Protected Areas Resilient to Climate Change, PARCC West Africa

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A Climate Change Vulnerability Assessment of West African Species

ENGLISH

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Table of Contents

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Executive Summary

This report summarizes an assessment of the vulnerability to climate change of almost all terrestrial and freshwater vertebrates of West Africa. Through using the information provided in this report, as well as in the accompanying dataset, we hope that conservationists working in West Africa will be better equipped to prioritize among species and locations to ensure the most efficient and effective use of resources when securing species survival in the face of climate change.

Through two expert workshops, remote consultations, and using data available from previous projects, we were able to collate biological and ecological trait data for 183 amphibians, 1,172 birds, 517 freshwater fish, 405 mammals and 307 reptiles. This data was used to infer, for each individual species, 'sensitivity' and 'adaptive capacity' to climate change and its impacts. Species distribution polygons, collated through the process of assessing species for the IUCN Red List, were overlaid with future climate projections provided by the UK Met Office Hadley Centre to determine the changes in the means and variability of temperature and precipitation that each species may be exposed to. Species that are both sensitive and poorly able to adapt to climate change, and are among the most severely exposed to climatic changes are described as 'climate change vulnerable'.

In this report we present the numbers of species qualifying under each component of our assessment framework, including for all individual traits used, for each individual framework 'dimension' (sensitivity, low adaptability and exposure) and the total numbers of species considered climate change vulnerable overall. This information can help conservationists identify the most prevalent mechanisms through which climate change may impact upon each taxonomic group in the region, and can help to begin to develop suitable responses. Used in combination with the dataset that accompanies this report, it will be possible for conservationists to develop suitable responses that can help in the amelioration of climate change impacts upon individual, or groups of, species.

Using combined species assessment results we are able to create maps that highlight the broad geographical areas that contain high numbers and/or proportions of climate change vulnerable species within a given taxon. These maps can be used to determine where conservation measures to reduce the impacts of climate change may be most urgently required, as well where such measures may be most effective, in terms of reducing impacts for the greatest number and/or highest proportion of species.

For each taxonomic group, we also present details of extinction risk, according to the IUCN Red List of Threatened Species, including maps showing densities of threatened species across the region. This includes assessments of reptile species, which were conducted as part of this project. Species that are both globally threatened and vulnerable to climate change should be seen as top priorities for conservation action. Similarly, species that are only one of threatened or climate change vulnerable should also receive attention, though the specifics of these will vary depending on the outcomes of the assessments. Species that are considered Data Deficient on the Red List and/or were unable to be assessed in terms climate change vulnerability due to insufficient information should be seen as priorities for research in order to determine the levels of risk that they may face.

Finally, we present broad examples of ways in which vulnerability assessments can be used to develop conservation strategies. With the exception of the completion of data gaps, the wide variety of vulnerability mechanisms, as well as contexts in which threats can occur, precludes the provision of widely applicable recommendations. Rather, we hope that practitioners will consider our findings on a species-by-species basis, and use them to modify existing, or develop new, conservation approaches, which explicitly address climate change impacts upon species.

1. Introduction

West Africa supports high levels of biodiversity and species endemism compared with many other regions of the world. However, in many cases this biodiversity faces serious anthropogenic threats, typically due to factors such as habitat loss and degradation, pollution and unsustainable harvesting, among numerous others[1]. In recent times the emerging threat of climate change has become increasingly recognised as an important factor that will affect the health of many populations of wild species, and is likely to exacerbate already existing threats[2]. In order to develop successful nature conservation strategies it is important to consider the impacts that climate change may have on species, and to integrate these into on-the-ground conservation actions. Climate change vulnerability assessments of individual species can help in the prioritization of sites and species that should receive conservation attention, and can also help provide insights into the specific actions that should be taken.

This report presents the results of extinction risk and climate change vulnerability assessments of almost all known terrestrial and freshwater vertebrates of West Africa. Following Chapter 2's description of the methods used to conduct these assessments, results are presented separately for amphibians, birds, freshwater fish, mammals and reptiles, in chapters 3, 4, 5, 6 and 7, respectively. These chapters present details on the species richness of each group throughout the region, as well as numbers of threatened species (according to the IUCN Red List of Threatened Species, including reptile assessments carried out within the framework of the PARCC project) and their locations within the region. The individual elements (or traits - see Chapter 2) used to assess each taxonomic group are presented in these chapters, including the numbers of species assessed as possessing these traits. For each taxonomic group, we also present a series of maps displaying the numbers and proportions of climate change vulnerable species throughout the region by the years 2055 and 2085. Chapter 8 concludes this report, and presents a range of broad conclusions and conservation recommendations based upon the findings of this work.

The series of tables that accompanies this report (climate change vulnerability of West African species: species accounts) presents the details of all 2,584 species assessed as part of this work, including their current threat status and specific details of the climate change vulnerability of each individual species assessed. We hope that these two documents, in combination, can be used to prioritise both species and geographic locations that require conservation attention to prevent species extinctions as a result of climate change, as well as to develop conservation actions that specifically aim to ameliorate the biological impacts that climate change will have upon species. These data will also be integrated into conservation planning efforts undertaken as part of the project 'Protected Areas Resilient to Climate Change (PARCC) West Africa'.

[1] Smith, K.G. *et al.* (Compilers) (2009) IUCN. x+94pp+4pp cover; GEF (2010) http://www.thegef.org/gef/sites/thegef.org/files/publication/west-africa-BIO.pdf. Norris, K *et al.* (2010) Biol. Cons. 143, 2341-2350; Macdonald, D.W. *et al.* (2012) Biol. Cons. 147, 107-114; United Nations. (2012). World Urbanisation prospects: the 2011 revision, highlights. New York, United Nations Economic and Social Affairs.

[2] Wittig, R. *et al.* (2007) Env Sci Pollut Res 14: 182-189; Jalloh, A. *et al.* (2013)International Food Policy Research Institute (IFPRI), Washington, DC, USA. 408 pp. ISBN 978-0-89629-204-8 [DOI: 10.2499/9780896292048].

2. Methods

2.1 Background to climate change vulnerability assessment framework

IUCN has been exploring the relationship between climate change and the biological and ecological traits that may increase or decrease its impacts on species, and has developed an approach to assessing species' vulnerability to climate change that incorporates such traits. This approach has been successfully piloted on the world's birds, amphibians and corals[3], as well at regional scale to range of taxonomic groups from the Albertine Rift of east and central Africa[4].

This approach, known as the Climate Change Vulnerability Assessment Framework, provides a series of 'rules' that are used to classify species according to three dimensions of climate change vulnerability (Figure 2.1):

<u>*EXPOSURE:*</u>
The extent to which a species' physical environment will change due to climate change.

<u>*SENSITIVITY:*</u>
The lack of potential for a species to persist *in-situ.*

<u>*LOW ADAPTABILITY:*</u>
A species' inability to avoid the negative impacts of climate change through dispersal and/or micro-evolutionary change.

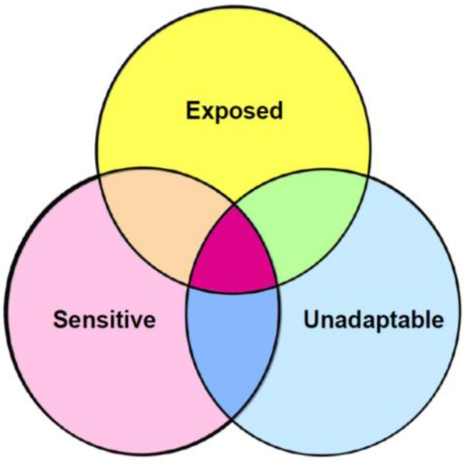

Figure 2.1 – Greatest climate change vulnerability occurs where species face highest exposure to climatic change, and also possess biological traits or characteristics that confer both Sensitivity and Unadaptability to such changes.

Species that are most highly Exposed, Sensitive and Unadaptable are considered most vulnerable to climate change. These species, represented by the, triangle in the middle of Figure 2.1, are flagged as being of greatest conservation concern. Important information can also be gained from species scoring highly in other combinations of the framework's vulnerability dimensions, and this is discussed more fully in Chapter 8.

The traits used to assess a species' *Sensitivity* have subsequently been classified into five 'trait groups (Box 2.1) and those used to assess *Low Adaptability* have been classified into two (Box 2.2):

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[3] Foden *et al.* (2013) PLOS One. DOI: 10.1371/journal.pone.0065427. Available at: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0065427.

[4] Carr *et al.* (2013) Occasional Paper of the Species Survival Commission No. 48 .Available at: https://portals.iucn.org/library/efiles/edocs/SSC-OP-048.pdf.

Box 2.1 – The five Sensitivity trait groups used in the Climate Change Vulnerability Assessment Framework.

a) Specialized habitat/microhabitat requirements:
Across many studies of both animals and plants, threatened and declining species include a disproportionate number of specialists compared to generalists and of species with extensive geographic ranges[5]. Under a changing climate, most species are likely to face changes in their habitats and microhabitats and those less tightly coupled to specific conditions and requirements are likely to be more resilient. Sensitivity is increased where a species has several life stages, each with different habitat or microhabitat requirements (e.g. water-dependent larval amphibians), or when the habitat or microhabitat to which the species is specialized is particularly vulnerable to climate change impacts (e.g. mangroves, cloud forests or polar habitats). However, in some cases (e.g. deep sea fishes), extreme specialization may allow species to escape the full impacts of competition from native or invading species, so the interaction of such traits with climate change must be considered carefully for each species group assessed. This trait group is not independent of species' low adaptive capacity as habitat and/or microhabitat specialization also decreases the chances of successful colonization if species are able to disperse to new climatically suitable areas (e.g. plants confined to limestone outcrops; cave-roosting bats).

b) Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle:
The physiology and ecology of many species is tightly coupled to very specific ranges of climatic variables such as temperature, precipitation, pH and carbon dioxide levels, and those with narrow tolerance ranges are particularly vulnerable to climate[6]. Even species with broad environmental tolerances and unspecialized habitat requirements may already be close to thresholds beyond which ecological or physiological function quickly breaks down (e.g. photosynthesis in plants; protein and enzyme function in animals).

c) Dependence on a specific environmental trigger that is likely to be disrupted by climate change:
Many species rely on environmental triggers or cues for migration, breeding, egg laying, seed germination, hibernation, emergence, and a range of other processes. While some cues (e.g. day length and lunar cycles) will be unaffected by climate change, others such as rainfall and temperature (including their interacting and cumulative effects) may be severely impacted. Species tend to become vulnerable to changes in the magnitude and timing of these cues when this leads to an uncoupling with resources or essential ecological processes e.g. early spring warming causes the emergence of a species before its food sources are available. Vulnerability is compounded when different stages of a species' life history or different sexes rely on different cues.

d) Dependence on interspecific interactions which are likely to be disrupted by climate change:
Many species' interactions with prey, hosts, symbionts, pathogens and competitors will be affected by climate change, either due to the decline or loss of these resource species from the dependent species' ranges or loss of synchronization in phenology. Species dependent on interactions that are vulnerable to disruption by climate change are at risk of extinction, particularly where they have high degree of specialization for the particular resource species and are unlikely to be able to switch to or substitute other species.

e) Rarity:
The inherent vulnerability of small populations to allee effects and catastrophic events, as well as their generally reduced capacity to recover quickly following local extinction events, suggest that many rare species will face greater impacts from climate change than more common and/or widespread species. We consider rare species to be those with small population sizes and those that may be abundant but are geographically highly restricted. In cases where only a small proportion of individuals reproduce (e.g. species with polygynous or polyandrous breeding systems or skewed sex ratios), we use an estimate of effective population size to assess species' rarity, and where species are known to be declining or subject to extreme (greater than ten-fold) fluctuations in population size, we set less conservative population size thresholds. Similarly, thresholds of larger population sizes were used for species with congregatory breeding systems, since they are more likely to experience catastrophic population declines

[5] Cardillo *et al*. (2005) Science 309: 1239 - 1241.
[6] Deutsch *et al.* (2008) PNAS 105: 6668 - 6672.

Box 2.2 – The two Low Adaptability trait groups used in the Climate Change Vulnerability Assessment Framework.

a) Poor dispersability:
In general, the particular set of environmental conditions to which each species is adapted will shift to increasing latitudes and altitudes in response to climate change. Species with low rates or short distances of dispersal (e.g. land snails, ant and rain drop splash dispersed plants) are unlikely to migrate fast enough to keep up with these shifting climatic envelopes and will face increasing extinction risk as their habitats become exposed to progressively greater climatic changes. Even where species could disperse to newly suitable areas, extrinsic barriers may decrease changes of dispersal success. Dispersal barriers may be geographic features such as unsuitable elevations (e.g. species confined to mountain ranges), oceans (e.g. for species on small islands or at the polar tip of a land mass), rivers, and for marine species, ocean currents and temperature gradients; unsuitable habitats and/or anthropogenic transformation may also act as dispersal barriers for habitat specialized species. In this context we describe species as having dispersal barriers both when suitable areas exist but extrinsic factors make them unlikely to reach them, as well as when no newly suitable areas are likely to exist (e.g. for polar species).

b) Poor evolvability:
Species' potential for rapid genetic change will determine whether they will be able to undergo evolutionary adaptation at a rate sufficient to keep up with climate driven changes to their environments. Species with low genetic diversity, often indicated by recent bottlenecks in population numbers, potentially face inbreeding depression and generally exhibit lower ranges of both phenotypic and genotypic variation. As a result, such species tend to have fewer novel characteristics that could facilitate adaptation to the new climatic conditions. Where they exist, direct measures of genetic variability can be supplemented with information on naturalization outside species' native ranges and on the success of any past translocation efforts. Indirect measures of evolvability relate to the speed and output of reproduction and hence the rate at which advantageous novel genotypes could accumulate in populations and species[7]. Evidence suggests that evolutionary adaptation is possible in relatively short time frames (e.g. 5 to 30 years[8]) but for most species with long life cycles (e.g. large animals and many perennial plants), such adaptation is unlikely to keep up with the rate of climate driven changes to their environments.

Guided by these trait groups, we select taxon-specific biological, ecological, physiological and environmental traits, as presented in chapters 3 -7 of this report. Challenges in selecting traits include balancing selection of the most theoretically sound traits with the practicalities of data availability and collection. A further challenge was defining traits in objective and replicable ways and, as far as possible, developing quantitative measures for them. Species were assigned scores of 'unknown', 'low' or 'high' for each trait, based on a broad range of information sources (discussed in more detail below). While in some cases, thresholds of risk were clear (e.g. 'occurs only on mountain tops'), in many cases there was no *a priori* basis for setting a particular extinction risk threshold. For such traits (e.g. tolerance of exposure to projected temperature changes), we use the arbitrary threshold of the 25% most severely affected species within the group, and categorize them as 'high' for this element.

Assessments of *Exposure* are conducted by overlaying projected changes in taxon-relevant climatic variables on refined range maps to obtain simple measures of climatic change to which each species will be exposed. Once again, species are scored as 'unknown', 'not high or 'high' under this dimension of the framework. Because thresholds for exposure to climatic changes have seldom been established, scores are typically derived by ranking species and selecting the worst affected species as those with highest exposure. Further information on the methods used to assess species exposure in this study is provided in Section 2.4 of this report.

[7] Chevin *et al*. (2010) PLoS Biology 8: e1000357.
[8] Bradshaw and Holzapfel (2006) Science 312: 1477–1478.

2.2 Application of the framework to West African species

This study applied the Climate Change Vulnerability Assessment Framework to the terrestrial and freshwater vertebrates (amphibians, birds, freshwater fish, mammals and reptiles) of 17 West African countries. The region comprising these countries, hereafter referred to as 'West Africa', is shown in Figure 2.2, which also highlights core PARCC project countries. Our assessments aimed to cover all known and taxonomically accepted species occurring in this region, within each of the groups described above. In some cases, however, it was necessary to exclude certain species from our assessment, typically due to a current lack of taxonomic clarity. Where they occur, such omissions are described in each respective taxonomic chapter.

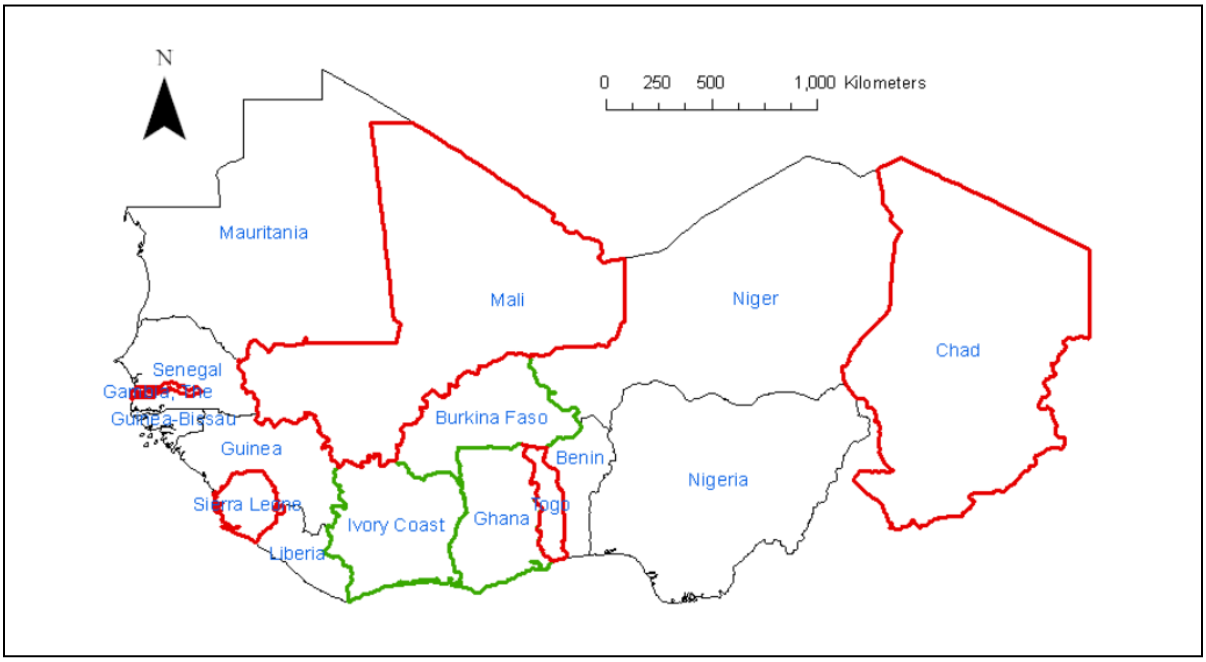

Figure 2.2 – Geographic scope of this study. Red borders indicate countries participating in all aspects of the wider PARCC project, and green borders indicate additional countries that may participate in transboundary activities.

2.3 Species data collection

Trait data for amphibians and birds were made available by Foden *et al.*[9], who conducted a global analysis of these two groups. For the remaining three taxonomic groups it was necessary to collate data anew. This was done through two regional species assessment workshops, as well as through remote consultations with species experts, as required. Assessment workshops were held in Lomé, Togo, in 2012, and considered reptiles at the first (16th – 20th July, 2012), and mammals and freshwater fish at the second (24th – 27th July, 2012). These workshops also provided opportunity for experts to review the traits used for the assessments.

For all taxonomic groups except reptiles, Red List assessments of extinction risk for all species occurring within our focal region had been conducted and data were readily available. This included the species distribution polygons that were used in this study to assess individual species' *Exposure*

[9] See footnote 3 on page 7.

to change (see following section), as well as to infer species' climatic tolerances under *Sensitivity*. In the case of reptiles, Red List assessments were conducted at the assessment workshop, concurrent with the collection of species trait data.

2.4 Exposure modelling

Exposure modelling, which aims to quantify change in biologically-relevant climatic factors across each species' geographical range, used a combination of species range polygons and projections of future temperature and rainfall across West Africa. For this project, and for this element of the study, we followed closely the process of Foden *et al*. (2013) and Carr *et al.* (2013)[10]. For brevity in this report, we only highlight key stages of the process and major deviations from this protocol.

Exposure modelling was conducted using a combination of ArcGIS 10 and Microsoft SQL Server 2005. The input data for this process was as follows:

Species distribution polygons collected as part of the Red List assessment process[11] were rasterised to a resolution of 30 arc minutes, and cells containing elevations[12] and habitats[13] deemed unsuitable for the species removed.

Climate projections were derived by the UK Met Office Hadley Centre, who provided 5 different projections of possible future climate for the focal region[14]. These were developed using a 17-member perturbed physics ensemble of global climate models (GCMs). Of the 17 individual GCMs run as part of this ensemble, the 5 GCMs that best captured the spread in outcomes produced by the full ensemble, whilst excluding any members that did not represent the African climate realistically, were selected for dynamical downscaling using a regional climate model (RCM). Subsequently, these five downscaled ensemble members were used in this study. These data were provided at a resolution of 30 arc minutes. For this study, we considered species' exposure to changes in temperature and precipitation by three different 30 year future time periods, centred around 2025, 2055 and 2085. For example, 2055 category refers to the period 2040 to 2069. These projections were compared to a commonly used baseline period centred around 1975 (i.e. 1961 to 1990).

For all cells in a species' range, overall baseline means (OBM) for temperature and precipitation were calculated. The differences between the baseline OBM's and those of the three future time periods were used as measures of projected change in the means of temperature across each species' current range for respective future period. For projected changes in mean precipitation, the absolute ratio between the baseline and future OBM values was used. In addition, the average absolute deviation (AAD), a summary statistic for dispersion, was calculated for all species and for both climate variables. The differences between the baseline and three future AAD's, and the absolute ratios of the baseline and projected AAD's, were used as measures of projected change in the variability of temperature and precipitation, respectively, across each species' current range. Outputs were ranked and scored as described in Section 2.1. Although species exposure was assessed using all five of the selected model runs, the majority of results presented in this report,

[10] See citations in footnotes 3 and 4 on page 7.

[11] IUCN Red List spatial data are available for download here: http://www.iucnredlist.org/technical-documents/spatial-data

[12] Based on the US Geological Survey's GTOPO30 global digital elevation model, available from: http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info.

[13] Based on the Global Land Cover 2000 dataset, available from: http://ies.jrc.ec.europa.eu/global-land-cover-2000.

[14] See: Jones, R., Hartley, A., McSweeney, C., Mathison, C. and Buontempo, C. (2012) Deriving high resolution climate data for West Africa for the period 1950 - 2100. UNEP-WCMC technical report., for information on model development and selection.

including maps, use only one single model run (named 'Q0' by the developers, this model represents the standard model setup, to which 'perturbations' in physical parameters were added in order to assess model uncertainty). When describing overall measures of vulnerability, however, the range of outcomes from all model runs are included.

2.5 Combining Sensitivity, Low Adaptability and Exposure scores into an overall assessment of climate change vulnerability

Sensitivity, Low Adaptability and Exposure scores for each species were then assembled and overall vulnerability scores calculated according to two simple logic steps: species were assigned a high score under each vulnerability dimension if they have any contributing trait (e.g. considered sensitive due to being a habitat specialist). They were considered highly vulnerable overall, however, only if they scored as ‘high’ under all three criteria of exposure, sensitivity and adaptive capacity. To account for missing trait data, each of the previous steps was run twice; missing trait information was firstly assumed to represent a low vulnerability score and secondly to represent high scores. This provided best-case (or optimistic) and worst-case (pessimistic) scenarios, respectively.

It is extremely important to note that, since many of the trait thresholds are simply relative cut-offs for continuous variables (e.g. 25% of species of greatest exposure to changes in mean temperatures), rather than empirically tested thresholds of vulnerability, our approach provides a relative, not absolute, measure of climate change vulnerability. The actual numbers and percentages of species emerging as vulnerable through this approach represent only the degree of overlap between the three vulnerability dimensions rather than a measure of vulnerability overall. It is therefore not appropriate to use our results to compare degrees of vulnerability between different taxonomic groups. Species identified as vulnerable to climate change should be regarded as estimates of the most vulnerable species, noting that in some taxonomic groups, all species may be at risk from climate change impacts while in others, far fewer than the most vulnerable species we identify may actually be seriously negatively impacted.

3. Results: Climate Change Vulnerability Assessment of West African Amphibians

West Africa, as defined by this project, supports a total of 183 amphibian species, the highest densities of which (a maximum of 66 species per one 30 minute grid cell) can be found in the Guinean Forest region, from Sierra Leone in the west, to southern Nigeria in the east (Figure 3.1). According to the most recent assessment for the IUCN Red List, 35 of these species (19%) are globally threatened, 41 species (11%) are considered Near Threatened, 28 species (15.4%) are Data Deficient, and the remainder (100 species; 54.6%) are Least Concern. Figure 3.2 shows that the distribution pattern of threatened amphibians is similar to that of species richness, with the highest densities (maximum of 10 species per 30 minute grid cell) found on the Côte d'Ivoire borders with Liberia, Guinea and Ghana, and in south-eastern Nigeria (on the Cameroon border).

As part of our climate change vulnerability assessment of the region's amphibians, we considered a total of 13 vulnerability traits, of which four related to 'Exposure', six to 'Sensitivity', and three to 'Low Adaptability'. These are shown in Tables 3.1, 3.2 and 3.3, respectively.

In our assessment of amphibian species' sensitivity, 121 species (66%) were assessed as possessing traits that make them highly sensitive to climate change. This number increased to 125 (68%) when assuming a pessimistic outcome for unknown species traits. Within the *Sensitivity* analysis, larval dependence upon aquatic habitats (Trait S2) showed up as the most commonly possessed sensitivity trait, with a known presence in 51 (28%) species. A narrow tolerance of temperature and precipitation ranges (Traits S3 and S4, respectively) were the next most commonly possessed, both highlighting 45 (25%) species. Note, however, that selection of species under these criteria is subject to the caveats described in the methods section of this report. Trait S5 (explosive breeding habits, following rainfall) was the most uncertain of the amphibian *Sensitivity* traits - it is unknown whether or not this trait is present in 31 (17%) of the species considered.

In our assessment of amphibian species' adaptive capacity, 70 (38%) species were assessed as possessing traits that make them poorly able to adapt to climate change. This number increased to 125 (68%) when assuming a pessimistic outcome for unknown species traits. Within the analysis of adaptive capacity, a poor intrinsic (i.e. due to an inherent biological feature) ability to disperse (Trait A2) was the most common, present in 56 (31%) species. Knowledge of species' generation turnover rates (Trait A3), believed to influence a species' capacity to adapt *in-situ* through genetic microevolution, was the most uncertain of the amphibian adaptability traits - data were unavailable for a total of 86 (47%) of the species considered.

Overall a total of 12 (7%), 18 (10%) and 46 (25%) amphibian species were considered climate change-vulnerable by the years 2025, 2055 and 2085, respectively, using Q0 climate projections (see methods, section 2.4), and an optimistic assumption of missing data values. When considering additional model runs, as well as pessimistic assumptions of data values, the minimum and maximum numbers of vulnerable species identified are 4 - 50 species (2 - 27%) for the year 2025, 17 - 89 species (9 - 49%) for the year 2055, and 46 - 89 species (25 - 49%) by the year 2085.

Figure 3.3 shows the concentrations and proportions of climate change vulnerable amphibian species throughout West Africa by both 2055 and 2085. When considering <u>total numbers</u> of vulnerable species, one notices that the greatest concentrations in 2055 (six to seven species per grid cell) are found in southern Nigeria. More typically, however, regions supporting the greater numbers of vulnerable species contain around four vulnerable species per grid cell, and are found across much of the sub-humid and a semi-arid zone, north of the southern coast, and spanning from Senegal and Guinea-Bissau in the west to Benin and Central Nigeria in the east.

By 2085, numbers of climate change vulnerable amphibian species remain similar across the region described above (typically three to five species per grid cell), but increase significantly in the more southern humid regions, including concentrations of seven to eleven species per grid cell at locations in Liberia, Guinea, Côte d'Ivoire, Ghana and Nigeria, and with peaks of 11 - 19 species per grid cell on the Liberia-Guinea-Côte d'Ivoire border, and on the southern border of Nigeria and Cameroon.

In terms of proportions of climate change vulnerable amphibian species, our assessments suggest that by 2055 the greatest impacts will occur in the more northern arid and semi-arid regions. Figure 3.3 suggests that in northern Senegal, southern Mauritania and south-eastern Mali, up to 25% of amphibian species present could be impacted by climate change by 2055. Similarly high levels of between 14 and 20% are depicted across much of Guinea, southern Mali, Burkina Faso, Ghana, and as far east as parts of Chad.

By 2085, increasing proportions of vulnerable species are visible in the more southern, and typically 'humid' zones, where, as shown in Figure 3.1, species richness is also significantly higher. In regions such as central and southern Liberia, Côte d'Ivoire and Ghana, as well as southern Nigeria, up to 19% (though more typically 6-11%) of species are among those considered most vulnerable to climate change.

Of the species identified as climate change vulnerable by 2055, and under an optimistic scenario for unknown data points, only one species[15] is currently considered globally threatened. Using a pessimistic assumption of unknown data points, an additional three species[16] are already considered globally threatened and could potentially be vulnerable to climate change impacts. By 2085, using an optimistic assumption of unknown data points, a further 10 species are considered both globally threatened and climate change vulnerable. Under a pessimistic assumption of missing data points, this number increases by an additional 18 species. Details of all species assessments, across all time periods, are available in the dataset which accompanies this document.

Conclusions

West African amphibians possess a high sensitivity to climate change and its impacts, particularly due to their dependence on specific habitats (typically fresh waters for larval development). Many species also depend upon rainfall to initiate breeding, although this trait is unknown (and warrants research) for a high number of species. Many amphibian species of the region are believed to be poorly able to disperse as a response to climate change, typically due to their intrinsic biological characteristics, which render them poorly equipped to move large distances over short timeframes. Although few species were assessed as having barriers that prevent their dispersal, this factor remains unknown for 31 species, and research into such elements would provide useful insights when conducting conservation planning efforts. Of all the traits considered for the taxon, knowledge of the reproductive capacity of many West African amphibians, a factor which can provide insights into a species' likelihood of adapting *in-situ*, is the greatest area of uncertainty.

[15] *Amietophrynus perreti* (VU; D2) (Schiøtz and Tandy 2004, http://www.iucnredlist.org/details/54732/0).

[16] *Amietophrynus taiensis* (CE; B2ab(iii)) (Rödel et al. 2004; http://www.iucnredlist.org/details/summary/54774/0); *Cardioglossa aureoli* (EN; B1ab(iii)+2ab(iii) (Schiøtz and Rödel 2004; http://www.iucnredlist.org/details/54397/0); *Conraua derooi* (CE; B2ab(iii) (Rödel and Schiøtz 2004; http://www.iucnredlist.org/details/58253/0).

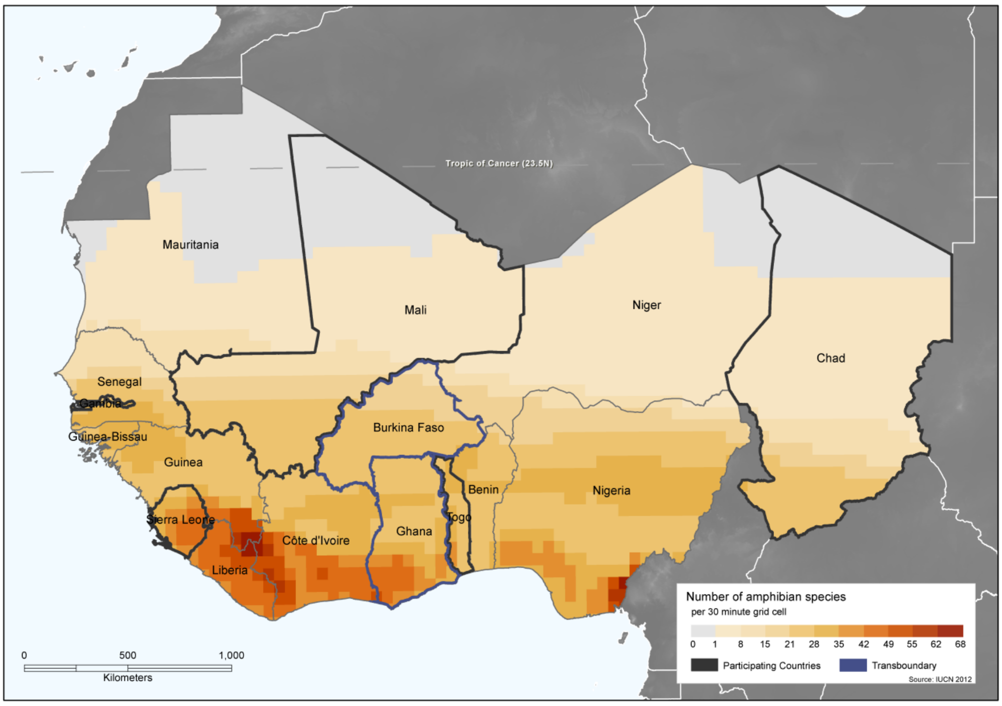

Figure 3.1 – Species richness of amphibians in West Africa.

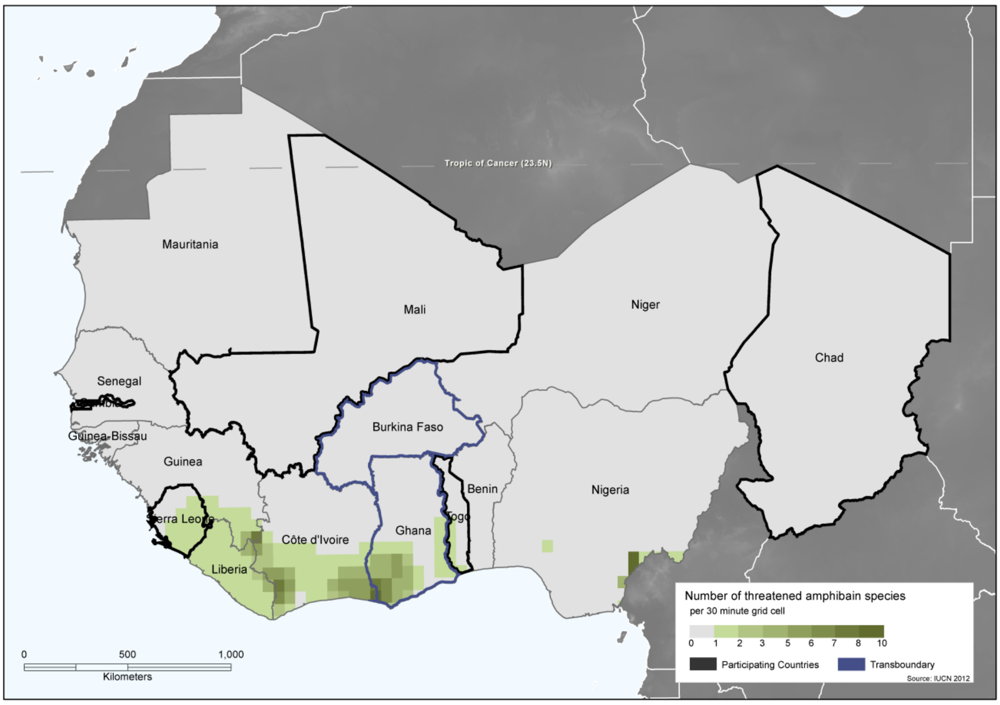

Figure 3.2 – Distribution of globally threatened amphibians across West Africa (IUCN 2013). Colours show counts of threatened amphibians per 30 minute grid cell.

Table 3.1 – Climate change *exposure* measures used to assess West African amphibians, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. This table presents results based on model run Q0 (see methods, section 2.4). Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 183		
				Number of species per category		
EXPOSURE				Low	High	Unknown
Climatic means	Substantial changes in climatic means occur across the species' range	**E1:** Absolute ratio of 1975 and 2055 values of mean precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	132	44	7
		E2: Absolute difference between 1975 and 2055 mean temperatures (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	132	44	7
Climatic variability	Substantial changes in climatic variability occur across the species' range	**E3:** Absolute ratio of 1975 and 2055 values of average absolute deviation in precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	132	44	7
		E4: Absolute difference between 1975 and 2055 values of average absolute deviation in temperature (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	132	44	7
Total				**83**	**93**	**7**
Percentage				**45**	**51**	**4**

Table 3.2 – Climate change *sensitivity* traits used to assess West African amphibians, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 183		
				Number of species per category		
SENSITIVITY				Low	High	Unknown
A. Specialized habitat and/or microhabitat requirements	Habitat specialisation	S1: Number of IUCN habitat types occupied by species	L = >1; H = 1	168	15	0
		S2: Freshwater-dependent and Larval development and occurs exclusively in an un-buffered habitat (i.e. not forest)	L = False; H = True	121	51	11
B. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle	Tolerance of temperature changes	S3: Temperature range (max temp -min temp)	Average absolute deviation in temperature across the species' historical range: L = highest 75%; H = Lowest 25%	135	45	3
	Tolerance of precipitation changes	S4: Tolerance of wide precipitation range (maximum and minimum annual precipitation used to calculate range tolerated)	Average absolute deviation in precipitation across the species' historical range: L = highest 75%; H = Lowest 25%	135	45	3
C. Dependence on a specific environmental trigger that is likely to be disrupted by climate change	Dependence on an environmental trigger	S5: Explosive breeder following a climatic event (e.g. rainfall)?	L = No; H = Yes	128	24	31
D. Dependence on interspecific interactions which are likely to be disrupted by climate change.	Increasing negative interactions with other species	S6: Known to be sensitive to chytrid fungus?	L = No; H = Yes	174	4	5
Total				**58**	**121**	**4**
Percentage				**32**	**66**	**2**

Table 3.3 – Climate change *low adaptability* traits used to assess West African amphibians, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 183		
				Number of species per category		
LOW ADAPTABILITY				Low	High	Unknown
A. Poor 'dispersability'	Barriers to dispersal	A1: Dispersal limited by geographic barriers?	L = No; H = Yes	150	2	31
		A2: Dispersal limited intrinsic biological factors?	L = No; H = Yes	119	56	8
B. Poor 'evolvability'	Low reproductive capacity	A3: Low annual reproductive output	L <50 and oviparous; H >=50 and/or viviparous	66	31	86
Total				58	70	55
Percentage				32	38	30

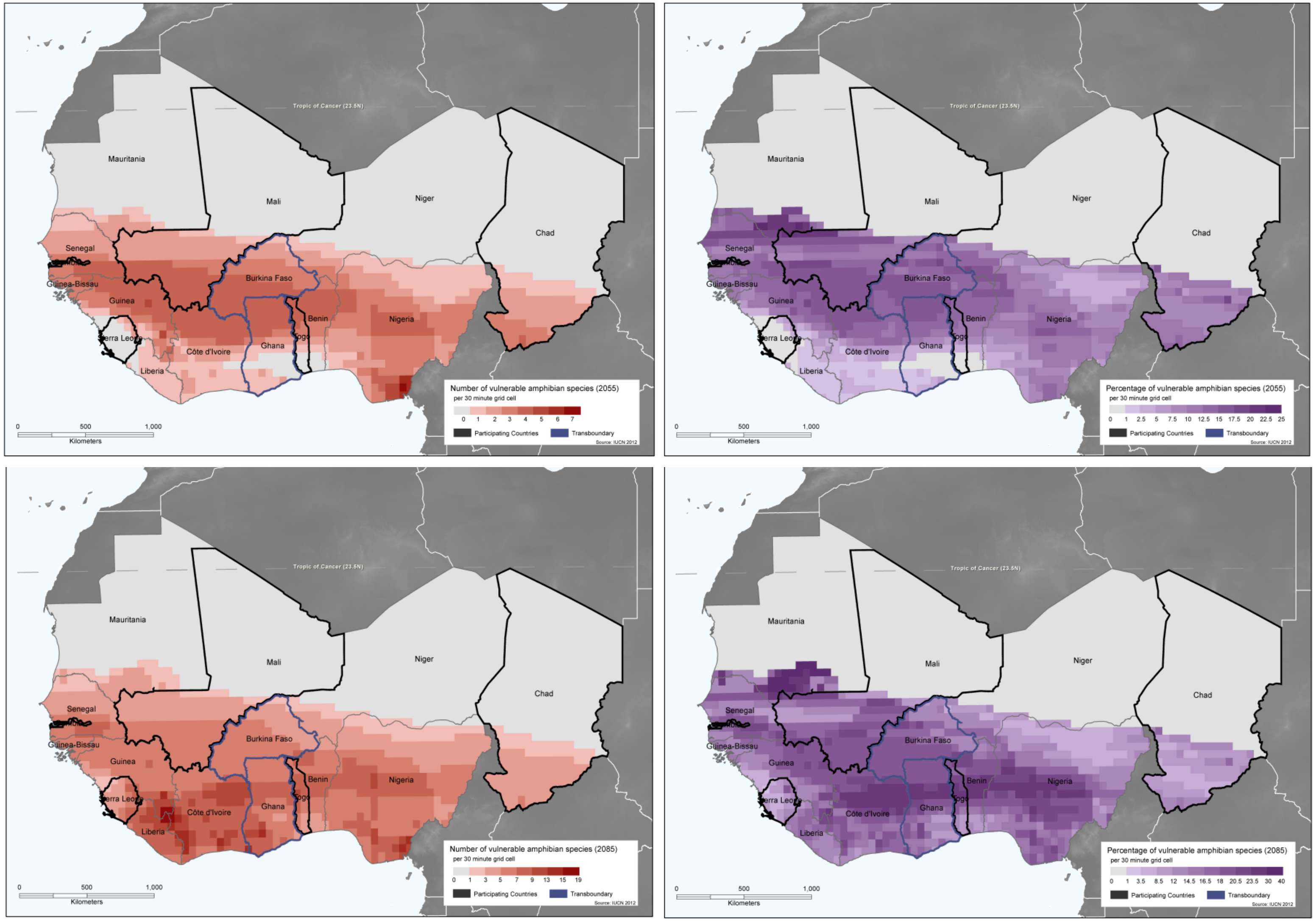

Figure 3.3 – Distribution of climate change vulnerable West African amphibians by 2055 (top) and 2085 (bottom). Maps on the left hand side show the total number of species per grid cell assessed as climate change vulnerable. Maps on the right hand side show the percentage of the total species in each grid cell assessed as climate change vulnerable. All maps use results based on exposure model using Q0 (see methods, section 2.4).

4. Results: Climate Change Vulnerability Assessment of West African Birds

As part of this project, we assessed the climate change vulnerability of 1,172 bird species of West Africa (as defined by this project). Of the species considered, the highest densities (up to 496 species per one 30 minute grid cell) can be found in areas of the Guinean Forest Biodiversity Hotspot[17], including parts of Liberia, Guinea, Côte d'Ivoire, Ghana and Nigeria (Figure 4.1). Densities are also high (upwards of 200 species per grid cell) across much of the humid and sub-humid zone, including countries listed above, and northwards into Senegal/The Gambia and southern Mali. According to the most recent assessment for the IUCN Red List, 42 of these species (3.6%) are globally threatened, 41 species (3.5%) are considered Near Threatened, 6 species (0.5%) are Data Deficient, and the remainder (1,083 species; 92.4%) are Least Concern. Figure 4.2 shows that the highest densities of threatened bird species (up to 11 species per grid cell) can be found at similar locations to those described above, as containing the highest levels of species richness. Particular 'hotspots' include much of Senegal and The Gambia, central Mali, much of Guinea and south-western Côte d'Ivoire, southern Ghana, and an area spanning the borders of Niger, Nigeria and Chad.

As part of our climate change vulnerability assessment of the region's birds, we considered a total of 17 vulnerability traits, of which four related to *'Exposure'*, eight to *'Sensitivity'*, and five to *'Low Adaptability*'. These are shown in Tables 4.1, 4.2 and 4.3, respectively.

In our assessment of bird species' sensitivity to climate change, 584 species (50%) were assessed as possessing traits that make them highly sensitive to climate change. This number increased to 1,010 (86%) when assuming a pessimistic outcome for unknown species traits. Within the sensitivity analysis, a narrow tolerance of temperature and precipitation ranges (Traits S4 and S5, respectively) were the most commonly possessed, both highlighting 248 (21%) species. Note, however, that selection of species under these criteria is subject to the caveats described in the methods section of this report. Dependence on specific microhabitats (Trait S2) and intolerance of disturbance (Trait S3) emerged as the two next most commonly possessed traits, with a known presence in 110 (9.4%) and 115 (9.8%) species, respectively. Traits pertaining to population size (Trait S7), including effective population size (Trait S8), are the most uncertain of the bird sensitivity traits considered – values for both of these traits are unknown for 799 (68%) of the species considered.

In our assessment of bird species' adaptive capacity, 610 (52%) species were assessed as possessing traits that make them poorly able to adapt to climate change. This number increased to 798 (68%) when assuming a pessimistic outcome for unknown species traits. Within the analysis of adaptive capacity, a long generation length (Trait A5, set at greater than or equal to six years per generation for this analysis), which is thought to influence a species capacity to adapt *in-situ* through genetic microevolution, was the most common trait – present in 375 species (32%). Trait A4 (small clutch size, set at less than or equal to two eggs per clutch), which is also believed reduce the likelihood of *in-situ* adaptation, was the next most common trait, present in 340 species (29%), but was also the trait with the greatest uncertainty – unknown for 243 species (21%). A poor intrinsic (i.e. due to an inherent biological feature) ability to disperse (Trait A2) is also a notably common trait in West African birds, present in 108 species (9%).

Overall a total of 17 (1.5%), 247 (21%) and 309 (26%) bird species were considered climate change-vulnerable by the years 2025, 2055 and 2085, respectively, using climate projections based on model run Q0 (see methods, section 2.4), and an optimistic assumption of missing

[17] Conservation International (2013) The Guinean Forests of West Africa Biodiversity Hotspot. http://www. conservation.org/where/priority_areas/hotspots/africa/Guinean-Forests-of-West-Africa/Pages/default.aspx.

data values. When considering additional circulation models, as well as pessimistic assumptions of data values, the minimum and maximum numbers of vulnerable species identified are 14 - 108 species (1 - 9%) for the year 2025, 149 - 666 species (13 - 57%) for the year 2055, and 309 - 669 species (26 - 57%) by the year 2085.

Figure 4.3 shows the concentrations and proportions of climate change vulnerable bird species throughout West Africa by both 2055 and 2085. When considering total numbers of vulnerable species, one notices that the greatest concentrations in 2055 (up to 137, though more typically 80-123, species per grid cell) are found in the humid tropics, and particularly in the Guinean Forests Biodiversity Hotspot (see citation on previous page). Concentrations generally decline as one moves northward. By 2085, the pattern described above remains visible, though the total numbers of climate change vulnerable species increase marginally throughout, with concentrations reaching 164 species per grid cell in the humid south.

In terms of proportions of climate change vulnerable bird species, our assessments suggest that by 2055 the greatest impacts will occur in the southern humid zone, as well as in the northern arid zone (from Mauritania in the West, to Chad in the East), where up to 31% of the species present were assessed as climate change vulnerable. Proportions of climate change vulnerable species are visibly lower in the sub-humid regions, where species richness is high, yet total numbers of climate change vulnerable species is low, relative to other regions.

As with total numbers of species, locations containing high proportions of climate change vulnerable species change little between 2055 and 2085. The pattern described above remains, though percentage values increase to nearly 35% in some cells.

Of the species identified as climate change vulnerable by 2055, and under an optimistic scenario for unknown data points, thirteen species[18] are currently considered globally threatened. Using a pessimistic assumption of unknown data points, an additional nine species[19] are already considered globally threatened and could potentially be vulnerable to climate change impacts. By 2085, using an optimistic assumption of unknown data points, a further seven species are considered both globally threatened and climate change vulnerable. Under a pessimistic assumption of missing data points, this number increases by an additional two species, to a total of 31. Details of all species assessments, across all time periods, are available in the dataset which accompanies this document.

[18] *Bycanistes cylindricus* (VU; A2cd+3cd+4cd); *Circaetus beaudouini* (VU; A2bcd+3bcd+4bcd;C1+2a(ii)); *Falco cherrug* (EN; A2bcde+3cde+4bcde); *Geronticus eremita* (CR; C2a(ii)); *Gyps rueppellii* (EN; A2abcd+3bcd+4abcd); *Marmaronetta angustirostris* (VU; A2cd+3cd+4cd); *Neophron percnopterus* (VU; A2bcde+3bcde+4bcde); *Phyllastrephus leucolepis* (CR; B1ab(i,ii,iii,v)); *Picathartes oreas* (VU; C2a(i)); *Psittacus erithacus* (VU; A2abcd+3bcd+4abcd); *Scotopelia ussheri* (VU; C2a(i)); *Torgos tracheliotos* (VU; C2a(ii)); *Vanellus gregarius* (CR; A3bcd+4bcd) (IUCN 2013 http://www.iucnredlist.org/).

[19] *Alauda razae* (CR; B1ac(iv)+2ac(iv)); *Bradypterus graueri* (EN; B2ab(ii,iii,iv,v)); *Campephaga lobata* (VU; A2c+3c+4c); *Criniger olivaceus* (VU; A2c+3c+4c); *Cryptospiza shelleyi* (VU; C2a(i)); *Estrilda poliopareia* (VU; D1); *Malimbus ballmanni* (EN; A2c+3c+4c); *Malimbus ibadanensis* (EN; C2a(ii)); *Melaenornis annamarulae* (VU; A2c+3c+4c) (IUCN 2013 http://www.iucnredlist.org/).

Conclusions

Across all species, West African birds appear to possess a lower level of sensitivity to climate change and its impacts compared with other groups, although microhabitat dependencies, and particularly a dependence upon primary forest, emerged as the most common sensitivity trait within the group. Uncertainty with bird sensitivity traits is particularly high due to a lack of knowledge of species' population sizes.

Assessment of the adaptive capacity of West African birds suggests a medium to low number of species will have the ability to adapt to climatic changes. This is predominantly due to a low reproductive output over time (also the greatest area of uncertainty in or assessment of adaptability in birds), but also due to intrinsically low dispersal distances in a number of species.

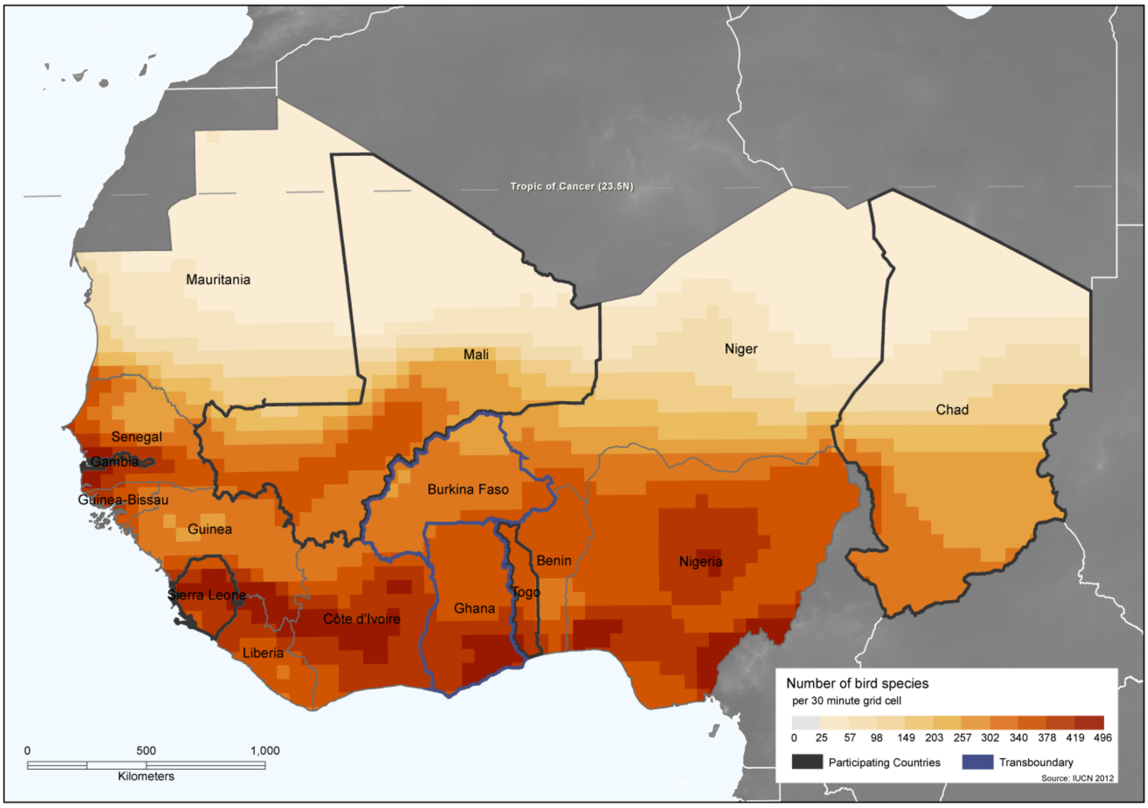

Figure 4.1 – Species richness of birds in West Africa.

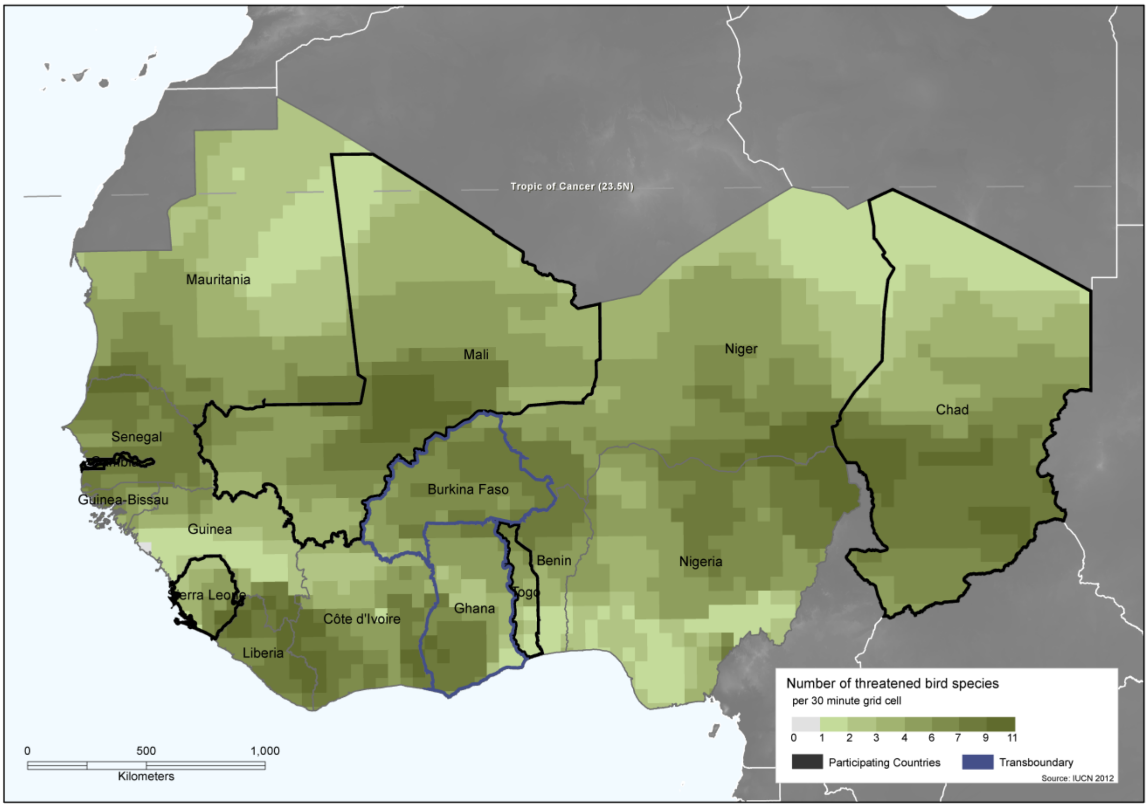

Figure 4.2 – Distribution of globally threatened birds across West Africa (IUCN 2013). Colours show counts of threatened birds per 30 minute grid cell.

Table 4.1 – Climate change *exposure* measures used to assess West African birds, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. This table presents results based on model run Q0 (see methods, section 2.4). Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 1,172		
				Number of species per category		
EXPOSURE				Low	High	Unknown
Climatic means	Substantial changes in climatic means occur across the species' range	**E1:** Absolute ratio of 1975 and 2055 values of mean precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	868	289	15
		E2: Absolute difference between 1975 and 2055 mean temperatures (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	868	289	15
Climatic variability	Substantial changes in climatic variability occur across the species' range	**E3:** Absolute ratio of 1975 and 2055 values of average absolute deviation in precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	868	289	15
		E4: Absolute difference between 1975 and 2055 values of average absolute deviation in temperature (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	868	289	15
Total				**439**	**718**	**15**
Percentage				**37.4**	**61.3**	**1.3**

Table 4.2 – Climate change *sensitivity* traits used to assess West African birds, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document. This table continues on the next page.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 1,172		
				Number of species per category		
SENSITIVITY				Low	High	Unknown
A. Specialised habitat and/or microhabitat requirements	Habitat specialisation	S1: Number of IUCN habitat types occupied by species	L = >1; H = 1	1107	65	0
	Microhabitat specialisation	S2: Species has one or more microhabitat dependencies	L = False; H = True	1053	110	9
	Intolerance of disturbance	S3: Species is dependent on primary forest and is intolerant of disturbance	L = False; H = True	1048	115	9
B. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle	Tolerance of changes to precipitation regimes	S4: Temperature range (max temp - min temp)	Average absolute deviation in temperature across the species' historical range: L = highest 75%; H = Lowest 25%	742	248	182
	Tolerance of temperature changes	S5: Precipitation range (maximum and minimum annual rainfall used to calculate range tolerated)	Average absolute deviation in precipitation across the species' historical range: L = highest 75%; H = Lowest 25%	742	248	182
D. Dependence on interspecific interactions which are likely to be disrupted by climate change.	Declining positive interactions with other species	S6: Dependence on one or more interspecific interactions that are likely to be impacted by climate change (e.g. specialised dependency on army ants)	H = Dependence on one or more interspecific interactions that are likely to be impacted by climate change; L = No dependency;	1153	10	9

Trait Group	Trait	Sub-trait	Thresholds	Total species = 1,172		
E. Rarity	Small population size	S7: Number of individuals in global population	L = ≥ 10,000; H = < 10,000	345	28	799
	Small effective population size	S8: Low number of reproducing individuals	H = < 20,000 and [(skewed sex ratio) or (polygynous or polyandrous breeding system) or (cooperative breeding system) or (declining or extremely fluctuating population trend)]; L = All other species	327	46	799
Total				162	584	426
Percentage				14	50	36

Table 4.3 – Climate change *low adaptability* traits used to assess West African birds, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 1,172		
				Number of species per category		
LOW ADAPTABILITY				Low	High	Unknown
A. Poor 'dispersability'	Extrinsic barriers to dispersal	A1: Extrinsic barriers to dispersal	L = No known barriers; H = Occurs exclusively on mountaintops, small islands and/or polar edges of land masses	1134	29	9
	Low intrinsic dispersal capacity	A2: Mean maximum intrinsic dispersal distance	L = >1 km/year; H = ≤ 1 km/year	1055	108	9
B. Poor 'evolvability'	Low genetic diversity	A3: Evidence of low genetic diversity or known genetic bottleneck	L = False; H = True	1162	1	9
	Slow turnover of generations	A4: Generation length	L = < 6 years; H = ≥ 6 years	788	375	9
	Low reproductive capacity	A5: Mean clutch size	L = >2; H = ≤ 2	589	340	243
Total				374	610	188
Percentage				32	52	16

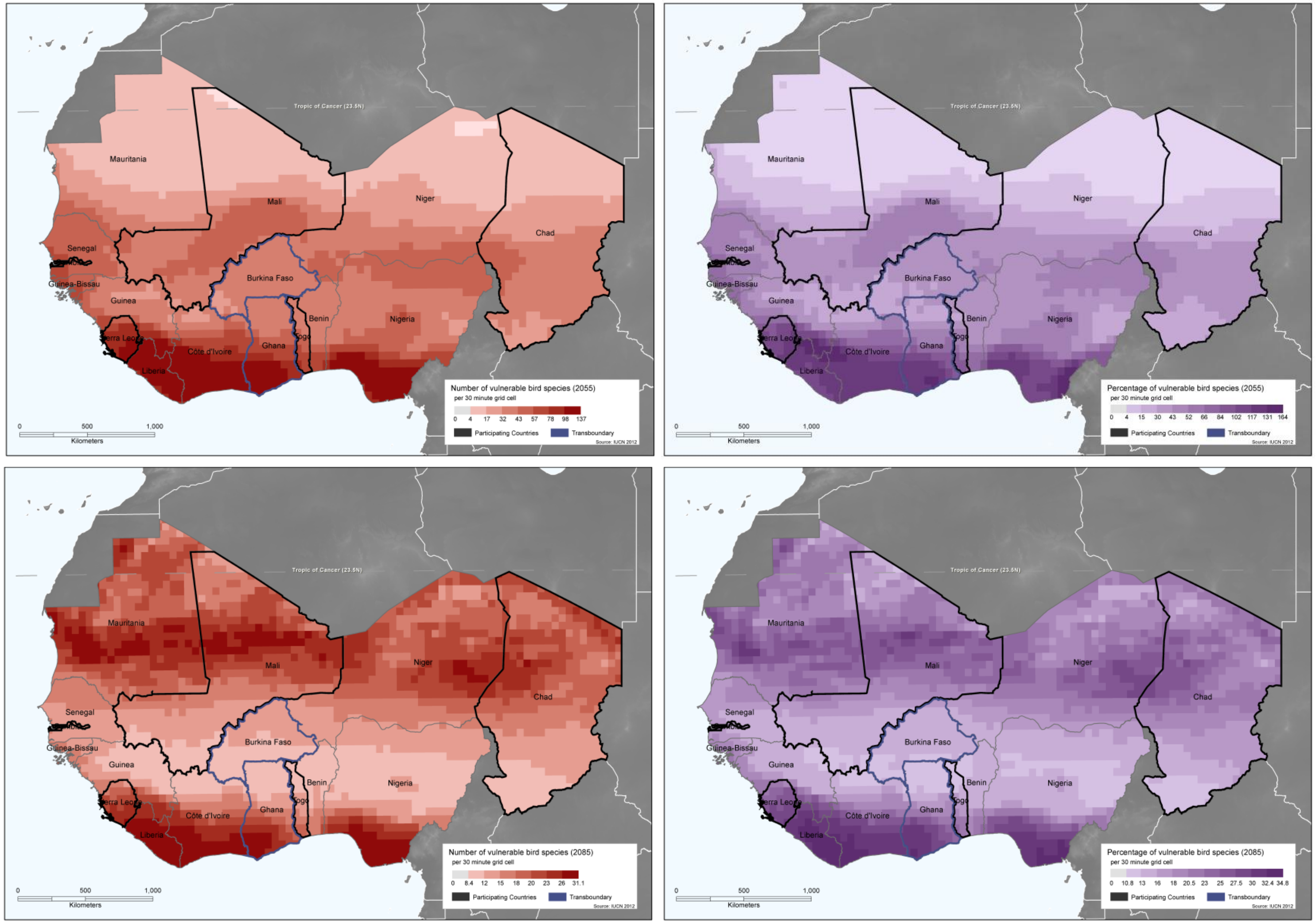

Figure 4.3 – Distribution of climate change vulnerable West African birds by 2055 (top) and 2085 (bottom). Maps on the left hand side show the total number of species per grid cell assessed as climate change vulnerable. Maps on the right hand side show the percentage of the total species in each grid cell assessed as climate change vulnerable. All maps use results based on model run Q0 (see methods, section 2.4).

5. Results: Climate Change Vulnerability Assessment of West African Freshwater Fish

As part of this project, we assessed the climate change vulnerability of 517 freshwater fish species of West Africa (as defined by this project). Of the species considered, the highest densities (up to 179 species per 30 minute grid cell) can be found in the far south of Nigeria, and in a smaller area running along the borders of Sierra Leone, Guinea and Liberia (Figure 5.1). Densities are also high (between 100 and 140 species per grid cell) along much of the coastal region (particularly in Sierra Leone and Ghana) and in southern Mali. According to the most recent assessment for the IUCN Red List, 115 of these species (22%) are globally threatened, 45 species (9%) are considered Near Threatened, 40 species (8%) are Data Deficient, 264 species (51%) are Least Concern, and the remainder (53 species; 10%) have not been evaluated for the Red List. Figure 5.2 shows that the highest densities of threatened freshwater fish species (up to 17 species grid cell) can be found at many of the locations described above, particularly in Sierra Leone, and surrounding Guinea and Liberia, as well as Ghana and southern Nigeria.

As part of our climate change vulnerability assessment of the region's freshwater fish, we considered a total of 17 vulnerability traits, of which four related to *'Exposure'*, eight to *'Sensitivity'*, and four to *'Low Adaptability'*. These are shown in Tables 5.1, 5.2 and 5.3, respectively.

In our assessment of freshwater fish species' sensitivity to climate change, 374 species (72%) were assessed as possessing traits that make them highly sensitive to climate change. One hundred and forty-three species (28%) were assessed as 'unknown' in terms of their sensitivity, and zero as 'low'. This means that, when assuming a pessimistic outcome for unknown species traits, all 517 species (100%) are considered sensitive.

Within the sensitivity analysis, 'microhabitat specialization' (Trait S6) emerged as the most commonly possessed, highlighting 150 species (29%). Temporary pools and shallow waters for egg-laying emerged as two microhabitats that are depended upon by a high numbers of species. A narrow tolerance of temperature and precipitation ranges (Traits S3 and S4, respectively) were the next two most commonly possessed traits, both highlighting 120 (23%) species. Note, however, that selection of species under these criteria is subject to the caveats described in the methods section of this report. Information on species' tolerances to increases in turbidity and/or sedimentation (Trait S5) and on environmental triggers that could be disrupted by climate change (Trait S8) was particularly lacking, and unavailable for 358 (69%) and 377 (72%) species, respectively.

In our assessment of freshwater fish species' adaptive capacity, 432 species (83.5%) were assessed as possessing traits that make them poorly able to adapt to climate change. Only two species (<1%) were assessed as 'low' risk in terms of their adaptive capacity, and the remaining 83 (16%) as 'unknown'. This means that, when assuming a pessimistic outcome for unknown species traits, 515 species (>99%) are considered poorly able to adapt to environmental change.

Within the analysis of adaptive capacity, an 'intrinsic low probability of dispersal' (Trait A2) was the most common trait – present in 430 species (32%). This element of the assessment uses a combination of traits itself (body length, trophic position, possession of an ancillary breathing organ, and tolerance to saltwater) to classify a species as either a 'good' or 'bad' dispersers, and is based upon the work of Hugueny *et al.* (1990)[20]. Traits providing insights into species' likelihood

[20] Hugueny (1990) Geographic range of West African freshwater fishes: role of biological characteristics and stochastic processes. Acta Oecologica 11 (3): 351-375.

of adapting to change *in-situ* were much more poorly known for the region's freshwater fish. Data on species' life history strategies (Trait A3) and genetic variability (Trait A4) were missing for 255 (49%) and 514 (99%) species, respectively.

Overall a total of 99 (19%), 202 (39%) and 311 (60%) freshwater fish species were considered climate change-vulnerable by the years 2025, 2055 and 2085, respectively, using climate projections based on model run Q0 (see methods, section 2.4), and an optimistic assumption of missing data values. When considering additional circulation models, as well as pessimistic assumptions of data values, the minimum and maximum numbers of vulnerable species identified are 11 - 212 species (2 - 41%) for the year 2025; 110 - 515 species (21 - >99%) for the year 2055, and 311 - 669 species (60 - >99%) by the year 2085.

Figure 5.3 shows the concentrations and proportions of climate change vulnerable freshwater fish species throughout West Africa by both 2055 and 2085. When considering total numbers of vulnerable species, one finds the greatest concentrations in 2055 (up to 67 species per grid cell) in southern Nigeria. Much of Guinea, as well as the adjoining area of southern Mali, also contain relatively high numbers of climate change vulnerable species - typically between 29 and 52 species. By 2085, the pattern described above remains visible, though the total numbers of climate change vulnerable species within these areas increases to up to 93 per grid cell at some locations. Total numbers increase marginally in other areas too by 2085, particularly along the coastal areas of Guinea, Sierra Leone, Côte d'Ivoire and Ghana.

In terms of proportions of climate change vulnerable freshwater fish species, our assessments suggest that by 2055 the greatest impacts will occur in the desert regions of northern Niger and Chad, where 100% of species are assessed as climate change vulnerable. Proportions of climate change vulnerable species are visibly lower at all other locations; typically between zero and ten percent in the southwest of the region, and increasing to 40-50% as one moves north and/or east. By 2085, areas in the east of Mauritania and in the east of Mali also stand out as having 100% and 80% of their freshwater fish fauna vulnerable to climate change, respectively. At all other locations numbers increase to between 10 and 40%.

Of the 202 species identified as climate change vulnerable by 2055 using an optimistic scenario for unknown data points, 62 species are currently considered globally threatened. Using a pessimistic assumption of unknown data points, an additional 17 species are already considered globally threatened and could potentially be vulnerable to climate change impacts. By 2085, using an optimistic assumption of unknown data points, a further 12 species are considered both globally threatened and climate change vulnerable, and under a pessimistic assumption of missing data points, this number increases by an additional 24 species, to a total of 115. Details of all species assessments, across all time periods, are available in the dataset which accompanies this document.

Conclusions

As a group, West African freshwater fish species show a high sensitivity to climate change and its impacts, particularly due to their specific habitat and microhabitat associations, which may be affected under a changing climate. Although uncertainty is high within this assessment, the high prevalence of sensitivity in species with sufficient data suggests that other species may be similarly sensitive.

Much as with sensitivity, West African freshwater fish species with sufficient data for assessment are believed to have a poor capacity to adapt to change, suggesting that those with missing data may also share similar traits. A low intrinsic capacity for dispersal was the most commonly possessed trait among all species.

The expected combination of high sensitivity and low adaptive capacity to climate change of West Africa's freshwater fish, means that additional attention to this group is recommended.

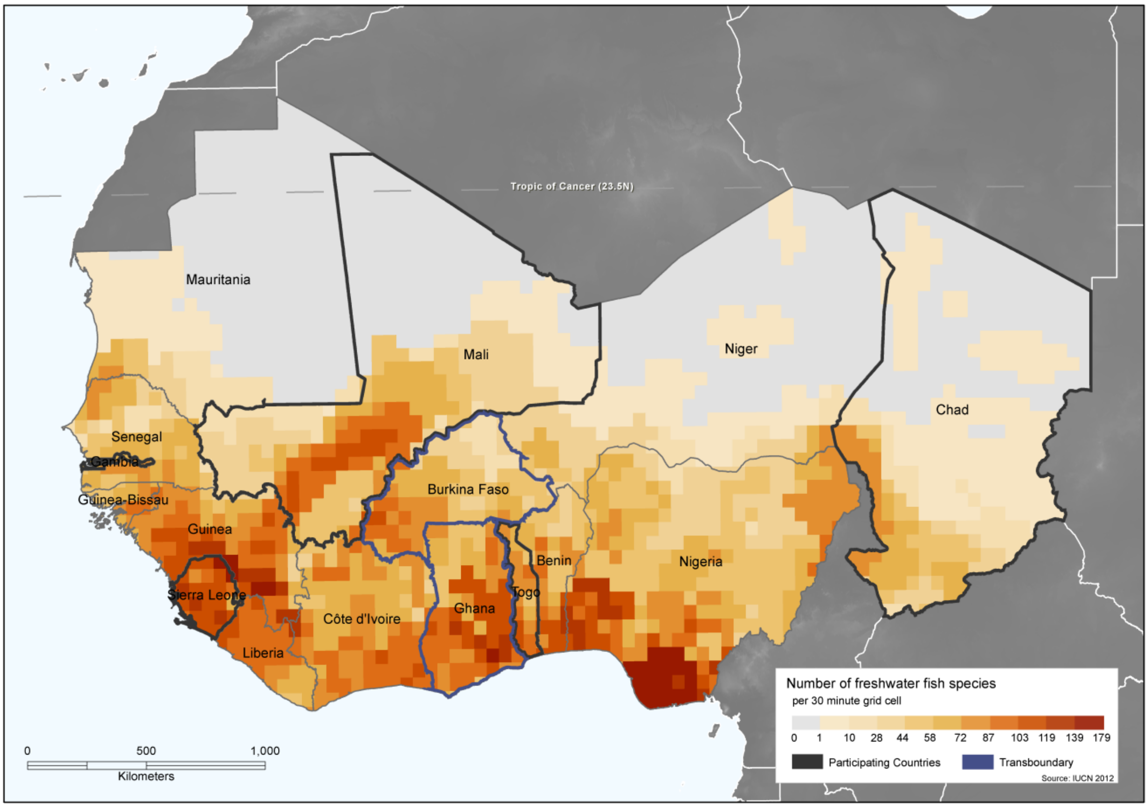

Figure 5.1 – Species richness of freshwater fish in West Africa.

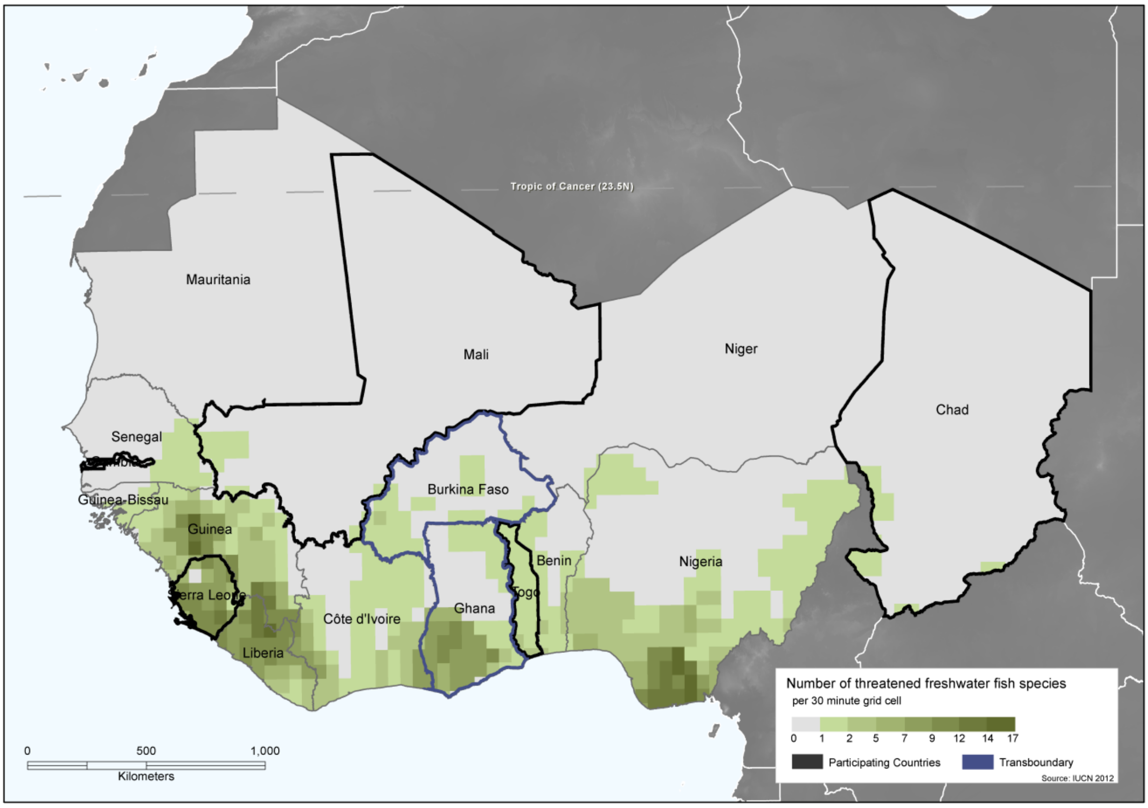

Figure 5.2 – Distribution of globally threatened freshwater fish across West Africa (IUCN 2013). Colours show counts of threatened fish per 30 minute grid cell.

Table 5.1 – Climate change *exposure* measures used to assess West African freshwater fish, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. This table presents results based on model run Q0 (see methods, section 2.4). Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 517		
				Number of species per category		
EXPOSURE				Low	High	Unknown
Climatic means	Substantial changes in climatic means occur across the species' range	**E1:** Absolute ratio of 1975 and 2055 values of mean precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	363	121	33
		E2: Absolute difference between 1975 and 2055 mean temperatures (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	363	121	33
Climatic variability	Substantial changes in climatic variability occur across the species' range	**E3:** Absolute ratio of 1975 and 2055 values of average absolute deviation in precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	363	121	33
		E4: Absolute difference between 1975 and 2055 values of average absolute deviation in temperature (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%	363	121	33
Total				**177**	**307**	**33**
Percentage				**34.2**	**59.4**	**6.4**

Table 5.2 – Climate change *sensitivity* traits used to assess West African freshwater fish, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document. This table continues on the next page.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 517		
				Number of species per category		
SENSITIVITY				Low	High	Unknown
A. Specialized habitat and/or microhabitat requirements	Habitat specialisation	S1: Number of IUCN habitat types occupied by species	L = >1; H = 1	334	113	70
	Microhabitat specialisation	S2: Species is dependent on one or more of the microhabitats identified[21]	L = False; H = True	296	150	71
B. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle	Tolerance of changes to precipitation regimes	S3: Tolerance of wide precipitation range (maximum and minimum annual rainfall used to calculate range tolerated)	Average absolute deviation in precipitation across the species' historical range: L = highest 75%; H = Lowest 25%	361	120	36
	Tolerance of temperature changes	S4: Temperature range (max temp -min temp)	Average absolute deviation in temperature across the species' historical range: L = highest 75%; H = Lowest 25%	361	120	36
	Tolerance of increases in turbidity and/or sedimentation	S5: Species uses a visual, intraspecific recognition system that could be affected by changes in turbidity and/or sedimentation	L = False; H = True (or highly likely)	118	41	358

[21] Temporary pools; bio-covered rocks; rapids; mountain rivulets; shallow waters for egg laying; flooded areas; forest streams; small rivers under forest canopy; submerged roots.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 517		
	Migration limited by water level changes	**S6:** Species migrates upstream to breed and/or spawn	L = Species does not migrate upstream; H = Species migrates upstream	417	22	78
C. Dependence on a specific environmental trigger that is likely to be disrupted by climate change	Climatic trigger	**S7:** Species requires change in temperature and/or precipitation regime to initiate egg development, nest construction and/or re-submergence after cocooning	L = False; H = True	124	16	377
D. Dependence on interspecific interactions which are likely to be disrupted by climate change.	Highly specific diet	**S8:** Species diet consists of only one category (of 11 identified)	L = False; H = True	517	0	0
Total				**0**	**374**	**143**
Percentage				**0**	**72**	**28**

Table 5.3 – Climate change *low adaptability* traits used to assess West African freshwater fish, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document. This table continues on the next page.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 517		
				Number of species per category		
LOW ADAPTABILITY				Low	High	Unknown
A. Poor dispersability	Barriers to dispersal	A1: Species' dispersal is restricted by physical barriers	H = species occurs exclusively within 2km of mountaintops, on islands with a maximum elevation of 500m, Within 10º latitude from the polar border of a continental mass, or in an area where dispersal is blocked by unsuitable habitat (natural or anthropogenic) or dams; L= all other species	512	5	0
	Intrinsic low probability of dispersal	A2: Categorized as 'good' or 'bad' dispersers based species' size, morphology and migratory habits, and following the work of Hugueny 1990[22]	H = 'Bad' disperser; L = 'Good' disperser	49	430	38
B. Poor Evolvability	Life history strategy	A3: Species has a life history strategy (as defined by Winemiller and Rose (1992[23])) that is not conducive to in-situ, micro-evolutionary adaptation.	L = Opportunistic or Periodic strategist; H = Equilibrium strategist	211	51	255

[22] See footnote 14 of page 19.

[23] Winemiller, K.O. and Rose, K.A. (1992) Patterns of life-history diversification in North American fishes: Implications for population regulation. Canadian Journal of Fisheries and Aquatic Science 49: 2196-2218.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 517		
	Genetic variability	**A4:** Species is known to have low genetic variability between all populations (e.g. a known past genetic bottleneck)	L = False; H = True	1	2	514
Total				**2**	**432**	**83**
Percentage				**0.4**	**83.6**	**16**

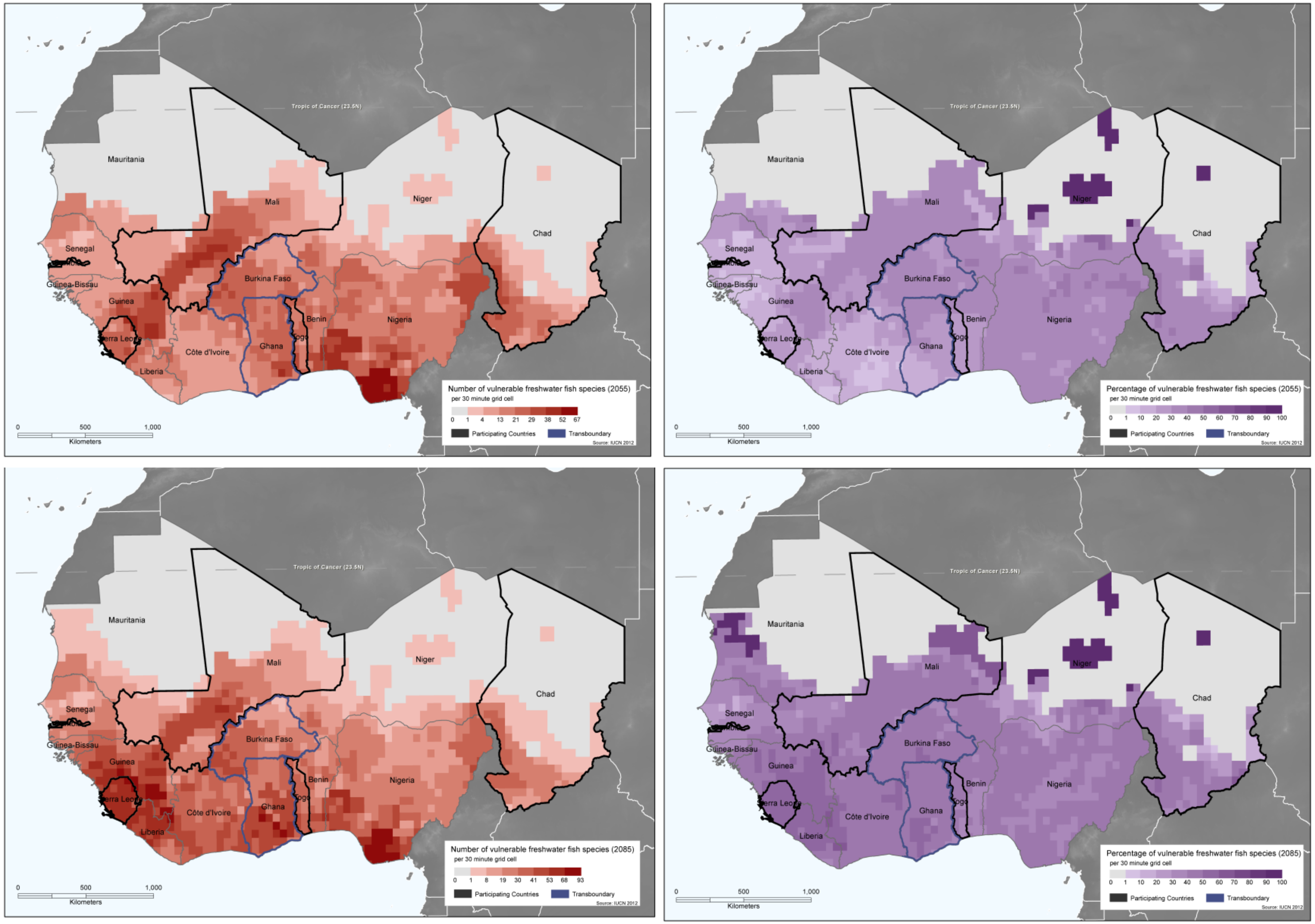

Figure 5.3 – Distribution of climate change vulnerable West African freshwater fish by 2055 (top) and 2085 (bottom). Maps on the left hand side show the total number of species per grid cell assessed as climate change vulnerable. Maps on the right hand side show the percentage of the total species in each grid cell assessed as climate change vulnerable. All maps use results based on model run Q0 (see methods, section 2.4).

6. Results: Climate Change Vulnerability Assessment of West African Mammals

As part of this project, we assessed the climate change vulnerability of 405 terrestrial and freshwater mammal species of West Africa (as defined by this project). Of the species considered, the highest densities (up to 175 species per one 30 minute grid cell) can be found in the area linking Liberia, Guinea and Côte d'Ivoire, in southern/central Ghana, and, to a lesser extent, in the area in between (Figure 6.1). Densities are also high (typically between 70 and 120 species per grid cell) in the regions surrounding those described above, including Guinea-Bissau and northern Guinea, Togo, Benin and much of Nigeria. A clear decrease in mammal species richness is evident as one moves northwards through the region. According to the most recent assessment for the IUCN Red List, 44 of these species (11%) are globally threatened, 22 species (5.5%) are considered Near Threatened, 31 species (8%) are Data Deficient, 306 species (75.5%) are Least Concern, and the remaining 2 species (<1%) have not been evaluated for the Red List. Figure 6.2 shows that the highest densities of threatened mammal species (up to 15 species grid cell) can be found in the southwest of the region, particularly in Liberia, Sierra Leone, Guinea and Côte d'Ivoire, though threatened mammal species can be found at most locations throughout the region.

As part of our climate change vulnerability assessment of the region's mammals, we considered a total of 21 vulnerability traits, of which four related to *'Exposure'*, twelve to *'Sensitivity'*, and five to *'Low Adaptability'*. These are shown in Tables 6.1, 6.2 and 6.3, respectively.

In our assessment of mammal species' sensitivity to climate change, 290 species (72%) were assessed as possessing traits that make them highly sensitive to climate change. One hundred and thirteen species (28%) were assessed as 'low' in terms of their sensitivity, and only zero as 'unknown'.

Within the *Sensitivity* analysis, no individual trait stands out as particularly common among a large number of species, though most traits are present in some species. Nevertheless, a narrow tolerance of temperature and precipitation ranges (Traits S5 and S6, respectively) emerged as the two most commonly possessed traits, both highlighting 101 (25%) species. Note, however, that the selection of species under these criteria is subject to the caveats described in the methods section of this report. Reliance upon a change in weather or climate to initiate some key life-history event (Trait S9), typically a seasonal change in rainfall to initiate breeding, is the second most common trait in the mammals assessed, present in 92 species (23%), the majority of which are bats (Order: Chiroptera). Data gaps on the sensitivity of mammal species were relatively few, when compared with other groups. Data for Trait S9, described above, was unavailable for 18 species (4%), and data on habitat associations was unavailable for five species (1%), while data for all other sensitivity traits was available for more than 99% of species.

In our assessment of mammal species' adaptive capacity, 155 species (38%) were assessed as possessing traits that make them poorly able to adapt to climate change. Thirty-three species (8%) were assessed as 'low' risk in terms of their adaptive capacity, though sufficient data were unavailable for 217 species (54%), meaning that they were assessed as 'unknown' in terms of their capacity to adapt to change.

Within the analysis of adaptive capacity, the existence of barriers that would prevent dispersal (Trait A1) was the most common trait – present in 86 species (21%). With the exception of low genetic diversity (Trait A3), data for other traits relating to a species capacity to adapt to change *in-situ* through genetic micro-evolution were missing in many cases, with information on species' reproductive outputs (Trait A4) unavailable for 239 species (59%), and information on species maximum longevity, a proxy for generation length (Trait A5), unavailable for 295 species (73%).

Overall a total of 22 (5%), 63 (16%) and 115 (28%) mammal species were considered climate change-vulnerable by the years 2025, 2055 and 2085, respectively, using climate projections based on model run Q0 (see methods, section 2.4), and an optimistic assumption of missing data values. When considering additional circulation models, as well as pessimistic assumptions of data values, the minimum and maximum numbers of vulnerable species identified are 15 - 63 species (4 - 16%) for the year 2025; 34 - 271 species (8 - 67%) for the year 2055, and 115 - 271 species (28 - 67%) by the year 2085.

Figure 6.3 shows the concentrations and proportions of climate change vulnerable mammal species throughout West Africa by both 2055 and 2085. When considering total numbers of vulnerable species, one finds the greatest concentrations in 2055 (up to 17 species per grid cell) in Liberia, as well as in the southern regions of Guinea, Côte d'Ivoire, Ghana and Nigeria. A band across the Sahel region of Mauritania, Mali, Niger and Chad also contains relatively high numbers of climate change vulnerable species - up to 11 species per grid cell. By 2085, the numbers of climate change vulnerable species increase in all areas, though Liberia, Guinea, Côte d'Ivoire and Ghana continue to contain the greatest numbers (up to 43 species per grid cell).

In terms of proportions of climate change vulnerable mammal species, our assessments suggest that by 2055 the greatest impacts will occur in the northern, desert regions of Mauritania, Mali, Niger and Chad, where up to 54% of species were assessed as climate change vulnerable. Proportions of climate change vulnerable species visibly decrease as one moves southwards through the region, to typical levels of 5 - 15% of species at any given location. By 2085, few changes in terms of the proportions of climate change vulnerable species are visible in the north of the region, although in central and southern regions proportions increase marginally throughout.

Of the 63 species identified as climate change vulnerable by 2055 using an optimistic scenario for unknown data points, eight[24] species are currently considered globally threatened. Using a pessimistic assumption of unknown data points, an additional two[25] species are already considered globally threatened and could potentially be vulnerable to climate change impacts. By 2085, using an optimistic assumption of unknown data points, a further 19 species are considered both globally threatened and climate change vulnerable, and under a pessimistic assumption of missing data points, this number increases by an additional 6 species, to a total of 35. Details of all species assessments, across all time periods, are available in the dataset which accompanies this document.

[24] *Cercopithecus erythrogaster* (VU; A2cd); *Cercopithecus sclateri* (VU; A2cd); *Eudorcas rufifrons* (VU; A2cd); *Gazella leptoceros* (EN; C2a(i)); *Gorilla gorilla* (CR; A4cde); *Monachus monachus* (CR; A2abc; C2a(i); E); *Nanger dama* (CR; A2cd; C2a(i)); *Procolobus pennantii* (CR; A2cd) (IUCN 2013 http://www.iucnredlist.org/).

[25] *Acinonyx jubatus* (VU; A2acd; C1); *Genetta cristata* (VU; A2cd) (IUCN 2013 http://www.iucnredlist.org/).

Conclusions

As a group, West African mammal species show a medium to high sensitivity to climate change and its impacts. The specific traits that render species sensitive to climate change vary widely within the group, likely due to the large variety among the species concerned, in terms of their biology, ecology and life-history. Data gaps and uncertainty surrounding this element of the assessment was low overall.

In terms of capacity to adapt to climate change and its impacts, West African mammals appear poorly able to adapt, with the presence of physical barriers that could prevent dispersal posing a particular problem. However, a significant knowledge gap exists surrounding the capacity of species to adapt *in-situ* through genetic micro-evolution, and this topic warrants further investigation.

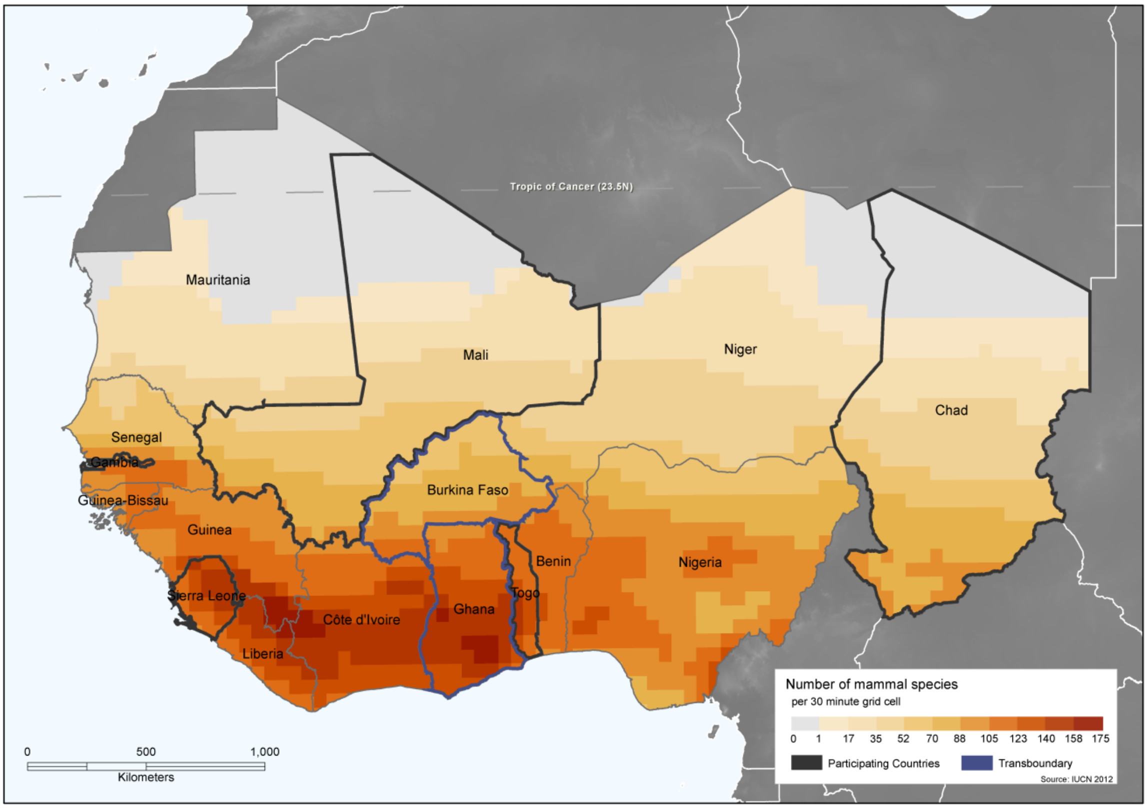

Figure 6.1 – Species richness of mammals in West Africa.

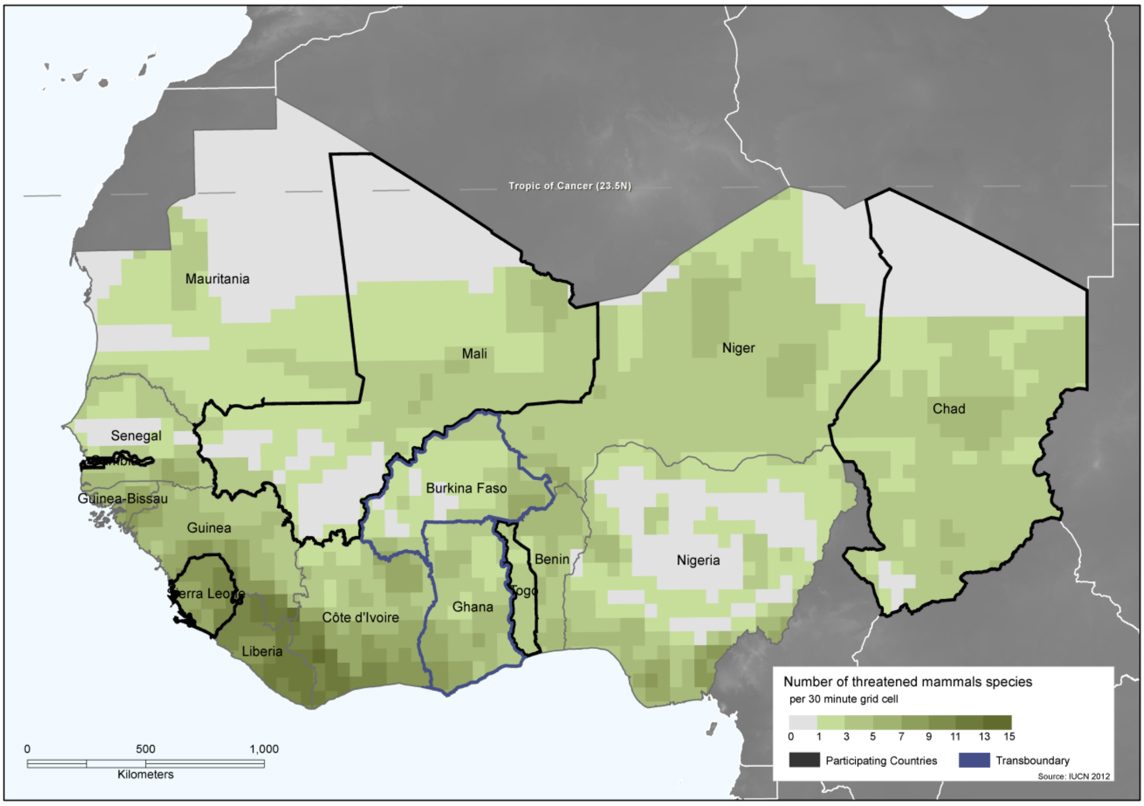

Figure 6.2 – Distribution of globally threatened mammals across West Africa (IUCN 2013). Colours show counts of threatened mammals per 30 minute grid cell.

Table 6.1 – Climate change *exposure* measures used to assess West African mammals, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. This table presents results based on model run Q0 (see methods, section 2.4). Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 405		
				Number of species per category		
EXPOSURE				Low	High	Unknown
Climatic means	Substantial changes in climatic means occur across the species' range	**E1:** Absolute ratio of 1975 and 2055 values of mean precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25	302	101	2
	Substantial changes in temperature variability occur across the species' range	**E2:** Absolute difference between 1975 and 2055 mean temperatures (for all months) across the species' current range	L = Lowest 75%; H = Highest 25	302	101	2
Climatic variability	Substantial changes in climatic variability occur across the species' range	**E3:** Absolute ratio of 1975 and 2055 values of average absolute deviation in precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25	302	101	2
	Substantial changes in precipitation variability occur across the species' range	**E4:** Absolute difference between 1975 and 2055 values of average absolute deviation in temperature (for all months) across the species' current range	L = Lowest 75%; H = Highest 25	302	101	2
Total				**171**	**232**	**2**
Percentage				**42**	**57**	**<1**

Table 6.2 – Climate change *sensitivity* traits used to assess West African mammals, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document. This table continues on the next page.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 405		
				Number of species per category		
SENSITIVITY				Low	High	Unknown
A. Specialised habitat and/or microhabitat requirements	Habitat specialisation	**S1:** Number of IUCN habitat types occupied by species	L = >1; H = 1	340	60	5
	Microhabitat specialisation	**S2:** Species is dependent on one or more of the identified microhabitats [26]	L = False; H = True	343	62	0
	Intolerant of disturbance	**S3:** Species is highly dependent on primary/old-growth forest, or is known to be highly intolerant of disturbance	L = False; H = True	358	47	0
	Restricted to montane habitat	**S4:** Species is found only above 1,000 metres above sea level	L = False; H = True	397	8	0
B. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle	Tolerance of changes to precipitation regimes	**S5:** Tolerance of wide precipitation range (maximum and minimum annual precipitation used to calculate range tolerated)	Average absolute deviation in precipitation across the species' historical range: L = highest 75%; H = Lowest 25%	302	101	2
	Tolerance of temperature changes	**S6:** Temperature range (max temp -min temp)	Average absolute deviation in temperature across the species' historical range: L = highest 75%; H = Lowest 25%	302	101	2

[26] Mountain rivulets; small streams; fallen trees; tree hollows; rocky areas and outcrops; cliffs; dunes; gallery/riverine forest; caves with specific (assessor-defined) characteristics.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 405		
	Tolerance of changes to fire regime	**S7:** Species relies upon a specific fire regime (or lack of) across its entire range	L = False; H = True	347	58	0
	Tolerance of flooding/ waterlogging	**S8:** Species relies upon a specific flooding regime (or lack of) across its entire range	L = False; H = True	400	5	0
C. Dependence on a specific environmental trigger that is likely to be disrupted by climate change	Species relies upon some form of cue or trigger that is likely to be disrupted by climate change?	**S9:** Species relies upon a change in weather/climate to initiate one or more of the following: Long distance movement (e.g. Migration); breeding; aestivation	L = False; H = True	295	92	18
D. Dependence on interspecific interactions which are likely to be disrupted by climate change.	Dependence on narrow range of food types	**S10:** Species diet consists of a low number of species from a single dietary category (of 28)	L = False; H = True	390	14	1
	Interspecific habitat modification	**S11:** Species is dependent upon another to modify or create habitat suitable for itself	L = False; H = True	396	9	0
	Increasing negative interactions	**S12:** Species could experience increases in one or more of the following as a result of climate change: Predation, competition, parasitism, disease, hunting by humans.	L = False; H = True	404	1	0
Total				**113**	**290**	**2**
Percentage				**28**	**72**	**<1**

Table 6.3 – Climate change *low adaptability* traits used to assess West African mammals, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 405		
				Number of species per category		
LOW ADAPTABILITY				Low	High	Unknown
A. Poor dispersability	Barriers to dispersal	**A1:** Barriers to dispersal (Existence of barriers that would prevent dispersal)	L = No known barrier; H = Dispersal by any of: mountaintop(s); ocean; unsuitable (micro)habitat(s) or other barriers	319	86	0
	Low intrinsic dispersal capacity	**A2:** Mean maximum intrinsic dispersal distance	L = >1 km/year; H = ≤ 1 km/year (or species is fossorial)	398	7	0
B. Poor Evolvability	Known low genetic diversity	**A3:** Known low genetic diversity	H = Species shows evidence of having low genetic variability (e.g. a genetic bottleneck) among all members of the species; L = Genetic variability is not thought to be low.	398	2	5
	Reproductive capacity/ genetic turnover	**A4:** Reproductive output (mean litter size x mean litters per year)	L = highest 75%; H = Lowest 25%	84	82	239
		A5: Generation length (Mean (or range) maximum known longevity (years))	L = highest 75%; H = Lowest 25%	81	29	295
Total				**33**	**155**	**217**
Percentage				**8**	**38**	**54**

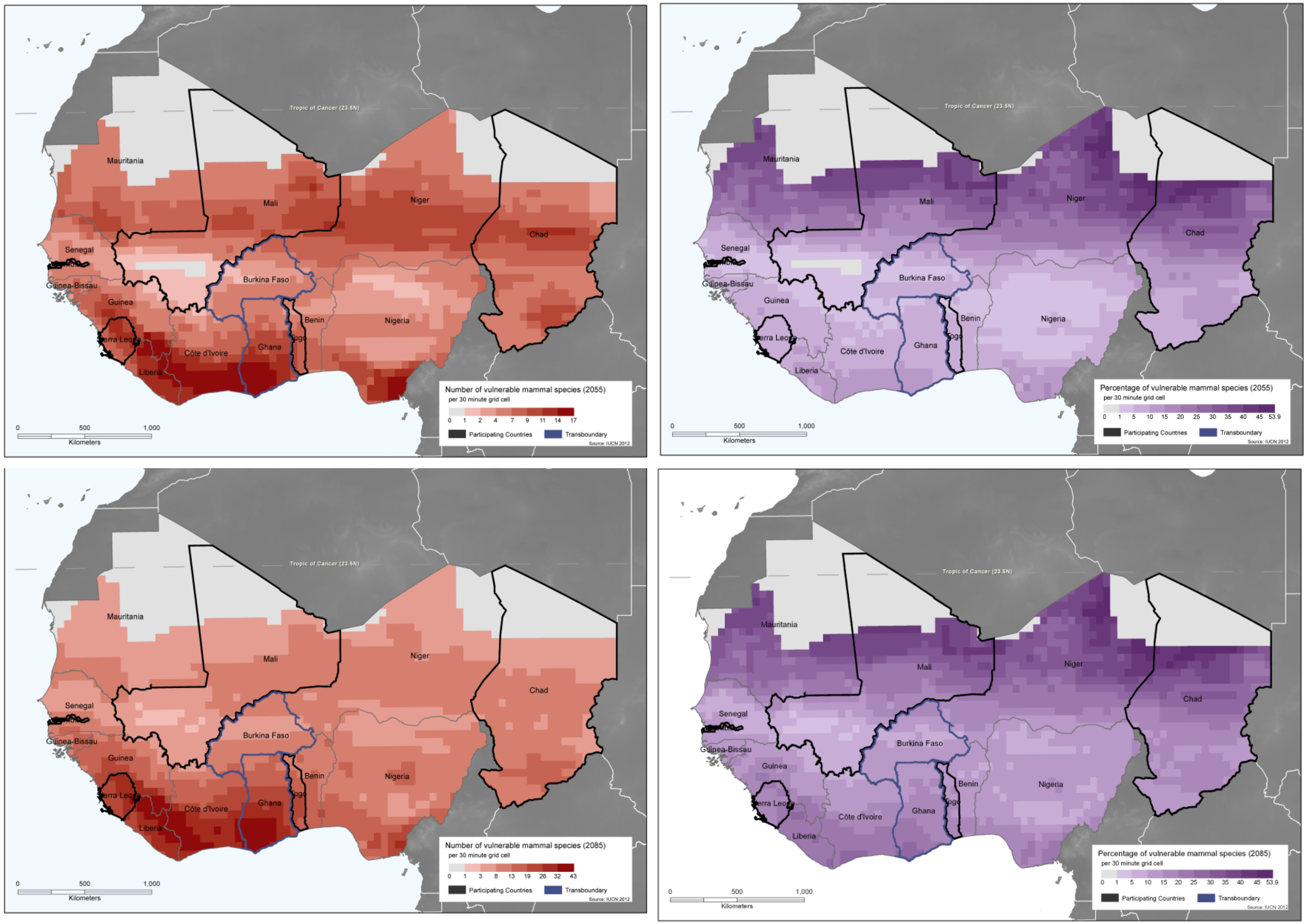

Figure 6.3 – Distribution of climate change vulnerable West African mammals by 2055 (top) and 2085 (bottom). Maps on the left hand side show the total number of species per grid cell assessed as climate change vulnerable. Maps on the right hand side show the percentage of the total species in each grid cell assessed as climate change vulnerable. All maps use results based on model run Q0 (see methods, section 2.4).

7. Results: Climate Change Vulnerability Assessment of West African Reptiles

As part of this project, we assessed the climate change vulnerability of 307 reptile species of West Africa (as defined by this project). It was necessary to omit a number of reptiles from this assessment due to taxonomic uncertainties. Of the reptile species assessed, the highest densities (up to 112 species) can be found in southern Togo and the neighbouring region of Ghana (Figure 7.1). Similarly high numbers (70 - 100 species) can be found along much of the coastal region, particularly in Liberia, Côte d'Ivoire, Benin and Nigeria, and richness decreases as one moves northward into the Sahel region and beyond.

Of the 307 species considered for this assessment, the global conservation status of 115[27] species has been assessed for the IUCN Red List, and a total of 10 species (9% of those assessed) are considered globally threatened. Two species (2% of those assessed) are considered Near Threatened, 35 species (30% of those assessed) are considered Data Deficient, and 68 species (59% of those assessed) are considered Least Concern. Due to incomplete coverage of Red List assessments of the region's reptiles, a map showing densities of threatened reptile species has not been included in this report, as it was deemed to be misleading.

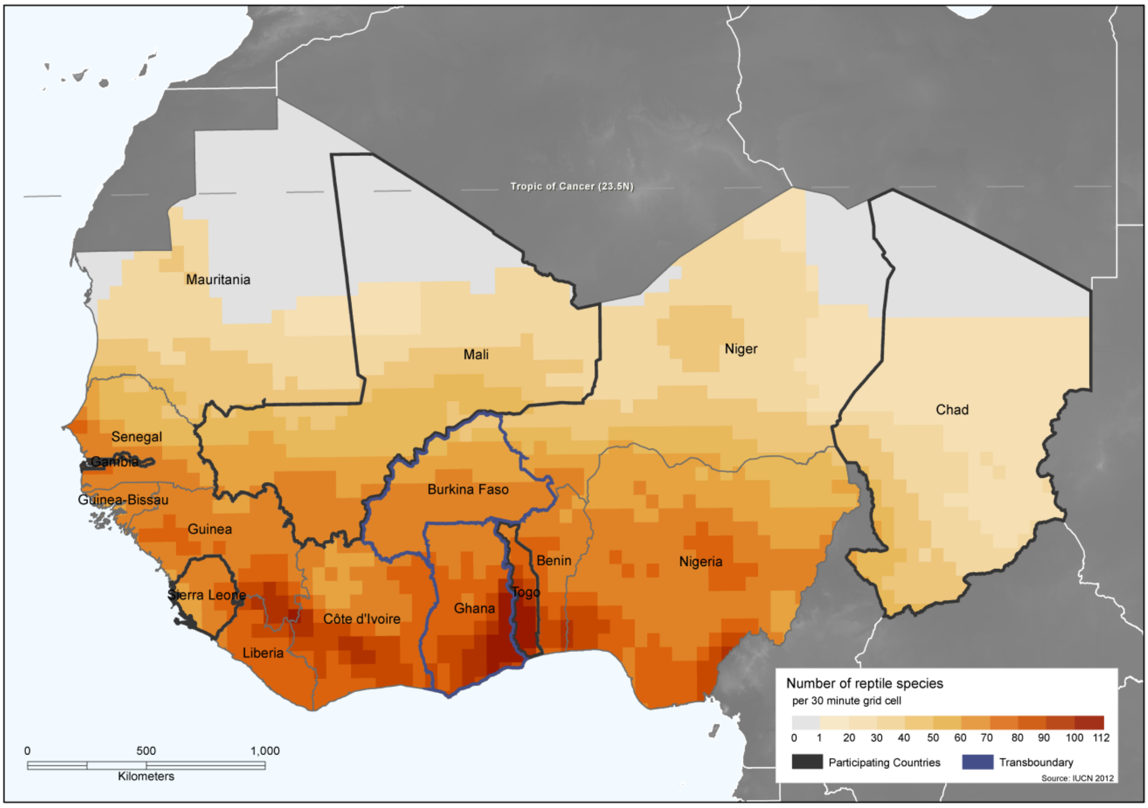

Figure 7.1 – Species richness of reptiles in West Africa.

As part of our climate change vulnerability assessment of the region's reptiles, we considered a total of 22 vulnerability traits, of which four related to *'Exposure'*, twelve to *'Sensitivity'*, and six to *'Low Adaptability'*. These are shown in Tables 7.1, 7.2 and 7.3, respectively.

[27] The Red List assessments of two species of crocodile (*Osteolaemus tetraspis* (Vulnerable) and *Mecistops cataphractus* (Data Deficient)) were not completed as part of this work, and are both known to require updating.

In our assessment of reptile species' sensitivity to climate change, 238 species (77.5%) were assessed as possessing traits that make them highly sensitive to climate change. Only one (<1%) species (*Pseudohaje nigra*) was assessed as 'low' in terms of its sensitivity, and 68 species (22%) were assessed as 'unknown'.

Within the Sensitivity analysis, the most commonly possessed traits were specific feeding habits (Trait S10), present in 98 species (32%) and dependence upon specific microhabitats (Trait S2), present in 95 species (31%). Under Trait S10, specific prey groups included centipedes, birds' eggs and burrowing reptiles, among numerous others. Under Trait S2, microhabitat dependencies were highly varied, with no single microhabitat type emerging as particularly important for large numbers of species. Data gaps on the sensitivity of reptile species were most common when considering temperature-dependent gender determination (Trait S8), which was unknown for 265 species (86%), and species' tolerances to change in precipitation (Trait S4) and temperature (Trait S5), which were both unknown for 197 species (64%). The lack of knowledge for traits S4 and S5 are due to incomplete knowledge of many species' complete spatial distribution. Although spatial data for the region's reptiles were gathered during the assessment workshop, these were only within the boundaries of this project's focal region, meaning that they are suitable for conducting exposure modelling at regional level, but may only be used infer the environmental tolerances of regionally endemic species.

In our assessment of reptile species' adaptive capacity, 132 species (43%) were assessed as possessing traits that make them poorly able to adapt to climate change. Nine species (3%) were assessed as 'low' risk in terms of their adaptive capacity, though sufficient data were unavailable for 166 species (54%), meaning that they were assessed as 'unknown' in terms of their capacity to adapt to change.

Within the analysis of adaptive capacity, a low intrinsic capacity to disperse (Trait A2) was the most common trait – present in 104 species (34%). Data for traits relating to a species capacity to adapt to change *in-situ* through genetic micro-evolution were missing in many cases. In particular, information on species' reproductive outputs (Trait A4) were unavailable for 253 species (82%), and information on species maximum longevity, a proxy for generation length (Trait A5), unavailable for 266 species (87%).

Overall a total of 22 (7%), 66 (21%) and 104 (34%) reptile species were considered climate change-vulnerable by the years 2025, 2055 and 2085, respectively, using climate projections based on model run Q0 (see methods, section 2.4), and an optimistic assumption of missing data values. When considering additional circulation models, as well as pessimistic assumptions of data values, the minimum and maximum numbers of vulnerable species identified are 9 - 86 species (3 - 28%) for the year 2025; 35 - 291 species (11 - 95%) for the year 2055, and 103 - 292 species (34 - 95%) by the year 2085.

Figure 7.2 shows the concentrations and proportions of climate change vulnerable reptile species throughout West Africa by both 2055 and 2085. When considering total numbers of vulnerable species, one finds the greatest concentrations in 2055 (up to 23 species per grid cell) in southern Nigeria, as well as in the southern regions of Guinea, Côte d'Ivoire and Ghana. Discrete areas across the Sahel and desert regions of Mauritania, Mali and Niger also contain relatively high numbers of climate change vulnerable species - between 10 and 13 species per grid cell. By 2085, the numbers of climate change vulnerable species increases at all locations. At some locations near to the coast up to 38 climate change vulnerable species per grid cell can be found, and numbers show a decreasing tendency as one moves northwards.

In terms of proportions of climate change vulnerable reptile species, our assessments suggest that by 2055 the greatest impacts will occur in the Sahel and desert regions of Mauritania, Mali, Niger and Chad, where more than 40% of species are assessed as climate change vulnerable at some locations. By 2085, proportions of climate change vulnerable species appear evenly spread across the region, with typical values of between 20 and 42% at most locations.

Of the 66 species identified as climate change vulnerable by 2055 using an optimistic scenario for unknown data points, three[28] species are currently considered globally threatened (although 41 have not been evaluated for the IUCN Red List). Using a pessimistic assumption of unknown data points, an additional three[29] species are already considered globally threatened and could potentially be vulnerable to climate change impacts. By 2085, using an optimistic assumption of unknown data points, the species *Tarentola chazaliae* is also considered both globally threatened (VU; A3cd; B1ab(iii,v)) and climate change vulnerable, and under a pessimistic assumption of missing data points, all ten[30] reptile species that are considered globally threatened are also considered climate change vulnerable. Details of all species assessments, across all time periods, are available in the dataset which accompanies this document.

Conclusions

As a group, West African reptile species show a high sensitivity to climate change and its impacts, particularly due to their specific habitat and microhabitat dependencies, as well as due to their specific feeding habits. Data gaps are significant for this group in terms of sensitivity, and particularly so for temperature dependent gender determination and species' environmental tolerances.

In terms of the capacities of West African reptiles to adapt to climate change and its impacts, the group appears poorly able to adapt to climate change, with species' low intrinsic capacities to disperse posing a particular problem. However, a significant knowledge gap exists surrounding the capacity of species to adapt *in-situ* through genetic micro-evolution, and this topic warrants further investigation.

Efforts to complete the knowledge-gaps described above, as well to complete global assessments of the distribution and risk of extinction of species for which this has not yet been completed, is highly recommended.

[28] *Cynisca leonina* (VU; B1ab(iii)); *Cynisca oligopholis* (EN; B1ab(iii)); *Hemidactylus kundaensis* (CR; B2ab(iii)) (IUCN 2013 http://www.iucnredlist.org/).
[29] *Cynisca gansi* (CR; B1ab(ii,iii)+2ab(ii,iii)); *Osteolaemus tetraspis* (VU; A2cd); *Philochortus zolii* (EN; B2ab(ii,iii)) (IUCN 2013 http://www.iucnredlist.org/).
[30] Additional species are: *Cnemaspis occidentalis* (EN; B2ab(iii)); *Cynisca kigomensis* (CR; B1ab(ii,iii)+2ab(ii,iii)); *Cynisca nigeriensis* (VU; D2) (IUCN 2013 http://www.iucnredlist.org/).

Table 7.1 – Climate change *exposure* measures used to assess West African reptiles, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. This table presents results based on model run Q0 (see methods, section 2.4). Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 307		
				Number of species per category		
EXPOSURE				**Low**	**High**	**Unknown**
Climatic means	Substantial changes in climatic means occur across the species' range	**E1:** Absolute ratio of 1975 and 2055 values of mean precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%;	224	75	8
	Substantial changes in temperature variability occur across the species' range	**E2:** Absolute difference between 1975 and 2055 mean temperatures (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%;	224	75	8
Climatic variability	Substantial changes in climatic variability occur across the species' range	**E3:** Absolute ratio of 1975 and 2055 values of average absolute deviation in precipitation (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%;	224	75	8
	Substantial changes in precipitation variability occur across the species' range	**E4:** Absolute difference between 1975 and 2055 values of average absolute deviation in temperature (for all months) across the species' current range	L = Lowest 75%; H = Highest 25%;	224	75	8
Total				**119**	**180**	**8**
Percentage				**39**	**58.5**	**2.5**

Table 7.2 – Climate change *sensitivity* traits used to assess West African reptiles, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document. This table continues on the next page.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 307		
				Number of species per category		
SENSITIVITY				Low	High	Unknown
A. Specialised habitat and/or microhabitat requirements	Habitat specialisation	**S1:** Number of IUCN habitat types occupied by species	L = >1; H = 1	232	63	12
	Microhabitat specialisation	**S2:** Species is dependent on one or more of the identified microhabitats[31]	L = False; H = True	203	95	9
	Restricted to montane habitat	**S3:** Species is found only at 1,000 metres above sea level or above	L = False; H = True	238	7	62
B. Narrow environmental tolerances or thresholds that are likely to be exceeded due to climate change at any stage in the life cycle	Tolerance of changes to precipitation regimes	**S4:** Tolerance of wide precipitation range (maximum and minimum annual precipitation used to calculate range tolerated)	Average absolute deviation in precipitation across the species' historical range: L = highest 75%; H = Lowest 25%	82	28	197
	Tolerance of temperature changes	**S5:** Temperature range (max temp -min temp)	Average absolute deviation in temperature across the species' historical range: L = highest 75%; H = Lowest 25%	83	27	197

[31] Rapids/rivulets; ephemeral pools; bamboo; vines; fallen trees; dead wood; tree hollows; trees bordering water; ant hills; dunes; open patches in grassland.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 307		
	Tolerance of changes to fire regime	**S6:** Species relies upon a specific fire regime (or lack of) across its entire range	L = False; H = True	269	17	21
	Tolerance of flooding/ waterlogging	**S7:** Species relies upon a specific flooding regime (or lack of) across its entire range	L = False; H = True	259	19	29
	Temperature-dependent gender	**S8:** Gender of offspring is known to be dependent upon temperature during incubation	L = False; H = True	31	11	265
C. Dependence on a specific environmental trigger that is likely to be disrupted by climate change	Species relies upon some form of cue or trigger that is likely to be disrupted by climate change?	**S9:** Species relies upon a change in weather/climate to initiate one or more of the following: Long distance movement (e.g. Migration); breeding; egg deposition; arrival of prey (e.g. following tree fruiting); aestivation (or emergence from)	L = False; H = True	161	46	100
D. Dependence on interspecific interactions which are likely to be disrupted by climate change.	Dependence on narrow range of food types	**S10:** Species diet consists of a low number of species from a single dietary category (of 19)	L = False; H = True	181	98	28
	Interspecific habitat creation/ modification	**S11:** Species is dependent upon another to modify or create habitat suitable for itself	L = False; H = True	306	1	0
	Increasing negative interactions	**S12:** Species could experience increases in one or more of the following as a result of climate change: Predation, competition, parasitism, disease.	L = False; H = True	195	2	110
Total				**1**	**238**	**68**
Percentage				**<1**	**77.5**	**22**

Table 7.3 – Climate change *low adaptability* traits used to assess West African reptiles, including thresholds used to categorize species, and the total numbers of species falling into each category for each trait. Note that the codes (in red text) given next to each sub-trait may be used to interpret the dataset that accompanies this document.

Trait Group	Trait	Sub-trait	Thresholds	Total species = 307		
				Number of species per category		
LOW ADAPTABILITY				**Low**	**High**	**Unknown**
A. Poor dispersability	Barriers to dispersal	**A1:** Barriers to dispersal (Existence of barriers that would prevent dispersal)	L = No known barrier; H = Dispersal by any of: mountaintop(s); ocean; unsuitable (micro)habitat(s) or other barriers	276	17	14
	Low intrinsic dispersal capacity	**A2:** Mean maximum intrinsic dispersal distance	L = >1 km/year; H = ≤ 1 km/year (or species is fossorial)	166	104	37
B. Poor Evolvability	Known low genetic diversity	**A3:** Known low genetic diversity	H = Species shows evidence of having low genetic variability (e.g. a genetic bottleneck) among all members of the species; L = Genetic variability is not thought to be low.	192	4	111
	Reproductive capacity/ genetic turnover	**A4:** Reproductive output (mean litter size x mean litters per year)	L = highest 75%; H = Lowest 25%	40	14	253
		A6: Generation length (Mean (or range) maximum known longevity (years))	L = highest 75%; H = Lowest 25%	33	8	266
Total				**9**	**132**	**166**
Percentage				**3**	**43**	**54**

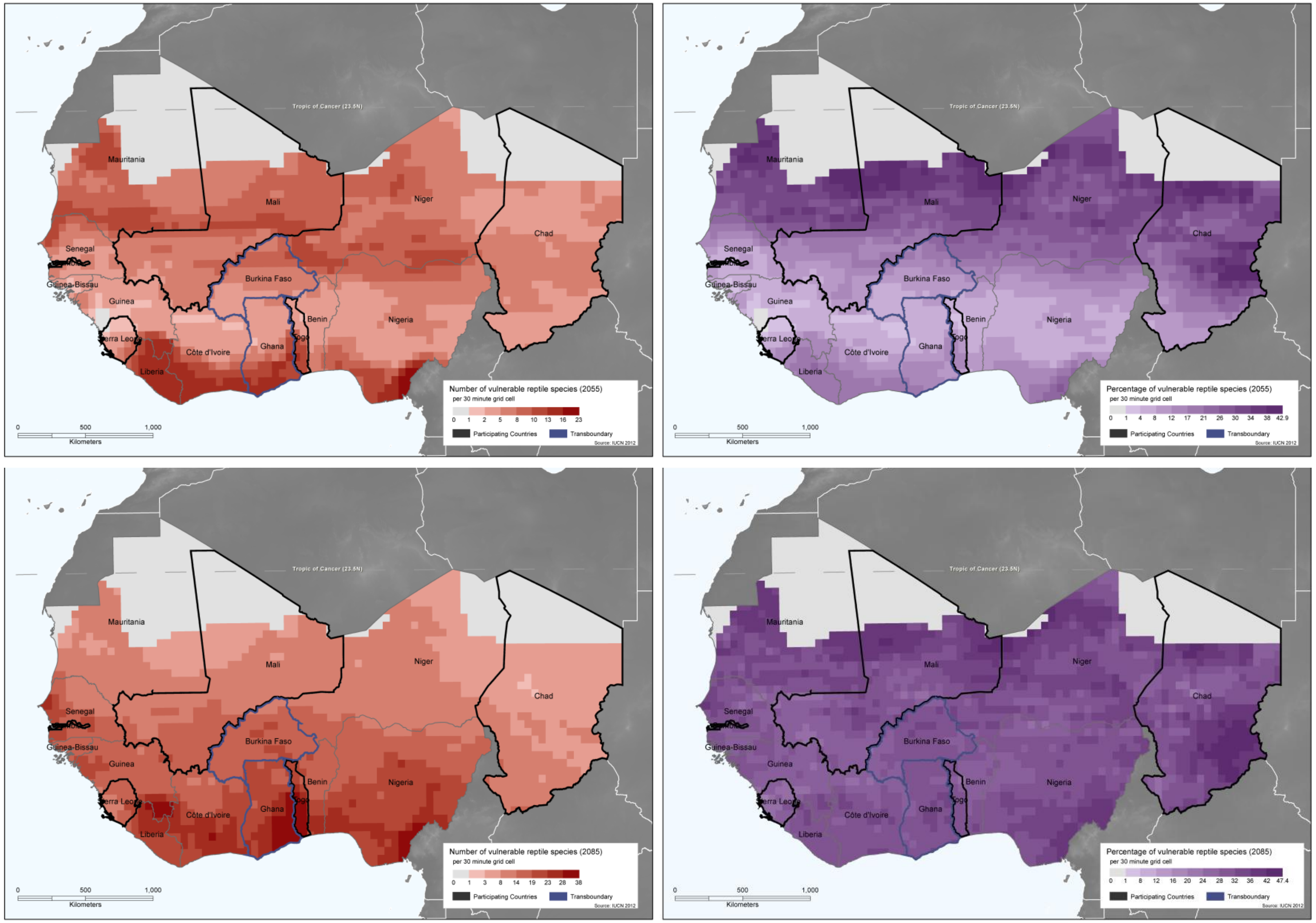

Figure 7.2 – Distribution of climate change vulnerable West African reptiles by 2055 (top) and 2085 (bottom). Maps on the left hand side show the total number of species per grid cell assessed as climate change vulnerable. Maps on the right hand side show the percentage of the total species in each grid cell assessed as climate change vulnerable. All maps use results based on model run Q0 (see methods, section 2.4).

8. Conclusions and recommendations

8.1. Geographic findings

In considering West African species across five taxonomic groups, we have identified a number of broad geographic locations that contain high numbers (relative to the size of the group) of total species, high numbers of threatened species, as well as high numbers of species that are believed to be at high risk of experiencing negative impacts of climate change by the years 2055 and/or 2085.

In terms of species richness, several hotspots emerge across all groups, including in areas of southern and southeastern Nigeria; Guinea, Liberia and Cote d'Ivoire (and particularly at the interface of the three); as well as Ghana and Togo (especially for reptiles). For birds and freshwater fish only, additional locations of high richness include southern Mali and Sierra Leone, as well as Senegal, The Gambia and Northern Benin (birds only).

The geographic locations of threatened species varies between the taxonomic groups investigated, and particularly in the case of mammals and birds. The region encompassing Sierra Leone, Liberia, southeastern Guinea and Cote d'Ivoire emerges as supporting threatened species from most groups. Ghana and Nigeria appear to support relatively high numbers of threatened fish, birds and amphibians, and the Sahelian zones of Senegal, Mali, southern Niger and Chad support relatively high numbers of threatened birds.

Regarding geographic locations containing high numbers of climate change vulnerable species, the more southern countries (and particularly coastal regions) emerge among most groups investigated. In particular, regions of Liberia, southern Guinea, Cote d'Ivoire, Ghana and southern Nigeria, are highlighted among most groups. A region in the sub-humid and a semi-arid zone, spanning from Senegal and Guinea-Bissau in the west to Benin and Central Nigeria in the east, also emerges as a hotspot of climate change vulnerability for amphibians in particular. Other more northern areas that appear to contain high numbers of climate change vulnerable species include southern Mali (freshwater fish only), a band across the Sahelian region of Mali, Niger and Chad (mammals only) and a large band spanning from Mauritania, through northern Mali and northern Niger, into northern Chad (birds only, by 2085).

In many cases (though not all), high concentrations of climate change vulnerable species reflects a high species richness in these areas. To account for this, and to highlight areas where climate change vulnerable species occur in areas of lower richness, we have presented for each group maps showing proportions of vulnerable species relative to the total number of species present. For reptiles, mammals and fish, these maps typically highlight the more northern desert regions (though for fish these are localised patches in Mali and Chad by 2055, and including Mauritania and Mali by 2085). By 2085, proportions of climate change vulnerable mammals appear homogeneous across the region. Areas containing high proportions of climate change vulnerable amphibians include Senegal, southern Mauritania, Southern Mali, Burkina Faso and northern Mali by 2055, as well as Cote d'Ivoire, Ghana, Togo, Benin and Nigeria by 2085. For birds, the coastal and forest regions of Sierra Leone, Liberia, Cote d'Ivoire and Nigeria contain the highest proportions of climate change vulnerable species by 2055, with the addition of Mauritania, northern Mali, northern Niger and northern Chad by 2085.

8.2 Trait-based findings

Although it is not strictly correct to compare the findings of this study between taxonomic groups, there are a number of key findings which are common between certain groups, and which warrant further mentions here.

For example, a requirement for specific habitats and microhabitats is a sensitivity trait that was common among many amphibians, freshwater fish and reptiles, highlighting the need to maintain a range of healthy habitats, including the microhabitats they support, in order to successfully conserve many of the species within these groups. In most cases, however, it will be necessary to conduct at least some additional species-specific research in order to truly define the specifics of these habitat dependencies, and how they might be impacted by changes in the climate.

Similarly, a low intrinsic capacity for dispersal (i.e. due to some inherent biological factor) is a low adaptability trait which emerged as important among many amphibians, birds, freshwater fish and reptiles. This highlights the importance of maintaining or increasing connectivity between habitat fragments, which will increase the capacity for these species to disperse naturally wherever possible. It is also important to monitor the distributions of these species, and to ascertain whether species' ranges are declining as a result of climatic changes. Where net declines (as opposed to shifts) in species ranges are evident, then conservation action may be required.

Ultimately, however, despite these commonalities between species and species groups, we encourage conservationists to consider each species, including their vulnerability traits, on a case-by-case basis, as is described further in the following section.

Among species groups, freshwater fish and reptiles both appear to have a high prevalence of sensitive species, as well as species that are believed to be poorly able to adapt to change, among those with sufficient data to complete a full assessment. For these groups, and for both sensitivity and low adaptability, very few species were assessed as 'low risk', suggesting that risk may be high in other species for which sufficient data were unavailable. As such, populations of species from these groups should be carefully monitored with respect to climate change, to ensure that any negative impacts arising are identified and subsequently ameliorated.

A number of uncertainties and data gaps were present throughout our assessment, highlight future research needs. The details and implications of these are discussed in the following section.

8.3 Recommendations

Given the broad taxonomic and geographic scope of this work, and the associated high variability of climate change impacts anticipated, it is difficult, if not irresponsible, to provide recommendations that can be applied at all locations or to all species. Rather, we hope that the information presented here, as well as in the associated document containing information on individual species assessments, can be used to guide informed actions and decisions, which take into account other context-specific factors not covered here. Nevertheless, the findings presented in this work may be used to prioritise the locations at which conservation actions occur, as well as the species (or groups of species) upon which they are focused.

When determining geographic priorities, it may be desirable to focus on locations that contain comparatively high numbers of climate change vulnerable and/or threatened species, particularly where resources are limited, as this will arguably have the greatest positive impact per unit effort, and should assist in the conservation of the greatest number of species. Nevertheless, it should be borne in mind that species occurring in areas with relatively low richness may also be equally vulnerable to climate change impacts, and should be acted upon by conservation groups operating in the area. In such cases, it may be useful to prioritize regions where high proportions of species are believed to be climate change vulnerable. This is neatly illustrated by the freshwater fish of central and northern Niger and Chad, where less than 11 species are found, yet 100% of which were assessed as climate change vulnerable, clearly warranting attention.

When planning for future conservation, it is imperative that planners account for the fact that many species are likely to shift their distributions as a response to climate change, necessitating forward thinking conservation that acknowledges the arrival of new species at new locations. With this in mind, when identifying priority regions for action and developing associated strategies, it will be essential for transboundary dialogue and collaboration to occur. By maximising the overall size of an area receiving conservation attention, one may also increase the likelihood of species adapting naturally to environmental changes. A good example (among numerous others) of a region where transboundary conservation efforts could be particularly beneficial is along the borders of Guinea, Sierra Leone, Liberia and Cote d'Ivoire, an area that was highlighted in most assessments as containing high numbers of climate change vulnerable species.

When prioritising among species, it will, in general, be desirable to focus greater efforts on those species which are both known to be threatened with extinction and have been assessed as vulnerable to climate change, while of course continuing to develop and apply conservation actions and strategies for species assessed as threatened on the IUCN Red List but not necessarily climate change vulnerable. Species that that were assessed as climate change vulnerable, but are not considered threatened on the IUCN Red List, should receive additional attention to ascertain to what extent these newly indentified threats may influence a species' likelihood of extinction. Similarly, species considered to be climate change vulnerable, and which are listed as Data Deficient on the IUCN Red List, should also receive additional attention, both to ameliorate climate change impacts and to determine whether other factors are already affecting species' populations.

It is also important to highlight once more that some elements of our assessments are based on ranked data, and, as such, relate to no biologically meaningful thresholds. This means that assessments cannot provide a definitive indication of vulnerability, but rather a relative measure that may be compared between species within a group. This is particularly the case for measures of exposure, meaning that for species assessed as both sensitive and poorly able to adapt to climate change, it may still be desirable to monitor their populations and take action as required, irrespective of our exposure measures.

Having identified conservation priorities, subsequent actions can be informed, at least in part, by the findings of this study. In many cases, nature conservation in the face of climate change can be achieved by simply modifying existing approaches or utilising existing tools in novel ways, and we cannot overstate the importance of reducing other non-climatic threats as an important tool to maximise as species' resilience to climate change. The acknowledgement and integration of climate change impacts in conservation strategies is known as 'climate smart conservation[32]', an approach which we fully advocate.

When determining climate change-related conservation measures, the traits used in this work, as well as their inferred mechanisms of impact, can provide valuable guidance on effective actions. As mentioned at the start of this section, it is not possible to provide a specific guidance on measures that would be most effective, due to the differences of context that will exist in almost all cases. However, in order to illustrate how vulnerability traits may inform conservation actions we provide some simple examples:

[32] For more information on climate-smart conservation see Hansen *et al.* (2010) Cons. Biol. 24: 63-69, as well as information made available by the US National Wildlife Federation at: http://www.nwf.org/What-We-Do/Energy-and-Climate/Climate-Smart-Conservation.aspx.

1) For species assessed as poorly able to disperse as a response to climate change, it may be desirable to facilitate their dispersal, whether through ensuring connectivity (i.e. removing barriers) or by manually relocating populations to areas with a more suitable climate.

2) For species assessed as possessing a narrow tolerance range to some environmental variable (e.g. fire, flooding, temperature etc.) it may be desirable to manually manipulate the environment (e.g. fire regime management, hydrology) to ensure that suitable conditions persist within the species range.

3) For species with known interspecific dependencies (e.g. specific prey species) it may be desirable to monitor the species upon which the focal species depends, and where necessary to manage this species to ensure that climate change does not negatively impact their populations.

Once again, we stress that the examples given above are not ubiquitously remedial, and certainly not an exhaustive list of options, but simply show ways in which species traits may be used to inform conservation actions. We hope that, armed with a knowledge of the mechanisms through which climate change may impact upon species, conservationists will be more equipped to become climate-smart, whether through the modification of existing strategies, or through the development of innovative approaches.

Finally, this report highlights a number of knowledge gaps, including in species' spatial distributions, current risk of extinction and/or climate change vulnerability traits. Efforts to fill these gaps and to remove the uncertainty surrounding species' current status should be seen as a priority. Though knowledge gaps are present throughout most of the traits used in our assessment, and should generally be considered on a species-by-species basis, those that stand out across multiple taxa include knowledge of species' traits that may affect the ability to adapt to climate change *in-situ* (e.g. reproductive output), and indeed the extent to which such factors may influence a species' capacity to adapt. Also, knowledge of the potential for negative species interactions (e.g. predation, competition etc.) to increase as a result of climate change is particularly sparse throughout our assessments, and this complex topic warrants further research.