and expert knowledge. These GIS derived surrogates make use of best available data and conceptual knowledge on abiotic drivers of freshwater systems. Such classifications are confounded by assigning thresholds to abiotic variables to define ecosystem types. This requires knowledge about how species, communities, and ecological and evolutionary processes respond to the physical and chemical environment. Based on the current limited knowledge of freshwater ecosystems, the scientific defensibility of such thresholds is dubious. In addition, the utility of unstratified physical surrogates has been heatedly debated in the terrestrial and marine realms (Araujo and Williams 2001; Brooks *et al.* 2004; Higgins *et al.* 2004), with research suggesting that without calibration by observational surveys at the appropriate scale, such surrogates should be applied with caution (Lombard *et al.* 2003).

Choice of surrogates ultimately depends on the availability of data at an appropriate scale, as well as the expertise and resources for undertaking the assessment. Rapid assessments or assessments in data poor regions where no species or observational data exist will only be able to make use of pure physical surrogates – recognising the limitations of this approach (see above) and tempering it wherever possible with expert knowledge. However, the key advantage of using surrogates based on actual biological data, as presented in this report for Africa, is their efficiency stemming from certainty of protecting a given amount of biodiversity per unit area. Conservation plans using only surrogates defined by top-down hierarchical classifications based on geomorphology (Frissell *et al.* 1986; Thoms *et al.* 2004), hydrology (Stein 2005) or a classification that incorporates climate, geology and hydrological boundaries (Snelder and Biggs 2002) may ensure the persistence of biodiversity where resources are unlimited because the features to protect could then be selected at a low level of the hierarchy. In most places, resources are, however, likely to be available to protect only the highest priority sites so, wherever possible, using surrogates based on observed patterns is preferable – once again, data such as provided here for Africa will prove extremely useful to inform the planning process. Using community-level surrogates (Ferrier and Guisan 2006) — especially if several community types can be combined — is desirable, because this may help account for unknown and under-surveyed species. It has also been argued that community-level surrogates may be particularly useful for representing differentiation diversity, that is, beta and gamma diversity (Ferrier 2002). In data-poor regions, definition of surrogates will inevitably rely largely on remotely defined features with low certainty, but it also may be possible to use data rich regions as test-beds for evaluating the performance of surrogates that can readily be applied to data-poor regions (Ferrier 2002).

9.3.2 Data requirements

Closely linked with the discussion of surrogates is the issue of data needs. A frequently heard criticism of systematic planning approaches is that they are too data hungry and, therefore, index-based biodiversity assessments are preferable. However, this is not a valid argument: while bias from incomplete data coverage has been acknowledged in systematic planning (see Rondinini *et al.* 2006), scoring approaches ultimately face the same limitations. For example, scoring approaches will also favour sites where data exist and ignore sites that have not been sampled – not necessarily because this is the only site in the landscape with this feature, but because no one has looked elsewhere.

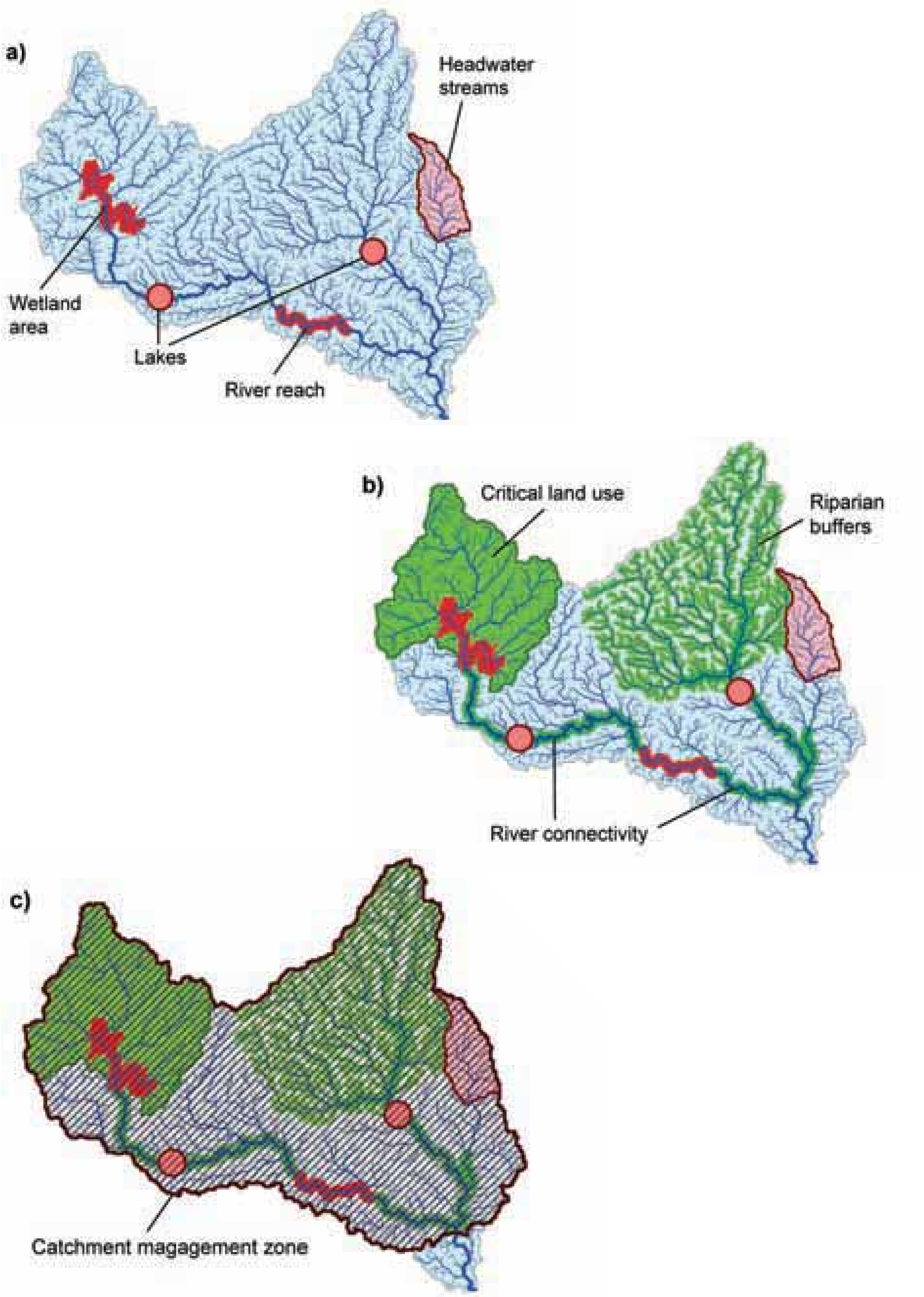
With increasing availability of both GIS data, as provided in this report for all of continental Africa, and new, user-friendly modelling techniques, it is rapidly becoming easier to produce modelled true surrogates or highly informed physical surrogates. Hence, we conclude that data availability for systematic freshwater conservation planning is not as much of an issue as it used to be, and especially no reason to justify not using systematic approaches. Moreover, with the availability of predictive modelling techniques that are robust to data poor inputs, the use of raw environmental surrogates is only necessary in extreme cases, for example in the Amazon (Thieme *et al.* 2007) or China (Heiner *et al.* 2011), where species data are extremely limited and the area very large. A key advantage of systematic approaches is that they make the best use of existing data. They can be applied where little data are available and generate reliable but coarse assessments. While continued inventorying of the world's freshwater species and habitats will improve the representativeness in conservation plans (particularly those in data poor regions), we believe that a much more significant challenge for freshwater conservation planning lies in addressing the adequacy of conservation plans – how do we ensure that freshwater biodiversity persists and evolves naturally over time, given both natural and human disturbances?

9.3.3 Planning and implementation spatial scales

The strong intra-basin connectivity that facilitates the propagation of threats along river basins contrasts with the low inter-basin connectedness for strictly aquatic species and the propagation of threats. Catchment boundaries pose impassable barriers to these species, hence they can be considered biogeographic islands, where speciation processes occur. Important ecological processes, such as speciation, occur within catchment boundaries (Rahel 2007). Lake Victoria is an example of the importance of the geographical isolation of catchments (either rivers or lakes), with more than 350 species of cichlids, most of them endemics that evolved from only a few common ancestors (Avise 1990; Verheyen *et al*. 2003). Catchment boundaries also limit the direct transference of threats between neighbouring river basins. This important role has recently been weakened by human interventions, and now, for example, freshwater species are constantly translocated between neighbouring catchments or introduced from distant areas (Clavero and Garcia-Berthou 2006). Some of these introductions, such as the Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*), have drastic consequences on endemic freshwater fish communities in Lake Victoria (Mumba and Howard 2005) (but see page 22, this volume).

When considering spatial scales in planning processes, two concepts are usually confounded: the scale of planning and the scale of implementation. To be successful, a conservation program should be planned at the whole catchment scale, as we state above, but does not necessarily have to be implemented at that scale (e.g., protect whole catchments). This way, catchment processes, such as migrations, can be more efficiently incorporated in the conservation plan. However, the misconception of planning and implementation scales and the lack of tools to address conservation planning at the catchment scale have prevented more effort and attention being dedicated to this key issue. Planning at the catchment scale does not mean protecting whole catchments but finding the best way to maintain the biodiversity it contains. In this respect, the recent hierarchical protection strategy by Abell *et al.* (2007) is highly relevant in the context of multiple-use freshwater

Figure 9.4. Schematics of proposed freshwater protected area zones. (a) Freshwater focal areas, such as particular river reaches, lakes, headwater streams, or wetlands supporting focal species, populations, or communities. (b) Critical management zones, such as river reaches connecting key habitats or upstream riparian areas, whose integrity will be essential to the function of freshwater focal areas. (c) A catchment management zone, covering the entire catchment upstream of the most downstream freshwater focal area or critical management zone, and within which integrated catchment management principles would be applied (reproduced with permission from Abell *et al.* 2007).



zones (Figure 9.4). According to this new schedule, high priority areas for the conservation of freshwater biodiversity would be declared a 'freshwater focal area' and use within these areas is likely to be fairly restrictive, similar to terrestrial protected areas (see Section 9.2). If — as in most cases — the entire catchment cannot be protected, some of the key areas upstream would be designated as 'critical management zones', which will be managed to maintain the key processes that support the downstream freshwater focal areas. Examples of critical management zones may be spatial, such as areas of high sediment load, key fish spawning habitat or corridors for spawning migration, as well as temporal. For example, environmental water allocations may only be needed at the times relevant to spawning and migration. The third, and final, level of the protection strategy is the 'catchment management zone', which is designated to the entire catchment upstream of the freshwater focal area. In this truly mixed-use zone, which also protects groundwatersheds (Pringle 2001), basic catchment management principles apply. Catchment management zones are similar to multiple-use protected areas, but the term emphasizes a whole-catchment perspective without being too restrictive across the entire catchment. However, more thought needs to be directed towards very large systems, such as the Amazon (South America), the Murray-Darling (Australia), the Mississippi (USA) or Congo and Nile River basins in Africa. In these systems, mixed-use protection schemes might not be realistic for entire upstream zones.

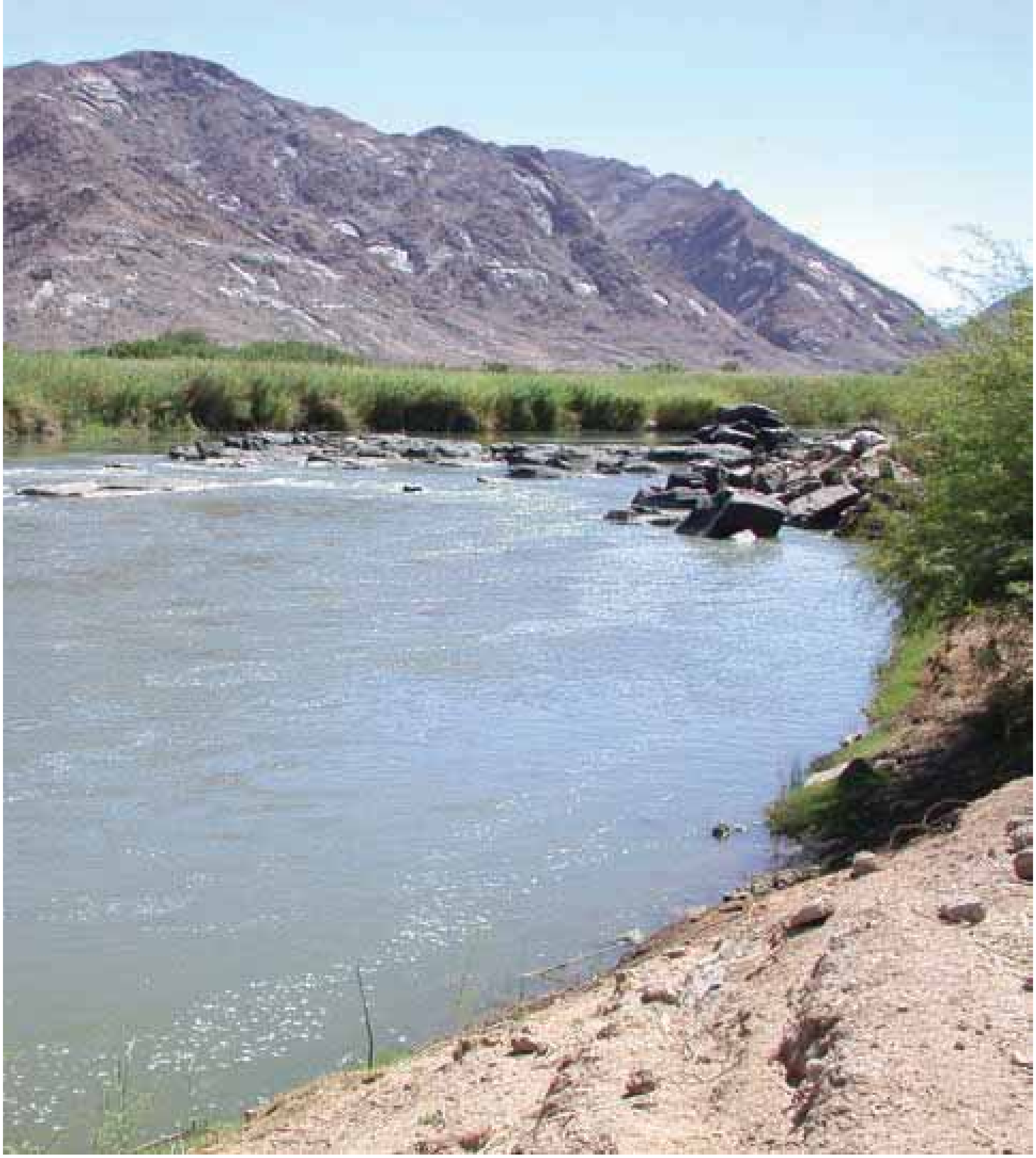
9.3.4 Freshwater ecoregions as units for conservation planning

Ecoregional classifications provide appropriate units for the representation of natural distinctiveness patterns in species assemblage composition, habitats, and processes across large spatial scales, such as the continental scale. They are usually defined using spatially-explicit information about the distribution of different biodiversity surrogates. Substantial efforts have been recently devoted to the description of freshwater ecoregions in the World (Abell *et al*. 2008) and Africa in particular (Thieme *et al*. 2007) (see Chapter 1, Figure 1.2, this volume). These ecoregions are designed to serve as conservation planning units – as biogeographically meaningful units for subdividing a larger river or lake basin, or for aggregating several basins sharing similar species assemblages and ecological processes into a single unit. However, although ecoregions can be useful to both stratify reporting units — as well as providing high-level surrogates — they can be too coarse to be used as meaningful planning units in conservation planning frameworks. A key problem is data heterogeneity within ecoregions. Heterogeneity in large planning units increases uncertainty around spatial patterns within them. Imagine if a species or other ecosystem attribute occurs just in the corner of a large ecoregional planning unit. Usually this is reported as 'present' in the ecoregion. If an ecoregion is now split into smaller planning units, it follows that this presence is translated from the ecoregion into the smaller units. Patchy distribution data can, in particular, lead to massive shortfalls of real representation. In the case where more detailed data are available — such as at the sub-basin scale, as presented here for Africa — it does not make sense to ignore finer spatial information. Smaller planning units outperform large planning units for a number of reasons:

1. Attribute information is more accurate (as discussed in the paragraph above).
2. This accuracy leads to an increase in efficiency. To cover a target – say, 100 habitat km of a species, one can hit this target more directly.
3. The data are more manageable.
4. Threats and the set of management actions to address them can be tackled more efficiently through a reduction in uncertainty for the spatial distribution of threats and the subsequent spatial allocation of management actions.

9.4 Conclusions

Given the advances — in terms of methods, data and conceptual understanding of freshwater ecosystems — and varied applications across the globe (e.g. *Freshwater Biology,* Vol. 56:1 Jan. 2011), there should be no excuses to delay or avoid implementation of systematic conservation planning in this traditionally ignored realm. Spatial connectivity is a major component of freshwater ecosystems structure and function, so it needs special consideration when planning for freshwater biodiversity. In this chapter, we have discussed how the main processes associated with spatial connectivity in freshwater ecosystems, such as migration or longitudinal movement of threats (for example, pollutants or invasive species) along river networks, can be effectively addressed with the tools (MARXAN, ZONATION) and methods available. Incorporating these ecological aspects in conservation planning will enhance the capacity of reserves to maintain the biodiversity they contain. Use of *ad hoc* or scoring criteria approaches that fall short at representing and protecting biodiversity efficiently are no longer justified by the pretext of a lack of the detailed data that systematic planning needs. In the last decade, extensive databases on biodiversity distribution and environmental surrogates have been gathered. For example, as presented in this current report, data on species status and distribution for more than 7,000 sub-catchments across the whole of continental Africa are already available. The idea that whole catchments have to be 'locked up' in order to preserve the biodiversity contained within has probably prevented conservation managers, stakeholders and the scientific



Lower Orange river at Pella Drift. © ROGER BILLS

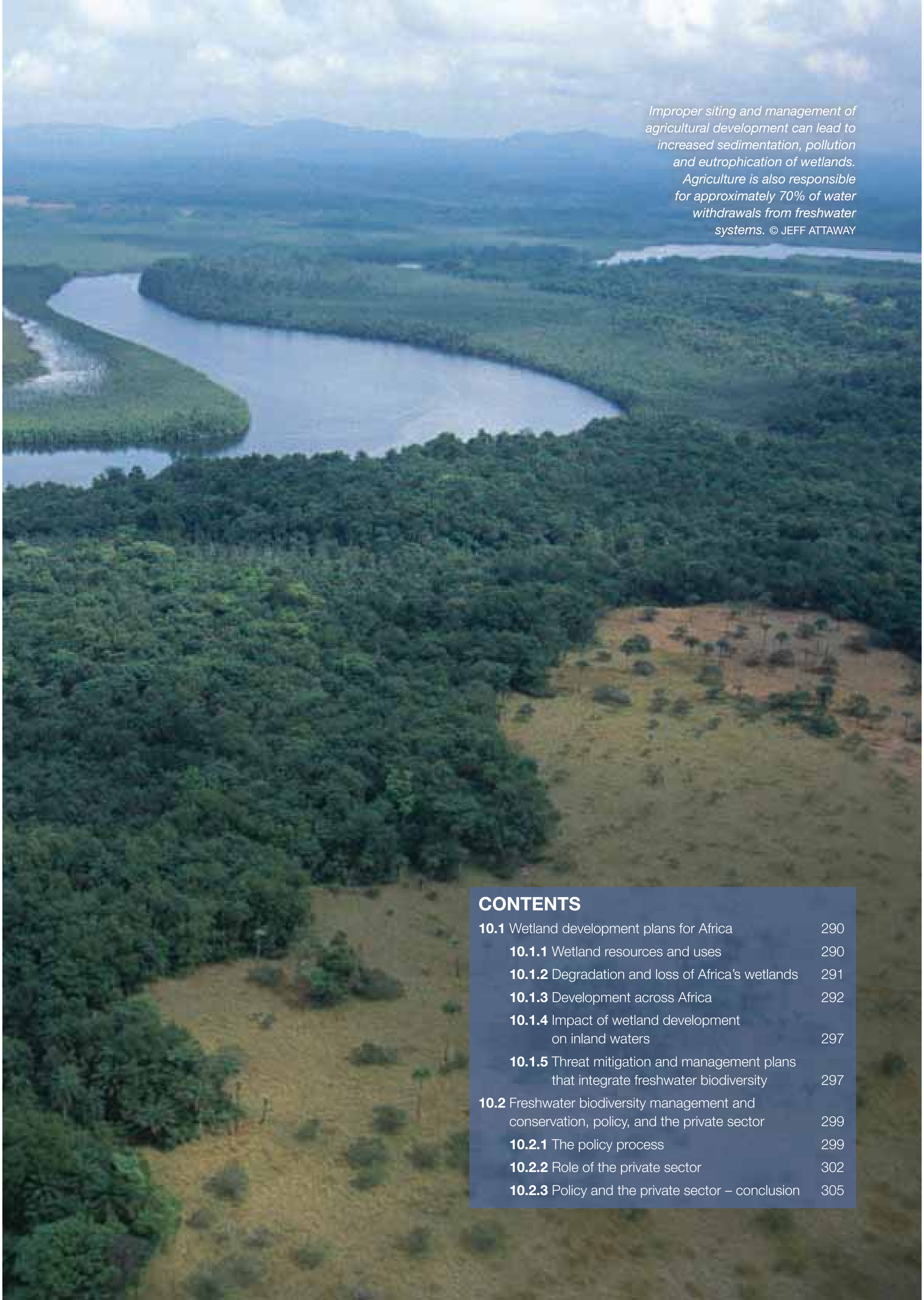
community from paying more attention to freshwater conservation planning, while marine and terrestrial plans were being developed. The traditional obstacles to freshwater conservation planning engendered by the misconception of planning and implementation scales has been overcome in recent times by the proposal of mixed conservation-land uses schemes. Freshwater conservation should ideally be planned at the whole catchment scale (minimum functional unit), since this allows the addressing of ecological processes more effectively. However, the implementation of such plans does not necessarily imply the strict protection of the whole catchment (e.g., see Section 9.2). Systematic conservation planning also accounts for the socio-economic component of conservation, by identifying the most cost-effective way of maintaining the targeted biodiversity. This enhances the likelihood of success for the implementation of conservation plans, by reducing potential social conflicts and minimizing the cost of its completion.

Chapter 10.

Development and policy plans for the future

Cross, K.[1], Niskanen, L.[1] and Dragisic, C.[2] (Section 10.1); Barrera, L.[3] and Canter Weikel, M.[4] (Section 10.2)

1 Eastern and Southern Africa Regional Office (ESARO), IUCN
2 Center for Environmental Leadership in Business, Conservation International
3 Center for Conservation and Government, Conservation International
4 Center for Environmental Leadership in Business, Conservation International



Improper siting and management of agricultural development can lead to increased sedimentation, pollution and eutrophication of wetlands. Agriculture is also responsible for approximately 70% of water withdrawals from freshwater systems. © JEFF ATTAWAY

CONTENTS

Lake Narasha in Kenya, part of the Lake Victoria basin which is one of the largest wetland systems in Africa.

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10.1 Wetland development plans for Africa

10.1.1 Wetland resources and uses

About 1% of the African continent surface (345,000 km^2) contains wetlands, and this does not include the many smaller or seasonal wetlands which have not been mapped, but are still of great importance to people and wildlife (Finlayson and Moser 1991). Equatorial Africa contains three of the largest wetland systems in the continent, the Congo swamps (80,000km^2), the Sudd in the Upper Nile (50,000km^2), and multitude of wetlands in the Lake Victoria Basin (approximately 50,000km^2) (Finlayson and Moser 1991). Other major wetlands across Africa include the Senegal River Delta, the Hadejia-Nguru wetlands in northern Nigeria and the Chari Logone floodplains in northern Cameroon (Wetlands International 2007). In southern Africa, there are the Zambezi and Limpopo floodplains and the Okavango Delta, as well as coastal estuaries and mangrove swamps.

As of December 2010, there were 298 sites in mainland Africa designated under the Ramsar Convention covering 20,471km^2, which is nearly 6% of the total area of wetlands in Africa (Figure 10.1).

African wetlands are crucial to providing ecological goods and services including the storage and distribution of water in space and time, to ensure availability of surface and groundwater throughout the year (Bakema *et al*. 2009) (also see Sections 1.3 and 8.4, this volume). Wetlands also provide immediate benefits in terms of water and food security, as well as supplementary income for millions of people. For example, many livelihoods within floodplains depend on seasonal flood cycles for fishing, livestock grazing and recession agriculture.

Figure 10.1 By December 2010 the Ramsar Convention had designated 298 sites across Africa, covering nearly 6% of wetlands in Africa. Source: Wetlands International 2011.

Lake edge wetlands and many seasonal wetlands in valley bottoms are used for food production, fishing and hunting, fuel wood collection, dry season grazing, water supply, clay and sand mining, and craft materials (Bakema *et al*. 2009). So, unless wetland ecosystems are managed appropriately,

A fisherman cast netting in a wetland in Burkina Faso. Wetlands provide food security and income for millions of people across Africa. © TIMO MORTIZ

the functions that support agriculture, other food security and ecosystem services are undermined.

10.1.2 Degradation and loss of Africa's wetlands

Throughout history, much of human settlement has occurred along rivers, oases, and lakes, as well as sea coasts, and human development is intimately tied to the use of water resources. In Africa, as in the rest of the world, freshwater ecosystems supply cities and rural communities with drinking water, irrigation for commercial and subsistence crops, hydropower, and fishing grounds. They serve as recreational venues, transit corridors and sewage systems. While wetlands and other freshwater ecosystems can absorb the impacts of these activities, overuse or improper management can lead to ecosystem degradation caused by changes in flows, increased turbidity, sedimentation, nutrient enrichment, decreased oxygen content, increased organic content, pollution, and the entrance of invasive species, among other effects. Part of the reason why there are so many threats to freshwater ecosystems is because national and international level decision makers are unaware of the ecological needs and values of the wetland resource in their charge (Finalyson and Spier 1999). To complicate matters, the diverse threats often have cumulative impacts, making the sum worse than its individual parts and mitigation strategies more complex.

The impact of development on freshwater resources can already be seen in Africa. Water withdrawals and sedimentation have caused Lake Haromaya and Lake Adele in Ethiopia to dry out completely (Alemayehu *et al*. 2007, in Thieme *et al*. 2010). In Lake Victoria, the introduction of the invasive Nile perch (*Lates niloticus*) and the water hyacinth (*Eichornia crassipes*), agricultural runoff, and overfishing of native species, combined with climate change and habitat degradation, have caused the possible loss (and certainly decline in abundance) of a large proportion of the cichlid

In Africa, as in the rest of the world, freshwater ecosystems supply cities and rural communities with drinking water. © ROBIN MOORE species native to the lake (Witte *et al*. 2007; Chapman *et al*. 2008; Hecky *et al*. 2010; all in Thieme *et al*. 2010).

Wetlands are also often lost completely when converted to other uses. According to WWF, it is estimated that wetland areas across the globe decreased in extent by 50% during the 20th century. Values given by OECD (1996) suggest that overall wetland loss in tropical and sub tropical Africa is around 2%. In certain areas, however, it is known that wetland loss is much greater. For example, in South Africa over 90% of wetland resources have been lost in the Tugela Basin (in Natal), and 58% of the original wetland in the Mfolozi catchment was estimated to have been lost. Other studies report that there has been an overall loss of 15% of wetland area and 84% loss in the Medjerdah catchment in Tunisia (Finlayson and Spier 1999).

At a local level, many wetlands in Africa are experiencing population pressure (from both people and animals), and this has resulted in habitat change and loss of species. In the Caprivi (Namibia), recent estimates are that 83,000 people reside in the wetland areas, exerting immense pressure on the wetland resources. In the Barotse floodplain (Zambia), people are settled on the river levees, banks of ponds, oxbow lakes and lagoons, and on termite mounds. Overexploitation of riverine vegetation, such as reeds and grasses, is threatening wetland ecosystems. The harvesting of grasses and reeds in the Caprivi/Chobe, Rufiji (Tanzania), and Shire River (south of Lake Malawi) and Barotse flood plains has caused habitat changes that have resulted in the losses of some of the hydrological functions of these wetlands (IUCN ESARO, unpublished). In western and central Africa, there has been substantial loss and degradation of natural ecosystems due to population increase and pressures such as dams and other water infrastructure over the last 80 years (Dugan 1990). Furthermore, there are estimates that half of the world's wetlands have been claimed and converted to urban and industrial uses (IUCN ESARO, unpublished).

10.1.3 Development across Africa

The scale of development underway, and proposed, on the African continent is significant, and the impact on wetlands, other freshwater bodies, and freshwater biodiversity (as discussed above) is likely to be correspondingly large. It is already estimated that, in Africa, 21% of freshwater species assessed for the IUCN Red List are threatened (see Chapters 3-8, this volume). Africa's ambitious development plans could well increase this figure if appropriate mitigation plans are not put in place.

The need for effective, sustainable development across Africa is undisputed. The continent's population, which stood at 840 million in 2009, is expected to grow at a rate of 2.5% per year. Gross Domestic Product (GDP) per capita, a proxy for income, is just USD 1,127 with wide disparities within the region. GDP growth of 1.7% per year, which is lower than the rate of population growth, is unable to maintain current standards of living. Infant mortality is 81 per 1,000 live births, and life expectancy at birth is just 52 years (World Bank, World Development Indicators, 2009). In many countries in the region, the statistics are far worse. To increase incomes and reduce income inequality, decrease infant mortality and increase life expectancy, there is a need for development which can be sustained over the long term, and whose benefits are distributed to local populations. Governments and other institutions are striving to address these needs through ambitious development plans.

At the same time, actors in other parts of the world are seeing opportunities in the richness of natural resources, and are seeking to develop these resources for their own gain. As available land becomes scarce, and water perhaps even scarcer, foreign companies and even governments are seeking to secure access to these resources in Africa (The Africa Report 2010). This includes large-scale land deals with major Gulf and Asian states. In just one example, a Sudanese government official claimed that Sudan would set aside roughly one fifth of the cultivated land for Arab governments (The Economist 2009). While this type of deal may bring in much needed income for African nations (after all, it may be seen as a type of payment for environmental services), it risks scarce resources being used for the production of commodities that will be exported, leaving behind few benefits for the local population.

Africa is an extremely large and complex continent; the development context for each country or region, and the ensuing impacts on freshwater ecosystems and freshwater biodiversity, will vary greatly from place to place. However, three major industries that have significant impacts on freshwater systems throughout the continent are discussed briefly below: mining, agriculture, and infrastructure.

Mining

Mining is a major, and growing, industry on the African continent. More than 60 products are mined in Africa, ranging from gold and diamonds to uranium, coal, manganese, and bauxite. Africa contains approximately 30% of the planet's total mineral reserves, including 40% of the world's gold, 60% of its cobalt and 90% of its platinum group metals (Smuts 2010; Mbendi 2011). Mines range from small, informal (and often dangerous) individual operations to large, commercial mines run by major multinational companies.

Mining practices vary by place and commodity. In general, however, mining processes are extremely water intensive, as water is often used for extraction and separation of materials. This is, by definition, a problem in areas such as South Africa and northern Africa, which are water-stressed.

An asbestos mine in Zimbabwe. Mining is widespread across parts of Africa providing income for national economies, but can also pollute connected wetlands impacting freshwater biodiversity. © KEVIN WALSH

In these regions the use of water for mining may compete with alternative uses, such as agriculture, and water shortages may ultimately require reclamation of water from mining by-products (Hanlon 2010). Contamination of water from mining processes is a major concern for the industry. Acid mine drainage (AMD), for example, results when iron sulfides in ore come into contact with water and produce sulfuric acid. This not only makes the water highly acid, but also leaves behind toxic metals, such as arsenic, mercury, nickel, iron, manganese, aluminum, and uranium (Hanlon 2010). Other contaminants, such as cyanide, enter the water from the washing process or from the leaching of tailings and other mine waste if these materials are not well managed. Needless to say, such contamination is devastating for freshwater ecosystems and the species that depend on them. Like many of the impacts of mining, AMD is a threat both during operations and after a mine has closed, as the mine fills with water (Hanlon 2010). Mining may also require the removal of a substantial quantity of topsoil and rock, disturbing water systems, drainages, and flows.

Mining will never be a low-impact industry. However, advances by the sector itself, as well as improved regulations in the host countries and the scrutiny of the international community, have led to substantial advancements in minimizing and mitigating the environmental (and social) impacts of large-scale mines (small-scale mining operations often lag behind on sustainability issues). Best practices for siting, development, and management can greatly reduce the negative effects of mines on freshwater ecosystems and species (Sweeting and Clark 2000; ICMM 2006.) Lessons from the application of these practices have been used to foster further adoption of best practices throughout the mining industry, as well as to refine recommendations (Smuts 2010).

Mining is relatively widespread in Africa. South Africa, Ghana, Zimbabwe, Tanzania, Zambia and D. R. Congo are all major players. In other countries like Angola, Sierra Leone, Namibia, Zambia and Botswana, mining is a major source of foreign currency earnings. The footprint of the industry will likely grow in the near term. Demand for mineral resources, especially those required for new technologies like cell phones and computer chips, is increasing. Major new mines have opened recently, or are under development, in South Africa, Namibia, Botswana, and Tanzania (Mbendi 2011). Major discoveries of potential diamond resources in Mauritania and potential marine diamond deposits in offshore southern Namibia (Mbendi 2011) could also greatly increase the impact of the mining industry on streams, lakes, wetlands, and the aquatic species that depend on these habitats unless the expansion is very well designed and managed.

Deforestation, seen here in Liberia, can have major impacts upon freshwater biodiversity by increasing sediment loads in rivers and changing water flow regimes. © CI/PHOTO BY JOHN MARTIN

Agriculture and forestry

Agriculture and forestry production in Africa is as varied as the continent itself – colonial-era rubber plantations in Liberia, sophisticated commercial-scale agriculture, ranching, and timber production in South Africa, a growing forestry sector in Mozambique, shifting livestock production in the arid north, and subsistence agriculture scattered throughout. In much of Africa, the climate is eminently suitable for commodity production. Yet the percentage of undernourished people remains higher in Africa than in any other region (FAO 2010), contributing to the continent's high infant mortality rate and low life expectancy. One in three people in Sub-Saharan Africa is undernourished, and Africa is a net importer of food (Gates Foundation 2009).

Because of this, there is a renewed effort on the part of development institutions to focus on agricultural development in Africa. Investment in research, development (or reintroduction) of new crop varieties, technological improvement, small-holder support, infrastructure, and policy frameworks have been announced by major donors such as the Gates Foundation (Gates Foundation 2009). Many of these donors have reflected on the lessons of the Green Revolution in Asia and Latin America, and are seeking to instil new development paradigms that include a greater focus on environmental and social sustainability, crop diversification, and equity and gender issues.

At the same time, many companies are realizing that the relative availability of land, sunlight, cheap labour, and areas abundant in water and good soils in parts of Africa provide a competitive advantage in commodity production over other regions. Large multinational companies, sometimes working in co-ordination with national governments, are announcing development plans at a scale seldom seen before. In one example, a Chinese firm has announced plans to develop between one and three million hectares of oil palm production in D. R. Congo (Mongabay 2009; The Economist 2009). China is reportedly also negotiating to grow biofuels on two million hectares in Zambia (The Economist 2009.) Wheat, forest plantations, and jatropha, among other crops, are being contemplated at large scales.

Agriculture and forestry production in any form can have a major impact on wetlands, other waterbodies, and freshwater biodiversity. Improper siting and management of agricultural development can lead to erosion and sedimentation. Clearing of vegetation cover, especially at a large scale, can effect evapo-transpiration cycles and water flows. Run-off from improperly-managed fertilizer and pesticide use, if unblocked by riparian buffers, can lead to pollution, eutrophication, and other water quality issues. Globally, irrigated agriculture is responsible for approximately 70% of freshwater withdrawals (Shiklomanov 2000; FAO 2009; in Thieme *et al*. 2010), a number likely to be mirrored in Africa if the use of irrigation increases. Over-abstraction of water for crop production can decrease water available for natural ecosystems and other human uses and, if extreme enough, could lead to aquifer collapse. As climate change threatens to modify rainfall patterns, the need for irrigation could increase, leading to further problems with over-abstraction and competition with other water uses.

Improper siting and management of agricultural development can lead to increased sedimentation, pollution and eutrophication of wetlands. Agriculture is also responsible for approximately 70% of water withdrawals from freshwater systems. © JEFF ATTAWAY

As with mining, many of the potential negative impacts of agricultural production on freshwater ecosystems and species can be mitigated through proper siting and management decisions. In the case of agriculture, voluntary standards and donor requirements may require adherence to stricter guidelines than government regulations. For example, the Roundtable on Sustainable Palm Oil (www.rspo.org) and Roundtable on Sustainable Biofuels (http://rsb.epfl.ch/) standards include criteria on freshwater, as do the World Bank's Safeguard Policies (www.worldbank.org). Best management practices include: proper siting; drip irrigation (when irrigation is necessary); precision fertilizer application; no-till agriculture; and maintenance of soil cover, and riparian zones. Many of these are widely known among more educated producers. This does not mean compliance is universal; it is likely to be lower among less sophisticated companies and less educated producers, and lower still where regulations are weak or enforcement lax. Still, the means exist to reduce the potential negative impact of agricultural production on freshwater.

This is especially important as agriculture and forestry continue to grow in Africa, in response to the needs of a growing population and the demands of outside players. With investments being promised in improving domestic agricultural production, especially for the poorest Africans, and the entrance of large and sophisticated commercial investors, African agriculture may be at a turning point. If agricultural development is managed intelligently, Africa's land and water resources may provide the underpinnings of sustained future growth. If not, unsustainable agricultural development — especially at the scale of expansion being discussed — could be highly detrimental to the continent's freshwater ecosystems and species, and could undermine the sustainability of future development options for Africa's people.

Dams and water related infrastructure

In terms of large-scale infrastructure, Africa currently has the fewest dams and other water control measures of any continent in the world. According to the FAO (2007), there are 1,300 large- and medium-size dams in Africa, 40% of which are in South Africa (see also Chapter 1, Figure 1.3). The majority of these have been constructed in the past 30 years to deal with rising demands for water from growing populations. The majority of dams have been built to provide water for irrigation (52%) and to supply water for municipalities (20%). Twenty percent of dams are for multiple use, which nearly always includes irrigation. Despite the fact that only 6% of dams were built with hydropower as a primary function, hydroelectric power (HEP) accounts for more than 80% of total power generation in 18 African countries. According to the World Commission on Dams, only 1% of African dams have been constructed to provide flooding control (FAO 2007).

Despite the low level of water infrastructure compared to other regions, there has been increasing pressure in recent years to adopt such water control measures as a means of enhancing food security and promoting development. The development of well planned infrastructure is recognised as a critical component of economic growth, especially in Sub-Saharan Africa, where such infrastructure, including dams, is built for a variety of reasons. This includes provision of both domestic and agricultural water supplies where water is scarce, to provide power, and control floods (McCartney and Sally 2005). This need is emphasised in the Africa Water Vision (AWV) 2025, developed in 2000, which focuses on the crucial role of water in accomplishing the needed socio-economic development goals. Targets include: the provision of safe and adequate water supply and sanitation for 95% of the population; doubling the irrigated area to 24 million hectares; and developing 25% of the hydropower needs (UN Water/Africa 2000). This vision was endorsed by African Ministers of Water Resources and other stakeholders at the 2nd World Water Forum in May 2000. At the 5th World Water Forum in Istanbul in March 2009, an update on the financing requirements to achieve this vision was provided. The estimated investment needed for Africa's water infrastructure under the AWV was USD 20 billion per annum at the time it was prepared in 2000. An updated estimate in 2008 puts the required investment at USD 50 billion per annum. The principal difference lies in the near ten-fold increase in estimations of the cost of water resources infrastructure to achieve economic growth, food and energy securities and hazard management, with the estimate for the development of hydroelectric power (HEP) driven multi-purpose storage (hydropower is part of the mix and probably the dominant) put at USD 20 billion per annum.

A number of dams for hydropower and multiple uses are either under construction or being planned on the African

The Akosombo Dam, on the Volta River, Ghana. The construction of dams has been identified as a major part of Africa's future development, however if this development is to be sustainable their impacts on ecosystems and biodiversity cannot be neglected. © KEVIN SMITH

continent. A number of these are described below. The Merowe Dam is a USD 1.8 billion hydropower project being built on the Nile in Sudan. In Zambia, there is the proposed Lower Kafue Gorge Dam, which plans to have a generating capacity of about 750MW and an estimated cost of USD 600 million. Zambia plans to export more electricity to the region. In Ethiopia, the Tekeze Dam, completed in 2009, has been built to generate 300MW of electricity. Dams under construction in Ethiopia include the 1,870MW Gilgel-Gibe III project and 100MW Fincha Amerti Neshe Project. There are also plans for Gibe IV (1,472MW) and Gibe V (560MW). In Mozambique, construction of the 1,500MW Mphanda Nkuwa project on the Zambezi River has been approved downstream of Cahora Bassa. There is also the proposed Boa Maria Dam on the Pungue River. In Nigeria, the 2,600MW Mambilla Dam has been approved but is not yet under construction. In Ghana, a hydropower dam is currently being constructed at Bui to improve energy security. The new dam has the potential to generate enough power for export to Burkina Faso, Côte d'Ivoire and Mali. In the Republic of Congo, the Imboulou Dam on the Lefini River, a tributary of the Congo River, has recently been commissioned. Grand Inga, the world's largest hydropower scheme, is proposed for the Congo River in D. R. Congo, and could produce up to 39,000MW of electricity (but see Chapter 1, Section 1.2.2.1). In Cameroon, there are development plans for Lom Pangar, Memve'ele and Nachtigal dams. Studies for the Baynes Dam on the Kunene River between Angola and Namibia are underway. In Uganda, two new dams include the Bujagali Hydropower Project (HPP) which is a 250MW power-generating facility being built on the Victoria Nile River, which was approved in 2007 and has not yet been completed, and construction of the 700MW Karuma Hydroelectric Power Plant that is expected to begin early 2011 (International Rivers 2011; International Water Power and Dam Construction 2011).

There are also many smaller dam projects for multiple use or water supply for domestic use and/or irrigation. There are also numerous irrigation projects throughout Africa that are often supported by agencies such as the African Development Bank, as well as national governments. The total area under irrigation in Africa is estimated to be about 13.4 million hectares, of which nearly 70% is in Egypt, Madagascar, Morocco, South Africa and Sudan. Schemes larger than 1,000 hectares exist in about two thirds of countries in Africa (FAO 2007).

If water and wetland development is to be sustainable, the impacts on ecosystems and biodiversity cannot be neglected. There is an understanding that it is imperative to study properly the environmental and social impact and provide proper compensation to all those communities and the environment that are affected. However, many ecosystems will be impacted, including wetlands.

10.1.4 Impact of wetland development on inland waters

Water infrastructure can have a variety of negative impacts on wetlands. For example, due to reduced flood peaks there can be a lower frequency and extent of overbank flooding. For example, in the Hadejia-Nguru wetlands in Nigeria, annual flooding was reduced to less than 1,000km^2 from an original area of 3,000km^2 following construction of upstream dams. Dams can result in a downstream reduction in sedimentation load in rivers, leading to increased erosion of river-banks and beds, loss of floodplains and degradation of coastal deltas. This can affect wetland systems that rely on sediments and flooding to sustain vegetation. Fish populations often are supported by wetlands, especially as breeding areas. Destruction of wetlands can have significant impacts on fish populations; furthermore, infrastructure such as dams can block migratory routes, and disconnect rivers from their floodplains (and associated wetlands). Reduced flooding that supports wetlands can alter vegetation that may be important for a wide range of mammal and bird species (McCartney and Sally 2005).

Flood control systems and various other types of development in the Sahelian river basins have caused major ecological and environmental changes in floodplains, resulting in decreasing natural resources such as fish stocks, pasturelands and biodiversity (Wetlands International 2007). In the Inner Niger Delta, the process governing the use and management of natural resources including water has deteriorated over time due to natural, socio-economic, governance and management constraints. Consequently, the government of Mali is restoring degraded habitats in the Inner Niger Delta with the involvement of local people, decentralized government, and development partners in the Delta areas. This is contributing directly to the national environmental protection policy (Wetlands International 2007).

Diminishing water supplies, declining water quality and conversion of wetland habitats due to upstream impoundment or local encroachment all have knock-on effects on biodiversity. While there are few long-term biodiversity monitoring programmes, a number of studies have noted dramatic declines in freshwater biodiversity in Lakes Tanganyika and Victoria within historical time scales (IUCN ESARO, unpublished).

10.1.5 Threat mitigation and management plans that integrate freshwater biodiversity

Although wetlands face serious threats across Africa, water governance institutions that can manage wetlands for multiple use present a potential mechanism for sustainable management of this ecosystem. Maintenance

Lake Wenchi, a crater lake in Ethiopia. The Wenchi Eco-Tourism Association (WETA) is a local, community-centred initiative which promotes sustainable eco-tourism to improve the livelihoods of local people. © ABEBE GETAHUN of wetlands to solely protect biodiversity is, in most cases, an unrealistic option in Africa, as there is a real need for people to use wetland resources as a key component in their livelihoods strategies (Bakema *et al*. 2009). If wetland management focuses purely on biodiversity conservation with no provision for alternative use, it can result in a lack of support by local populations who may lose access to key resources. However, if conservation efforts have a hydrological function or can promote tourism, then these broader benefits are more likely to raise support for conservation measures (Bakema *et al.* 2009).

The way forward to sustaining wetlands and the biodiversity they support is through implementing the principles of integrated water resource management (IWRM), which take into account all aspects of wetland use including people, wildlife, ecosystem dynamics, as well as the needs of industrial and commercial development. This requires strengthening institutions that manage water and wetlands, awareness raising and education, and promoting the concept that wetlands are 'natural infrastructure'. Interventions can include controlled release from dams to provide environmental flows, construction of smaller dams across rivers, and smaller and more diverse irrigation schemes that can incorporate wildlife sanctuaries (Finlayson and Moser 1991).

The future of the region's wetlands depends upon a strong political will to protect them, based on sound wetland policies and encouragement for community participation in their management. Indeed, the importance of sustainable management of wetlands and their biodiversity is being increasingly recognised in the wide-ranging debate on managing the world's water resources. Recommendations from the report *Strengthening policies for the wise use and management of wetlands in four ecoregions (West and Central Africa)* by Wetlands International (2007) point to adopting an IWRM approach in all water management policies and creating a sustainable development framework that takes into account the ecosystem services provided by wetlands.

Although the goal for protected wetlands should continue to be conservation of threatened and fragile sites and their component species, greater efforts should be focused on wetlands outside protected areas, and new management strategies formulated which incorporate the stakeholders. A key step in achieving sustainable multiple-use of wetlands is through the strengthening and integration of policies and strategies at the national level (Bakema *et al*. 2009). The government of Uganda passed the National Policy for the Conservation and Management of Wetland Resources in 1995, and it is one of the few governments in Africa that has a government department responsible for the management of wetlands. The wetland policy encompasses wetlands in protected and non-protected areas and offers an example of strong political will to conserve wetlands and their biodiversity (IUCN ESARO, unpublished).

To avoid further environmental degradation, countries need to take into account all water needs, especially environmental flows, in water resource allocation and environmental impact assessment. Adoption and effective implementation of IWRM principles depends on the existence of the enabling environment within the country. The policy and legislation, level of infrastructure development, availability of sustainable finance, institutional arrangements, and institutional capacity provide a yardstick for measuring the enabling environment. Most countries have developed the necessary policy, legal and institutional frameworks for effective implementation of IWRM. However, there is limited infrastructure development, sustainable financing and institutional capacity (IUCN ESARO, unpublished).

For sustainable management, the knowledge of wetlands and their species across the continent must be increased. The *Global Review of Wetland Resources and Priorities for Wetland Inventory* (Finlayson and Spier 1999) found that, like South America, there is an extreme lack of published quantitative studies on wetland loss in Africa. Information must be collected on biophysical and socio-economic parameters such as hydrology, socio-economy, soils, land-use, vegetation and climate (FAO 1998). Therefore, there is a critical need for further research in order to have a clearer understanding on the status of wetlands in Africa. Environmental flow releases from dams can contribute to the restoration of wetlands and other downstream ecosystems. However, detailed scientific and engineering studies are required to understand the complex processes and interaction of flows and the impacts of different flow release strategies (McCartney and Sally 2005). For example, in the Pangani basin in Tanzania, an in-depth flow assessment which developed a number of scenarios found that a basin-wide revision of the operating rules for the HEP dams could allow some improvement in river condition and substantial re-flooding of a downstream wetland with no overall decrease in HEP generation but with some loss of agricultural area. Conversely, scenarios that maximised agricultural development would lead to a further decline in the health of the river ecosystem including the wetlands, and to a decrease in HEP generation as the basin's water resources are essentially already fully used. In order to use the information to make informed water allocation decisions, institutional frameworks and capacity need to be in place and functioning.

According to Bakema *et al*. (2009), wetlands require rules that spell out rights and responsibilities of all stakeholders. Respected institutions that can resolve conflicts between different users and guarantee equitable distribution of benefits are also needed. Local knowledge should form the basis for wetland management systems in conjunction with other knowledge systems that encourage sustainable multiple use.

The balance of the local community's activities around wetland use is an essential part of the ecosystem dynamics. Therefore, conservation areas to protect wetlands must be designed to maintain the balance between people and nature. An example is through the Extending Wetland Protected Areas through Community Conservation Initiatives (known as COBWEB) in Uganda, funded through the Global Environment Facility, United National Development Programme, government of Uganda and other partners. The rationale is that wetland biodiversity needs to be conserved and the socio-economic importance and values of these areas must be maintained by engaging the communities in managing the protected wetland areas. The goal is to establish and strengthen community-based regulation and sustainable wetlands resource use within wetlands with important biodiversity. The project is currently being implemented by IUCN and partners, and by its conclusion in 2012 it will have community conservation models for wetland biodiversity integrated into national wetland planning processes and national protected area network.

The water resources management strategies in the region are still very much guided by the traditional approach to water management, whose main emphasis is on engineering solutions without consideration of environmental goods and services (see also Vörösmarty *et al*. 2010 for discussion of the cost of engineered solutions and the implications to management of freshwater ecosystems). The soils, wetlands, watercourses, aquifers and floodplains of watersheds can be considered as natural infrastructure. Just as built infrastructure stores, moves, regulates and cleans water, so does nature. Lakes and wetlands provide water storage and can therefore reduce reservoir volume needed in dams, consequently reducing the need for built infrastructure and the associated cost. Thinking about wetlands in terms of natural infrastructure introduces the concept of managing a catchment with both built and natural components and reduces the perceived conflict between engineering solutions and nature (Smith 2010).

The investment required in sustaining natural infrastructure is different to that in engineered water infrastructure projects, which need significant financing and top down decision making from large institutions and governments. Instead, bottom up strategies and actions are needed to rehabilitate or conserve wetlands for multiple uses. What is needed is to empower relevant stakeholders with the capacity to negotiate trade-offs and build consensus on priorities that benefit nature as well as people (Smith 2010). For example, if part of a wetland is to be used for rice cultivation, then there needs to be agreement or regulation on how this will be managed to prevent destruction and loss of benefits to other users (including the environment). In the Komadugu Yobe basin of northern Nigeria, dams built in the 1960s and 1970s have resulted in damage to downstream wetlands and cultivation areas. This resulted in the loss of livelihoods from the multiple use of wetlands. However, the current investment in managing and restoring natural infrastructure – wetlands – has resulted in clearing water channels for water transport, restoration of wetlands for fisheries and re-operation of dams to support grazing and farming on floodplains (Smith 2010). This has all been made possible by several actions: knowledge exchange and capacity development for decision makers and stakeholders; the reform of governance arrangements for water; increased accountability of government institutions, and enabling consensus building among stakeholders; and establishment of a trust fund for basin restoration and improved land and water management, including community-led action (Smith 2010).

10.2 Freshwater biodiversity management and conservation, policy, and the private sector

Successful management and conservation of freshwater biodiversity necessitates the involvement of a variety of stakeholder groups, including local communities, scientists, policy makers, and the private sector. The role of the latter two groups—policy makers and the private sector—is explored in more detail below.

10.2.1 The policy process

Policy making at all levels is essentially an ongoing process of incremental change that is punctuated by times of rapid change when a 'policy window' opens up. Good information, based on good data, is an essential component of ensuring that policies emerging from both of these phases of the process are sound.

There is always a problem that requires a policy solution, and the values, beliefs and perceptions of decision makers influence attitudes towards this problem, shaping the ideas presented as solutions for negotiation. Coalitions of stakeholders from government institutions, advocacy organizations, the general public, the private sector and the political process that share core beliefs and interests come together to promote their perspectives to the policy problem. The most dominant of those coalitions will have the upper hand in terms of setting the agenda for negotiation and ensuring results that serve their interests (Johnson *et al*. 2003). Once the agenda is set, then change tends to be slow; this is the period of 'incremental change', and change during this time is accomplished by influencing those basic values and beliefs of the stakeholders. A key way to do this is by increasing the level of knowledge and understanding of the stakeholders so that, as their views and beliefs change over time, so do their preferred policy solutions; that is, it is a period of gradual 'enlightenment' based on the accumulation of information (Sabatier 1991).

One important strategy is to target one or a small number of influential individuals who can then champion a particular cause of interest within the larger policy arena. Ultimately, policy making is a political process, and having vocal and influential champions that are a part of the process is critical to achieving change; often just one dedicated person can be the key to creating change.

When a ‘policy window’ opens up, rapid changes can occur in the policy making process, and great leaps in policy design are usually achieved. The creation of a policy window requires three elements: a known problem, a proposal for a viable solution, and the political circumstances that make it advantageous to support the proposal (Kingdon 1984). In practice, the opening of a policy window is usually catalyzed when something occurs to bring renewed attention to an issue – this can be a crisis of some sort, such as: a natural disaster; plans for a large development project with far reaching implications; the emergence of new information; uncovering of corruption related to the issue; or other similar events that can propel the policy discussion into the public eye. Once the window has been opened, however, it is necessary to provide good information and potential solutions, in order to maximize the opportunities to move through this window and achieve new outcomes. This information and the solutions must be based on reliable data, but they will have a different context to the supporting data. We’ll examine this further in the next section.

In times when policy windows open, the new information and decisions being made, and the high rates of change in policy attract a large number of actors to the process; everyone with a related interest tends to want to be involved. By comparison, the periods of incremental change that come before and after the policy windows are slow, and it can seem that engaging in them represents an unprofitable commitment of resources. However, they are actually very important to achieving key goals when policy windows open up. This is because, when a window is created, the ensuing rapid changes occur within an established ideological and contextual framework and are, therefore, almost always based on information and proposals that are already on the table, even if they have not been the dominant views. Even if the information and proposals had not been the dominant views, they are still an important part of the overall ’period of enlightenment‘ (mentioned above) on which subsequent decisions may be based. So, it is crucial to be involved in these slow periods, by engaging policy leaders and like-minded groups, in order to have scientific information reflected both in the slow periods and the periods of rapid policy change. Engagement throughout the process is also important for building trust with partners and other stakeholders.

The Economics of Ecosystems and Biodiversity (TEEB) study is an important example of how to integrate scientific data into the decision-making processes of business and policy (TEEB 2011). TEEB is founded on a proposal for a study on ‘The economic significance of the global loss of biological diversity’, made at the March 2007 meeting of the environment ministers of the G8 countries and five major newly industrialising countries (the so-called ’Potsdam Initiative‘ for biodiversity). TEEB is a major international initiative, which aims to draw attention to the global economic benefits of biodiversity, highlighting the growing costs of biodiversity loss and ecosystem degradation, and drawing together expertise from the fields of science, economics and policy to enable practical actions moving forward.

In considering how to package freshwater biodiversity data for policy applications, two key ideas merit further consideration:

i. Collective decision making, as in a policy context, is strongly influenced by being able to trust in the knowledge and reliability of experts, and in the levels of knowledge of decision makers;
ii. Increasing knowledge and understanding involves more than simply providing raw data.

As most scientists who have attempted to insert science into policy can attest, raw data alone may not be especially helpful to policy makers. The data must be analysed and synthesized to provide results that can directly influence policy decisions. TEEB has attempted to achieve this, for example, in several reports that synthesize ecological and economic data (e.g., Kumar 2010) and present guidelines and recommendations for policy makers (TEEB 2010; ten Brink in press).

Useful analyses will share two key characteristics: they present information on the implications of the policy discussion, and they do so in a way that is meaningful to the interests of stakeholders beyond the conservation community. Two examples specific to Africa, are given here.

Economic evaluation of hydropower development in the Tana river basin

Emerton (2005a,b) reported on some analyses of ecosystem function and value in the Tana River basin in Kenya. The Tana River provides approximately 75% of Kenya’s hydropower. The river has a biannual flooding regime which supports grasslands, lakes, seasonal streams, riverine forest and mangrove ecosystems and which helped to maintain fertile riverbanks for seasonal agriculture. Five hydrodams on the river had already altered the amount of yearly flooding and were in place when a final dam was proposed in the early 1990s. The construction of this dam would have put an end to the small amount of flooding left and would have cut

The Oued Za, a tributary of the Moulouya River. The ecological needs of freshwater species is now incorporated into the Moulouya catchment management plan. © JEAN-PIERRE BOUDOT

most of the downstream ecosystem off from water flow, impacting the livelihoods of more than 1 million people by reducing water sources for humans and cattle, fertile ground for riverbank farming (because the banks of the Tana are the only arable land in the region), and fish catches in the wetlands, mangrove areas and the main river channel.

Pre-construction analyses for the Mutonga-Grand Falls dam showed that the favoured design option for the dam would not include flood release mechanisms because of the cost involved. An analysis was carried out, looking at the entire flood-dependent area downstream of the dam, and detailing what the impacts on these ecosystems would be from a new dam. This showed that the construction of dams on the upper reaches of the Tana River had already imposed approximately USD 27 million in lost production costs, and that the cost of building an additional dam would have a median present cost of almost USD 20 million. With this information, which could be easily fit into the more traditional economic appraisal framework, the most economically viable design option was revealed to be the one that considered economic costs and integrated a flood release mechanism that could simulate the Tana's biannual flood regime.

This analysis would not have been possible without detailed data on the ecosystems that rely on the Tana's flow and flooding regime, as well as hydrological models of the river system. However, these data would not have been enough to change the preferred design option of the Mutonga-Grand Falls Dam – the additional analysis of impacts on human livelihoods and the economic costs of those impacts was needed to encourage a different policy choice.

Moulouya River Basin river regulation

IUCN, working with the Moulouya River Basin Agency and the University of Oujda in Morocco, developed a pilot project for the integrated management of aquatic biodiversity at the level of the Moulouya River catchment (IUCN 2011a). The aim of the project was to incorporate environmental requirements into the catchment management plan. Prior to this project, little was known about the freshwater species within the Moulouya Basin, and there was little appreciation for their values to people, or their ecological requirements. Catchment management at this time was primarily focused on the allocation of water to people's needs. Through the close involvement of a wide range of stakeholders, and an intensive awareness-raising campaign based on findings from the basin-wide biodiversity assessment conducted through the project, this focus has been significantly altered. A scientific committee has now been formed to focus on the environmental aspects of catchment management, and an 'Aquatic Biodiversity Monitoring Network' has been established to monitor the status of freshwater species throughout the catchment.

The result is that the Moulouya catchment management plan now incorporates a specific component to address the ecological needs of freshwater species. The Moulouya is the first river basin in Morocco to integrate biodiversity into catchment planning in this way, and it is now presented as an example to the other basin agencies throughout Morocco. This provides an example for how policy can be influenced through involvement of key stakeholders, public awareness raising, and the provision of new information on the basins' freshwater biodiversity.

These two examples illustrate some important factors in successful integration of freshwater biodiversity data into the policy process:

1 **Using data to create scenarios of impacts from different policy choices.** In the Tana River case study, scenarios were presented for how the hydropower development would impact downstream ecosystems, and how that would impact local populations under different designs of the dam. Providing viable solutions is an important part of the policy processes, especially when there are legitimate interests from both sides of the policy debate.

2 **Speaking to the interests of other stakeholders.** Both examples demonstrate the importance of integrating biodiversity concerns with the requirements of land resource management. The Tana River case provides a particularly good example of this. In this case, the other stakeholders valued economic development from electricity generation and financial viability of the dam. Showing that eliminating the Tana River's biannual flooding cycle would actually have a net negative economic impact was the key factor in achieving the desired outcome. An argument based only on the loss of species would have had plenty of support from those stakeholders that share the values of biodiversity conservation, but would not have been likely to change the course of the decision in the way the more comprehensive analysis did.

3 **Raising awareness of biodiversity values and needs.** The Moulouya catchment case demonstrates the power of stakeholder involvement and use of real data on species diversity and their ecological needs to influence policy.

The policy process and the type of information needed to influence the processes described here apply at all scales of national and regional policy making and even within large institutions, such as multilateral development banks. In all of these situations, policy making is a process of incremental change punctuated by times of rapid change that requires useful analysis, and it is a negotiation amongst multiple stakeholder groups, all with different interest – some of which have more influence than others.

10.2.2 Role of the private sector

Policy decisions that allow particular development activities to occur in an area typically precede private sector entry into that area to implement those activities. In that respect, as recognized by TEEB, business and enterprise have a huge role to play in the management and conservation of natural resources, such as freshwater systems. There is, therefore, a need to supply the private sector with all the necessary biodiversity information to make sustainable business decisions that also benefit the environment.

As reported here, IUCN has completed an in-depth analysis of the status of freshwater biodiversity across mainland Africa. This reveals significant problems, in that many species are threatened by development actions so something needs to be done. Ideally, the biological sensitivity of a catchment should be taken into account at the time that policy decisions are made, that is, before private sector development begins. This can be achieved using tools like Strategic Environmental Assessments (SEAs) or other integrated land-use planning processes. However, in practice this often does not happen. Environmental Impact Assessments (EIAs) or Environmental and Social Impact Assessments (ESIAs) are additional points at which the private sector should evaluate the biological sensitivity within a proposed location for development.

As defined by the International Association of Impact Assessment (IAIA), EIAs are the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made (IAIA 1996). EIAs are often compelled by a country's regulatory framework, and typically include identification of issues and impacts, baseline establishment, assessment of alternatives, mitigation and impact management measures, and evaluation of significance of residual impacts.

EIAs are increasingly taking an explicit look at biodiversity and ecosystem services, such as freshwater services, and the data and tools presented in previous chapters of this publication can be extremely helpful for those scoping and implementing EIAs. There is even growing literature on how biodiversity can more explicitly be built into the EIA process (Energy and Biodiversity Initiative 2003; IAIA 2005). In addition to the data in existing data sets serving as useful information for input to the EIA process itself, EIA processes can also help to build freshwater biodiversity data sets. In this way, the knowledge of the species and their vulnerabilities will be greatly improved and will, if used wisely, help to reduce impacts and improve the status of freshwater species. A key feature of the Red List data on species is that it allows the conservation value of any species identified within the assessment area to be determined within a broader regional or global context.

The Okavango Delta is home to countless freshwater and terrestrial species. It is now an aim to include within the Delta management plant the use of bio-indicators to monitor long term water quality. © RODERIC B. MAST

Water hyacinth had major ecological and economic impacts upon Lake Victoria during the 1990s when the invasive plant covered tens of thousands of hectares of the lake surface. © STEPHAN MAGDALINSKI

However, EIAs as they are often implemented do have shortcomings (Jay *et al*. 2006), and even when they do take place in a rigorous manner, they often occur relatively late in a project's development lifecycle. Typically, this means that a large portion of the investment has already been sunk into the project, so companies, governments, and other stakeholders are already quite vested in seeing the project move forward, even if the area's freshwater resources are determined to be biologically sensitive.

Considering these observations, it is clear that the sooner comprehensive biodiversity data sets are made available to companies considering development projects, the more likely it is that these data will positively influence decisions on project development. In the case of freshwater ecosystems, the types of data that are required are: information on the diversity of species present (how many species; how many are endemic; population status of species and how many species are threatened); utilization of the species (commercial or artisanal); and the ecohydrology of the freshwater system being investigated (characteristics of flow in terms water quantity, quality and timing). There will be other broader data sets that will also be important – for example, information on the presence of reserves, regional or national parks and protected areas, and world heritage sites.

It is important that biodiversity data sets are presented to companies in a relevant and usable format for guiding their development decisions. This challenge is just as important as ensuring the data are presented in a way that is accessible to policy makers (as discussed above). TEEB has recognized the importance of properly informing the private sector, and has developed a report (TEEB in press) aimed at providing practical guidance on the issues and opportunities created through inclusion of ecosystem and biodiversity related considerations in business practices. Conservation organizations are becoming increasingly attuned to the need to make biodiversity data more easily accessible to businesses, and have developed various tools and approaches to achieve this. One such tool is the Integrated Biodiversity Assessment Tool (IBAT).

The Integrated Biodiversity Assessment Tool represents a vision for improved collection, update, management and use of critical biodiversity data. By providing information on both protected and unprotected high priority sites for conservation—such as protected areas and Key Biodiversity Areas (KBAs)—IBAT informs the practical implementation of environmental safeguard policies and industry best practice standards. This includes terrestrially defined KBAs for Africa, and will eventually include freshwater KBAs for the continent based on the species data collected through the project reported on in this volume.

Access to this information at the earliest stages of project planning makes it easier to consider alternative projects, approaches or locations at a time when such changes are still economically viable. IBAT can help inform and prioritize subsequent data collection, assessment and planning in the project cycle. IBAT can also be used to take into account networks of conservation priority areas when designing national or regional development strategies.

This vision for IBAT was developed and is being realized by an alliance of global organizations, including BirdLife International, Conservation International (CI), IUCN, and United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). For the first time, decision-makers can access critical site level information from all four organizations to inform biodiversity risk assessment processes.

The first output of the IBAT vision, the *IBAT for Business* tool (http://www.ibatforbusiness.org), was launched at the IUCN

World Conservation Congress (WCC) in October 2008. *IBAT for Business* provides key decision-makers with access to critical information on sites of special interest, in terms of their biodiversity and its conservation, so that this information can be used to inform decision-making processes and address any potential biodiversity impacts (The Economist 2008). IBAT was built on an assessment of business needs, coupled with innovative work to integrate these databases into a web-based interface. In addition to supporting integration of the best conservation science into project planning and management decisions, IBAT also provides opportunities for the private sector to financially support the acquisition of additional knowledge and data on biodiversity and conservation priorities, including freshwater.

Companies can also positively contribute to filling in freshwater data gaps through support for biological surveys. When desktop surveys and use of tools like IBAT reveal that significant data gaps exist within the context of a development project under consideration, a biological survey of key taxonomic groups conducted prior to a formal ESIA can be extremely helpful in guiding early decision-making for a potential development.

One such approach developed by Conservation International, utilizing the in-house expertise of the Rapid Assessment Program (RAP; also see Chapter 8, section 8.5.2), has produced several successful partnerships between CI and companies to better understand the biodiversity of a given area in the earliest stages of development projects. In one example of this type of partnership, CI joined forces with mining companies Alcoa World Alumina LLC and Alcan Inc. in 2005 to collect scientific data on the diversity and status of species at a number of sites in coastal Guinea where the companies were considering placement of a bauxite refinery and related infrastructure. In addition to feeding information into the project ESIA, the survey also made several important observations to advance scientific understanding of the region. Notably for freshwater species, an Endangered crab, *Afrithelphusa monodosus*, was recorded for the first time since its original collection in 1947 (Cumberlidge 2006).

In addition to the potential impacts that private sector development can have on freshwater biodiversity, biologically rich freshwater ecosystems and species can also provide services that contribute to the economic success of the private sector. The Okavango Delta Ramsar site (55,374km^2) in north-western Botswana, for example, is a vast inland freshwater wetland and home to countless freshwater and terrestrial species, including charismatic species of tourism value, such as two globally threatened bird species (the wattled crane (*Grus carunculatus*) which is classified as Vulnerable, and the slaty egret (*Egretta vinaceiqula*) also classified as Vulnerable) and large mammals including the African elephant (Mfundisi 2008). The tourism industry, largely dependent on the freshwater species and ecosystems found in the delta, also represents the second largest income earner for Botswana (after diamond mining), contributing 5% of the country's Gross Domestic Product (GDP) and 40% of employment in northern Botswana (Turpie *et al.* 2006).

In relation to one specific aspect of management in the Okavango Delta, IUCN (in collaboration with The Okavango Research Institute formerly known as The Harry Oppenheimer Okavango Research Centre) conducted a case study with the aim of improving long-term monitoring of water quality through use of bio-indicators (IUCN 2011b). A key recommendation of this study was that a 'coffee-table' style publication be made which would appeal to all the relevant stakeholders and key decision-makers across the region. The resulting book (Mendelsohn *et al.* 2010) vividly presents the wonderful diversity of species within the delta, and its value to people's livelihoods and economies, in a format that is easily accessible and appealing to a broad cross-section of stakeholders and decision-makers. The book has been made widely available, free of charge, throughout the region, and it is hoped will prove an effective way to influence policy.

There are many examples where ineffective management of freshwater resources, and the species present, can inhibit the economic success of the private sector. This may be especially noticeable when conditions promote the expansion of invasive species. A well-known example of the ecological and economic impact of invasive species is given by the invasive water hyacinth in Lake Victoria in eastern Africa, which, during the late 1990s, blanketed tens of thousands of hectares of the lake's surface. Lake Victoria is the second largest freshwater lake in the world, at 68,800km^2 surface area, and the catchment's annual gross annual economic product is in the order of USD 3 to 4 billion. During the infestation, the fish catch was reduced by a factor of 2 to 45%, in addition to hampering lake transportation and hydropower facilities (Vincent *et al*. 2008). Many sources indicate one major contributing factor to the proliferation of the weed on the lake was the nutrient inputs from upstream agricultural development. In this case, a greater understanding by the agriculture sector as to how their upstream inputs were affecting downstream biodiversity (i.e., proliferation of the water hyacinth and declining fish stocks) may have led to better practices and a reduced impact during this time of crisis.

10.2.3 Policy and the private sector – conclusion

Across these examples, it is clear that there are important linkages between policy, the private sector, and the management and conservation of freshwater biodiversity. The more easily accessible the scientific and conservation communities can make information to policy makers, as well as companies and industries, the greater is the chance that positive conservation outcomes can be achieved.

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Chapter 1 References

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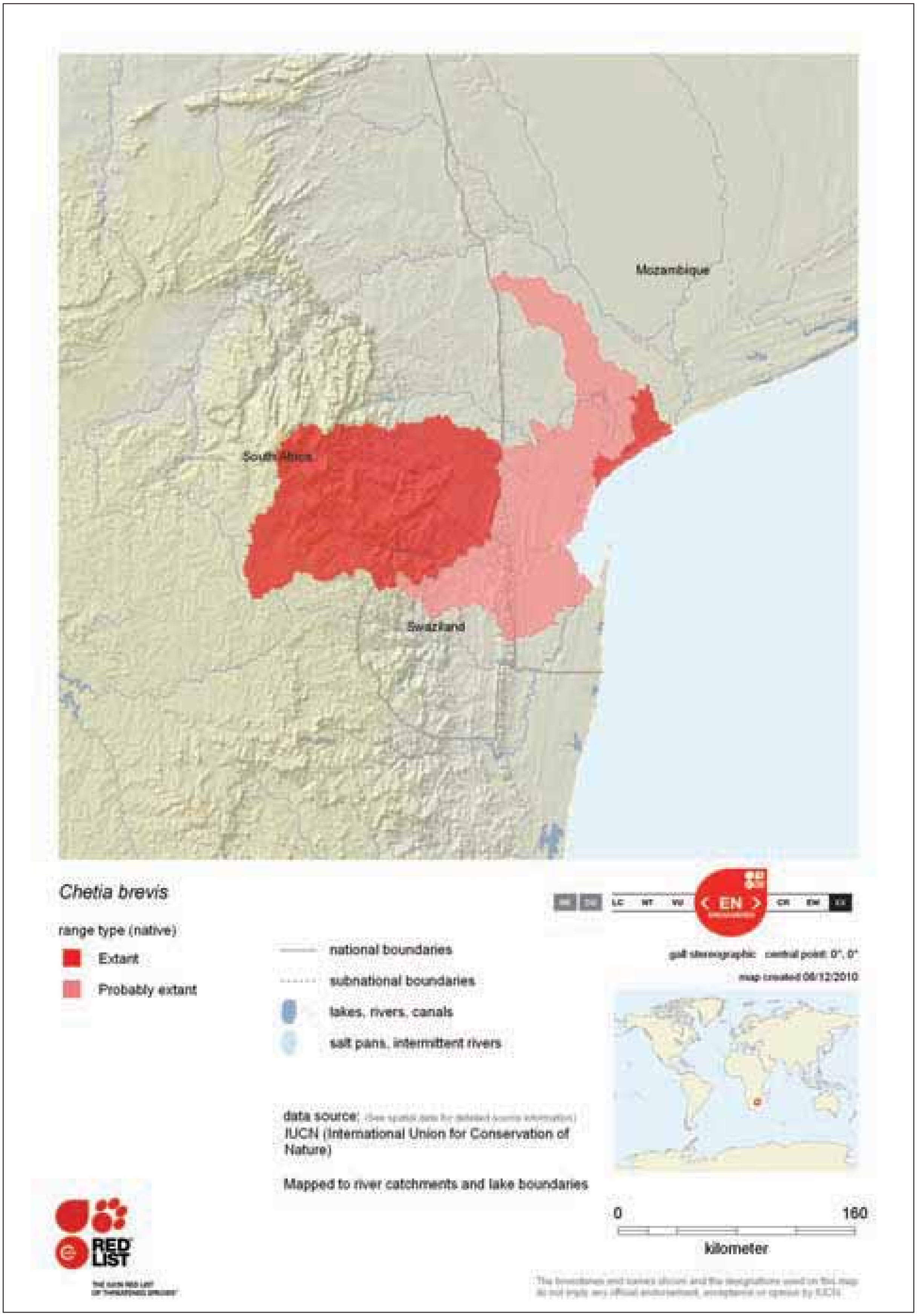
Other key materials

Important Bird Areas and Potential Ramsar Sites in Africa
http://www.birdlife.org/action/change/ramsar/ibas_ramsar_africa.html
International Course on African Wetland Management
http://www.kws.org/about/training/kwsti.html
Ramsar convention on wetlands
http://www.ramsar.org
Ramsar sites information services
http://ramsar.wetlands.org
Wetland Development And Management In SADC Countries
ftp://ftp.fao.org/agl/aglw/docs/wetlands.pdf
Wetlands International
http://www.wetlands.org

Appendix

An example of a species assessment summary and distribution map



Chetia brevis - Jubb, 1968

ANIMALIA - CHORDATA - ACTINOPTERYGII - PERCIFORMES - CICHLIDAE - Chetia - brevis

Common Names: Lomati Grootbek (Afrikaans), Orange-fringed River Bream (English)
Synonyms: No Synonyms

Red List Assessment

Red List Status
EN - Endangered, B1ab(iii,v)+2ab(iii,v) (IUCN version 3.1)

Assessment Information

Assessor(s): Engelbrecht, J. & Bills, R.

Reviewer(s): Snoeks, J. (Freshwater Fish Red List Authority) & Darwall, W. (Freshwater Biodiversity Assessment Unit)

Assessment Rationale

This rare species has an estimated extent of occurrence (EOO) less than 5,000 km². Its area of occupancy (AOO) is less than 500 km². Given the main threats of alien fish predators, subsistence fishing, and impacts from agricultural activities, fewer than five locations are estimated for the species. The alien fish species *Serranochromis robustus* continues to spread throughout the lower Lomati and Komati River systems; continuing population declines are anticipated.

Reasons for Change

Nongenuine Change: New Information, Knowledge of criteria

Distribution

Geographic Range

Lomati River (low-veld) system in Swaziland and Mpumalanga, South Africa.

Biogeographic Realms

Biogeographic Realm: Afrotropical

Occurrence

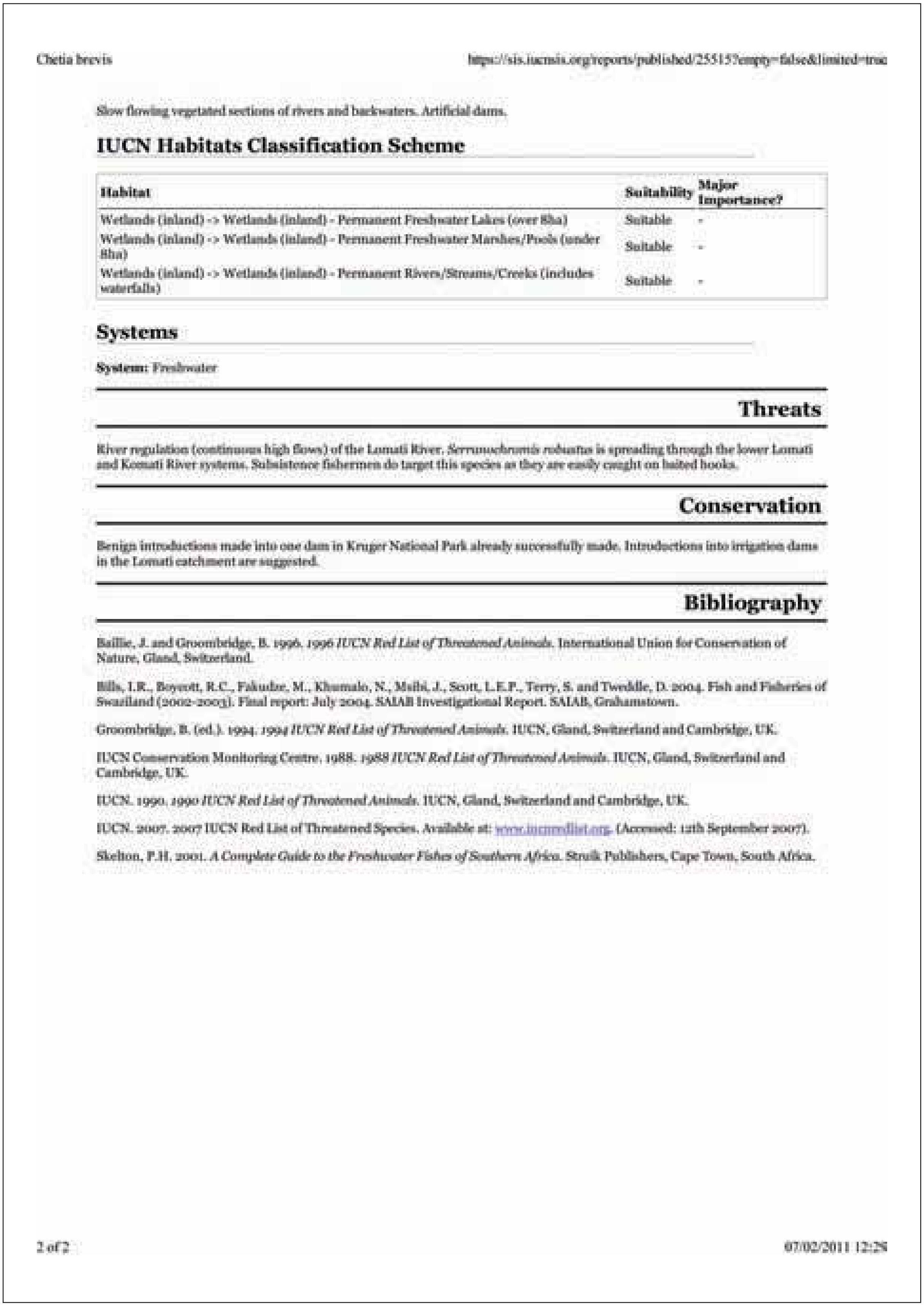
Countries of Occurrence

Country	Presence	Origin	Formerly Bred	Seasonality
Mozambique	Extant	Native	-	-
South Africa	Extant	Native	-	-
South Africa -> Mpumalanga	Extant	Native	-	-
Swaziland	Extant	Native	-	-

Population

A rare species - typically encountered in ones and twos in riverine habitats. Does very well in Dams (e.g., Driekoppies and Lomati Draai Dam).

Habitats and Ecology



Chetia brevis https://sis.iucnsis.org/reports/published/25515?empty=false&limited=true

Slow flowing vegetated sections of rivers and backwaters. Artificial dams.

IUCN Habitats Classification Scheme

Habitat	**Suitability**	**Major Importance?**
Wetlands (inland) -> Wetlands (inland) - Permanent Freshwater Lakes (over 8ha)	Suitable	-
Wetlands (inland) -> Wetlands (inland) - Permanent Freshwater Marshes/Pools (under 8ha)	Suitable	-
Wetlands (inland) -> Wetlands (inland) - Permanent Rivers/Streams/Creeks (includes waterfalls)	Suitable	-

Systems

System: Freshwater

Threats

River regulation (continuous high flows) of the Lomati River. *Serranochromis robustus* is spreading through the lower Lomati and Komati River systems. Subsistence fishermen do target this species as they are easily caught on baited hooks.

Conservation

Benign introductions made into one dam in Kruger National Park already successfully made. Introductions into irrigation dams in the Lomati catchment are suggested.

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Species Survival Commission