CONSERVATION BIOLOGY OF ENDANGERED FRESHWATER FISHES – LINKING CONSERVATION OF ENDANGERED FRESHWATER FISHES WITH RIVER CONSERVATION, FOCUSSING ON THE CEDERBERG

Report to the Water Research Commission

Edited by

IR Bills[1] and ND Impson[2]

[1]South African Institute of Aquatic Biodiversity
[2]CapeNature

WRC Report No. KV 305/12
ISBN 978-1-4312-0348-2

JANUARY 2013

OBTAINABLE FROM

Water Research Commission
Private Bag X03
Gezina, Pretoria, 0031
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The publication of this report emanates from a WRC project entitled *Conservation biology of endangered freshwater fishes – Linking conservation of endangered freshwater fishes with river conservation, focusing on the Cederberg.* (WRC Project No.K8/592)

ACKNOWLEDGEMENTS

We thank the Water Research Commission for providing the funding for this work. Cape Nature and the South African Institute for Aquatic Biodiversity provided varied logistical support for most of the sub-projects. In particular Mrs. Sally Terry (SAIAB) helped with all aspects of coordination and curation of samples at SAIAB. Dr Olaf Weyl co-supervised Vusi Mthombeni's MSc work and together with R. Bills provided additional funding for the catfish biology study.

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1. INTRODUCTION

ROGER BILLS[1] & DEAN IMPSON[2]

[1]SOUTH AFRICAN INSTITUTE FOR AQUATIC BIODIVERSITY (SAIAB), PRIVATE BAG 1015, GRAHAMSTOWN 6140. (E-MAIL: r.bills@saiab.ac.za)
[2]SCIENTIFIC SERVICES, CAPENATURE, PRIVATE BAG X5014, STELLENBOSCH 7600. (E-MAIL: dimpson@capenature.co.za)

Motivation for the project

There are approximately 120 species of fishes occurring in South Africa freshwaters of which about 28 are recognised as threatened in the IUCN's Red Data list (www.iucn.org, 2011). In general threats to aquatic systems and all aquatic species have been increasing and this is reflected in a trend of increasing numbers of species included in the IUCN listings and the levels of these estimated threats (Skelton 1987 & 2001). Despite this, very few of South Africa's threatened freshwater fishes have dedicated conservation programmes aimed at realistically reducing threats and down-listing their conservation status. This project focused on the Olifants-Doring River System (ODRS) which straddles the western part of the Western and Northern Cape provinces. This river system is the nation's most significant freshwater fish conservation "hotspot" (Skelton *et al*. 1995), with 8 of its 10 currently recognized species endemic and listed as threatened (Table 1.1). Rivers in the fynbos region are also renowned for very high levels of aquatic macro-invertebrate diversity and endemicity (de Moor and Barber-James, Chapter 9) and for plant species diversity, encompassing two biomes that are international conservation hotspots, namely the Fynbos and Succulent Karoo (Low & Rebelo 1996).

Table 1.1: Indigenous freshwater fish species of the Olifants-Doring River system (*denotes endemic species) (www.iucn.org, 2011).

Scientific name	Common name	Conservation status
*Austroglanis barnardi**	Spotted rock catfish	Endangered
*Austroglanis gilli**	Clanwilliam rock catfish	Vulnerable
Barbus anoplus	Chubbyhead barb	Not threatened
*Barbus calidus**	Clanwilliam redfin	Vulnerable
*Barbus erubescens**	Twee River redfin	Critically Endangered
*Barbus serra**	Clanwilliam sawfin	Endangered
Galaxias zebratus	Cape Galaxias	Data deficient
*Labeo seeberi**	Clanwilliam sandfish	Endangered
*Labeobarbus capensis**	Clanwilliam yellowfish	Vulnerable
*Pseudobarbus phlegethon**	Fiery redfin	Endangered

During the last decade members of this project's team have been involved in several research projects on aquatic animals in the ODRS and we have observed increasing impacts on aquatic habitats and species. Impacts include:

- expanding ranges of alien fishes, e.g. *Micropterus dolomieu* (Lacepéde 1802);
- new fish species invasions such as carp (*Cyprinus carpio* Linnaeus, 1758);
- over abstraction of water during summer drought periods;
- physical damage to habitats such as channelization and bulldozing of stream beds;
- damage to riparian zones through farming encroachment; and
- varied pollution of waters from municipal and agricultural activities;

These impacts have already resulted in extinctions of some tributary populations of endemic fishes, and as impacts are increasing, the likelihood of further population extinctions and perhaps entire species extinctions seems high. Specific actions are needed in order to halt and reverse these processes (Bills 1999; Woodford *et al*. 2005).

This WRC project aimed to provide a practical conservation action plan to reduce threats for three threatened endemic fish species in the ODRS based on a multidisciplinary scientific approach. These fishes are the Critically Endangered Twee River redfin (*Barbus erubescens* Skelton 1974), the Endangered Barnard's rock catfish (*Austroglanis barnardi* (Skelton 1981)) and the Vulnerable Clanwilliam rock catfish (*Austroglanis gilli* (Barnard 1943)). These species were chosen based on their current conservation status and our level of knowledge about them.

The aims of the project were multi-faceted: to improve the conservation of the three fish species over the short to medium term period by producing detailed chapters on the conservation biology of each species; to improve the overall conservation status of aquatic environments in the Olifants-Doring system; to involve conservators and scientists in formulating and implementing conservation actions plans; and to develop a conservation action plan. This was achieved by undertaking the following:

- Synthesising current knowledge.
- Filling in key knowledge gaps with specific research projects.
- Producing a series of specialist scientific reports (chapters in this report).
- Conducting a workshop with specialists and local CapeNature conservators to discuss specialist reports and overall conservation issues.
- Using the above reports and workshop discussions to develop species chapters and the overall conservation action plan.

Contents of the report

This report comprises the following.

1. Chapter 1 an introduction by Roger Bills and Dean Impson on the aims and scope of the project.

2. Chapters 2 to 4 by Roger Bills on the current state of knowledge of the Twee River redfin, Clanwilliam, the Clanwilliam and Barnard's rock catfishes. The most comprehensive information to date on the morphology, distribution, conservation status, biology and ecology of each species and the types of threats affecting each species.
3. Chapter 5 by Gordon O'Brien and Andrew Husted on the culture requirements of each species. The Twee River redfin is one of South Africa's most threatened fish species, and culture of the species is one of the tools that could be considered as a means of saving the species from extinction.
4. Chapter 6 by Vusi Mthombeni describes aspects of the biology of the two rock catfishes. This was a research project conducted during this project. Results are critical in understanding the conservation needs for these species and data were used in conservation modelling by Michael Cunningham (Chapter 10).
5. Chapter 7 by Ernst Swartz examines the conservation genetics of the three species. Genetic issues are becoming increasingly important in the conservation management of threatened fish species, for example the establishment of refuge populations in dams and aquaculture programmes that aim to help save such fishes.
6. Chapter 8 by Ferdinand de Moor and Helen James described the aquatic macro-invertebrate fauna of the study area. This chapter looks at aquatic macro-invertebrate diversity in selected rivers with the aim of highlighting the conservation value of the rivers beyond their ichthyofauna.
7. Chapter 9 by Michael Cunningham investigated population viability for *A. barnardi*. This chapter uses the available biological data from chapter 4 to explore the risk of extinction in *A. barnardi*, using the population viability analysis software program VORTEX.
8. Chapter 10 by Michael Cunningham reports on the importance of rivers in the study area for amphibian conservation.
9. The concluding chapter 11 by Dean Impson and Roger Bills describes the aquatic conservation initiatives in the region and the development of a conservation action plan for the three species and their associated ecosystems.

Innovation

We believe this project has been highly innovative in several ways.

- The multidisciplinary approach in terms of fish conservation biology (e.g. taxonomy, genetics, population viability and conservation needs), is possibly the first of its kind for a comprehensive conservation assessment of an African fish species.
- The report has used a multidisciplinary approach at the aquatic ecosystem faunal level (fishes, frogs, aquatic invertebrates), which integrates the needs of each taxon group in the development of a conservation action plan.
- The population viability analysis for *A. barnardi* has been used only once before for southern African freshwater fishes (in the assessment of the Maloti minnow *Pseudobarbus quathlambe*).

- The project, whilst based on scientific methods, is specifically aimed at producing a practical conservation management plan for three threatened endemic freshwater fish species.
- The conservation authority (CapeNature) that has the leading responsibility for implementation of conservation actions has been intimately involved with most aspects of the science in this report and in drawing up the conservation action plan.

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2. THE CONSERVATION BIOLOGY OF BARNARD'S ROCK CATCFISH (*AUSTROGLANIS BARNARDI*).

ROGER BILLS

SOUTH AFRICAN INSTITUTE FOR AQUATIC BIODIVERSITY (SAIAB), PRIVATE BAG 1015, GRAHAMSTOWN 6140. (E-MAIL: r.bills@saiab.ac.za)

Introduction

The following three chapters are a synopsis of the current information available on the taxonomy, distribution, biology and conservation of the three target species – the two rock catfishes (Clanwilliam rock catfish *Austroglanis gilli* and Barnard's rock catfish *Austroglanis barnardi*) and the Twee River redfin minnow (*Barbus erubescens*). The information together with research dedicated to filling gaps in the current knowledge during this project will go towards synthesizing conservation plans for these and other aquatic species within the Olifants River system.

Austroglanis barnardi, Skelton 1981, Barnard's rock catfish

Synonym: *Gephyroglanis barnardi*, Skelton 1981

Skelton, P.H. 1981. The description and osteology of a new species of *Gephyroglanis* (Siluriformes, Bagridae) from the Olifants River, South West Cape, South Africa. Ann. Cape Prov. Mus. Nat. Hist. v. 13 (no. 15): 217-249.

Type locality. Noordhoeks River at road bridge, tributary of Olifants River, Western Cape Province, South Africa (32°43'15"S, 19°03'59"E).

Holotype: AMG P7647(a). Paratypes: AMG P893 (5); SAM 29232 (7); USNM 227619 [ex AMG P1369] (5). Additional material: AMG P8202 (1), P8206 (1).

Identification and relationships

Austroglanis barnardi is a small (75 mm SL) bagrid-like riverine catfish (Skelton 1981, 1987) (Figure 2.1). It is adapted to living in crevices in cobble habitats and has a laterally compressed body and slightly depressed head. Eyes are small and located dorsally. The dorsal fin is short
and positioned just behind the head, dorsal fin formula I, 6. Pectoral fin spines are short and slightly curved. Anal fin is large, anal fin formula iii-vi, 10-13. Caudal fin is truncate in form. Four pairs of short barbels are present although the nasals are very small. The mandibular barbels are unusually placed posteriorly, away from the jaw (Figure 2.2). Colouration typically is light to golden brown with scattered darker spots. However, individuals that are almost black and others that are unspotted occur in all populations.

The sister species to *A. barnardi* is the more widespread Clanwilliam rock catfish, *A. gilli* with which it occurs sympatrically although has slightly different habitat preferences (Bills 1998, 1999). The third member of the genus *A. sclateri* occurs in the Orange River. The family Austroglanididae has few unique characteristics (Mo 1991; Diogo et al. 2006) and seems to be rather generalised and primitive catfish group. Their inter-relationships remain unresolved despite a fair degree of research and a sister group may be outside Africa.

Figure 2.1. *Austroglanis barnardi* in lateral view from a) the lower Noordhoeks River (type locality) the typical spotted form, and b) an untypical dark non-spotted form and c) from the Thee River.

Figure 2.2. *Austroglanis barnardi* (ventral head view) from the Thee River showing the unusual placement of the mandibular barbels.

IUCN Conservation assessment

Assessed as Endangered (EN: B1ab(ii,iii,v)+2ab(ii,iii,v)) by Swartz, Bills & Impson (2007)(see text box below). Three tributary populations exist with little or no immigration between them. Each population has, to some extent, been invaded by alien fishes although *Austroglanis* appear to be quite resilient to alien fish impacts alone. This is likely related to the fact that they hide under cobbles during the day when predatory alien fishes are active. The major threats, however, are from continuing agricultural developments (water extraction, deciduous fruit farming, use of pesticides), which are expanding up river valleys. Typically, lower *Austroglanis* limits occur where several impacts combine which is usually associated with the first farm in a catchment.

"Locations have been identified as the three surviving populations. Bills (1999) established the lower limits and in some cases upper limits of this species in the three tributary streams where they currently still occur and also showed that they still occur in the mainstream Olifants River near the Heks tributary. Since his last assessment, there has been a reduction in range in the Noordhoeks River due to changes in the extent of water extraction. The Noordhoeks has been established as the most important population for conservation, since it has the best habitat and has the largest population. The occurrence of this species in the mainstream Olifants River is unsure, since the habitat where they occurred has dried up several times since 1999 and may only be colonized from the Heks River during times of favorable flow when the cobble habitat has been flushed of sediments. These two reductions in range may account for a large loss of the species' EOO. However, category A is not relevant, since the loss of habitat probably does not result in a reduction of at least 30% in EOO or AOO. The species has an EOO of less than 5000 km^2, an AOO of less than 10 km^2, is severely fragmented and only three populations remain (less than 5 localities) with continuing decline in AOO, habitat and number of mature individuals. However, despite being severely fragmented, the three populations are probably each large enough to survive on their own without the need for immigration. It therefore qualifies under Endangered B1a (iii), B1b (ii,iii,v) and B2a (iii) and as Critically Endangered in B2b (ii,iii,v). The overall assessment for category B is therefore Endangered (only qualifies for one category for Critically Endangered). There are not reliable population estimates at this stage, but provisional indications are that it would not qualify under category C or D and no quantitative analysis has done for category E. Decreasing." Ernst Swartz, Roger Bills & Dean Impson 2007.

Distribution

Three populations occur in tributary streams of the Olifants River near to Citrusdal – the Heks River (32° 26' 26"S, 18° 58' 45"E), the Noordhoeks River (32° 43' 15"S, 19° 03' 59"E) and the Thee River (32°47' 39"S, 19° 05' 50"E) (Figure 11.3) (Skelton 1981; Bills 1999). A few individuals have also been collected in the main stream Olifants River just down-stream of the Heks-Olifants confluence (32° 25' 51"S, 18° 57' 34"E). The latter site is however not considered to harbour a viable population as individuals were few and in extremely poor condition. The Olifants River at this point is polluted, has poor summer flows due to severe upstream abstraction and has several alien fish species. The Boskloof-Boontjies River occurs between the Noordhoeks and Heks Rivers and would seem an obvious place for *A. barnardi* to occur and it has suitable habitats. Several surveys, however, have not found any specimens in either of these two rivers.

The lower distributional limits of *A. barnardi* in tributary systems are close to the confluences with the Olifants River. Historically *A. barnardi* was probably present all the way down tributaries and into the Olifants River connecting these, which allowed gene flow between populations. Due to water extraction by farmers, tributary streams now typically dry up in their lower reaches and thus the lower limits are more determined by farming activities today. The upper limits to *A. barnardi* have only recently been located for the Heks River as all three tributaries are difficult to access. At this point *A. barnardi* was rare (only a single individual was collected). In contrast *A. gilli* was abundant in this upper section of stream. Thus although *A. barnardi* is reasonably widespread in the tributary rivers the main populations seem to exist in the low gradient cobble zones near to their confluences with the Olifants River, making them more susceptible to agricultural impacts than their sister species.

Alien fish distributions / limits

There are a growing number of alien fish species present in the wider Olifants-Doring river system. Individual species distributions vary but are continuing to spread each year. For the most part, alien species dominate the main river channels of the system and to varying extents have invaded certain tributary systems. The three rivers inhabited by *A. barnardi* have all, to varying degrees, been invaded by alien fishes.

In the Noordhoeks River banded tilapia *Tilapia sparrmanii* A. Smith, 1840 was recorded from two sites (32° 43' 38"S, 19° 04' 43"E and 32° 43' 19"S, 19° 04' 14"E). It seems likely that this invasion has occurred from the main Olifants River through the Noordhoeks Farm system of irrigation dams and channels. This is assumed because the lower Noordhoeks River is usually dry during the summer period when most fish are trying to migrate upstream. *Tilapia sparrmanii* may not be particularly successful in upper stream habitats of the Cederberg mountains as it is better adapted to low flows found in marginal habitats of large rivers, so it is unlikely to establish a strong population in the upper river.

The Heks River has been invaded by *Micropterus dolomieu* (Lacepede, 1802) for a considerable period of time. The Heks River farmer does not always extract all the water from this river, which is perhaps why this invasion has been so successful. Alien *M. dolomieu* were recorded (Bills 1999) from a site about 5 km above the road bridge (32° 26' 14"S, 19° 00' 40"E) although local farmers who fish the river reported they occur much higher upstream than this point. Thus the exact upper limit for bass has not yet been identified.

Interestingly, *A. barnardi* and *A. gilli* are present in reasonable numbers throughout the range of alien fishes. It would seem that providing the physical habitat remains pristine and there is good water flow and quality, *Austroglanis* catfishes are capable of surviving, albeit in lower numbers, where alien fish predators occur. The Thee has only recently been reported to have spotted bass *Micropterus punctulatus* (Rafinesque 1819) in its lower reaches (32° 47' 38"S, 19° 05' 44"E) (pers. com. Mr. Craig Garrow, see text box below). Whether this is due to migration up the river during winter flows or an introduction is not known nor is its extent. CapeNature and partner organisations are currently involved in a project to physically remove this new bass invasion using nets. Control of alien fish invasions into the three *A. barnardi* streams is a conservation priority. Two invasions appear to be in their early stages and it is possible that control measures could be effected with something simple such as a fyke netting programme. The Heks invasion is well established and a catchment down eradication programme, starting at the top of the bass distribution, is suggested.

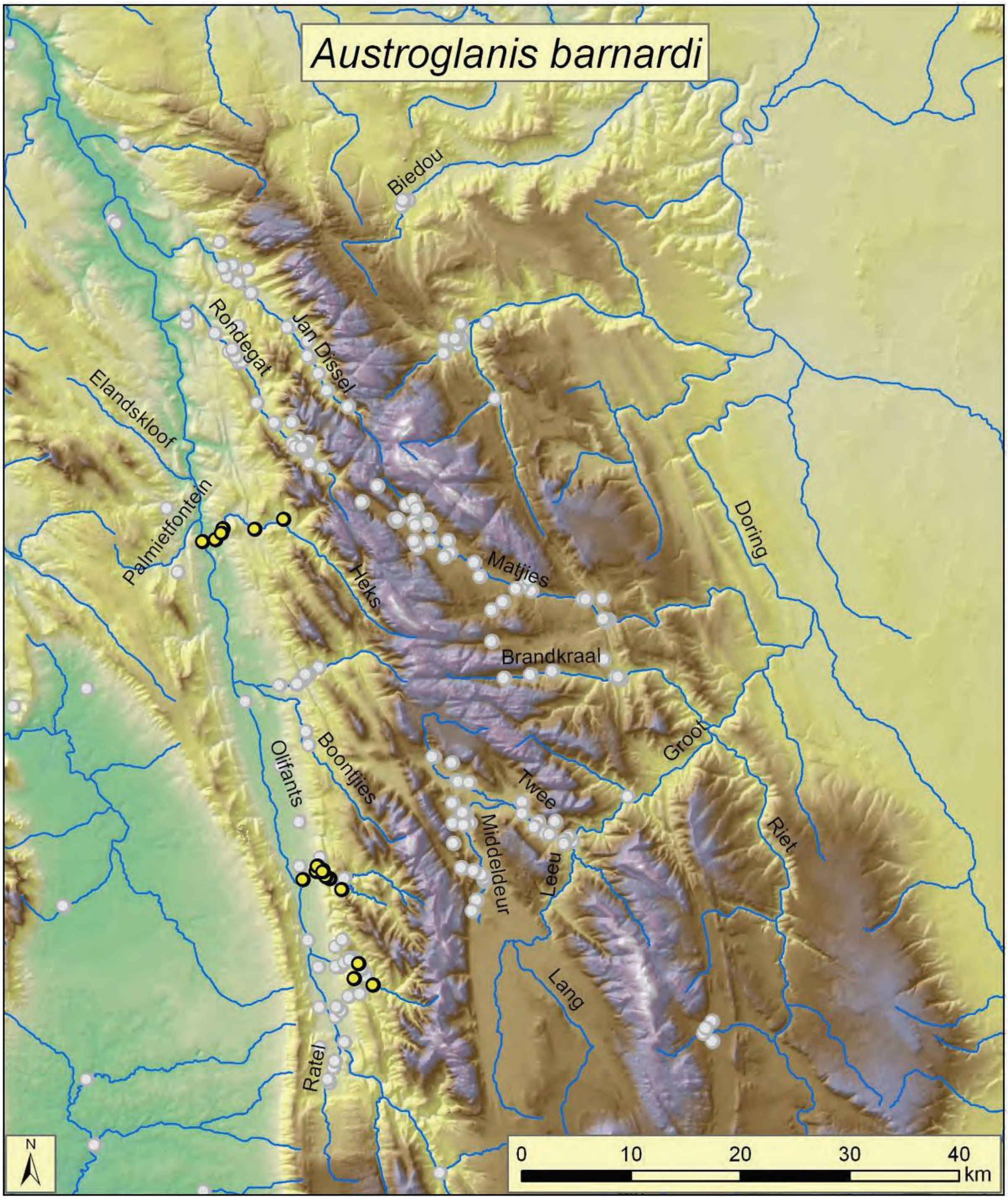

Figure 2.3. A map showing the distribution of *A. barnardi* in the Olifants River system based on museum records (yellow spots – positive records white spots – negative records).

From: Craig Garrow [mailto:craig@prontoclearing.co.za]
Sent: 29 January 2007 11:38 AM
To: Dean Impson; Kas Hamman
Subject: Bass in the Theeriver Citrusdal
Hi Kas/Dean,
….. Last October I was at Noordhoeks and Thee to do some shots but the water was too cold so I never got much done. I did notice however that the Thee had very few fish in the lower stretch (about 1 km upstream of tar road where the water abstraction takes place). I thought nothing of it as the flow was still a bit strong. This weekend I was back there and went several km upstream before taking shots. Everything as normal. Phlegethon and calidus in abundance. See attachment.
On the way down I stopped at the pool adjacent to the three bush cottages (upstream of the water abstraction). There was no activity so I checked it out with goggles. I encountered two bass, one of about 5cm and one of about 17cm. Very few indigenous fish. So bass are obviously in the lower reaches of the Thee!!!
Kind regards, Craig Garrow, Pronto Clearing cc, E96 Platinum Junction, School st., Milnerton, 7441, Cape Town, South Africa.

Habitats

Austroglanis barnardi occurs almost exclusively in shallow, cobble, riffle habitat (Figure 2.4) (Skelton 1981; Gore et al. 1991; Bills 1999). This habitat is comprised of layers of cobbles (rounded river-eroded rocks) in fast flowing water. Water depths are typically less than 30cm. Rocks have a well-developed fauna and algal flora. This habitat is most common in sections of tributary streams just before they enter the main Olifants River although it does occur in higher sections of tributary streams and in the mainstream Olifants River.

Small body size and the presence of short and slightly curved dorsal and pectoral fin spines would seem to be adaptations to moving between small crevices in this habitat. Day and night-time snorkelling did not result in any observations of *A. barnardi* so they appear to confine themselves to the deeper crevices. *Austroglanis barnardi* was not sampled in deeper pools adjacent to riffles.

Figure 2.4. The preferred habitat for *A. barnardi* on the Noordhoeks River (March 2005) (32° 43' 32"S, 19° 04' 30"E).

Figure 2.5. *Austroglanis barnardi* in an aquarium were observed to be highly territorial – aggressively chasing away conspecifics from preferred refugia.

Biology

Prior to this project very little was known about the biology of either *Austroglanis* species. Information is anecdotal.

- The diet is thought to comprise predominantly aquatic invertebrates and possibly tadpoles and fish eggs (Skelton 1981, 2001, pers. obs.).
- *A. barnardi* have been artificially spawned in channels set up next to the river (Bills 1999). Gravid specimens were injected with Aquaspawn and they spawned overnight although the eggs were unfertilised. Eggs were laid in a clump which implies that the species is a nester and guarder.
- A small number of *A. barnardi* have been held in recirculating tank at SAIAB and fishes were noted to have high fidelity to crevices and aggressive behaviour towards conspecifics (Figure 2.5).
- Examination of daily rings in otoliths of juveniles indicated a November spawning period (Bills 1999).

The biology of *Austroglanis* catfishes was identified as a gap prior to this project and this was studied by Mr. Vusi Mthombeni for an MSc degree at SAIAB and the Ichthyology Department of Rhodes University (DIFS) (Chapter 6).

Population estimates

The only attempts at adult population estimates for *A. barnardi* have been by Bills (1999) (Table 2.1). Methods involved electric-fishing with seine-block nets which seems to be the best method for capturing *Austroglanis* species. Due to *Austroglanis* behaviour of hiding in deep cobble habitats and the fact that we were not able to survey the entire tributary populations these estimates must be regarded as underestimates. Electrofishing efficiency tests are also on-going and so the refinement of these estimates is likely.

Table 2.1. Population estimates for *A. barnardi* (Bills 1999).

Austroglanis barnardi	**km surveyed**	**Population estimate**
Heks	8	1860
Noordhoeks	5.5	2590
Olifants	0.5	50
Thee	3.5	160
Total	17.5	5020

The Olifants River population is essentially fed from the lower Heks River population and is probably a non-viable ‘sink’ population. The Olifants River below Citrusdal is polluted, poorly flowing and has several alien fish species. The Thee population seems to be widespread but very sparse. Probably the bulk of the historical population has been exterminated through habitat destruction associated with citrus farming (bulldozing and water abstraction) in the rivers lower reaches.

More accurate population estimates were made using capture-mark-recapture methods which are testing the efficiency of single pass electric-fishing techniques. Further surveys are adding to distribution information.

Conservation threats

Alien fishes have to varying degrees invaded all three of the tributaries inhabited by *A. barnardi* (Skelton 1987; Gaigher et al. 1980; Bills 1999). The impacts of *Micropterus* species on small cyprinids is dramatic with complete extinctions being achieved rapidly. In contrast, both *Austroglanis* species seem capable of co-existing in the long-term with *Micropterus*. It is unknown if *A. barnardi* can co-exist indefinitely with *Micropterus* species and this will be investigated using Population Viability Analysis later in this project. Possibly a critical factor in *A. barnardi*'s current survival is that, except for alien fishes, the three rivers are largely pristine.

Areas where *A. barnardi* has been severely impacted are in the lower sections of the tributaries where farming activities commence. Here riparian zones have been destroyed by bulldozing (Figures 2.6 & 2.7) over many years and complete abstraction of water during the summer months is the annual norm. Ironically, the abstraction of water in the Noordhoeks and Thee Rivers may well be the reason for *Micropterus* species not being able to invade these systems. Despite the current shortage of water during summer period, agricultural development is continuing with new areas for orchards being planted. New dams are being constructed and water abstraction points are going higher into systems each year. A particular threat to the Noordhoeks River population is the development of old lands higher up in the system. There is an old road and land is cleared so the development of orange orchards about 2 km up river is quite feasible. This would impact the single largest population of *A. barnardi*.

The actual impacts of farming activities are unknown but multiple impacts probably work synergistically and include direct mortalities and loss of refugia (from bulldozing), loss of flow and complete drying out of rivers (from water abstraction), sedimentation from reduced flows and pollution from agro-chemicals used in citrus farming (Skelton 1987; Bills 1999).

Unfortunately, agricultural developments typically coincide with the area of highest abundance for *A. barnardi*. In the Heks and Thee Rivers it seems that the prime habitat for this species has been destroyed in the lower river and all that remains are very sparse upper catchment populations. The rehabilitation of the lower sections of all three *A. barnardi* rivers and the protection of the remaining large Noordhoeks population should be considered a conservation priority.

Figure 2.6. An aerial view of the lower Thee River showing bulldozed area (source – Google Earth) – historically this river section should be the center of the *A. barnardi* population.

Figure 2.7. A view of the lower Thee River from the main road bridge showing bulldozed area.

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3. THE CONSERVATION BIOLOGY OF THE CLANWILLIAM ROCK CATFISH (*AUSTROGLANIS GILLI*).

ROGER BILLS

SOUTH AFRICAN INSTITUTE FOR AQUATIC BIODIVERSITY (SAIAB), PRIVATE BAG 1015, GRAHAMSTOWN 6140. (E-MAIL: r.bills@saiab.ac.za)

***Austroglanis gilli*, (Barnard, 1943), Clanwilliam rock catfish**

Synonym: *Gephyroglanis gilli*, Barnard 1943.

> Barnard, K.H. 1943. Revision of the indigenous freshwater fishes of the s.w. Cape region. Annals of the South African Museum. Vol. 36(2): 101-262.

Type locality: Jan Dissels River, Boontjies River, Noordhoeks River and the mainstream Olifants River at Keerom.

Lectotype: SAM 29231 [now at AMG]. Paralectotypes: SAM 19359 [now at AMG] (17), 22467 [ex SAM 18607 and 18757, now at AMG] (12). Lectotype designated by Skelton 1981.

Identification and relationships

Austroglanis gilli is a medium sized (150 mm SL) bagrid-like riverine catfish (Barnard 1943; Skelton 2001) (Figure 3.1). It is adapted to living in varied rocky habitats and crevices in banks. It has a laterally compressed body and slightly depressed head. Eyes are medium to small and located dorsally. The dorsal and pectoral fin spines are straight and long. Dorsal fin formula I, 6-7, anal fin formula v-vi, 10-13. Anal fin is large, caudal fin is truncate in form. Four pairs of short barbels are present although the nasals are very small. The mandibular barbels are characteristically positioned away from the jaw. Colouration varies from olive, brown to grey and is typically unspotted.

Austroglanis gilli can be distinguished from its sister species *Austroglanis barnardi* (Skelton 1981) by its stronger and straighter pectoral and dorsal fin spines, its larger size, its preference for deeper water habitats and typically it is unspotted or largely so. However, in some populations spotted forms, with varying degrees of spotting, do occur, e.g. the Jan Dissels and the Noordhoeks Rivers (Figure 3.1).

Relationships. *Austroglanis gilli* is most closely related to *A. barnardi*.

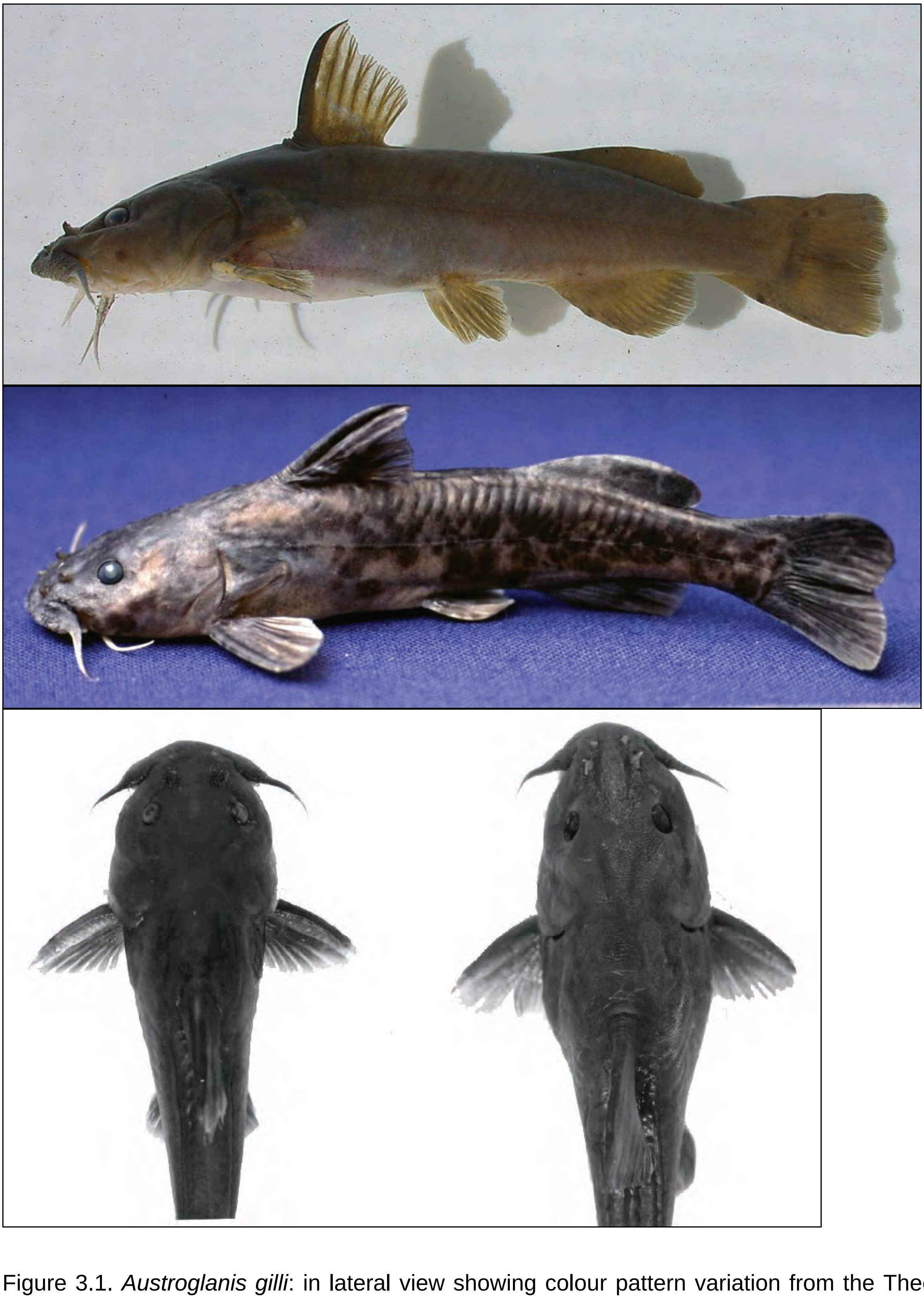

Figure 3.1. *Austroglanis gilli*: in lateral view showing colour pattern variation from the Thee (upper) and Jan Dissels (middle) rivers and a dorsal view (lower) showing morphological variation in the Jan Dissels River population.

IUCN Conservation assessment

Assessed as Vulnerable (VU: B2 ab (iii & v)) by Swartz, Bills & Impson (2007) (see text box below).

Austroglanis gilli is known from 16 tributary streams in the Clanwilliam Olifants River system and occasional recent records have been noted within the mainstream Olifants. Today, however, with the combined impacts of alien fishes, over-extraction of water and pollution there are no known viable populations in the main rivers. Recent records thus probably represent stragglers washed downstream from tributaries. Certain tributary populations are geographically close and are essentially under the same overall threats. Thus, the number of effective *A. gilli* populations, from a conservation perspective, was considered to be under 10.

Bills (1999) established most of the range of this species, especially the lower limits and in some cases upper limits in tributary streams. They occur in more than ten tributaries of the Olifants River system in the Cederberg Mountains, and there are records and unconfirmed reports of their presence in some mainstream areas. Small reductions in range are occurring in the Noordhoeks, Thee and possibly the mainstream Olifants River, but less than the 30% for qualification in category

A. The species has an EOO of less than 5000 km^2, an AOO of less than 10 km^2, is severely fragmented with continuing decline in AOO, habitat and number of mature individuals. Despite being severely fragmented, most of the populations are large enough to survive on their own without the need for immigration. However, locations have been identified as ones where aliens and habitat degradations can impact them together namely the Oudste, Thee, Noordhoeks, Boontjies-Boskloof, Heks, Rondegat, Jan Dissels, Biedou and Matjies-Krom. The Tra Tra-Eselbank is not considered to be large enough. Therefore nine locations. It therefore only qualifies under Vulnerable for locations (6) and Endangered B1b (ii,iii,v) and as Critically Endangered in B2b (ii,iii,v). The overall assessment for category B therefore is Vulnerable. Provisional indications are that population size is large enough not to qualify under category C or D and no quantitative analysis has done for category E. Current Population Trend: Decreasing. Ernst Swartz, Roger Bills & Dean Impson 2007.

Distribution

Austroglanis gilli is known from 16 tributary streams of the Olifants River system draining both the east and western tributaries of the Cederberg mountains (Figure 3.2). Odd records are also known from the mainstream Olifants River at Keerom (Barnard 1943), below the Heks River confluence (Bills 1999), in the lower Doring River (diver sighting, Dr Steve Lamberth, pers. com.) and below the Clanwilliam Dam (a fin spine from an otter scat, Bills 1999). Thus it would seem that this species had a wider distribution in the past including main stream habitats. Areas that are poorly explored and may provide further records are the lower Matjies, areas of the Doring River below confluence with known *A. gilli* populations, Oorlogskloof River and the lower Olifants in the Northern Cape.

Alien fish distributions / limits

Austroglanis gilli occurs together with alien smallmouth bass *Micropterus dolomieu* (Lacepede, 1802) and largemouth bass *Micropterus salmoides* (Lacepede, 1802) in numerous tributaries. In the Jan Dissels, the single largest population for *A. gilli*, the majority of the *A. gilli* population co-exists with *M. dolomieu*. If *Micropterus* species and banded tilapia *Tilapia sparrmanii* A. Smith, 1840 are the only impacts they would appear not to seriously threaten *A. gilli* populations.

Habitats

The pattern of distribution and habitat preferences of *A. gilli* and *A. barnardi* appears to mirror the two redfin minnows, Clanwilliam redfin *Barbus calidus* Barnard, 1938 and fiery redfin *Pseudobarbus phlegethon* (Barnard, 1938). *Austroglanis gilli* and *B. calidus* are more common and widespread in both the lower and headwater sections of tributary streams and they also appear to prefer larger pools and deeper water. In contrast, *A. barnardi* and *P. phlegethon* are most abundant in the mid to lower sections of tributary streams where they occur in shallower water and in complex cobble habitats (riffles) (Bills 1999).

Austroglanis gilli inhabits cobble riffles as juveniles but as they mature they are found in a wide variety of habitats such as deeper runs and pools (Figure 3.3). However, they were observed during the day and night over smooth mud, sand and bedrock substrates. Electrofishing and snorkelling in these areas indicated that they use holes in the banks, crevices under rocks and vegetation root stocks as refuges. *Austroglanis gilli* was also found in deep pools in the Tratra and Biedouw Rivers (4-5 metres depth).

Although Gore *et al*. (1991) showed fast flowing water preference for *Austroglanis* we found high numbers of *A. gilli* in good condition in some places where water flow was nil, e.g. isolated side channels of the Matjies River. The most important factors would appear to be the complexity of habitat and high water quality.

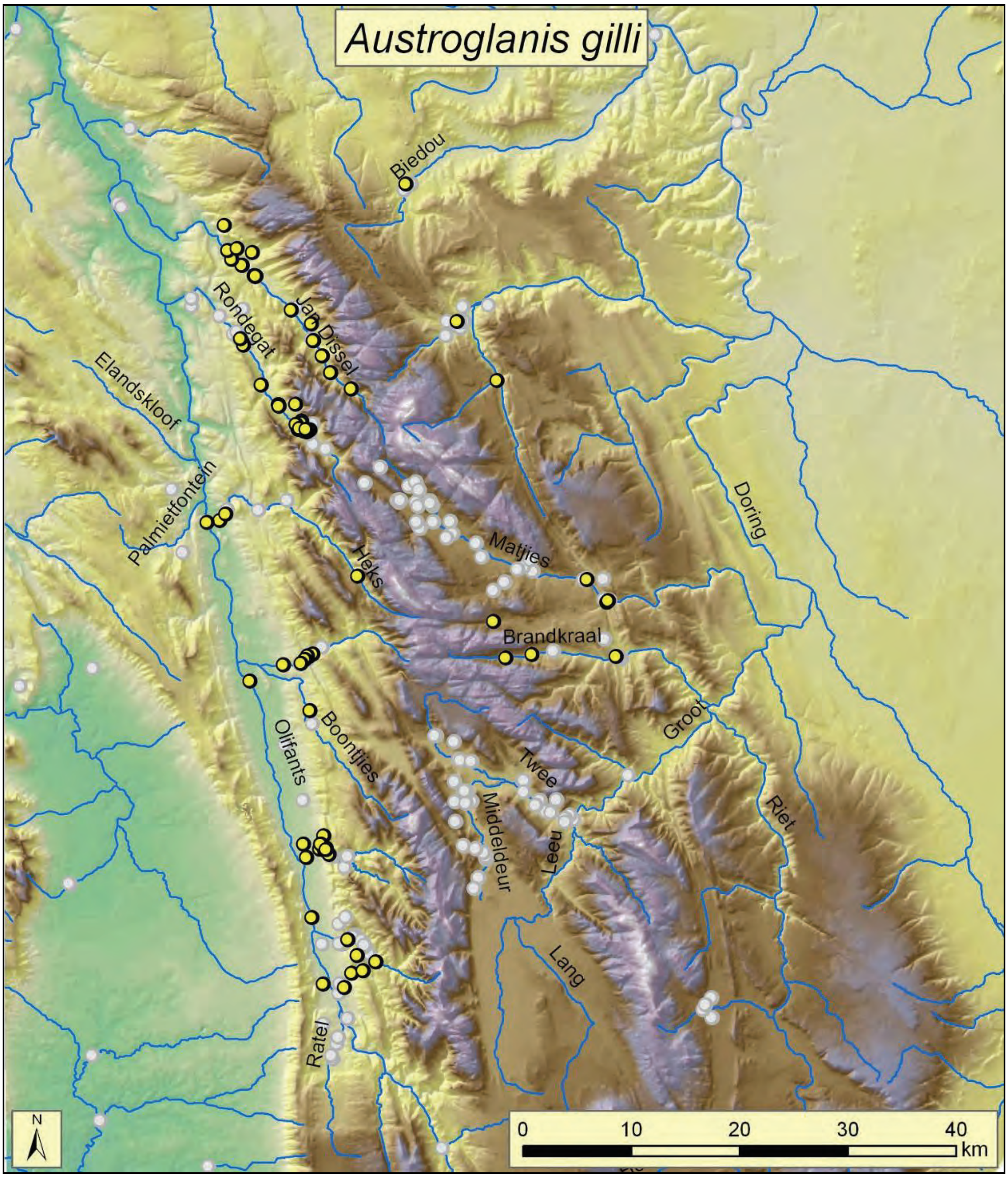

Figure 3.2. A map showing the distribution of *A. gilli* based on museum records (yellow spots – positive records, white spots – negative records).

Figure 3.3. The Rondegat River below the Algeria – Clanwilliam road bridge. The Rondegat has one of the largest populations of *A. gilli* in the system.

Biology

Prior to this project very little was known about the biology of either *Austroglanis* species (Bills 1999; Woodford et al. 2005). The biology of *Austroglanis* catfishes was thus identified as a gap and was studied by Mr. Vusi Mthombeni for an MSc degree at SAIAB and the Ichthyology Department of Rhodes University (DIFS) (Chapter 6).

- The diet is thought to comprise predominantly aquatic invertebrates and possibly tadpoles and fish eggs. The abundance of ghost frog tadpoles (*Heleophryne purcelli*) drops dramatically where *A. gilli* occurs.
- Examination of daily rings in otoliths of juveniles indicated a November spawning period.
- During collections in 2005, juveniles which are typically rarely caught, were captured in an invertebrate drift net during January. Nets set two months later caught no specimens. It may be that juveniles range away from spawning sites, establish territories and then move very little after that.
- Genetic studies on the Jan Dissels River by Swartz (Chapter 7) indicate *Austroglanis* does not migrate even within the same tributary system.

Table 3.1. Population size estimates for *A. gilli* populations (Bills 1999).

Austroglanis gilli	**km surveyed**	**Population estimate**
Biedouw	2	260
Boontjies	6	200
Boskloof	6	9600
Breekkrans	3	1020
Dwars	2	1379
Eselbank	0.5	45
Heks	8	920
Jan Dissels	13	18005
Krom	3	1350
Matjies	1	520
Noordhoeks	5.5	2075
Olifants	0.5	200
Oudste	3.5	1235
Rondegat	15	8342
Thee	5	1580
Tratra	0.5	100
TOTAL	74.5	46831

Population estimates

The only attempt at population estimates for *A. gilli* is by Bills (1999) (Table 3.1). The largest single population is the 13 km stretch of the Jan Dissels River which was estimated to be over 18,000 individuals. For the most part, this population exists with bass (*Micropterus* spp.) although the habitat is otherwise pristine. There are large populations (possibly more than 1000 mature individuals) in the Oudste, Thee, Noordhoeks, Boskloof, Heks (including the mainstream Olifants nearby), Rondegat, Jan Dissels, Dwars, Breekkrans and Krom tributaries and smaller populations (possibly less than 1000 mature individuals) in the Boontjies, Biedouw, Tra Tra, Eselbank and Matjies tributaries (Bills 1999).

Conservation threats

In most instances *Austroglanis* are confined to pristine areas of headwater streams. Rapid changes occur once rivers enter farming lands – water is extracted, river beds are bulldozed, a variety of pollutants (especially pesticides) enter rivers and alien fishes become common. The net result is that indigenous fishes usually disappear from streams soon after entering the farming regions. Factors considered associated with the loss of *Austroglanis* catfishes and other indigenous fishes are presented below. It must be noted that many factors are linked and may compound each other's effects. For example, the Jan Dissels has bass for most of its length but *Austroglanis* only become severely reduced or absent after the second farm (Dwars River). The loss of cobble habitat through sedimentation together with the presence of an alien predator and pollution are considered to work together in this instance, and exclude the rock catfish.

Alien fishes: In our surveys of the study area, we have found seven species of alien fish – *M. dolomieu*, spotted bass *Microterus punctulatus* (Rafinesque 1819), *M. salmoides* (Figure 3.4), bluegill sunfish *Lepomis macrochirus* Rafinesque 1819, *T. sparrmanii*, rainbow trout *Oncorhyncus mykiss* (Walbaum, 1792) and brown trout *Salmo trutta* Linnaeus 1758. Of these, *M. dolomieu* is the most widespread and common as it actively moves up into headwater streams where it preys upon all species of indigenous fishes. Interestingly, both *Austroglanis* species do exist with substantial populations of small mouth bass in the Jan Dissels, Heks, Matjies, Boontjies, lower Oudste rivers and parts of the Olifants River mainstream. In other rivers, *Austroglanis* were not found with bass, e.g. Olifants at Keerom, lower Rondegat, lower Tratra and lower Breekkrans. The spread of all alien fish up rivers is continuing naturally and with the aid of farmers. Farmers are aiding movement both by actively by stocking into farm dams, which is illegal without CapeNature approval, and inadvertently through irrigation systems which bypass natural river barriers. Examples are: the Eselbank river where *M. dolomieu* had moved above a small waterfall, which was a natural barrier, via a contour irrigation channel from; it is suspected that irrigation channels and dams have allowed *T. sparrmanii* access into the Noordhoeks River which until recently had no alien species present and is one of the most diverse and important rivers in the system. The process of alien fish spreading needs to be halted. There is tremendous concern about future spread by sharptooth catfish *Clarias gariepinus* (Burchell, 1822), which according to angler reports is a new invader in Clanwilliam Dam on the Olifants River.

Water extraction: Excessive water extraction results in numerous rivers either drying up or ceasing to flow during the height of summer, e.g. Noordhoeks and Heks Rivers. Several farms take the entire flow of rivers during summer for irrigation purposes which cannot be regarded as environmentally acceptable under the new Water Act (Figure 3.5). At the least, this practice has several probable effects: reduces the amount of available habitat for riverine organisms, concentrates fish populations (increasing predation levels in some species), reduces or stops certain species running up rivers to spawn (e.g. Clanwilliam yellowfish *Labeobarbus capensis* (A. Smith, 1841) and increases the effects of pollutants. At worst large sections of rivers run dry killing thousands of fish and invertebrates.

In the case of *Austroglanis,* loss of populations may be more significant than with other species as genetic evidence suggests they do not move very much within river systems. Thus the drying of rivers is resulting in the loss of diversity and rivers will not simply repopulate when the river regains flows in the winter.

Figure 3.4. *Micropterus salmoides* juvenile – one of seven alien predatory fishes collected during our survey work in the study area.

Figure 3.5. The Noordhoeks River blocked to take its entire dry season (November to April) flow for irrigation on the Noordhoeks Farm (April 2005).

The establishment of base-line Environmental Flow Requirements for rivers within the Cederberg region is essential if the high levels of endemicity are to be maintained in the long term. Reducing water extraction by farmers will affect agricultural production and loss of crops which are possible reasons why little has been done to stop this practice in the past.

Pollution: Three main forms of pollutants are considered significant to fish conservation in the Olifants River system:

- chemicals from agricultural activities;
- sewage from human settlements; and
- sedimentation from a variety of agricultural activities.

Agro-chemicals: The main citrus industry uses a cocktail of pesticides and fertilisers to reduce parasites and unwanted plant growth in orchards and to improve citrus health. It is thought that these chemicals are having significant effects upon fishes (Marriott 1998), especially as orchards are often planted within 5 m of rivers. Chemicals which may have marked effects upon fishes are copper based compounds which are used to combat crinkle leaf – a fungal infection. Copper is highly toxic to fishes and will affect them directly. Insecticides used for killing various insect pests on citrus may significantly reduce aquatic insect diversity and thus food availability to fish. This could affect sexual maturation, fecundity, early development and recruitment rates in fish eating insects. The affects of agro-chemicals on fishes remains untested and was not the focus of this study. Due to the magnitude of citrus farming in the Olifants River catchment, and its continuing growth, a specific study examining this problem is urgently required.

Sewage treatment at major towns and on farms needs to be reviewed by Health Departments. Although sewage treatment facilities were not examined during this study, malfunctioning plants are a common problem in many towns in South Africa. Water quality in rivers directly below Citrusdal and Clanwilliam seem indicate significant inputs of pollutants with increased water turbidity, water conductivity and increased sediments and declines in fish populations. Aside from biodiversity aspects this must be a serious health risk to humans.

Sedimentation: The loss of habitat complexity through smothering of cobble zones (Figure 3.6) with sediments is considered a major threat to *Austroglanis* catfishes, juveniles of other fish, aquatic invertebrates and algae, which form the food of these fishes. Several causes of sedimentation were identified: farm crops abut directly onto river banks; natural riverine vegetation has been removed preventing natural sediment traps functioning; borehole companies pump untreated borehole effluent directly into rivers; driving cars and tractors through drifts; grazing of stock in the river removes vegetation, breaks and widens banks and causes increased erosion; damming of rivers to raise water levels for water extraction results in sedimentation (Bills 1998). Of these the most widespread causes are probably the loss of riverine vegetation and poor farming practices, e.g. grazing of stock in rivers, planting of crops up to river banks, which both result in increased erosion.

Figure 3.6. Sedimented rocks in pools in the Noordhoeks River (April 2005).

Figure 3.7. The Boskloof River just below Boskloof farm near Citrusdal, recently bulldozed (photo taken in March 2007).

Habitat loss and damage: Bulldozing of rivers occurs frequently in the Cederberg region and appears to serve two functions:

- the scouring of river channels by bulldozers to allow rapid flow-through of winter floods (Figure 3.7); and
- the damming of rivers to divert summer flows into farm irrigation systems.

Impacts from bulldozing are considered to include the following:

- Bulldozing of river bed material must result in high mortalities of *Austroglanis* catfishes by direct physical damage as they are by nature taking refuge in the substrate.
- Rocks and sediments are essential for normal river functioning. Substrate surface areas, for growth of algae and attachment of invertebrates which are food sources for fish, are reduced significantly. Thus water quality decreases with reduced habitat complexity.
- The loss of habitat complexity also reduces refuges for fish probably resulting in higher levels of predation by larger fish and otters.
- Bulldozing is a major problem in the lower sections of many tributary streams and still continues today. and coincides with the region in rivers where *A. barnardi* and *P. phlegethon* (both endangered species) are most abundant.

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4. THE CONSERVATION BIOLOGY OF TWEE RIVER REDFIN (*BARBUS ERUBESCENS*).

ROGER BILLS

SOUTH AFRICAN INSTITUTE FOR AQUATIC BIODIVERSITY (SAIAB), PRIVATE BAG 1015, GRAHAMSTOWN 6140. (E-MAIL: r.bills@saiab.ac.za)

***Barbus erubescens*, Skelton 1974, Twee River Redfin**

Skelton, P.H. 1974. A new *Barbus* species (Pisces, Cyprinidae) from the Olifants river system, western Cape Province, South Africa. J. L. B. Smith Institute of Ichthyology. Special Publication No. 13: 1-12.

Type locality. Suurvlei River, Olifants River system, Western Cape Province, South Africa, 32°38'56"S, 19°12'21"E.

Holotype: AMG P2424. Paratypes: AMG P2425-P2429 (21, 2, 2, 2, 2); BMNH 1974.6.13.1-10 (10); MRAC 192171-74 (4), 192175-80 (6); RUSI 74-265 to 74-269 (1, 1, 1, 6, 1).

Identification and relationships

Barbus erubescens is an open-water foraging cyprinid minnow with a fusiform body and large eyes (Figure 4.1). It has red fin bases and superficially resembles *Pseudobarbus* redfin minnows. It is, however, not a *Pseudobarbus* based on a weakly serrated dorsal fin spine, a different tubercle form and a variety of osteological characteristics (Skelton 1988). *Barbus erubescens* is characterised by the following features (Skelton 2001). Dorsal fin formula IV, 8, anal fin formula iii, 7. Scales in the lateral line series are 35-40 and 16 around the caudal peduncle. Two pairs of well-developed barbels. Typical body colour is olive to olive brown upper body with a darker band along the midline and silvery white ventral. Breeding males develop brighter scarlet fin bases and reddish body colour. During the summer both sexes develop breeding tubercles on the head and upper body. Attains 105 mm SL.

Relationships. *Barbus erubescens*' sister species is the more widespread *Barbus calidus* Clanwilliam redfin Barnard, 1938 which occurs in most other tributaries of the Olifants-Doring River system draining the central Cederberg mountains. These two species share several characteristics with the larger sawfins such as the Clanwilliam sawfin *Barbus serra* Peter, 1864 and the Berg-Breede whitefish *Barbus andrewi* Barnard, 1937, e.g. tetraploidy, serrated primary dorsal fin rays, tubercle form, colour pattern of scattered spots on the flanks and upper body.

Figure 4.1. *Barbus erubescens* from the Suurvlei Stream – adult male (upper) and juvenile (lower).

IUCN Conservation assessment

A detailed biological and conservation study on the species was conducted by Michael Marriott (1998). Unfortunately, continuing development within the Twee catchment has rendered much of the conservation information out of date. New distribution surveys are probably needed to determine present distribution limits and numbers of both indigenous and alien fish species.

Assessed in 2007 as Critically Endangered (CR: B2ab(ii, iii, iv)) by Dean Impson and Ernst Swartz (see text box below). Depending on how IUCN criteria are interpreted others could also qualify, e.g. CR: B1ab (i, ii, iii, iv, v) & 2b(I, v).

"It is speculative to estimate how much the population has declined since 1987. It is likely that population decline started with the advent of intensive agriculture in the catchment in the 1960s and 1970s. These declines have been accelerated by the introduction of several species of fish, and it is possible that at least a 50% decline has occurred since 1987, but as mentioned previously this is speculative. Criterion B applies because of the very small size of its distribution range, increasing levels of threats and the fragmented nature of populations. Adult Barbus erubescens were stocked about 10 months ago into off-stream dams; too soon to benefit the overall population size of the species or to assess whether the introduction was successful. Its current actual Area of Occupancy is less than 1 km^2 and according to protocol (1 km^2) as 9 km^2. It qualifies as Critically Endangered under B2a(i)b(iii,v). Two locations have been defined as the Suurvlei and Heks (little reqruitment in Twee), but the two populations are probably too small to survive on their own long-term. Decreasing."
Dean Impson & Ernst Swartz (IUCN 2007)

During this project Roger Bills, Vusi Mthombeni and Dean Impson visited sites on the lower Twee at Raaswater (32º 40' 36.92"S, 19° 16' 05.84"E) and just above the third large waterfall (32º 41' 54.5"S, 19° 18' 28.47"E). These were sites where *B. erubescens* were found to be abundant during Marriott's 1996-97 surveys. A single specimen of *B. erubescens* was observed during nearly an hour of snorkeling and Raaswater was snorkeled both in the day and night-time. The species appears to have declined significantly during the last 10 years due largely to the increasing impact of alien fishes and expanding agricultural developments that have substantially reduced summer flow. Thus, although present in the lower river it appears to be very uncommon now. This has been confirmed by Marr *et al*. 2009. The remaining healthy populations in the upper Suurvlei and Middeldeur streams both have dams above them into which Clanwilliam yellowfish *Labeobarbus capensis* (A. Smith, 1841) have been stocked (outside natural distribution). The potential for other alien fishes (e.g. *M. salmoides*) to be spread further is high given the number of dams within the system.

Distribution

Barbus erubescens is endemic to the Twee River System, a small tributary system of the Doring River, south east of Citrusdal, Western Cape (Figure 4.2) (Skelton 1974). The Twee River has several smaller streams comprising its upper reaches – the Suurvlei, Middeldeur and Heks streams.

The downstream limit of distribution in the Twee River is a large waterfall (32° 41' 53.91"S, 19° 18' 32.31"E) just upstream of the confluence of the Twee and Leeu Rivers. This waterfall historically marked the upper limit to other indigenous Olifants River fishes. Large adult *L. capensis* are still present in the falls pool today together with alien bass (*Micropterus* spp.). Above this waterfall, only *B. erubescens* and *Galaxias zebratus* Castlenau, 1861 occur naturally. However, several alien species such as Cape kurper *Sandelia capensis* (Cuvier, 1831), *L. capensis*, rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) and bluegill sunfish *Lepomis macrochirus* Rafinesque, 1819 have been introduced into the Twee catchment for varied reasons, with yellowfish and sunfish now abundant in the lower Twee River.

Today the only present ‘strongholds’ for *B. erubescens* are the Middeldeur and Heks Rivers above the waterfall on Die Straadt Farm (32º 43' 24.34"S, 19° 13' 39.13"E) and in the upper Suurvlei stream above a small cascade on Tuinskloof Farm (32º 37' 52.38"S, 19° 11' 00.63"E) (Marriortt 1998). The Suurvlei population occupies less than 1 km of stream, the Heks population is about 2 km and the Middeldeur is approximately 5 km. Much of these stream courses, however, are not suitable for minnows and harbour no or few fishes.

Table 4.1. Physical barriers to fish migration within the Twee catchment.

Feature	**Significance to fish distribution**
Heks River upper cascade (32º 43' 14.02"S, 19° 12' 14.57"E)	upper fish limit for *B. erubescens*
Middeldeur upper cascade (32º 45' 23.92"S, 19° 13' 04.20"E)	upper fish limit for *B. erubescens*
Middeldeur waterfall (32º 43' 24.34"S, 19° 13' 39.13"E)	upper limit to alien fishes in Middeldeur
Suurvlei waterfall	upper fish limit for *B. erubescens*
Suurvlei cascade (32º 37' 52.38"S, 19° 11' 00.63"E)	upper limit for *S. capensis* in Suurvlei
Suurvlei lower road crossing weir (32º 39' 33.11"S, 19° 13' 31.06"E)	upper limit for *L. capensis* and *L. macrochirus* in Suurvlei, artificial barrier to all upward fish migration
Twee upper waterfall (32º 41' 11.25"S, 19° 16' 43.42"E)	barrier to all upward fish migration
Twee middle waterfall (32º 41' 37.40"S, 19° 17' 41.36"E)	barrier to all upward fish migration
Twee lower waterfall (32º 41' 54.5"S, 19° 18' 28.47"E)	lower distributional limit for *B. erubescens,* barrier to all upward fish migration

Alien fish distributions / limits

As mentioned above, four species of fishes have been introduced into the Twee River –*O. mykiss*, *L. macrochirus*, *S. capensis* and *L. capensis*. One of these, *O. mykiss*, introduced into the middle part of the Twee River, has not been successful and has likely disappeared (Marr et al. 2009). This is probably due to unsuitable environmental conditions with low water flows and high water temperatures occurring during the summer period. The remaining three alien species are abundant and widespread in the lower parts of the Twee River system and have for the most part eradicated indigenous fishes, through predation and competition. Physical barriers restrict alien fishes to sections of the system (Table 4.1).

Lepomis macrochirus and *L. capensis* both occur from the lower Twee waterfall up to the Middeldeur waterfall on Die Straadt Farm. They do not occur in the Suurvlei Stream as there is a substantial man made barrier on the lower Suurvlei preventing upstream movement. *Sandelia capensis* was introduced into the Suurvlei Stream during the 1980s (Hamman *et al*. 1984) and now appears to be the only fish species present in most of this system. It has also been spread to the wider Twee system where it is abundant and its limits in the Middeldeur and Twee are the same as the other alien species. *Labeobarbus capensis* was introduced by the Cape Department of Nature and Environmental Conservation (CDNEC) into the Twee System, above the natural waterfall barrier on the lower Twee in the 1980s in a misguided attempt to create "sanctuaries" for this species (Impson *et al*. 2007). The species is now abundant in the bigger pools, with fish over 2 kg common, and is regarded as a serious predatory threat to the much smaller *B. erubescens*.

Dams

From examining the Twee River system using Google Earth (http://earth.google.com/), there appears to be about 15 dams of varying sizes within the system (Figure 4.3, Table 4.2). Amongst the other impacts that dams have on a river system, these dams are a particular conservation threat in two main ways: they remove water from the streams and thus reduce river functioning, and they are points into which alien fishes are often stocked and then spread when dams spill. The former scenario is evident from our March 2005 visit to the Twee when the river was not flowing and was overgrown with thick floating mats of filamentous algae. The latter scenario has already happened with the introduction of *S. capensis* into a small dam on the Suurvlei Stream (Hamman *et al*. 1984). *Lepomis macrochirus* were probably also introduced in the same way although the source in not known.

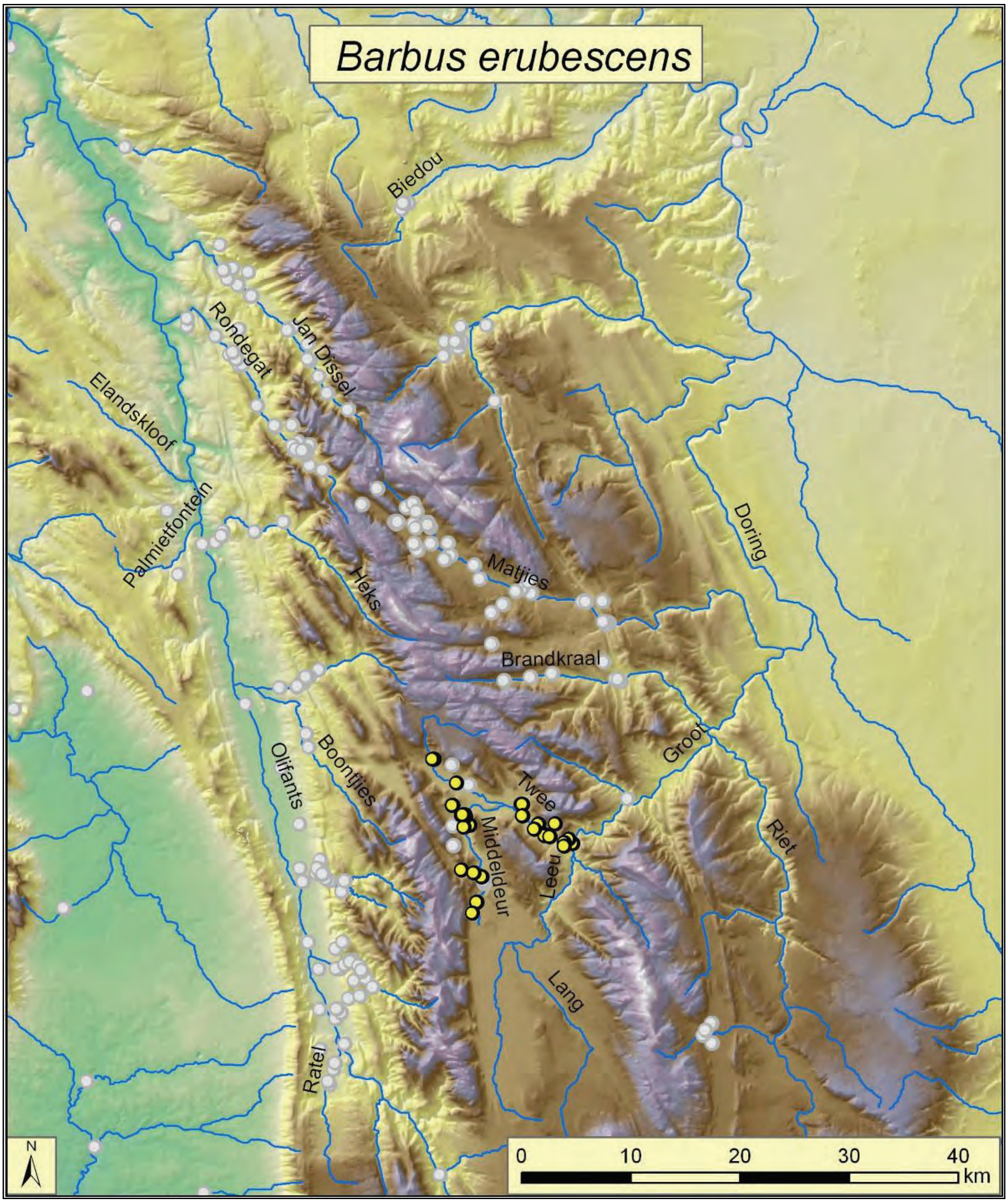

Figure 4.2. A map showing the distribution of *B. erubescens* based on museum records (yellow dots positive records, white dots negative records).

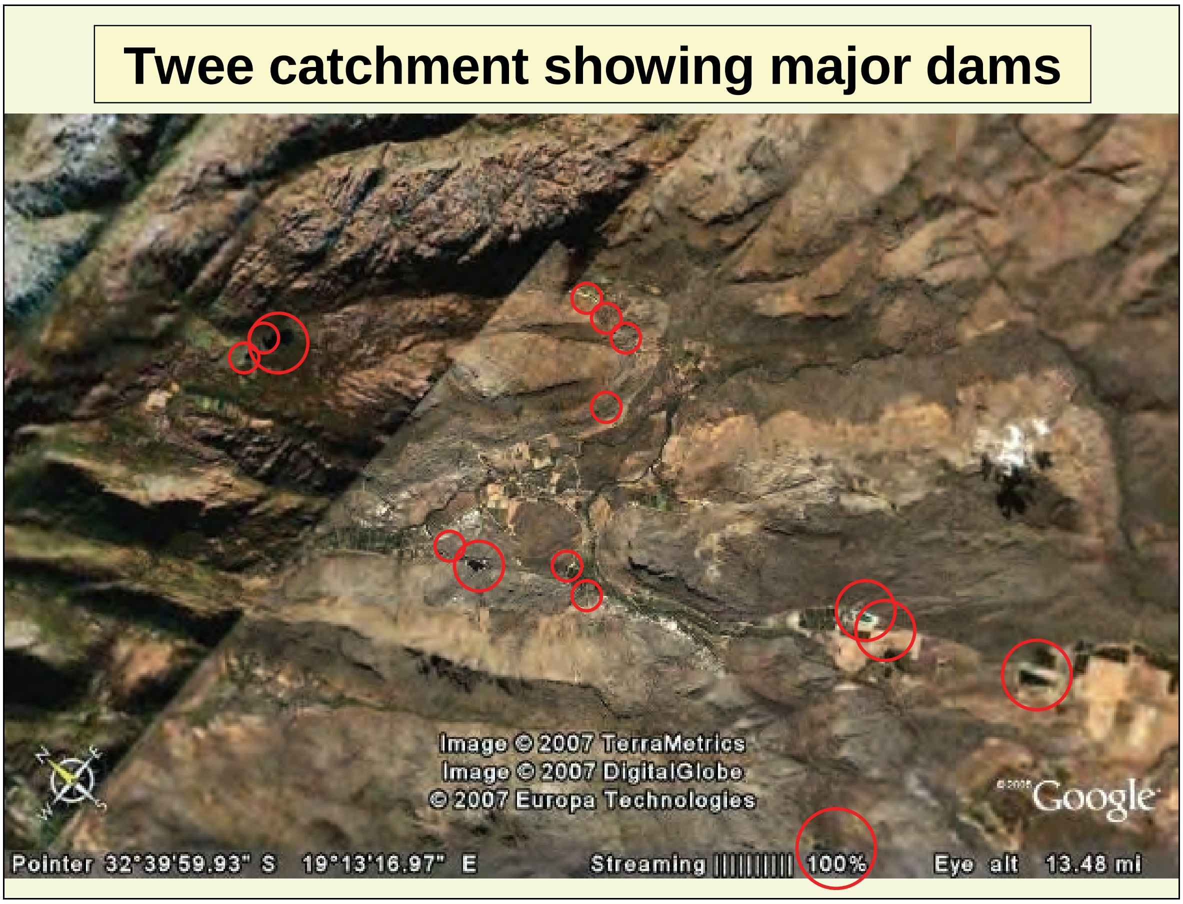

Figure 4.3. The locations of dams within the Twee catchment.

According to farmers, at least two dams have been stocked with yellowfishes (*L. capensis*) by the then CDNEC in the 1980s although the details of these are not known. Unfortunately, these dams are at the top of the Twee catchment – Suurvlakte Farm dam (32° 36' 09"S, 19° 12' 05"E) and Middeldeur upper catchment dam (32° 45' 00"S, 19° 11' 50"E). The status of these yellowfish introductions needs to be determined and if they are extant they need to be eradicated.

Dams could be used in a positive way to act as refugia for indigenous species whilst we attempt to rehabilitate the river system. This process has already been initiated. The Tuinskloof Farm dam (32° 39' 29.96"S, 19° 11' 33.12"E) was stocked with a small number (48) of *B. erubescens* in 2005 by Cape Nature. It was planned to evaluate the success of this translocation and to make an additional translocation before the end of this project. The programme of translocations should be developed to include all 15 dams and include both *B. erubescens* and *G. zebratus*. Aspects of genetic diversity and the highly threatened status of the lower Twee *B. erubescens* populations need to be considered in such a programme. The presence of alien species also needs to be determined in all dams prior to introductions, as dams with alien fishes must not be stocked for obvious reasons.

Table 4.2. The locations of dams within the Twee catchment.

Middeldeur stream	Suurvlei stream
Upper catchment – 1 dam	Suurvlakte Farm- 3 dams at least
32° 44' 59.70"S, 19° 11' 49.38"E	32° 36' 06.84"S, 19° 10' 57.06"E
	32° 36' 00.56"S, 19° 11' 41.67"E
Die Straadt Farm – 2 dams	32° 36' 08.57"S, 19° 12' 05.05"E
32° 43' 15.19"S, 19° 14' 26.21"E	
32° 43' 43.50"S, 19° 14' 13.89"E	Tuinskloof Farm – 2 dams
	32° 39' 29.96"S, 19° 11' 33.12"E
Tandfontein Farm – 1 dam	32° 39' 06.20"S, 19° 11' 20.73"E
32° 45' 02.48"S, 19° 15' 13.40"E	
	Suikerbossie Farm – 4 dams
Kunje Farm – 2 dams	32° 39' 19.24"S, 19° 15' 12.51"E
32° 40' 19.81"S, 19° 12' 14.30"E	32° 38' 38.05"S, 19° 15' 16.68"E
32° 39' 39.45"S, 19° 12' 55.64"E	32° 38' 34.28"S, 19° 15' 19.00"E
	32° 38' 27.76"S, 19° 15' 17.26"E

Habitats

As with most of the Cederberg streams, those of the Twee system are naturally clear flowing draining from table mountain sandstone substrates (Skelton 1974;,Marriott 1998). Water is typically peat stained and of low conductivity (<100 µS/cm^{-1}).The upper reaches are small rocky cascades, runs and pools (typically less than 2 m depth) (Figure 4.4). The lower system comprises mostly deeper runs and large pools (>3 m depth). Several large waterfalls occur in the Twee and there are large deep pools below each of these. The margins of the river are fynbos dominated by ericoid, restioid and proteoid groups (Low & Rebelo 1996). Large areas of the rivers pools, particularly in the lower river are covered by the emergent/floating palmiet (*Prionium serratum*).

Adult *B. erubescens* occur in deeper pools and runs most frequently and are typically quite shy and difficult to see whilst snorkeling. They frequent areas where there are large rocks and weedbeds and swim in and out of these refuges. During the spring and early summer adults change their behaviour, migrating up the system to the heads of pools and runs. Breeding groups remain in open water congregating at the heads of pools and runs. Juvenile *B. erubescens* can be seen at the quiet margins of pools in open water, and are common next to palmiet beds. They occur in shoals of same sized individuals and feed in the water column and off the substrate.

In the upper river during summer, low flows often result in the fragmentation of the stream into a series of pools. Numbers of *B. erubescens* in these pools appears to be highly variable with some harbouring considerable numbers while others none (Table 4.3). In this case, the most extreme situation is in the upper Suurvlei population which occurs in about 1 km of stream section. During the spring *B. erubescens* migrate up the stream to the waterfall pool forming the upper distributional limit. Almost the entire population exists in this pool during the summer period as it becomes cut off from the lower pools.

Figure 4.4. The upper Heks River (Twee system) with typical upper catchment habitat for *B. erubescens* (32° 43' 23.43"S, 19° 12' 57.69"E).

Biology

Females attain a significantly larger size than males (up to 105 mm SL) and adults reach a maximum age of six years. Sexual maturity is attained after two years at an average size of 45 mm SL in males and 42 mm SL in females (Marriot 1998). All specimens were mature at 50 mm SL. They spawn in late spring (October) to early summer December, with an asynchronous, iteroparous pattern of egg development (Marriot 1998). Females contain up to 400 ova at various stages of development (Marriot 1998). Maximum GSI values occurred one month earlier in males.

During the spawning season the body and fin bases of both sexes develop an overall reddish hue and small nuptial tubercles develop on the head and upper anterior body (Skelton 2001). Breeding is similar to *B. calidus* and *B. serra*. Gravid females swim into a male school at the head of a pool and attract several males. The female and males then swim to areas where there are bedrock cracks and larger rocks in the stream flow away from the main shoal of fishes. Eggs are deposited into cracks and underneath rocks. It is possible that reduced water flows during the summer period will impact on hatching rates of eggs and may affect cues for later season spawning thus reducing numbers of eggs spawned.

The diet of *Barbus erubescens* comprised of 22 identified invertebrate taxa, with almost 90% being insects and diptera 73% (Marriott 1998). A large component of the diet was allochthonous material and adults were observed feeding at the surface at dusk. Benthic algae and sand were also present in small quantities indicating substrate foraging. Thus *B. erubescens* seems to be an opportunistic drift-substrate predator. Given the primary food of *B. erubescens* are insects the impact of insecticides, used in the citrus industry within the Twee River valley, needs examination.

During translocation work juveniles held together with adults were eaten. This was unexpected and is of significance as adults are frequently confined to breeding pools for the summer due to low summer flows and thus low water levels. Recruitment could be very low in such pools and it may be a worthwhile short-term conservation strategy to harvest both juveniles and adults from such pools for translocations.

Population estimates

In pristine habitats where there are no agricultural or alien fish impacts the species is abundant. Marriott (1998) estimated the population size at 4100 adult fishes. However, Marriott's primary method involved day-time snorkeling counts. Generally there can be a host of problems associated with visual surveys, e.g. water clarity, shyness of adult fishes, fish activity patterns, complex rocky habitats and vegetation cover. We noticed a specific problem with this method for *B. erubescens* – adult fishes appeared to be most active at dusk and could be observed more easily at night with underwater torches. Thus we conducted a few day-night snorkel counts to determine if night-time assessments could be better for assessing fish numbers (Table 4.3). Although few counts were made, night snorkel counts appear to be significantly more effective and we suggest that future estimates incorporate this method. It seems likely that Mariott's 1998 estimates were an underestimate.

Table 4.3. Day and night-time fish counts in the Twee catchment streams.

Site	**Day**	**Night**
Heks River pool 1 (32° 43' 24"S, 19° 12' 59"E)	14	90+
Heks River pool 2 (32° 43' 24"S, 19° 12' 59"E)	0	4
Heks River pool 3 (32° 43' 29"S, 19° 13' 26"E)	0	15
Middeldeur River pools (32° 43' 24"S, 19° 12' 59"E)	0	0
Upper Suurvlei pool (32° 37' 42" S 19° 10' 58" E)	100+	300+
Twee River – Raaswater (32° 43' 24"S, 19° 12' 59"E)	0	0

These observations may also be of use in a translocation programme. The collection of stock for translocations may be most effectively made at night with hand nets and torches, seine and fyke nets. Due to increasing impacts since Marriott's 1998 surveys, the distribution range of *B. erubescens* and its number have declined considerably (Marr et al. 2009).

Conservation threats

Two major threats to the overall health of the Twee River system and specifically its indigenous fishes are the presence of several alien fish predators and varied and widespread agricultural impacts associated mainly with deciduous fruit farming.

Four alien fishes have been introduced to the Twee system (*S. capensis*, *L. macrochirus*, *L. capensis* and *O. mykiss*). Three of these have become common and appear to have extirpated indigenous species (see above). Waterfall barriers have prevented movements of aliens into the last remnants of the indigenous fish populations in the upper Heks, Middeldeur and Suurvlei streams. However, there are numerous dams within the Twee catchment and several above present alien fish barriers. It is quite likely that aliens can gain access to upper indigenous fish populations through farm dam introductions and subsequent escape. Dams need to be urgently surveyed for the presence of alien fishes and farmers need to be educated about the dangers of introducing alien fishes to their dams. Dams could be used for conservation purposes by stocking with indigenous species. Eradication of alien fishes in the Twee system is urgently needed – a phased approach is recommended.

The other major threat is habitat degradation caused primarily by intensive farming of deciduous fruit and citrus. Agricultural developments bring a suite of impacts – some of which are:

- over-extraction of water particularly during the summer breeding season;
- loss of riparian zone vegetation;
- growth of alien trees in riparian zone; and
- use of a cocktail of pesticides and fertilisers.

Many of these impacts compound each other, e.g. the loss of water flow reduces the rivers ability to function and filter and so the impact of chemical pollutants is exacerbated. The acidic, low conductivity waters may also be particularly sensitive to low levels of chemical pollutants. An assessment on the impacts of agrochemicals in the Twee and wider Olifants River system is long overdue.

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5. A STUDY OF THE MAINTENANCE AND CULTURE REQUIREMENTS OF *BARBUS ERUBESCENS, AUSTROGLANIS BARNARDI* AND *A. GILLI*.

GORDON O'BRIEN AND ANDREW HUSTED

ZOOLOGY DEPARTMENT, UNIVERSITY OF JOHANNESBURG, P.O. BOX 524, AUCKLAND PARK
2006.

Introduction

The Cape Floristic Region (CFR) is one of the world's most unique ecosystems and one which been listed as an endangered bioregion (CEPF 2002). In addition to the endangered status of the region, the fish fauna of this region has a high degree of endemism where as many as 16 of the 19 indigenous species which occur in this region are endemic to this area and 15 of these endemic species are listed on the IUCN red data list (Skelton 2001;, Impson *et al*. 2002; Woodford 2005). Conservation authorities and research specialists have agreed that a conservation management plan be established to protect and conserve the fishes of this area in-order to ensure the continued survival of these species. One component of this plan should include the establishment of a maintenance and culturing methodology for *Barbus erubescens*, *Austroglanis barnardi* and *A. gilli* in an artificial environment. These methodologies should be available to conservation authorities' in-order to harvest, maintain and culture the species in the event of a serious environmental disaster which would threaten the continued survival of the species.

Marraro *et al.* (2005) propose that in order to manage and conserve freshwater fish species, a good understanding of the reproductive biology and environmental requirements of these fishes is paramount. These environmental requirements, which have conservation importance of their own (Cambray & Hecht 1995), should include the identification and simulation of the required spawning conditions of the species being studied (De Villiers 1991). The differences in the natural ecosystem variables of freshwater ecosystems and the often complex environmental cues which the fishes require to carry out specific life stages makes the understanding of and the provision for these conditions important to this type of research.

Maintaining/culturing freshwater fishes in artificial environments is often not easily achieved (Lickey *et al.* 1970). Difficulty is often experienced in attempting to provide a suitable artificial environment (based on water quality and quantity, substrate and flow provision as well as a suitable lighting regime) for the species being maintained and then to provide suitable nutritional requirements for the species to achieve optimal growth and gonad recrudescence.

Some criticism to the traditional approach taken by conservationists to culture rare or threatened species in artificial environments for re-release into natural ecosystems has been raised. Conservationists are of the opinion that the traditional approach of using selected breeding stock to generate a large stock of a species for re-release can actually hamper conservation efforts by promoting the dominance of a selected and possibly inferior gene-pool of organisms. These specialists suggest that this approach should remain as a "last resort" to saving a critically threatened population of fishes and that upon release the breeding stock used should be released with the offspring (Kleynhans 2003; De Villiers 2005 & pers. comm.).

The aim of this study is to assess the ecological preferences of three endangered species in order to maintain and culture them successfully. The specific objectives set to achieve this aim include:

- Assess the general environmental parameters of the aquatic ecosystems where the threatened species naturally occur.
- Acquire substrate material from the natural ecosystems for the construction of an artificial culturing system at the UJ.
- Construct an artificial culturing facility in the aquarium at the UJ, to replicate the habitat and physico-chemical variables of the natural ecosystems.
- Acquire wild stocks of fishes of the selected species.
- Assess the preferences of each species to maintain and culture them.
- Develop the ecological requirement framework for each species in terms of habitat and physico-chemical variables.
- Develop a culturing and breeding protocol for each species.

Materials and Methods – General environmental parameter preferences.

The general environmental parameters of the Rondegat, Noordhoeks and Twee rivers were briefly assessed whilst keeping the concept of the species selection to specific ecosystems variables in mind. Habitat requirement of fishes refers to the abiotic features of the environment which is necessary for the continued survival or individual and/or populations of fishes (Rosenfeld 2003). According to Kleynhans (2003), the species requirements to environmental parameters refer to the degree to which a species is able to withstand alterations of the environmental conditions under which it occurs. These requirements furthermore relate to the ability of each species to complete specific life-stages in a given ecosystem based on the environmental requirements of the species. In this study only habitat selection (or preferences) of each species being assessed was considered. The rationale which exists behind this approach is that if one can assess the environmental requirements of the species and then maintain these conditions in natural ecosystems, the species would be able to complete all life-cycle components. Similarly, if one can replicate these conditions in an artificial environment again, the species should be able to complete all life-cycle components. The environmental variables which were considered in this study includes: depth/flow classes where the fish were observed, substrate preferences of the observed/sampled fishes, flow tolerances/requirements of the species and water quality tolerances/requirements.

The habitat assessment technique implemented in this study has been primarily based on the approach adopted by Kleynhans (2003) to assess the preferences of fishes. Based on the habitat variables including depth/flow classes, substrate variables, flow and water quality requirements, the approach implemented contains three components; the assessment of the availability of each habitat variable, the sampling success of each habitat variable and finally the occurrence of each species researched within each habitat variable

The sampling techniques implemented during this study to sample fishes included the use of a 2.6KVA 220V (AC) electro-fisher in all shallow and some deep habitats and a small (15 m) and medium (30 m) sized seine nets (mesh size 8 mm) which was used in all deep habitats. In addition a snorkeling approach was adopted to facilitate the establishment of habitat preferences of the fishes surveyed in the Rondegat and Twee rivers.

Two *in situ* surveys were carried out during the course of this study; the first (3-15 November 2004) was focused on assessing the environmental conditions of the Rondegat, Noordhoeks and Twee rivers, where the species occur and to collect substrate material which would be used in the establishment of an artificial maintenance/culturing facility at the UJ. The aim of the survey was to sufficiently assess the ecological parameters (depth/flow classes where the fish were observed, substrate preferences of the observed/sampled fishes, flow tolerances of the species and water quality tolerances) of the system in-order to establish a comparable but artificial system in the Aquarium of the UJ.

The second survey (12-18 December 2005) was carried out with the aim of breeding *A. gilli* and *A. barnardi in situ* from the Rondegat and Noordhoeks rivers. However, during the second survey additional *B. erubescens* were collected and the environmental parameters of the Twee River were also assessed.

Construction of a maintenance/culturing facility.

Following the environmental parameter assessments, findings of these surveys and information from past studies have been used in the design and then construction of the maintenance and culturing facilities in the aquaria of the UJ. These facilities were constructed in the environmental control rooms of the UJ aquaria. The environmental control rooms in the aquaria of the UJ allow researchers to control the temperature and lighting cycles for the room. All maintenance/culturing facilities were placed into one of these environmental control rooms where ecosystem conditions could be replicated.

Environmental preferences of the species being assessed in this study indicated that different facilities were required to maintain and culture the three species. However, all species have a strong preference for submerged rock and to mimic the natural environment, about 500 kg of mixed sand, gravel and cobble was collected in the Cederberg (away from the river bank) for use in UJ maintenance and culture aquaria.

Figure 5.1. presents a schematic diagram of the re-circulating flow through system which was constructed in an environmental room in the aquarium of the UJ. The second system constructed was designed to maintain the *B. erubescens* (Figure 5.2). This simple tank system consisted of a large (1.2 m (length) x 0.6 m (width) x 0.6 m (height)) tank, an approximately 0.45 m^3 system of water excluding the biological filter. As in the housing facility for the *Austroglanis spp.* maintenance facility another 110 l biological filter was included in this system. The third system constructed, was designed to culture the *Austroglanis spp.* (Figure 5.3). This simple tank system consisted of a hexagonal channel (300 mm deep and approximately 400 mm wide) build out of glass panes with a glass hexagonal centre. Water was pumped in an anti-clockwise direction by submersible pumps placed into the channel. The flow rate and substrate provided was related to the flow rates determined to be preferred by the two *Austroglanis spp.*

The water used for each system was “soft” reconstituted water. Reverse Osmosis (RO) water and laboratory grades of various salts were used to make up the reconstituted water according to APHA (1992) methodology. In this reconstituted water the final salt ionic concentrations were approximately 3.3 mg Na/l, 1.8 mg Ca/l, 1.5 mg Mg/l, 0.26 mg K/l and 0.24 mg Cl/l. 15% of the water of the *Austroglanis spp.* maintenance system was replaced/topped-up on a bi-weekly basis. 10% of the water was replaced bi-weekly for the rest of the systems. Throughout the study general *in situ* water physico-chemical variables including conductivity, oxygen concentration and % saturation and pH were monitored. The temperatures and day-night cycles of the control room and as a result the systems were managed thorough the study according to the following cycles:

The light-darkness cycles were maintained from 12h light: 12h dark initially during the conditioning period of all fish to 14h light: 10h dark during the conditioning and experimental period of the study. Temperatures were managed from $18^{+}/_{-}1^{o}$C during the acclimatisation period to $23^{+}/_{-}1^{o}$C maximum during the conditioning period.

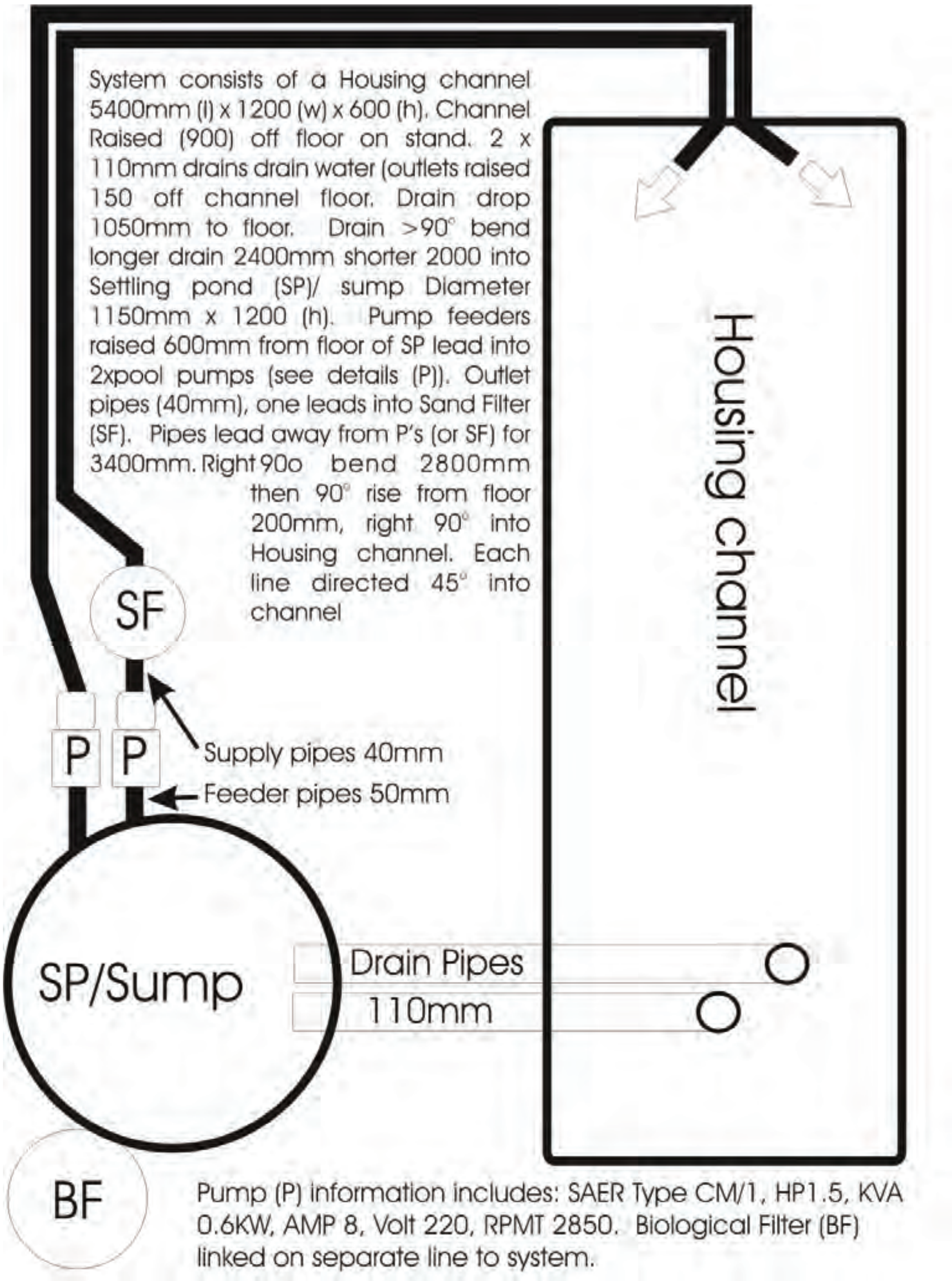

Figure 5.1. Schematic diagramme of the re-circulating flow through system what was constructed in the aquarium of the UJ to house the *Austroglanis spp.*

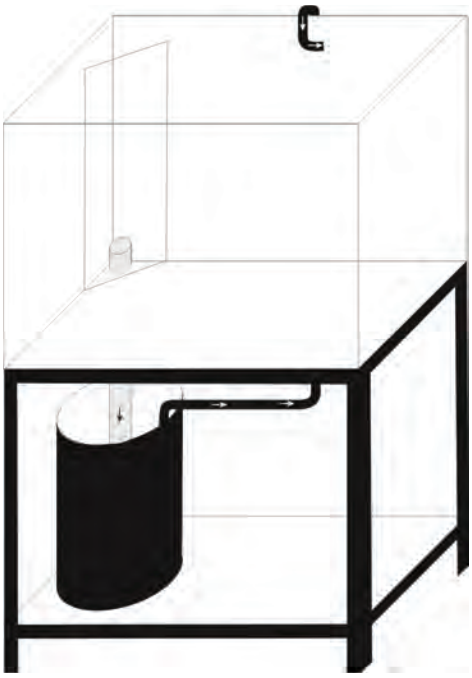

Figure 5.2. Schematic representation of the maintenance facility used to house *B. erubescens.*

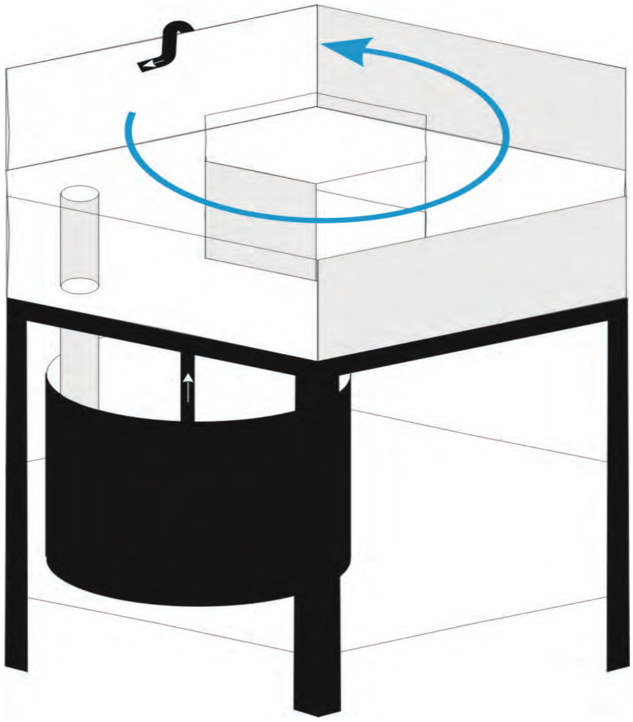

Figure 5.3. Schematic representation of the culturing facility used to carry out breeding experiments on the *Austroglanis spp.* Blue arrow shows the movement of water.

Acquire individuals and maintain species

For this study a permit (Cape Nature no: AAA003-00042-0011) was issued to the UJ to collect and study 50 individuals of each species. Individual *A. gilli*, *A. barnardi* and *B. erubescens* specimens were collected by Mr. R.Bills (SAIAB) and Mr. D. Impson (Cape Nature) from the Noordhoek and Twee rivers during a survey carried out in February of 2005. Twenty two *A. gilli*, 19 *A. Barnardi* and 26 *B. erubescens* were successfully airfreighted from Cape Town to Johannesburg and then acclimatised in the artificial systems at the UJ. Throughout the acclimatization period (two weeks) only 4 individual *A. barnardi* and one *A. gilli* were lost. Surprisingly the *B. erubescens* began to jump out of the system after about 10 days of acclimatising. Three individual *B. erubescens* were lost in this way before a net was used to cover the tank.

A vital component of this study was to successfully feed the fish in an artificial environment in order to satisfy their nutritional requirements and to "condition" the individuals. Due to all species being considered to be predacious, the dominant food source consisted of live and frozen Chironomid larva (Blood worms). In addition supplementary food sources included lettuce leaves, chopped up earth worms and high protein fish flakes and pellets. All *Austroglanis spp.* individuals began to feed very slowly at first but then began to feed more aggressively after approximately one week. Only enough food which was completely consumed in 20 min was provided.

Breeding experiments – In situ experimentation with adult fishes.

During the study a conditioning and breeding assessment was carried out *in* situ in December 2005 for both *Austroglanis spp*. This experiment was carried out along the Rondegat River, at the Rangers station at the Algeria campsite. Nine 1.2 m lengths of PVC guttering were used to create the artificial environment which housed the fishes during the experiments (Figure 5.4). Initially the water was re-circulated through the system but due to temperature fluctuations (approximately 8^{o}C per day) the design was change into a flow through system. Piped river water was supplied to the channels and a feed-through system was established were the water flowed through the channels and back into the river. During the course of the experiment general water physico-chemical variables (conductivity, temperature, oxygen and pH) were monitored using a WTW 350i multi meter.

Twenty eight *A. gilli* (22 x from the Rondegat River and 6 from the Noordhoeks River) and 16 *A. barnardi* (from the Noordhoeks River) were used in the experiments. The experiments involved collecting general health, length and weight data from each individual and then to carry out induced spawning experiments on the individuals using Aquaspawn. Both *Austroglanis spp.* were studied. Six individuals at a time (ratio 1:3 ♂:♀) were injected with different concentrations of aquaspawn. The females selected in the experiments were all gravid and it was not possible to determine the state of the males. Individuals were injected with 0.1 ml and 0.2 ml of aquaspawn following the methods adopted by Dr H. Kaiser in the practical guidelines to breed and rear *Synodontis* petricola by the Department of Ichthyology and Fisheries Science, Rhodes University.

<u>Experiment 1:</u>

1. Treated 6 individuals of *A. gilli* with 0.1 ml aquaspawn ratio of 1:3 ♂:♀.
2. Two ♀'s and one ♂ were sacrificed after 24hrs to attempt artificial fertilization.
3. Retreated all individuals with 0.1 ml aquaspawn.
4. 48hrs – Remaining three individuals were sacrificed to attempt artificial fertilization.

<u>Experiment 2:</u>

1. Treated 6 individuals of *A. gilli* with 0.2 ml aquaspawn ratio of 1:3 ♂:♀.
2. Two ♀'s and one ♂ were sacrificed after 24hrs to attempt artificial fertilization.
3. Retreated all remaining individuals with 0.2 ml aquaspawn.
4. 48hrs – Remaining three individuals were sacrificed to attempt artificial fertilization.

<u>Experiment 3:</u>

1. Treated 3 individuals of *A. barnardi* with 0.1 ml aquaspawn ratio of 1:3 ♂:♀.
2. 24hrs later – retreated all individuals with 0.1 ml aquaspawn.
3. 48hrs – all individuals were sacrificed after to attempt artificial fertilization.

<u>Experiment 4:</u>

1. Treated 3 individuals of *A. barnardi* with 0.05 ml aquaspawn ratio of 1:3 ♂:♀.
2. 24hrs later – retreated all individuals with 0.1 ml aquaspawn.
3. 48hrs – all individuals were sacrificed after to attempt artificial fertilization.

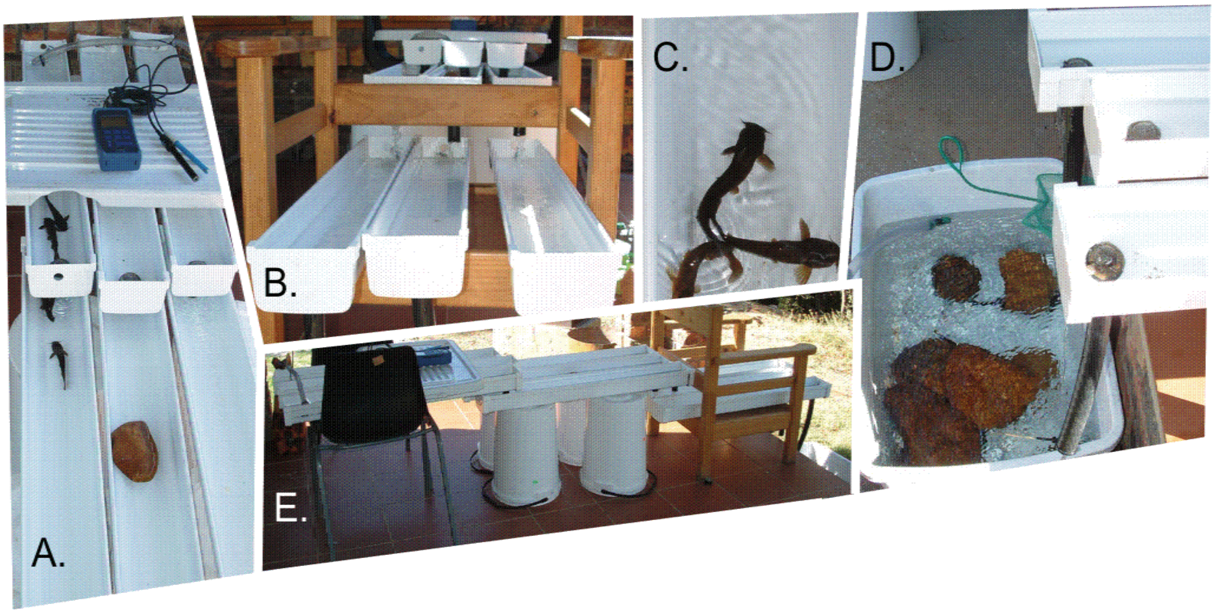

Figure 5.4. *Austroglanis sp.* in situ breeding experiment equipment. Diagrams represented are (A., B. and E.) the channels which housed the fish. Diagram C. depicts a group of *A. barnardi* in the channel and D. depicts the sump where the original stock of fish was kept.

Experimentation with adults in aquaria at UJ.

Laboratory based breeding experiments included the treatment of conditioned *Austroglanis spp.* specimens and the attempt to bring all *B. erubescens* individuals into breeding conditions for a breeding experiment. Within the laboratory the environmental conditions of the environmental control room were changed gradually over a two month period from an initial light/darkness cycle of 12hrs light and 12hrs darkness to 14 hours light to 10 hours darkness. The temperature of the system was additionally altered from $21^{o}C$ to 23.5 ($^{+}$/. $1^{o}C$) over the two month period.

In the laboratory an artificial closed flow through system was established for use in the spawning experimentations of the *Austroglanis spp*. This flow through system was constructed in the same manner as the system established in the field. As in the field two breeding experiments were undertaken per species based on the Aquaspawn treatment proposed by Dr H. Kaiser in the practical guidelines to breed and rear *Synodontis petricola* by the Department of Ichthyology and Fisheries Science, Rhodes University. The experiments involved the once off exposure of 0.1 ml and 0.2 ml of aquaspwan in the *A. gilli* experiments and 0.1 ml and 0.05 ml of aquaspawn in the *A. barnardi* experiments.

Before a final round of breeding experiments could be carried out a series of system management problems occurred which resulted in massive mortalities of all individuals. Following these problems the remaining specimens were heavily impacted and the conditions of all specimens dropped. Without a new stock of individuals and time to condition these new individuals these experiments were concluded.

Results and discussion – Habitat preferences of the species.

The habitat assessment of the Noordhoeks, Rondegat and Twee rivers which were carried out in this study were carried out in a manner which would allow for the determination of the habitat preferences of the three fishes being researched in this study. Results (Table 5.1) indicate that each river assessed in this study was unique in terms of the dominance of specific habitat types and the habitat requirements of the fish.

The Rondegat River is dominated by fast-shallow habitats in the form of glide, riffle and rapid biotopes. The Rondegat River has numerous deep (fast and slow) habitats which primarily comprise of pools with a depth greater than 0.5 m. As is the case in the fast-shallow habitats, the pools are dominated by a sandstone cobble and boulder substrate. The Rondegat River has an abundance of marginal, overhanging vegetation, isolated clumps of aquatic vegetation and the undercut banks which provide substrate and cover functions to the aquatic biota of the system.

A. gilli individuals were only sampled from cobble/boulder substrates and as expected the preference scores of the habitat preference/requirement reveal a strong preference for substrate and for all flow depth habitat types.

In comparison to the historical determination of the habitat and environmental variable preferences of *A. gilli* (Table 5.1), the results from this survey follow a very similar trend to the historical assessment, i.e. a sensitive species with a requirement for clean flowing water in a silt free cobble dominated river.

Table 5.1. Overview the habitat preferences of the three fishes being assessed in this study.

Variables and variable categories		Historical data (Kleynhans 2003)				Survey data		
		Rating range	AGIL	ABAR	BERU	AGIL	ABAR	BERU
Depth / Flow classes	Fast deep	Any	3.5	N/A	N/A	3.2	0.0	0.3
	Fast shallow	Any	3.7	5	N/A	3.3	4.0	0.7
	Slow deep	Any	3.5	N/A	4	3.4	2.3	4.6
	Slow shallow	Any	3.5	N/A	N/A	2.4	2.4	1.9
Substrate preferences	Overhanging vegetation	>3	N/A	N/A	N/A	1.7	2.4	2.3
	Undercut banks	>3	3.5	N/A	N/A	3.4	1.3	0.8
	Substrate	>3	4.7	5	4	4.9	4.7	3.6
	Aquatic macrophytes	>3	N/A	N/A	3.5	1.2	1.3	2.3
	Water column	>3	N/A	N/A	4	2.3	1.3	3.9
Flow Tolerance	Int. no-flow	>4	4.7	5	4.5	4.7	5.0	4.5
	Mod. Int. no flow	>3-4	N/A	N/A	N/A	N/A	N/A	N/A
	Mod. Tol. no flow	>2-3	N/A	N/A	N/A	N/A	N/A	N/A
	Tol. no flow	1-2	N/A	N/A	N/A	N/A	N/A	N/A
Water Quality tolerances	Int. wq	>4	4.3	5	N/A	4.3	5.0	N/A
	Mod. Int. wq	>3-4	N/A	N/A	3.5	N/A	N/A	3.5
	Mod. Tol. Wq	>2-3	N/A	N/A	N/A	N/A	N/A	N/A
	Tol. Wq	1-2	N/A	N/A	N/A	N/A	N/A	N/A

Note: AGIL refers to *A. gilli*
ABAR refers to *A. barnardi*
BERU refers to *B. erubescence*

The Noordhoeks River occurs in the same eco-region as the Rondegat River (Western Folded Mountains) and as a result the surrounding vegetation types (Sandstone Fynbos) are similar. The Noordhoeks River is significantly smaller than the Rondegat River, in terms of channel size. This river is dominated by fast-shallow habitats in the form of riffle and rapid biotopes with some slow habitats (pools) which separate extensive riffle/rapid habitats.

A. barnardi individuals were predominantly sampled in the fast shallow habitats and exclusively between the cobble substrate. In comparison to the historical determination of the habitat and environmental variable preferences of *A. barnardi* the results from this survey confirm that the species is a habitat specialist, requiring fast-shallow habitats, substrate (cobble and possibly boulders), extremely intolerant to no-flow conditions and intolerant to water quality alterations.

The Twee River was completely different to the Rondegat and Noordhoeks rivers. This system was dominated by instream and backwater pools (slow-deep and slow-shallow habitats), with isolated riffles and cascades (fast-shallow and deep habitats) which separated these pools. In this system overhanging vegetation, aquatic macrophytes and complex substrate in the form of boulders and fractured bedrock predominantly were abundant and provided good habitat for *B. erubescens*. These habitat types and good water column (up to three meters in some pools) provided good habitats to assess the habitat preferences of this species.

Table 5.2. In situ water quality variables sampled in each system during the habitat assessments.

Water Parameters	Tweede River	Noordehoek River	Rondegat River
Conductivity (µS/cm)	32	28	29
pH	6.09	6.2	6.1
O2	7.07	6.85	6.8
Dissovled O2 (%)	82%	78.2	79.1
Temperature (ºC)	19.9	21.5	20.8

All three rivers had similar water chemistry from the water quality data taken in the field. The water quality assessment of the system was included to facilitate the assessment of the habitat preferences of the fishes being studied. Table 5.2 presents the results of the *in situ* water quality assessment. Results indicate that all systems are highly oxygenated systems with a slightly acidic pH, and a very low conductivity.

Establishment of the maintenance facilities.

The *Austroglanis spp.* maintenance system proved to be adequate to sustain both *A. gilli* and *A. barnardi*. Both species demonstrated high preferences for substrate in the form of cover. After an acclimatisation period of six week behavioural observations revealed that all individuals displayed territorial behaviour. This territorial behaviour was deemed to be more intra-specifically pronounced where *A. gilli* individuals would aggressively compete with other *A. gilli* individuals and similarly *A. barnardi* individuals would aggressively compete with other *A. gilli* individuals. This behaviour was based on size and did not appear to be based on the sex of the individuals. During feeding, this behaviour was reduced and all individuals would temporarily leave cover to feed aggressively. During the entire conditioning period, although the condition of both species seemed to be improved to approximate field conditions, no change in breeding related behaviour was noted. Individuals of both species (12 *A. gilli* and 16 *A. barnardi* – ♂:♀ ratio of 1:2) were selected for breeding experiments in the *Austroglanis spp.* culturing system. During this experiment the environments of the culturing and the maintenance systems were altered to determine if changes in the temperature, and day night cycles would result in any breeding behaviour. In addition, the diet of the selected breeding experimental individuals were changed to include mashed earth worms, live daphnids and live chironomid larva which were all preyed upon with aggression by the individuals. Observations made during the light and dark period of the experiment resulted in no changes in behaviour. During all laboratory experiments no breeding experiments were successful. The *in situ* breeding experiments revealed little success in that only a few of what appeared to be viable eggs were released by *A. gilli* and *A. barnardi* individuals into the experimental channels which were being used in the experiments.

Culturing experiments of the *B. erubescens* individuals were initiated by changing the environmental conditions of the environmental room and altering the diet of the individuals. The condition of the individuals began to improve and the colouration of the fish began to change. Males were easily distinguishable from females by the end of the experiment which did not result in any breeding behaviour.

Culturing techniques.

All breeding experiments were unsuccessful as no viable offspring were produced in this study. The breeding experiments conducted *in situ* produced no offspring but eggs were released by both *Austroglanis spp.* into the breeding channels. *A. gilli* females injected with 0.2 ml of aquaspawn released very few eggs into the exposure channels. *A. barnardi* females treated with both 0.1 ml and 0.05 ml of aquaspawn had eggs released into to exposure channels. Only very few eggs (no more than 20 released by as many as three individuals per channel) were released into the channels. No laboratory based experiments resulted in the production of eggs or any altered behavior which may be attributed to a breeding behavior.

Conclusions

The habitat preference assessments of the *Austroglanis spp.* revealed that both species require very specific environmental conditions. The Rondegat and Noordhoeks rivers are two of the few remaining tributaries of the Olifants River catchment which still contain a relatively natural fish fauna. These two tributaries have stable populations of *Austroglanis spp*. which due to their current threatened status and our limited understanding of their biology elevates the conservation value of these systems. Should the impacts of the surrounding catchment extend into these tributaries the results may be catastrophic to these remaining refuges.

Similarly the habitat preference assessment of *B. erubescens* in this study reveals that this species is a specialist and provision for slow-deep habitats as well as the cobble/boulder substrates must be maintained. System specifics include the provision of flows for these species and to a lesser degree the maintenance of the water quality. Similarly, due to the highly utilised and related, impacted state of the tributaries of the Twee River (CFR) the remaining refuges of this species are considered to be extremely important for the continued survival of this species.

Maintenance experiments were successful and this study has determined that if preferred habitats of each individual are provided and a varied diet of frozen and live chironomid larvae, live cladocera and earthworms are provided, maintaining all three species can be achieved. Breeding experiments were unsuccessful and this study did not establish breeding protocols for any of the three species studied. Findings however suggest that a successful protocol can be achieved with extended research into this topic.

Acknowledgements

Acknowledgements for support on this study must be made to all of the collaborators specifically Roger Bills and Dean Impson for continued support in all areas of this project. Secondly to fellow University of Johannesburg for support in this endeavour, including Victor Wepener, Richard Greenfield, Solomon Tshabalala, Nkhacani Mathonsi Mithiel-nell Jonker, Martin Ferreira, Maryke Coetzee, Cameron von Bratt, Mathew Ross and Melissa Brand.

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6. BIOLOGICAL STUDIES ON *AUSTROGLANIS* ROCK CATFISHES FROM THE OLIFANTS-DORING RIVER SYSTEM.

VUSI MTHOMBENI

SOUTH AFRICAN INSTITUTE FOR AQUATIC BIODIVERSITY (SAIAB), PRIVATE BAG 1015, GRAHAMSTOWN 6140. (E-MAIL: Vusi.Mthombeni@agr.ecprov.gov.za)

Introduction

The indigenous freshwater ichthyofauna of the Western Cape Province of South Africa is considered as one of the most threatened in Africa (Impson *et al*. 2000). This fauna is characterized by low diversity, a high level of endemicity and a low resilience to disturbance (Skelton 1987, 1994; Skelton *et al*. 1995). Many of these fish also have highly restricted geographical and ecological distributions and 13 of the 19 indigenous fishes are IUCN red-listed IUCN (2009). Consequently, the two endemic catfish of the province, Barnard's Rock Catfish (*Austroglanis barnardi* Skelton 1981) which is endangered; and the Clanwilliam Rock Catfish (*Austroglanis gilli* Barnard 1943) which is vulnerable require a conservation intervention. These two species are endemic to the tributaries of the Olifants River in the Cederberg area (Skelton 1987, 2001). Previous studies showed that *A. gilli* from the Rondegat and Jan Dissels rivers are genetically distinct from each other and from species found in other rivers (Impson *et al.* 2000). While management of these species is a priority, the development of effective management depends on good information on the biology and ecology of a species and this is presently lacking. The primary objective of this study was therefore to investigate the biology and ecology of *A. barnardi* and *A. gilli* in the Olifants River System and to use this information to make recommendations for management interventions necessary for their conservation.

Methods

The samples of *A. gilli* and *A. barnardi* from the Noordhoeks River, and *A. gilli* from the Rondegat River, collected by electric-fishing and seine netting from 1996 to 1999 were used for feeding and breeding studies. Specimens were collected by SAIAB and Cape Nature staff and all are accessioned in the South African Institute for Aquatic Biodiversity (SAIAB) fish collection. A complete list of specimens is available from SAIAB (http://saiab.ac.za/loans/index.asp). The fish were fixed in the field using 10% formalin solution and later stored in 70% ethanol.

On assessment of existing samples, it was found that the otoliths of fish in the collection had deteriorated as a result of the use of formalin as a fixative. Additional seasonal samples were collected in January 2005 (summer); July 2005 (winter); September 2006 (spring) and November 2006 (summer). Fish standard length (SL), fork length (FL) and total length (TL) of each fish was measured to the nearest millimeter. Subsequently, otoliths from these samples were removed in the field and were stored dry in marked capsules for later processing in the laboratory. After the removal of the otoliths, the fish were fixed in formalin and accessioned into the SAIAB collection to supplement samples for diet and gonad analysis. The November samples also supplemented feeding studies and were also important for breeding studies as this is the breeding peak for both species.

Otolith length and width were measured using a calibrated ocular eyepiece fitted to a compound microscope. Either the left or the right otolith was randomly selected for ageing as there was no obvious asymmetry in both of them. This otolith was embedded in a clear polyester casting resin. The otoliths were then ground using 100 grit sandpaper to expose its nucleus. The otolith was ground longitudinally, on both sides, to result in a section. Subsequently, 800-grit sand paper was used to smooth the section. Grinding was undertaken until growth zones became visible. The otolith sections were then mounted on slides using DPX mountant and viewed under a dissecting microscope at 10X magnification. The prepared otolith specimens were read in a microscope by Vusi Mthombeni and Dr Olaf Weyl of the Department of Ichthyology and fisheries Science at Rhodes University. Length-at-age was modeled using the Von Bertalanffy Growth Function, which is described as $L_t = L_\infty\left(1 - \exp\left(-\left(t - t_0\right)\right)\right)$, where L_t is length at time *t*, L_∞ is the theoretical asymptotic length, *K* is the Brody growth coefficient and t_0 is the age of a zero-length fish (Ricker 1975; Cope & Punt 2007).

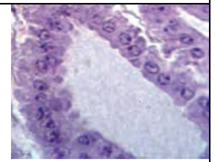
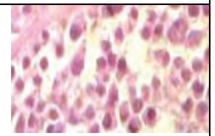
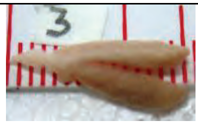
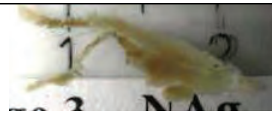
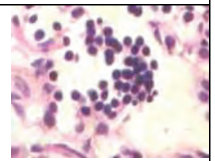
For observation, SL, FL and TL of each fish were measured to the nearest millimeter for all specimens. Subsequently the fish were dissected and the gonads and gut were removed. Gonads were staged according to the criteria presented in Tables 6.1 and 6.2.

Gonads and eviscerated body mass were weighed to the nearest 0.001g and 0.01g respectively. Female gonads collected in November which were in a spawning stage were used for fecundity studies. Dissecting needles were used to pull off the connective tissue, thereby releasing eggs from the ovary. Egg counts were done using a tally counter and the dissecting microscope with ocular micrometer facilitated the separation of eggs into sizes.

Reproductive periodicity was determined by using a gonadosomatic index (GSI) calculated by the equation: $GSI = \frac{Gonad\ mass\,(g)}{Eviscerated\ mass\,(g)} \times 100$, and by visually assessing the maturity state of the gonads in each season. Visual staging was validated latterly using histological techniques by hydrating 12 gonads through a series of increasing alcohol concentrations, clearing in xylene and then impregnating them with paraffin wax. Subsequently, they were sectioned to 8 µm using a Lipshaw rotary microtome, mounted onto a glass slide, stained using Gill’s Haematoxylin and Papanicoloau’s Eosin and were allowed to dry. To increase sample size, a further 151 representative gonads were sent to the National Health Laboratory Service and Amanzi Biosecurity for histological preparation and sectioning and staining using the same technique.

The length-at-50%-maturity (l_{50}) was determined by fitting a logistic function of the form $P_a = \left(1 + \exp^{-(l - l_{50/\delta})}\right)^{-1}$ to the proportion of reproductively active male and female fish in each 5 mm size classes (stages 3, 4, 5 and 6, Table 1) collected between October and January, where P_a is the percentage of fish matured at length L, l_{50} the length at which 50% of the fish in the size-/age class are sexually mature and δ the steepness of the ogive.

Table 6.1. Visual stages assigned for male and female *Austroglanis gilli.*

Stage	Visual description female	Visual – photo	Histological description	Histological photo	Visual description Male	Visual – photo	Histological description	Histological photo
1. Immature/ Juvenile	Hard to distinguish sex with the naked eyes. Gonad of each of the sexes appears as thin gelatinous strips.		Follicle cells, early perinuclear oocytes, late perinuclear oocytes dominate ovary.		Hard to distinguish sex with the naked eyes. Gonad of each of the sexes appears as thin gelatinous strips.		Large empty lumen surrounded by lobules containing spermatogoni a	
2. Resting	Sexes distinguishable, ovary is a little bigger than the previous stage. Eggs in the ovary are not visible to naked eye.		Ovary is dominated by early perinuclear oocytes and late perinuclear oocytes.		Testes distinguishabl e, as lobules are clearly visible for the entire strip of the branch. Testes occupy larger space than in the previous stage.		Spermatocyte s dominate lobules. Lumen is still empty.	
3. Developing	Whitish eggs clearly visible to naked eye, ovaries occupy half the body size.		Primary yolk vesicle, cortical alveoli, zona radiata, zona granulosa.		Testes are greatly enlarged, with lobule appearing partially thick.		Spermatocyte s dominate. Spermatids present in the lobules. Lumens still empty.	

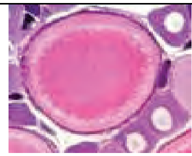
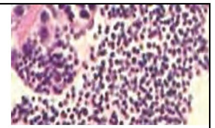
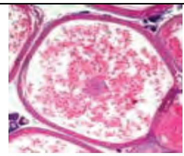
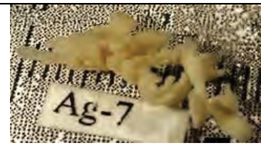
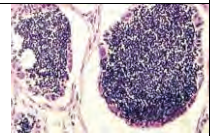
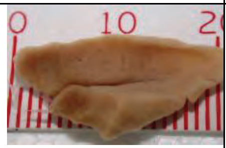
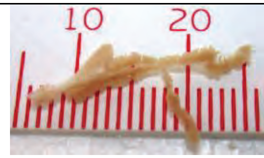
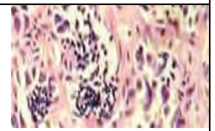
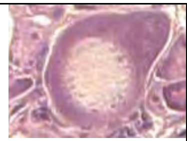
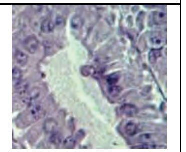
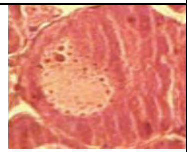
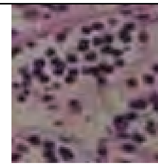
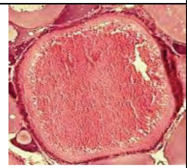
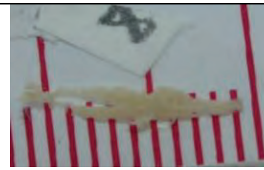
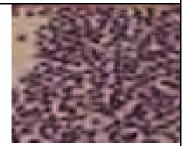
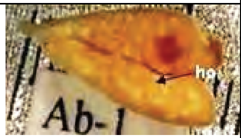
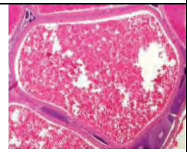
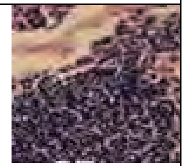
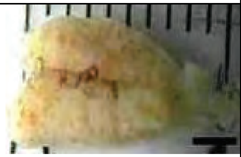
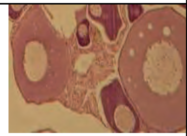
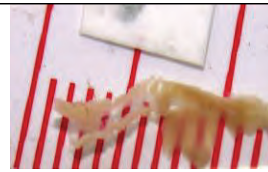
4. Maturing	Yellowish eggs are visible to the naked eye but do not appear hydrated. Ovaries occupy nearly three quarters of body cavity.		Secondary yolk vesicle. Non-vitellogenic oocytes are also present.		Lobules of the testes appear partially swollen.		Spermatids fill the lumen.	
5. Spawning	Hydrated orange eggs, ovaries occupy most of the body cavity. Oocytes of different sizes are clearly visible in an ovary		Hydrated oocytes with yolk globules which are evenly dispersed throughout cytoplasm.		Lobules of the testes are fully swollen and whitish in colour.		The lumen is dominated by spermatozoa.	
6. Spent	Ovaries appear deflated and occupy less body cavity than in the previous stage.		Atretic oocytes, but mainly dominated by oocytes of cortical alveoli stage.		Testes appear deflated with lobules appearing as stage three. However, the sizes of the testes are enlarged.		Empty lumen, sometimes contains residual spermatozoa.	

Table 6.2. Visual stages assigned for female and male *Austroglanis barnardi.*

Stage	Visual description female	Visual – photo	Histological description	Histological photo	Visual description Male	Visual – photo	Histological description	Histological photo
1. Immature/Juvenile	Hard to distinguish sex with the naked eyes. Gonad of each of the sexes appears as thin gelatinous strips.		Follicle cells, early perinuclear oocytes, late perinuclear oocytes dominate ovary.		Hard to distinguish sex with the naked eyes. Gonad of each of the sexes appears as thin gelatinous strips.		Large empty lumen surrounded by lobules containing spermatogonia	
2. Resting	Sexes distinguishable, ovary is a little bigger than the previous stage. Eggs in the ovary are not visible to naked eye.		Ovary is dominated by early perinuclear oocytes and late perinuclear oocytes.		Testes distinguishable, as lobules are clearly visible for the entire strip of the branch. Testes occupy larger space than in the previous stage.		Spermatocytes dominate lobules. Lumen is still empty.	
3. Developing	Whitish eggs clearly visible to naked eye, ovaries occupy half the body size.		Primary yolk vesicle, cortical alveoli, zona radiata, zona granulosa.		Testes are greatly enlarged, with lobule appearing partially thick.		Spermatocytes dominate. Spermatids present in the lobules. Lumens still empty	

Stage	Visual description female	Visual – photo	Histological description	Histological photo	Visual description Male	Visual – photo	Histological description	Histological photo
4. Maturing	Yellowish eggs are visible to the naked eye but do not appear hydrated. Ovaries occupy nearly three quarters of body cavity.		Secondary yolk vesicle. Non-vitellogenic oocytes are also present.		Lobules of the testes appear partially swollen.		Spermatids fill the lumen.	
5. Spawning	Hydrated orange eggs, ovaries occupy most of the body cavity. Oocytes of different sizes are clearly visible in an ovary		Hydrated oocytes with yolk globules which are evenly dispersed throughout cytoplasm.		Lobules of the testes are fully swollen and whitish in colour.		The lumen is dominated by spermatozoa.	
6. Spent	Ovaries appear deflated and occupy less body cavity than in the previous stage.		Atretic oocytes, but mainly dominated by oocytes of cortical alveoli stage.		Testes appear deflated with lobules appearing as stage three. However, the sizes of the testes are enlarged.		Empty lumen, sometimes contains residual spermatozoa.	

Some feeding structures, including the gill arch, premaxillae, dentary, lower and upper pharyngeal tooth pads were dissected out from nine specimens of *A. gilli* and seven specimens of *A. barnardi*. Muscle tissue was removed from these bony structures by cutting with a scalpel and pulling with a pair of forceps. Subsequently, these structures were soaked in 5% trypsin to remove remaining muscle tissues. They were then dried and gold-splutter coated, viewed under Scanning Electron Microscope (SEM) and photographs taken.

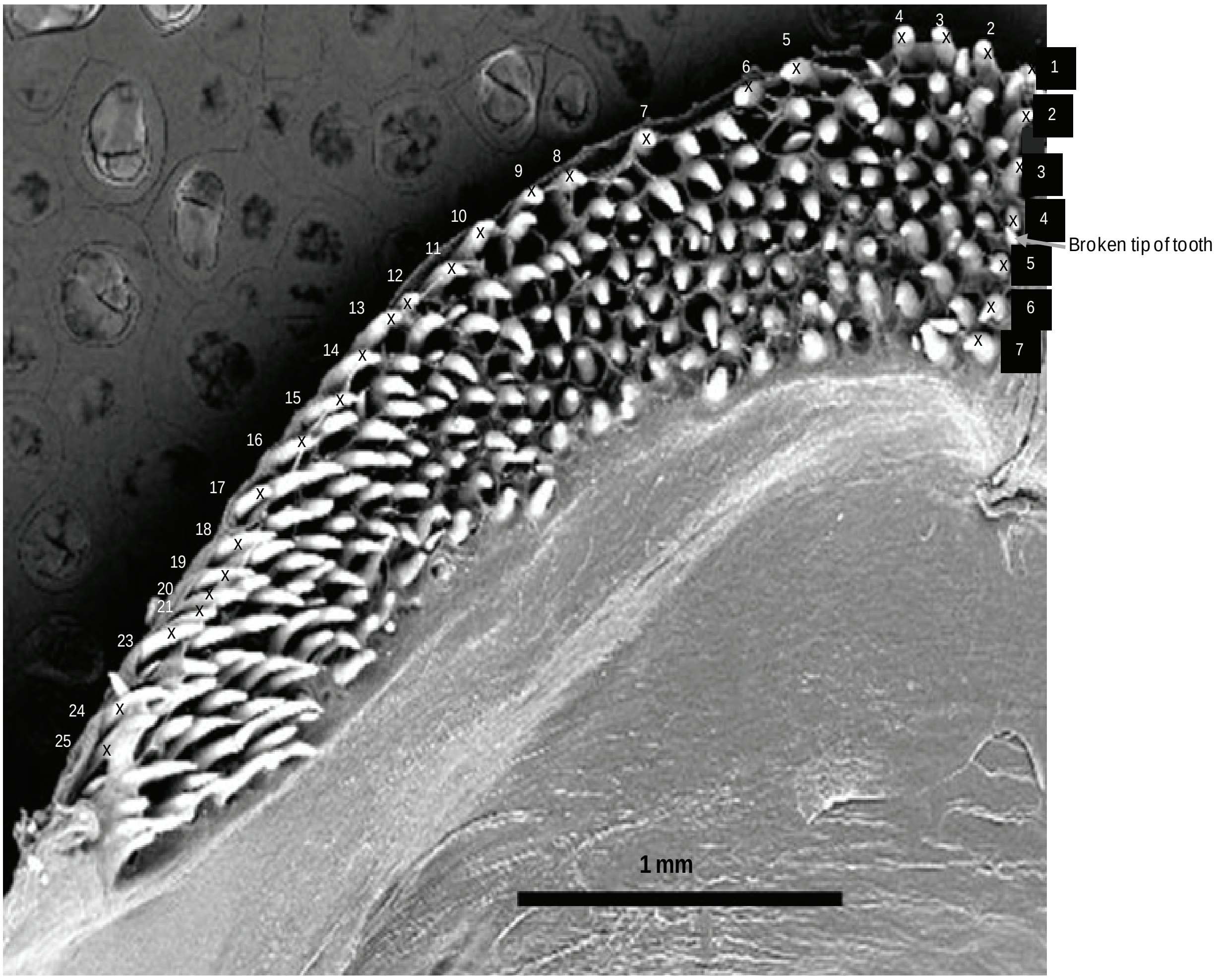


Figure 6.1. An illustration of the method used for counting the number of teeth of the lower jaw. Teeth marked with x were considered to belong to the same row along the edge.

Tooth counts were done along the outer rows of the dentary, premaxillary and lower pharyngeal tooth pads. The outer rows of the upper pharyngeal tooth pads were difficult to count as they were not clearly distinct. Counts were done also on the rows of the edges where the two halves of the lower jaw join together (Figure 6.1). Gill rakers were counted from the first gill arch.

Gut contents were assessed according to recommendations by Hyslop (1980) by using an Index of Relative Importance (IRI) expressed as: $\mathrm{IRI} = (\%\mathrm{N} + \%\mathrm{W}) \times \%\mathrm{FO}$, where %N is the number of prey items of a specific type expressed as a percentage of all prey items; %W is the total weight of any prey type as a percentage of the combined weight of all prey and %FO is the frequency of guts containing a prey taxon expressed as a percentage of all guts (Pinkas *et al.* 1971). Because invertebrate prey were all of a similar size the IRI was modified such that: $\text{IRI} = \%\text{N} \times \%\text{FO}$. This modification was previously applied to assessing the gut contents in *Pseudobarbus phlegethon* Barnard 1938 in the Clanwilliam-Olifants (Whitehead *et al.* 2007).

In order to determine ontogenic shifts in the diet, IRI was calculated for 20 mm SL size classes for *A. gilli* and in10 mm SL size classes for *A. barnardi*. Spearman rank correlation was used to test for the dependency of diet composition on fish size and season. Chi-square contingency tables (2 species X Chironomidae, Simuliidae, Baetidae, Trichoptera and others) were used to compare the diet for *A. gilli* and *A. barnardi* from the Noordhoeks River and to compare the two *A. gilli* populations.

Results

a. Age and growth

Sectioned otoliths of *A. barnardi* and *A. gilli* showed alternating opaque and translucent rings (Figure 6.2). Marginal zone analysis and marginal increment analysis showed a uni-modal peak for both species, suggesting a single annulus deposition. These rings were then used to infer age and growth for *A. gilli* and *A. barnardi*. The oldest specimens of *A. gilli* and *A. barnardi* aged 12 and 14 years, respectively. The observed length-at-age was fitted to the von Bertalanffy growth function (Figure 6.3). Growth was rapid for the first three years and thereafter started to slow down.

The average mortality rates estimated using catch curve analysis were 0.37 ± 0.12 for *A. gilli* from the Rondegat River, 0.39 ± 0.04 per year and 0.71 ± 0.05 per year for *A. gilli* and *A. barnardi* from the Noordhoeks River, respectively. The best fits for the estimated mortality rates are given in Figure 6.4.

b. Reproductive biology

Visual staging of gonads of the matured *Austroglanis* were in the spawning stage during summer and remained in the spent condition for the rest of the year (Figure 6.5). The GSI showed a similar trend, peaking in summer and remained relatively low for the rest of the year (Figure 6.6). Histology of female gonads sampled between November and January contained previtellogenic and vitellogenic oocytes in various stages of development. The resorption of yolk took place from all vitellogenic oocytes sampled between February and March. Secondary yolk vesicle oocytes started appearing in September.

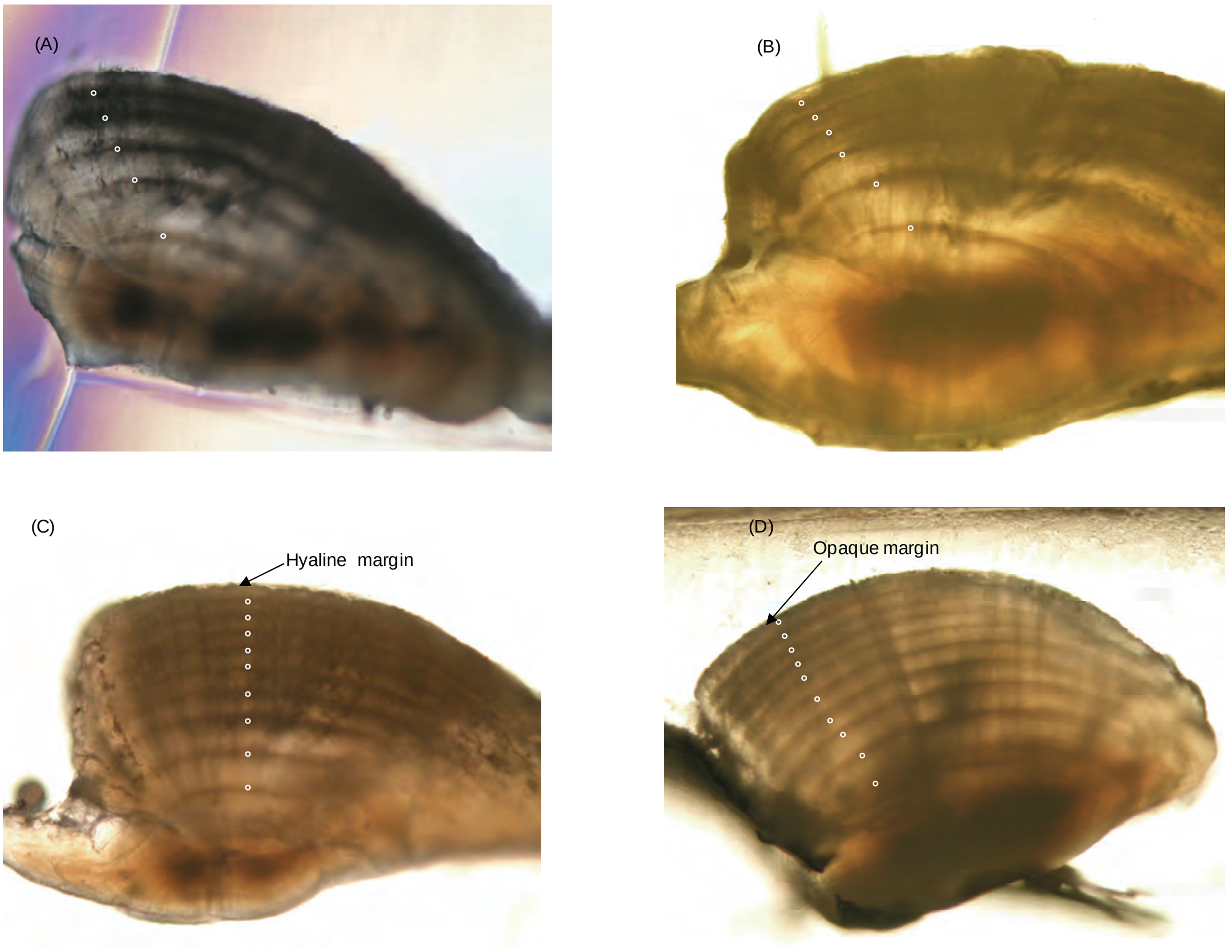


Figure 6.2. Photomicrographs of sectioned lapillar otoliths of (A) 111.3 mm SL of a five year old female *A. gilli* from the Rondegat River, (B) 142.9 mm SL of a six year old female *A. gilli* from Jan Dissels River, (C) 106.2 mm SL of a nine year old male *A. gilli* from the Noordhoeks River and (D) 66.0 mm SL of a 10 year old female *A. barnardi* from the Noordhoeks River

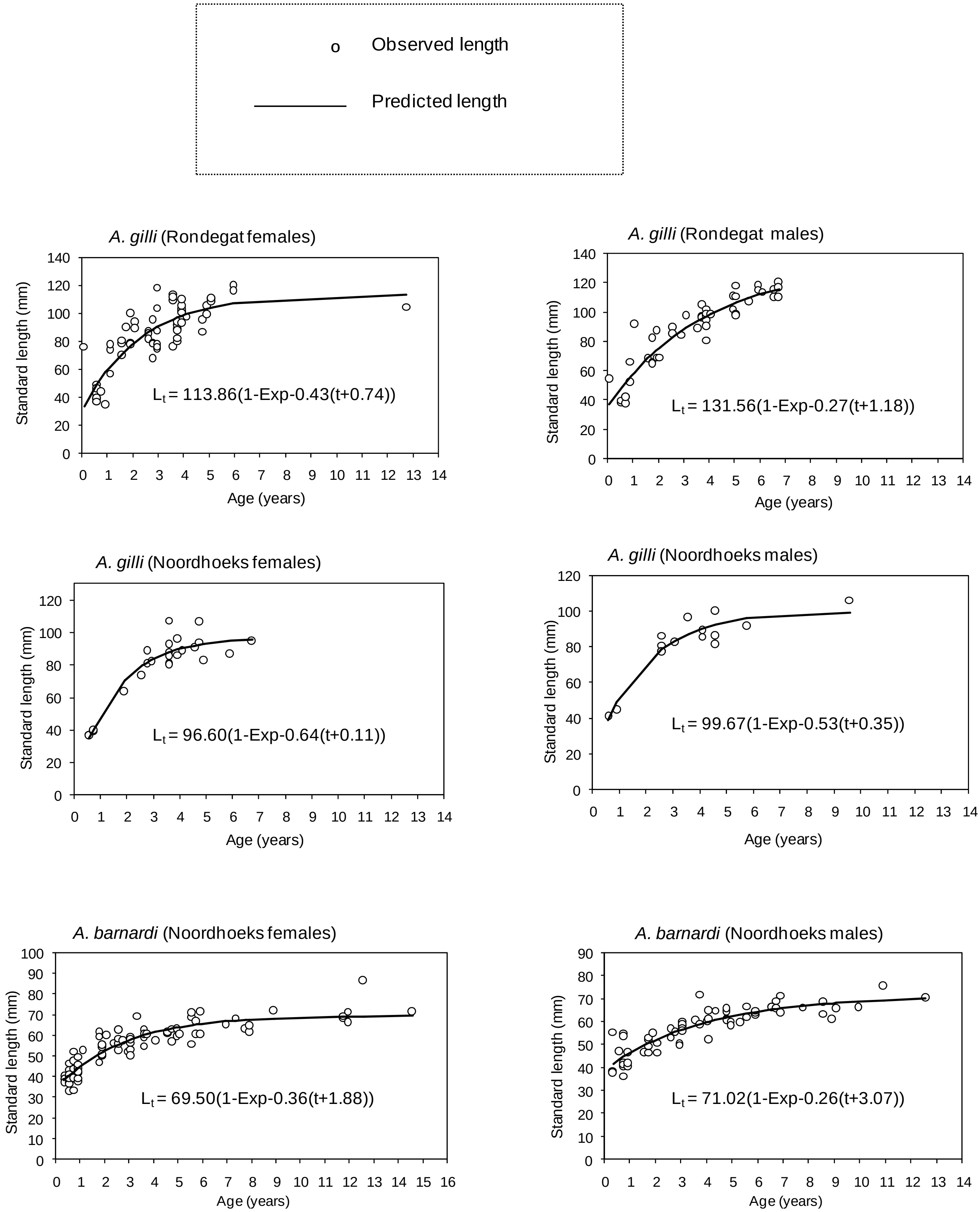


Figure 6.3. Observed individual lengths-at-age and fitted Von Bertalanffy growth functions for combined sex of *Austroglanis* populations.

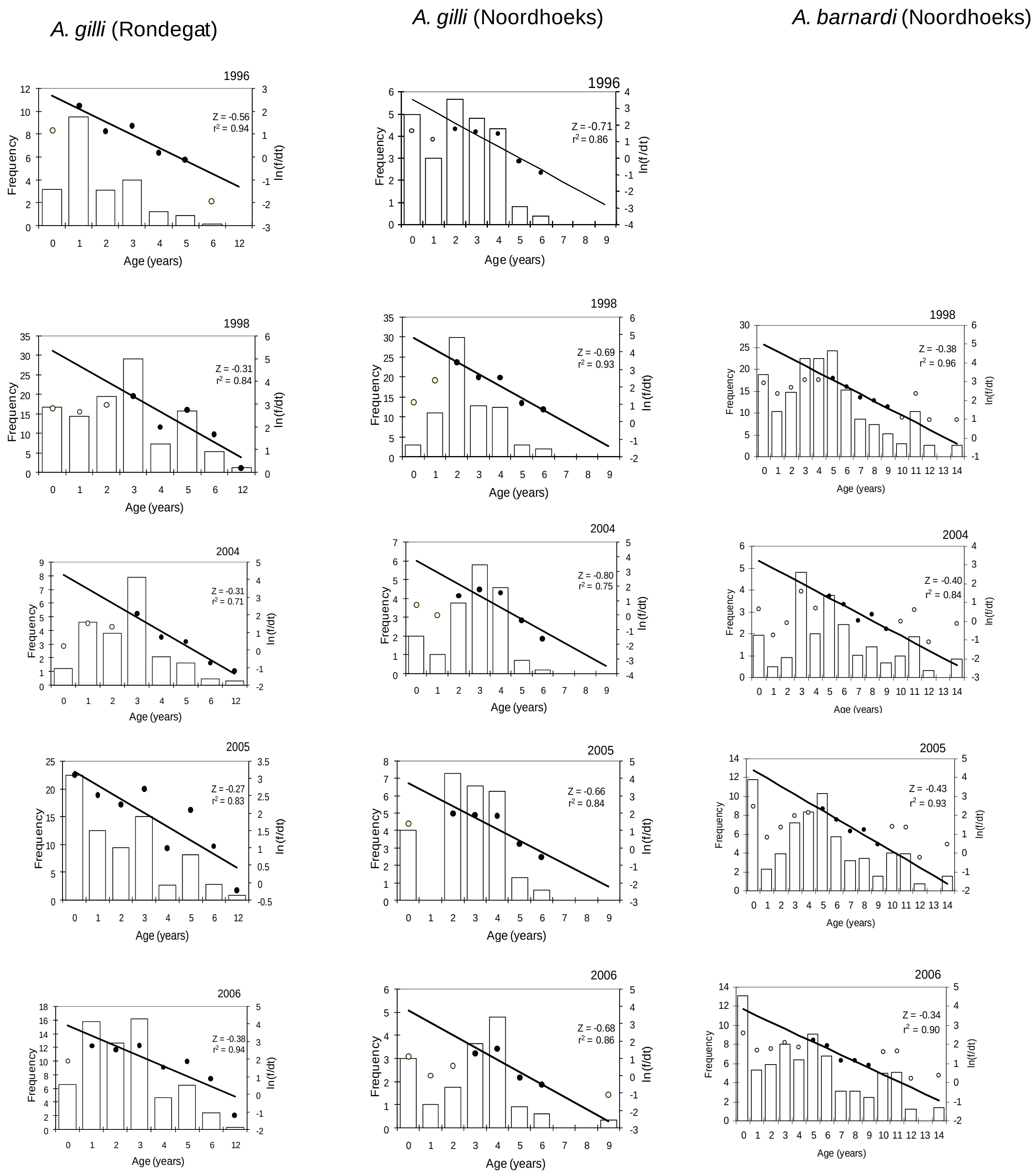


Figure 6.4. Catch curve analysis of combined sexes of *Austroglanis gilli* and *Austroglanis barnardi* sampled from Rondegat and Noordhoeks rivers.

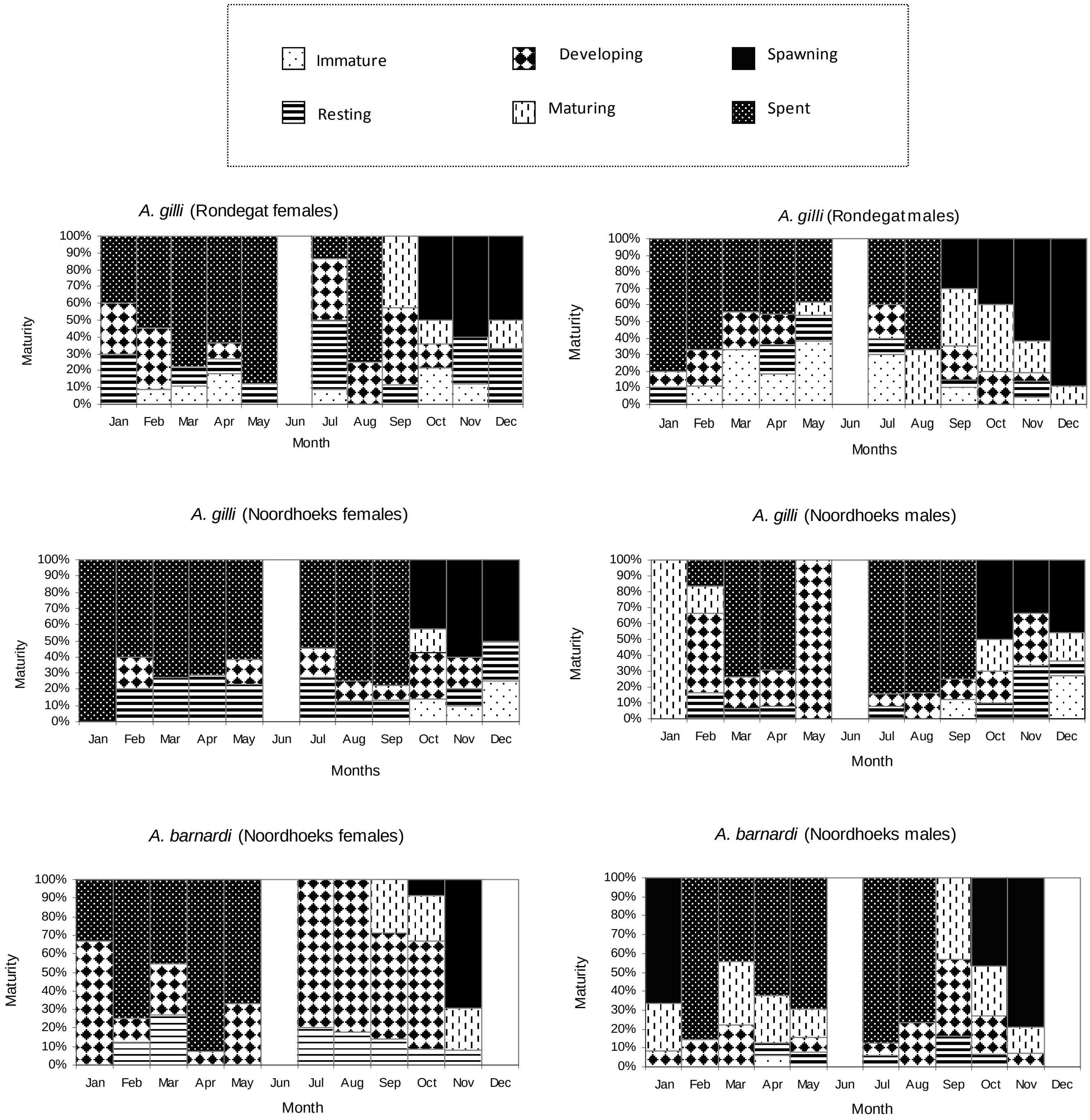


Figure 6.5. Visual assessment of the state of gonads assigned to the gonads of *A. gilli* and *A. barnardi* sampled from Rondegat and Noordhoeks Rivers

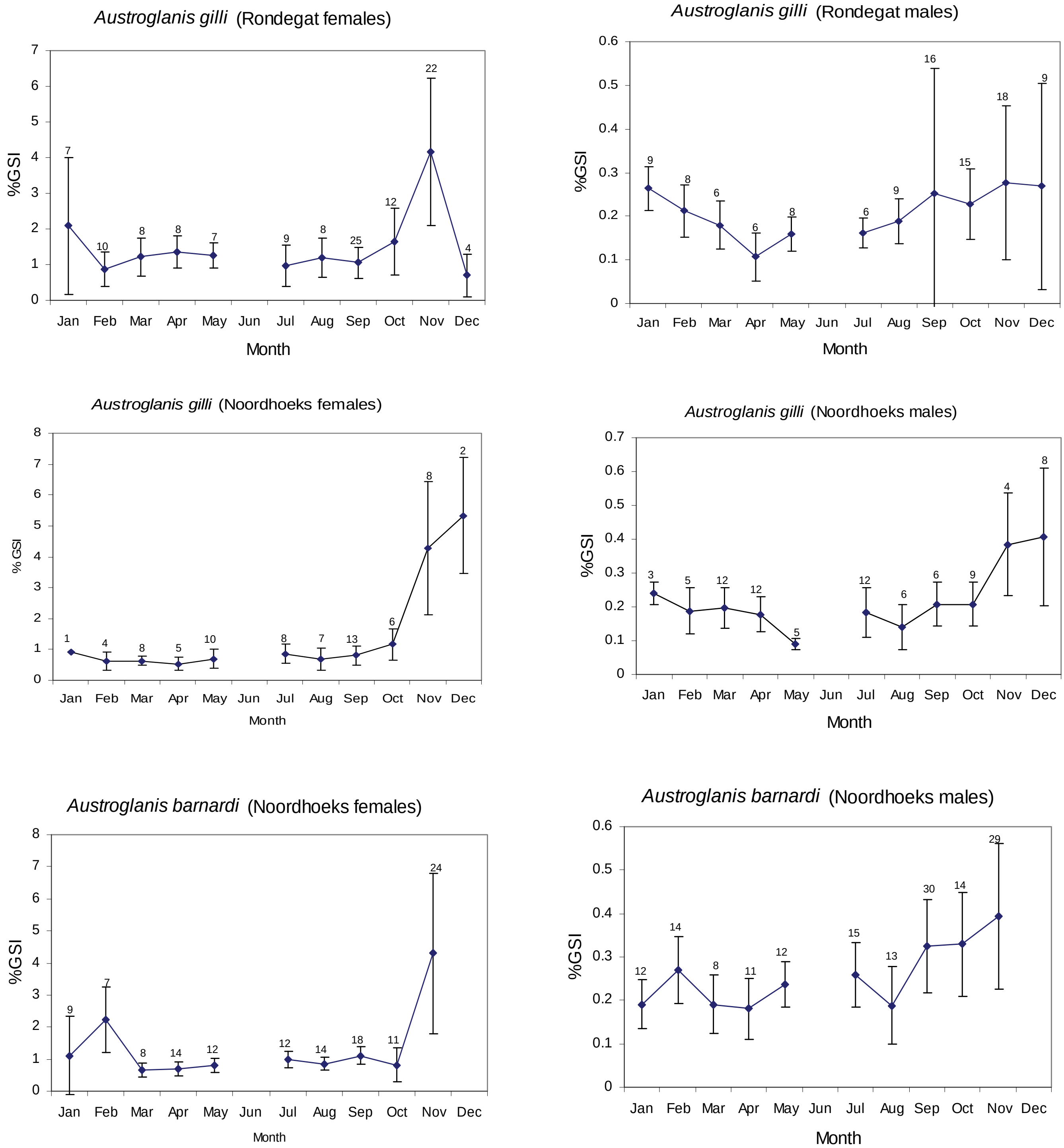


Figure 6.6. GSI of male and female *Austroglanis barnardi* and *Austroglanis gilli* from the Rondegat and Noordhoeks rivers.

The lengths at maturity for each of the *Austroglanis* spp. are given in Figure 6.7. For *A. gilli* from the Rondegat River, maturity was estimated at 97.3 mm SL (3.1 years) for males and 94.3 (3.3 years) for females. In the Noordhoeks River, males *A gilli* matured at 71.9 (1.7 years) and females at 66.4 (2.0), and 58.9 (2.0 years) and 55.0 (2.2 years) males and female *A. barnardi*, respectively.

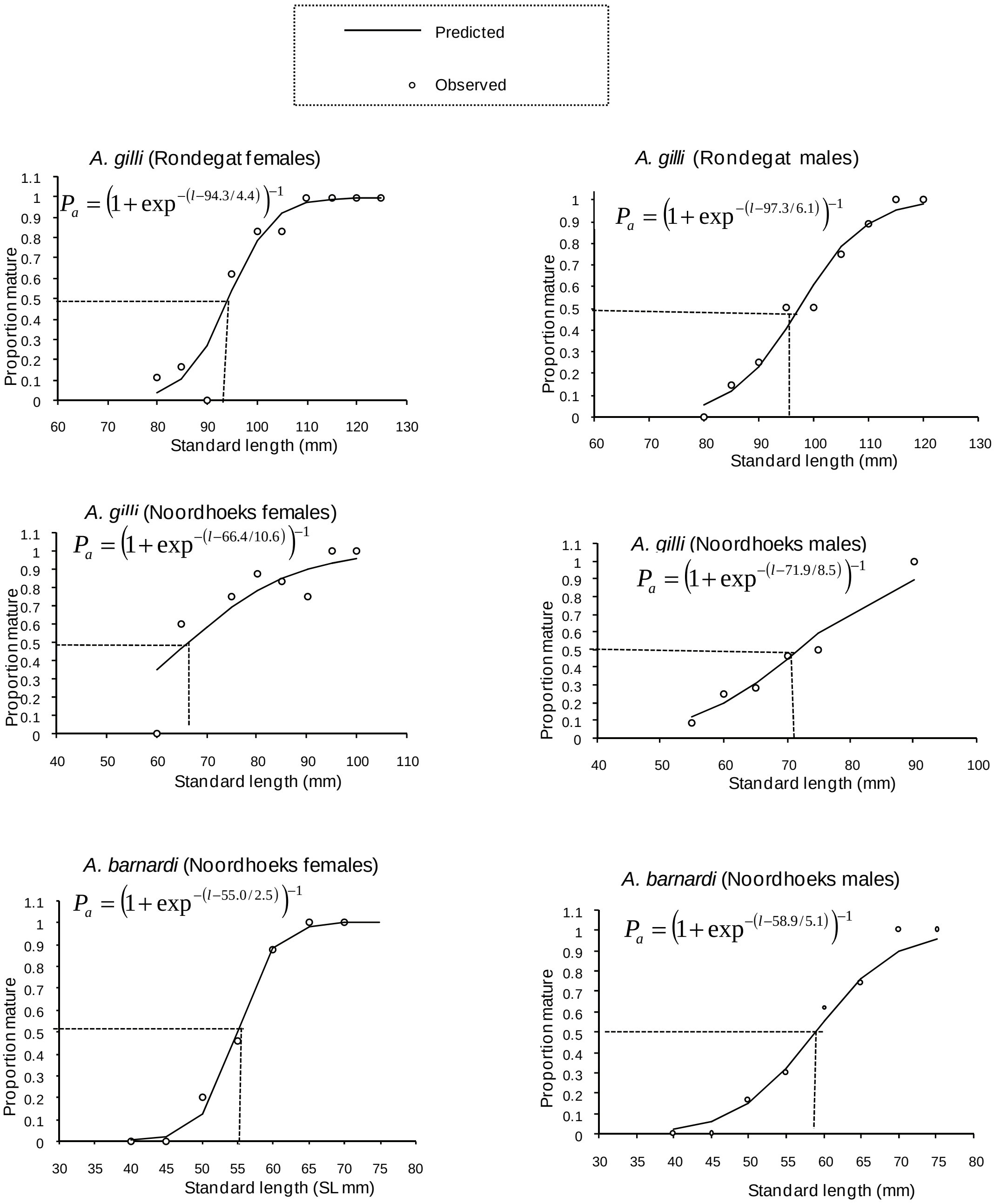


Figure 6.7. Length at 50% sexual maturity of *A. gilli* and *A. barnardi* females from Rondegat and Noordhoeks rivers sample determined from logistic ogive.

The number of vitellogenic oocytes per fish of *A. gilli* from the Rondegat River ranged from 152 to 1474. In the Noordhoeks River, this range was counted at 164-640 oocytes/fish and 28-238 oocytes/fish for *A. gilli* and *A. barnardi*, respectively. Relative fecundity (number of vitellogenic oocytes per gram of eviscerated fish mass) of *A. gilli* from Rondegat, and *A. gilli* and *A. barnardi* from Noordhoeks were estimated at 60.2 ± 17.8 ova/fish g, 61.6 ± 18.1 ova/fish g and 65.4 ± 23.9 ova/fish g respectively.

c. Feeding

The index of relative importance revealed that *A. gilli* feeds predominantly on the benthic ephemeropteran (particularly the Baetidae) and dipteran (particularly Chironomidae and Simuliidae) larvae. *Austroglanis barnardi* feeds predominantly on dipteran larvae (Chironomidae and Simuliidae). An index of relative importance showing different size classes for all the samples examined is given by Figure 6.8.

Chi square contingency tables revealed a significant difference between the dominant prey items for *A. gilli* and *A. barnardi* from Noordhoeks River ($\chi^2 = 53.79$, d.f. = 4, $P > 0.001$), and the dominant prey items for *A. gilli* between Rondegat and Noordhoeks rivers ($\chi^2 = 34.74$, d.f. = 4, $P > 0.001$).

Oral and pharyngeal tooth structures, including gill arch are presented in Figure 6.9. Gill raker for *A. gilli* comprised sharp pointing ends and their counts ranged from 11 to 14, whereas gill rakers for A. barnardi comprised blunt ends, ranging from eight to 10. Oral and pharyngeal comprised unicuspid caniniform teeth, appearing to serve piercing rather than chewing function.

A summary of tooth and gill raker counts for A. gilli and A. barnardi are given in Table 6.3. *Austroglanis gilli* comprised a higher number of teeth and gill raker counts than *A. barnardi*.

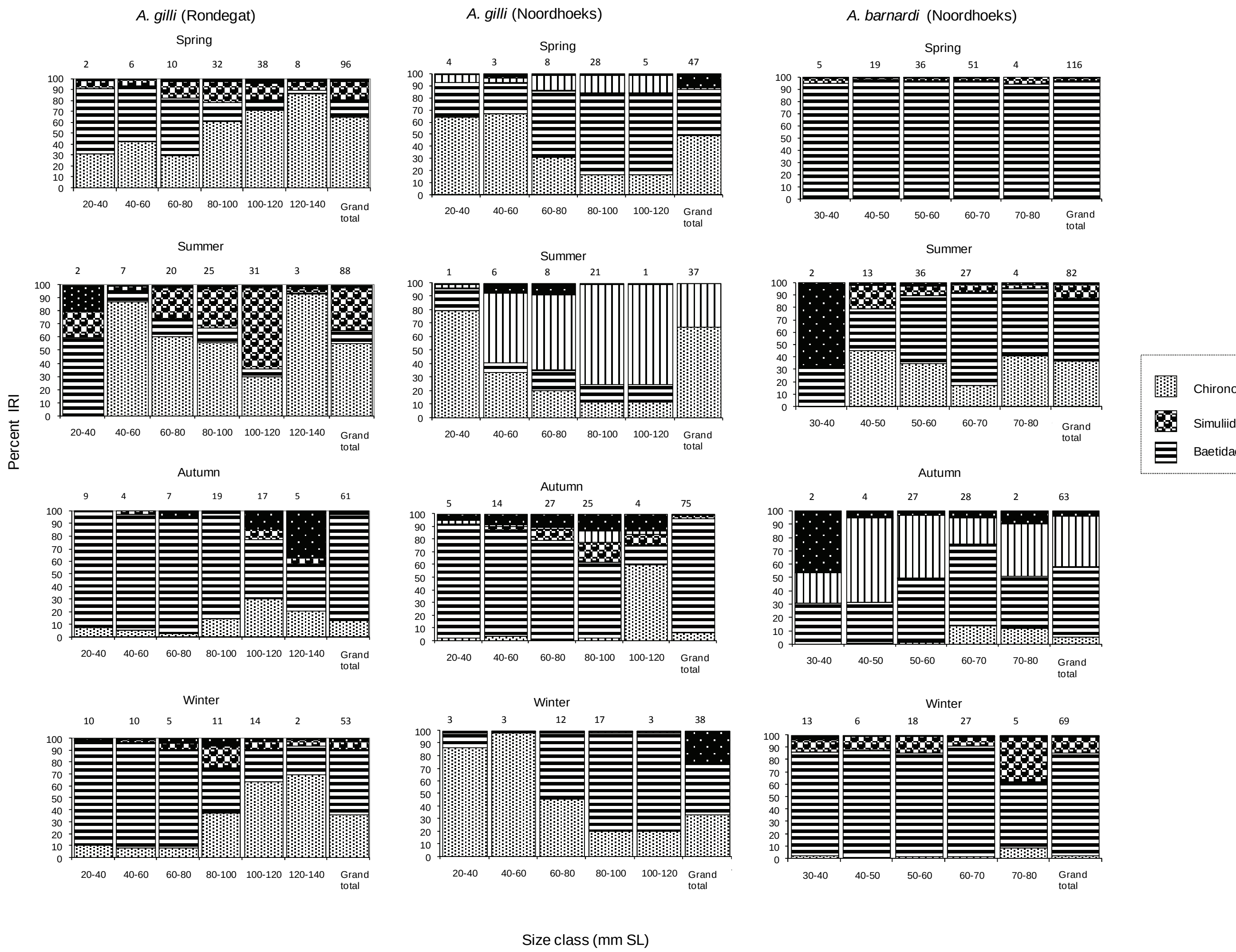


Figure 6.8. Seasonal summary of the gut contents of *A. gilli* and *A. barnardi* from the Rondegat and Noordhoeks Rivers in the Western Cape Province of South Africa. The numbers above each bar denote fish stomachs.

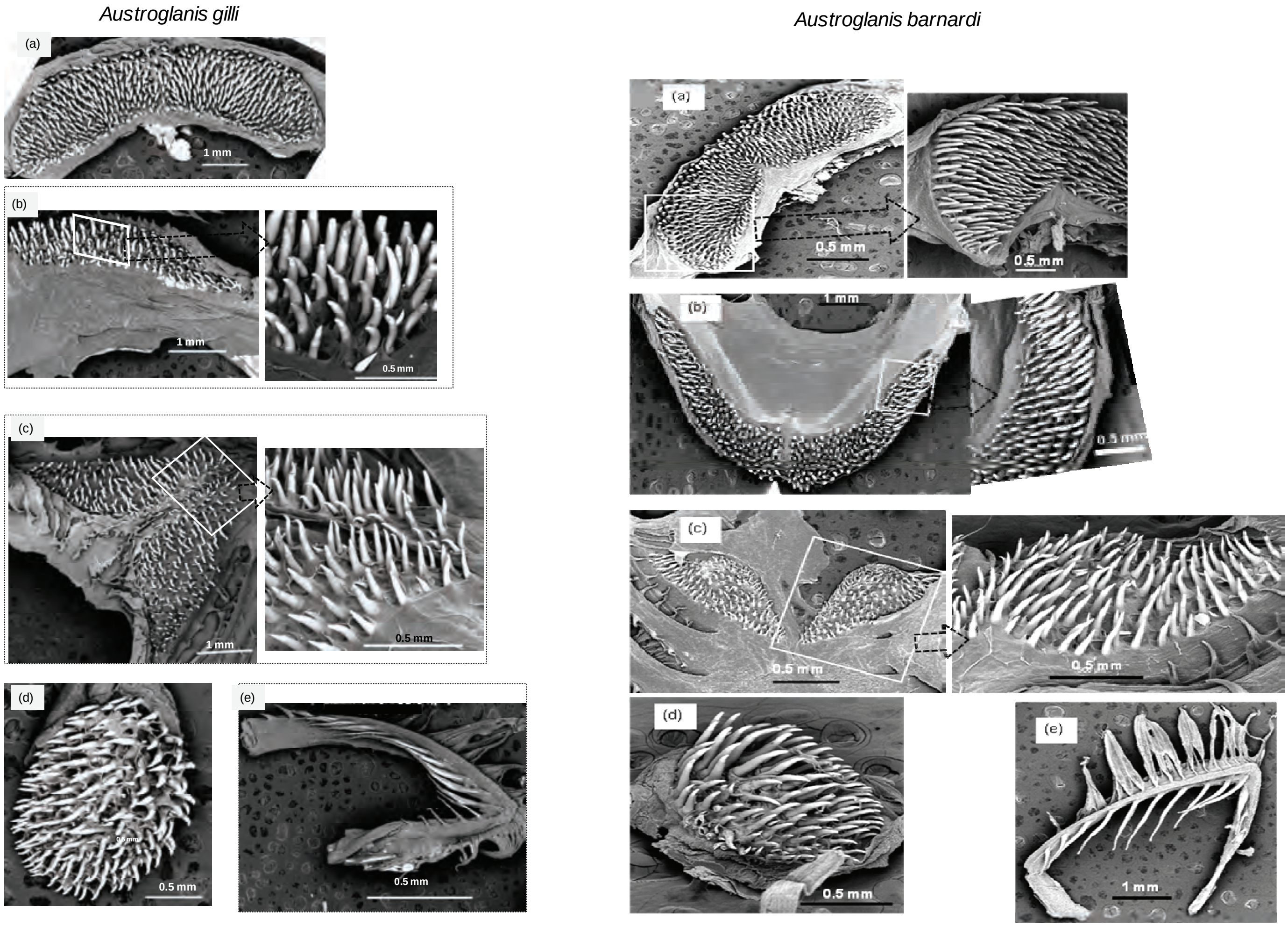


Figure 6.9. Electron micrographs illustrating (a) the premaxillary tooth plate and enlarged side view, (b) dentary and enlarged side view, (c) pair of lower pharyngeal tooth pads and one enlarged view (d), upper pharyngeal tooth pad, and (e) an anterior part of the first gill arch showing the form and arrangement of the gill rakers of *A. gilli* sampled from Rondegat River and *A.barnardi* sampled from the Noordhoeks River.

Table 6.3. A summary of tooth and raker counts for *A. gilli* and *A. barnardi* from Rondegat and Noordhoeks rivers.

SEM structure	*A. gilli* (Rondegat)	*A. barnardi* (Noordhoeks)
Premaxilla (outer row)	70–76	35–47
One half of the lower jaw (outer row)	26–36	24–29
Row between the joining edges of the lower jaw	6–8	6–7
Lower pharyngeal jaw (outer row)	18–24	10–18
Gill raker counts	11–14	8–10

Discussion

This study revealed that *A. gilli* and *A. barnardi* are slow-growing and long-lived species, whose life expectancy exceeds 10 years. The average mortality rates of 0.37 ± 0.12 per year for *A. gilli* from Rondegat River and 0.39 ± 0.04 per year for *A. barnardi* from Noordhoeks River were considerably low for these catfishes. However, the mortality rate of 0.71 ± 0.05 per year for *A. gilli* from the Noordhoeks River, which is nearly double the mortality rate of other *Austroglanis* populations investigated could suggest that environmental conditions are not favorable for this population. It could be that *A. barnardi* out-competes juvenile *A. gilli* in the shallow riffles or that adult *A. gilli* are more susceptible to predation by otters in the deeper runs and pools. These suppositions, however, require some investigation.

The two *Austroglanis* spp. in the Noordhoeks River were characterized by delayed maturity, attaining their first maturity at two years, and *A. gilli* from Rondegat River at three years. The maximum egg size of 2 mm in diameters was considered large for such small catfishes. Their relative fecundities estimated at 60 ± 18 ova/fish g for *A. gilli* and 65 ± 24 ova/fish g for *A. barnardi* could also be considered low. However, a behavioural study in captivity would be useful in understanding the exact number of batches and eggs spawned by each species as some vitellogenic oocytes undergo atresia.

The simultaneous occurrence of previtellogenic, primary, secondary and tertiary yolk oocytes in the ripe ovaries of each of the *Austroglanis* spp. collected in summer suggested asynchronous, iteroparous, serial spawning strategy (West 1990). A serial spawning over a protracted summer season in *Austroglanis* spp. could be comparable to other small catfishes including, *Chiloglanis pretoriae* van der Horst 1931 (De Villiers 1991), *Chiloglanis bifurcus* Jub & Le Roux 1969 (Kleynhans & James 1995), *Amphilius natalensis* Boulenger 1917 (Marriot *et al*. 1997) and *Chiloglanis emarginatus* Jub & Le Roux 1969 (Kleyhans 1997) which are summer spawners. It could be that an increase in temperature triggers gonad development in these catfishes. The hot and dry summer conditions in the Western Cape Province could provide suitable environment for the survival of larvae as the water is clear and slow-flowing. Invertebrate abundance in the Cederberg is seasonal, being low in winter and high in summer (King 1983). The spawning of *Austroglanis* spp. coincides with the period of high invertebrate abundance.

A serial spawning throughout the summer season also increases the chances of larval survival in case one batch becomes unsuccessful through predation. Serial spawning could also be advantageous as it may minimize intra-competition during the first exogenous feeding (Cussac & Ortubay 2002). This strategy, however, could be disadvantageous in that a female could be eaten before laying all years' eggs. Other disadvantages in the spawning season of *Austroglanis* spp. is that it coincides with the period of excessive water abstraction for irrigation, a condition that causes habitat loss in rivers of the region (Gaigher 1980; Skelton 1987; Impson et al. 2002). Various agrochemicals used in the citrus farming are considered as potential threats to the recruitment of *Austroglanis* spp. during summer season. The bulldozing of riverbeds reported previously (Gaigher 1980; Skelton 1987; Impson et al. 2002) would appear to negatively impact on the recruitment of these catfishes. The recruitment during low water flow in summer could increase chances of predation on *Austroglanis* fry as they would be concentrated in a small channel.

These catfishes appeared to be opportunistic benthic feeders capable of exploiting the most available prey items using their oral and pharyngeal teeth which could serve piercing function. The Rondegat River was previously noted to be dominated by insects of the orders of Ephemeroptera, Diptera and Trichoptera (Lowe *et al*. 2008), and the dominance of insects of these orders in the guts of *Austroglanis* spp. and the presence of allochthonous materials from terrestrial environment support the proposed opportunistic feeding guild. The feeding habits of *Austroglanis* spp. is comparable to *Leptoglanis* spp. of the Zambezi River (Winemiller & Kelso-Winemiller 1996), *A. natalensis* (Marriot *et al*. 1997) and *C. pretoriae* (De Villiers 1991) which are benthic insectivores.

The anthropogenic disturbances in the rivers of the Cederberg would appear to impact the distribution and abundance of invertebrate fauna which is the main diet for these catfishes. In the Noordhoeks River, for example, field observations have noted no fish in the farmland, which could be attributed to agrochemical pollution. This could also be a reflection of inability of fish to repopulate a disturbed area during the flow seasons as the section of the river was once dried out completely in summer.

Under such anthropogenic disturbances, the populations of *Austroglanis* spp. characterised by life-history traits of slow growth, long life span, low adult mortality rate, more investment to offspring survival (as they produce large egg sizes) and low relative fecundity would vulnerable. The life-history traits of *A. gilli* and *A. barnardi* are typical of a precocial and *K*-selected species whose population is density dependent. If their population numbers were to be greatly reduced, they would take a long time to rebuild. The two *Austroglanis* spp. therefore require an urgent conservation intervention.

Conservation

Inappropriate agricultural development which includes water abstraction, bulldozing of riverbeds and agrochemical pollution are regarded as threats to the *Austroglanis* catfishes (IUCN 2009). These activities may result to the loss of habitat and agrochemicals may possibly cause lethal or sublethal effects on *Austroglanis* spp., though this remains to be quantified. These anthropogenic activities appeared to have not only wiped out the populations of these catfishes in certain sections of the rivers but also impacted the abundance and distribution of macro-benthic invertebrates which are the main dietary prey items for both *A. gilli* and *A. barnardi*.

Conservation actions, should, therefore consider a holistic approach and target the maintenance of the complex benthic structures and the normal river flow.

Conclusion

This study has provided comprehensive information on the biology and ecology of *A. gilli* and *A. barnardi*. Some attributes of the study includes the following.

- Information on the reproduction biology will assist Cape Nature in the formulation of conservation management strategy, as agrochemicals, water abstractions and bulldozing of riverbeds during summer would impact on the recruitment of these catfishes.
- Such information will also be useful in the future investigation of the breeding behaviour of these catfishes. This can be achieved by setting up an experiment in the field or an aquarium breeding programme.
- The dominance of benthic invertebrates in the prey items of *A. gilli* and *A. barnardi* suggests the importance of maintaining the biodiversity and abundance of the invertebrate fauna in the conservation management of these catfishes. This would require the maintenance of the complex benthic habitats, normal river flow throughout the year and prevention of agrochemicals from entering the streams.
- Information on the biology of *A. gilli* and *A. barnardi* will be useful in the population viability analysis modeling to predict some possibilities of extinctions. Such information will assist Cape Nature in prioritising conservation actions.

Acknowledgements

This research report is the result of my MSc thesis which was supervised by Dr Olaf Weyl and Roger Bills and both data and results will be submitted for peer-review as a co-authored paper. The samples used for this study were museum specimens of the South African Institute for Aquatic Biodiversity (SAIAB) which were mainly collected by Roger Bills, Ernst Swartz and Dean Impson. Dean Impson arranged collecting permits. Sally Terry helped with accessioning of samples and data. Shirley Pinchuck of Electron Microscopic Unit at Rhodes University provided guidance on the use of scanning electron microscope. Doctor Steven Lowe, ex post-doctoral fellow at SAIAB helped with the identification of gut contents. Doctor Anna Mousson of Amanzi Biosecurity and Genny Grewar of the National Health Laboratory Services prepared gonad histology.

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7. CONSERVATION GENETIC MANAGEMENT OF *AUSTROGLANIS GILLI*, *A. BARNARDI* AND *BARBUS ERUBESCENS*

ERNST SWARTZ

SOUTH AFRICAN INSTITUTE FOR AQUATIC BIODIVERSITY (SAIAB), PRIVATE BAG 1015, GRAHAMSTOWN 6140. (E-MAIL: E.SWARTZ@SAIAB.AC.ZA)

Approach.

The main focus of this conservation genetics chapter is as follows.

1. To determine which populations will have to be conserved to allow future survival of the species.
2. To assess the conservation value and status of each population in terms of genetic diversity (how much does each population contribute to overall genetic diversity).
3. To assess what we know of diversity within populations.
4. To determine how important is genetic diversity over a gradient within a single population.
5. To make recommendations concerning possible future translocation of fish.
6. To make recommendations regarding captive breeding of each species.

These aspects will be addressed in the following sections.

7.1. Genetic variation within and among populations

7.2. Most valuable populations for conservation genetic management

7.3. Recommendations and principles for conservation genetic management

- 7.3.1. What is a viable population size, what is the implications of small population size and when should action be taken?
- 7.3.2. Should small populations be augmented if population size becomes too small especially with regards to rehabilitation plans?
- 7.3.3. Should small populations be increased in size by moving them above their natural upstream barriers?
- 7.3.4. Does breeding programs have a role to play, what are the dangers and how should it be implemented?
- 7.3.5. What information is needed for efficient conservation genetic management?
- 7.3.6. Specific conservation genetic recommendations of *A. gilli*
- 7.3.7. Specific conservation genetic recommendations for *A. barnardi*
- 7.3.8. Specific conservation genetic recommendations for *B. erubescens*

7.4. Priority actions for conservation genetic management

7.1. Genetic variation within and among populations

Three separate genetic studies have been conducted on the two species of *Austroglanis* and *Barbus erubescens*. An M. Sc. at the University of Stellenbosch was completed in 2000 which assessed the allozyme diversity of the redfin species (including *B. erubescens*) that occur in the Cederberg (Impson, Swartz 2002; Swartz 2000; Swartz *et al.* 2004; Swartz *et al.*

unpublished). Additional mitochondrial DNA work has been completed at the University of Pretoria, which gives an additional perspective on the evolution of these species (Swartz, unpublished data). Both allozymes and mitochondrial DNA was used over the last few years to investigate the speciation and population structure of the two species of *Austroglanis* in the Cederberg (Cunningham, Bills & Swartz, Unpublished data). Out of all these investigations, important conservation implications have emerged that has to be included in conservation assessments and recovery programs. The most important and direct implication of the genetic studies, is that priorities can be drawn up in terms of conserving populations, in order to maximize the conservation of as much of the intraspecific genetic diversity as possible. Recognising and conserving as much of the genetic diversity as possibly will improve the species' chances of long-term survival.

Superficially *Austroglanis gilli* and *A. sclateri* has a similar external morphology. However, analysis of the mitochondrial cytochrome *b* and 16 s RNA genes and allozyme loci has revealed that *A. sclateri* is most divergent. *Austroglanis barnardi* and *A. gilli* cannot be reliably distinguished using mitochondrial DNA sequences, although there are gene frequency differences between all populations within and between species. Allozyme electrophoresis has shown that no current hybridisation is occurring between these two species in the Noordhoeks and in the Heks Rivers, suggesting that the mitochondrial introgression between the two species is due to historical hybridization. This has the effect that there is more differentiation in *A. gilli* between the Olifants and Doring catchments than between *A. gilli* and *A. barnardi* within the Olifants catchment.

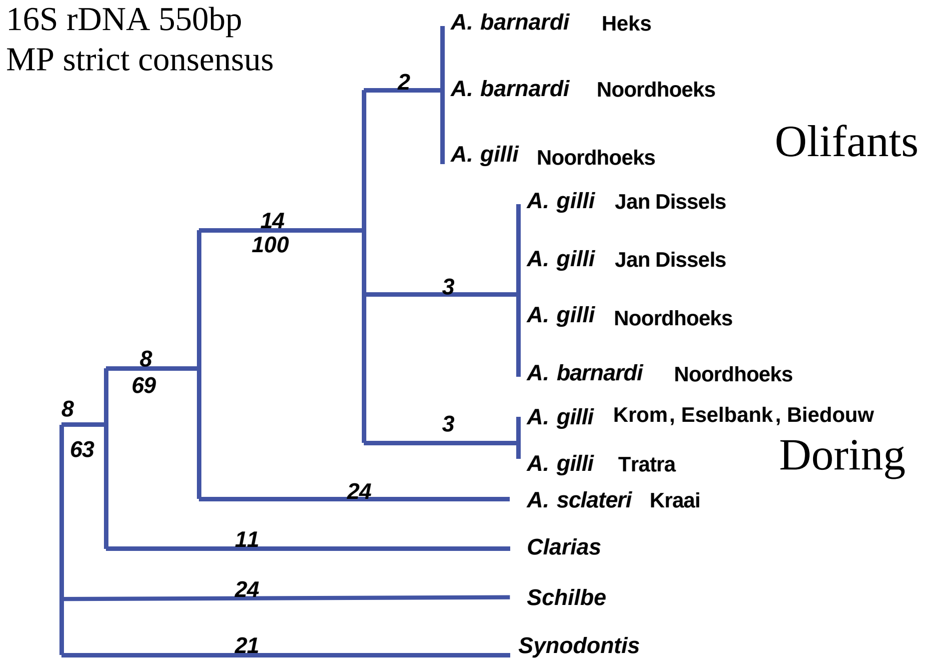

Figure 7.1. Maximum parsimony phylogenetic tree showing the 16s RNA mitochondrial DNA variation within and between *Austroglanis* species.

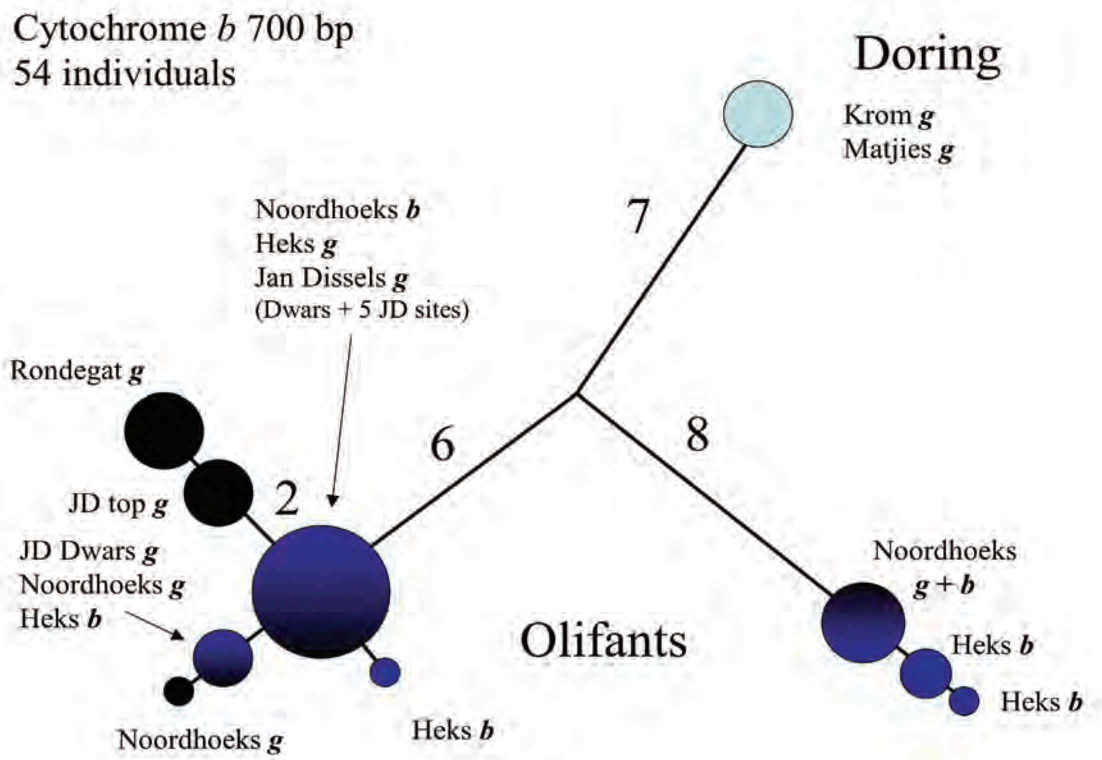

Figure 7.2. Maximum parsimony phylogenetic network showing cytochrome *b* mitochondrial DNA variation within and between *Austroglanis gilli* and *A. barnardi*.

There are also important genetic patterns worth conserving across a gradient within a single tributary. Spotted, non-spotted and intermediate forms exist within the Jan Dissels tributary of the Olifants catchment. There are frequency differences in the occurrence of these different forms across the Jan Dissels River, with spotted being more abundant in the upper reaches and non-spotted being more abundant in the lower reaches. No spotted fish were recorded in the Dwars River tributary. There are also frequency differences in allozyme and mtDNA alleles across the Jan Dissels River, suggesting that there are low levels of gene flow between sites and that the home range of this species in this population might be very small.

Barbus erubescens is the sister species of *B. calidus* and both are Cederberg endemics. Whereas *B. calidus* occurs across the Olifants River system, both in the Olifants and Doring catchments of the Cederberg mountains, *B. erubescens* is restricted to the Twee River catchment, a small catchment of the upper Doring. Genetic differentiation within *B. erubescens* has not been investigated to date apart from mitochondrial DNA sequencing two localities. The sequences from the lower Twee River and the Heks tributary of the Twee catchments did not differ from each other, suggesting that there is only one lineage of *B. erubescens*. The same seems to be true for *B. calidus*, where Swartz *et al*. (2004) and preliminary sequencing results suggest that only one lineage is widely distributed across the

Olifants River system. Frequency differences in alleles were observed with the allozyme loci, and therefore several management units exist that needs to be monitored.

For *B. erubescens*, Swartz *et al*. (2004) did not find variation at any of the 26 allozyme loci investigated. This is probably due to historical bottleneck events, or just due to a lack of variation at those particular loci. Genetic diversity in this species is nevertheless of concern due to its small range that makes it more vulnerable to small population size.

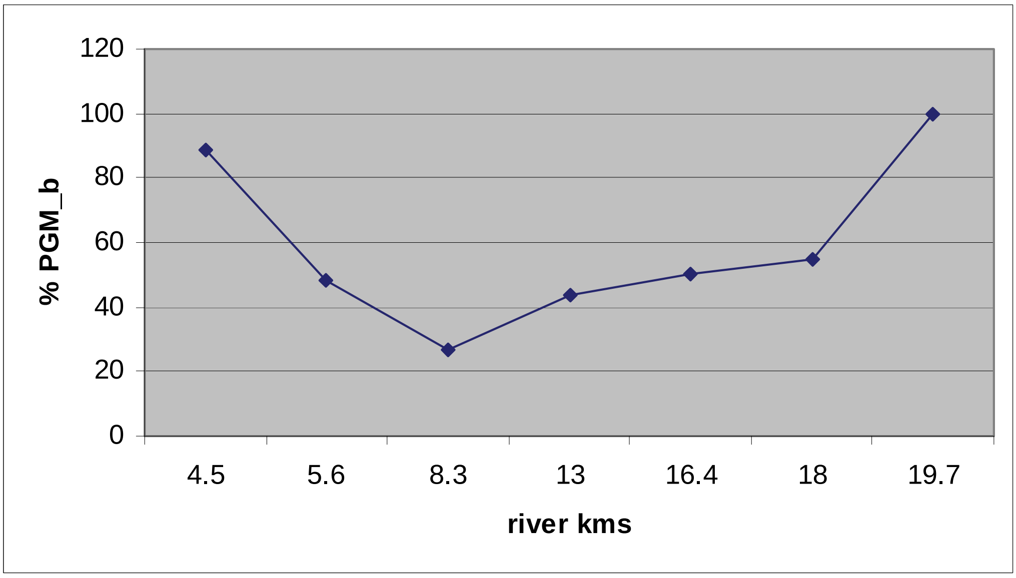

Figure 7.3. Allozyme allele frequency differences among localities of the Jan Dissels River for the PGM-b locus (unpublished data).

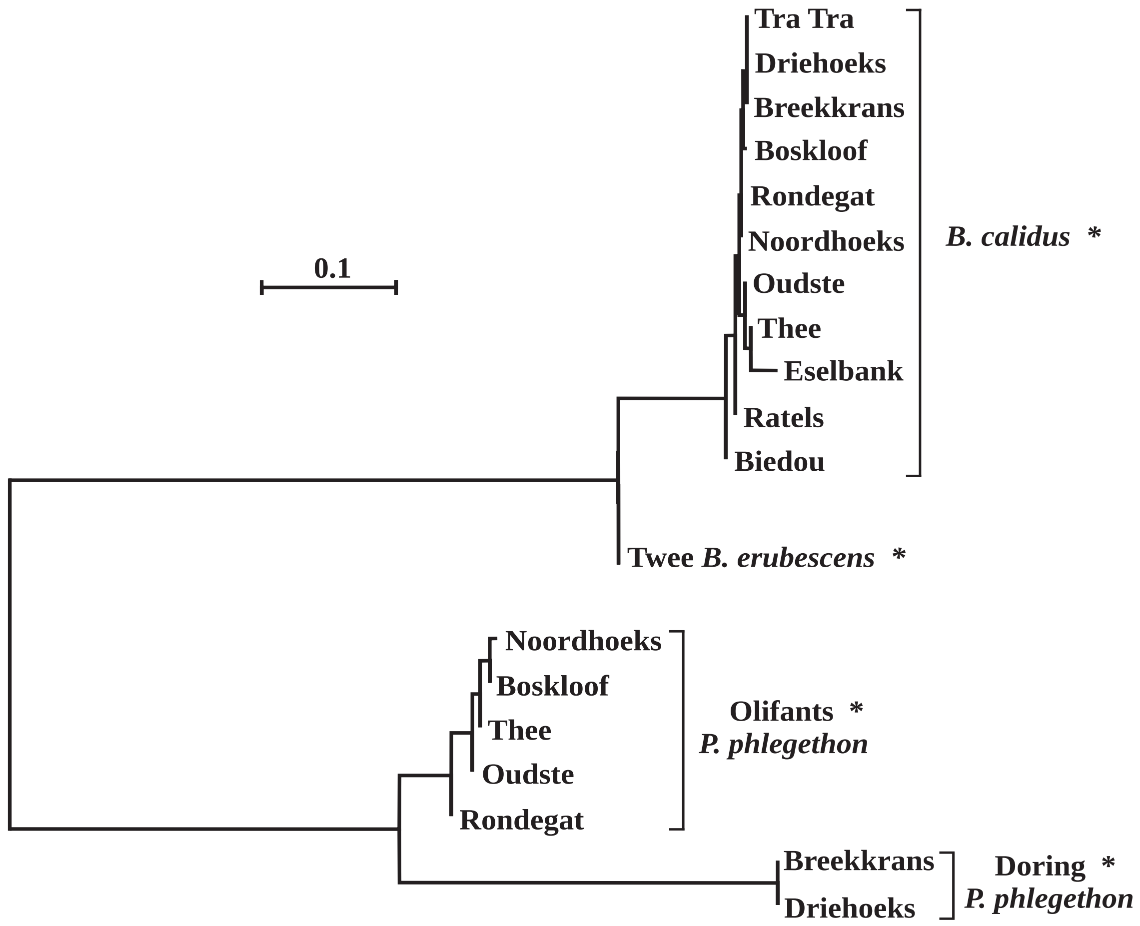

Figure 7.4. Neighbour-joining phylogram from Swartz *et al.* (2004) showing the genetic distance between *Barbus erubescens* and several *B. calidus* populations, in relation to the genetic distance found between two lineages of *Pseudobarbus phlegethon*.

7.2. Most valuable populations for conservation genetic management

This question is relatively simple to answer for *B. erubescens* and *A. barnardi*, since both species are very restricted and only occur in a few locations. Therefore, as many of the existing locations as possible, will have to be conserved. However, for *A. gilli* the situation is much more complex, not only because many more populations exist, but also because the distribution of genetic diversity is also much more complex. Firstly there is a differentiation between the Olifants and Doring catchments. Populations of both these catchments will have to be conserved to maximize the maintenance of genetic diversity in the future.

There is also differentiation occurring within Jan Dissels mentioned above and the population in the Rondegat is also carrying some unique alleles. Even within the Doring catchment where there is no genetic differentiation, morphological differences occur between populations that might be reflected in faster-evolving genes. A precautionary approach will have to be taken unless it can be shown that the morphological variation and genetic diversity that remains, will not have an effect on the species' survival.

In the Doring catchment, the Biedou and Tra Tra populations will have to be conserved because of unique morphological variation that was observed in these populations. These morphological differences may be expressed in faster-evolving genes to those that have been studied thus far.

At least one population in the rest of the Doring catchment will have to be conserved from the Matjies, Krom or Breekkrans Rivers. The high number of populations that needs to be conserved for this catchment is due to morphological variation that has been observed and because the major differentiation in *A. gilli* is between the Olifants and Doring catchments.

The Jan Dissels with its different forms will have to be conserved. It is also the largest population of *A. gilli* that can probably carry the most genetic diversity. Populations of *A. gilli* will also have to be conserved across the gradient of the Jan Dissels River to maximize the retention of genetic diversity across the range of the different forms.

The Rondegat tributary carries unique allozyme and mtDNA alleles and therefore deserves protection. In the rest of the Olifants catchment, at least one other population will have to be protected, preferably the largest one, either from the Heks, Boskloof, Noordhoeks or Thee Rivers.

For *A. barnardi* options are much more limited. The two largest populations are in the Noordhoeks and Heks tributaries with a significant population in the Thee River as well. The relatively recent records of this species in the Olifants mainstream does not represent a viable population in our opinion and are therefore not considered. All three populations will have to be conserved to give this species a realistic chance of survival long-term.

The situation for *B. erubescens* is even more serious, since there are only three locations within one catchment where this species can be protected, namely the Suurvlei and Heks tributaries of the Twee River and the Twee River itself lower down in the catchment. All three locations need to be protected, but the focus should be on the upstream sites where alien fishes do not occur. The range of these upstream populations can more easily be increased through the eradication of alien fishes and they can more easily be protected against re-invasion.

The Doring populations (Biedou, Tra Tra, Matjies, Krom and Breekkrans) together contribute a unique lineage of *A. gilli*, but are amongst the most threatened populations of this species in the Cederberg and they carry relatively low diversity within populations. The Biedou and Tra Tra populations are very small with only a few individuals recorded above the distribution of alien fishes (none seems to occur with aliens in these tributaries). Small waterfall barriers protect these two tributaries, but the population size is probably too small to be viable long-term. The Matjies and Krom populations are probably larger, but are under more threat from agricultural activities and alien fishes with which they occur. The Breekkrans population is probably also small and aliens have progressed very high up this catchment as well.

The Jan Dissels, Rondegat, Heks, Boskloof, Noordhoeks, Thee and Oudste contribute the other unique lineage of *A. gilli*. The Rondgat tributary also carries some unique alleles, but the Jan Dissels, being the largest, can probably carry more diversity than any other population. Most of the Jan Dissels population occurs with smallmouth bass, but because of the high habitat integrity and complexity they have survived to date and will probably continue to survive if the land-use does not change. The Rondegat population is relatively large and is protected by a waterfall from alien fishes. The Heks population occurs with bass throughout its known range. The Boskloof population is large and protected by a man-made weir from alien invasion. A small Boontjies population remains, but may not be large enough to survive and multiple impacts from alien fishes and agricultural activities might make it too difficult to protect this population. The Noordhoeks and Thee populations are relatively large, but does not have a secure barriers to protect them from invasion by alien fishes. The Oudste population is probably small and does not have a clear barrier to prevent alien invasion. There are also mainstream areas in the Olifants where this species might still survive on occasion, but these habitats are not stable enough to be of value for conservation management, since they are nowadays often dry in summer.

Loss of the Doring populations will not only constitute the loss of a unique lineage, but also of unique morphological forms that might have an adaptive significance. Loss of all the Olifants populations will also constitute the loss of a unique lineage. Loss of the Jan Dissels and Rondegat population will not constitute the loss of a unique lineage, but certainly unique morphological and color pattern variations that might be of adaptive significance in the case of the Jan Dissels and loss of unique alleles in the case of the Rondegat. The scenario in the Jan Dissels, illustrates how important it is to consider genetic diversity over short distances and within one tributary, since significant genetic diversity can be uncovered across a gradient within what was considered a single population in the past.

Each one of the *A. barnardi* populations carries several alleles, but the Noordhoeks and Heks can each probably carry more diversity than the Thee population.

Since genetic diversity within *B. erubescens* has not been studied in any detail, not much can be said about the significance of the different sub-populations, except that all of them have to be maintained to increase the overall population size to maintain this species' ability to carry diversity in future.

7.3. Recommendations and principles for conservation genetic management

7.3.1. What is a viable population size, what is the implications of small population size and when should action be taken?

The minimum effective population size needed to avoid inbreeding depression or general effects of inbreeding differs between species. It depends on the sex ratio, breeding system and aspects of population demography. Inbreeding is an effect of breeding between related individuals, which is a much bigger problem in small populations compared to large ones. Population size fluctuates over time and it is during population bottlenecks that inbreeding occurs. The severity of inbreeding is dependant on:

1) the severity of the bottleneck (number of surviving individuals); and
2) the duration of the bottleneck (length of time that only a few individuals contributed to breeding success).

Inbreeding depression is the most serious effect of small population size. It can cause depressed breeding behaviour, ineffective sperm functioning, weaker immune response, deformed morphology, etc. This occurs when effective population size typically fall below 50 individuals.

General effects of inbreeding cause a loss of genetic diversity (loss of unique alleles), which might not cause such visible effects as inbreeding depression. It can, however, affect the population/species potential to adapt to different environmental and climatic conditions and may affect their ability to resist new pathogens.

The following populations are at risk of inbreeding depression (compare this to PVA):

- Suurvlei *B. erubescens*
- Thee *A. barnardi*
- Biedou *A. gilli*
- Tra Tra *A. gilli*
- Eselbank *A. gilli*
- Boontjies *A. gilli*

The following populations are at risk of general effects of inbreeding (compare this to PVA):

- Heks *B. erubescens*
- Lower Twee *B. erubescens*
- Heks *A. barnardi*
- Krom *A. gilli*
- Breekkrans *A. gilli*
- Matjies *A. gilli*
- Thee *A. gilli*
- Dwars *A. gilli*
- Oudste *A. gilli*
- Heks *A. gilli*

The following populations are probably able to maintain their current levels of genetic diversity (compare this to PVA):

- Noordhoeks *A. barnardi*
- Jan Dissels *A. gilli*
- Boskloof *A. gilli*
- Rondegat *A. gilli*
- Noordhoeks *A. gilli*

7.3.2. Should small populations be augmented if population size becomes too small especially with regards to rehabilitation plans?

Small populations should not be augmented unless there is evidence of severe loss of genetic diversity or inbreeding depression. Loss of genetic diversity is prevented much more effectively by the following.

- Maintaining a large effective size for each population individually (ability to maintain high genetic diversity).
- Allow as many populations as possible to survive (captures geographic genetic variation).
- Restore historical corridors (allowing natural migration patterns).
- Prevent very low numbers of individuals (below 50 effective population size) and minimize the time that populations spend in a bottleneck.

If augmentation is considered (as a last resort), the following principles should apply.

- Augmentation should only be done between populations that belong to the same historically isolated lineage.
- As few individuals as possible from the donating population should be translocated to maintain as much of the original genetic diversity in the receiving population as possible.
- Augmentation should form part of a genetic management strategy based on a PVA.
- Other factors should be taken into consideration (mistaken translocation of other species, transfer of pathogens and parasites).

Augmentation should only be considered for the following populations if evidence as outlined above shows inbreeding to be a problem (best donating population candidate in brackets).

- Suurvlei *B. erubescens* (Lower Twee *B. erubescens*)
- Biedou *A. gilli* (further studies required since they might be unique, best candidates are probably Tra Tra *A. gilli* and Eselbank *A. gilli*)
- Tra Tra *A. gilli* (Eselbank *A. gilli*)
- Eselbank *A. gilli* (Tra Tra *A. gilli*)
- Boontjies *A. gilli* (Boskloof *A. gilli*)
- Oudste *A. gilli* (Thee and Noordhoeks *A. gilli*)

7.3.3. Should small populations be increased in size by moving them above their natural upstream barriers?

The main problem with moving any species outside its natural range is that they can affect the ecosystem that receives them in an unpredictable manner and native species may go extinct. This can occur over very short distances, such as moving a fish species above a waterfall. The CFR has high aquatic invertebrate diversity that is not very well studied and many invertebrates will be vulnerable to fish predation. Informed decisions about possibly compromising certain invertebrate populations can only be made if the following is understood.

- Accurate identification of all the invertebrate species that occur in the targeted stretch of river.
- Conservation status of each invertebrate species.
- The relationships of the invertebrate populations to other populations in the region.
- Distributional limits of each invertebrate species in relation to the targeted area.
- Effects on the ecosystem functioning as a whole.

Translocations, which do not consider the above-mentioned information, can cause the loss of genetic diversity in other species. Upstream translocation may also not significantly increase genetic diversity if the source population is immediately below the barrier, since one-way gene flow will occur from the top to the bottom. In addition, the upstream habitat might be outside the environmental tolerance of the species. Downstream rehabilitation and restoration of migration corridors will benefit the conservation of genetic diversity much more than upstream translocation.

7.3.4. Does breeding programs and translocation have a role to play, what are the dangers and how should it be implemented?

Captive breeding as a management strategy should also be avoided as far as possible. Apart from the risk of introducing parasites, captive breeding should be avoided for the following genetic reasons (taken from Swartz 2001).

- Artificial selection in captive breeding programs can eliminate adaptive gene complexes (Garcia de Leániz *et al.* 1989; Waples & Teel 1990) and invariably leads to loss of genetic diversity (Briscoe *et al.* 1992; Leary *et al.* 1993; Quattro & Vrijenhoek 1989).
- There is an increased possibility that different species or populations from different river systems or regions can be mistakenly mixed, especially in large facilities and when record keeping is not very systematic and accurate.
- Fish individuals inevitably escape into the local river systems, where they can hybridize with native species, causing a breakdown of genetic integrity of species.
- Lack of knowledge of the genetic structure of the species prior to stocking can lead to the loss of unique evolutionary lineages through hybridisation and/or homogenisation

of genetic diversity (Avise *et al.* 1997; Dowling, Childs 1992; Leary *et al.* 1993; Quattro *et al.* 1996).

Captive breeding should therefore only be used as a last resort. It should preferably be done as natural as possible and preferably within the catchment of capture, with escape routes leading directly to natural populations (therefore don't move fish outside their natural range).

Translocations should be avoided as far as possible and should be seen as a last resort. The following are important reasons for avoiding translocations.

- The CFR has an impressive aquatic invertebrate diversity that is not very well studied. Whereas translocations can increase the population size of a threatened fish species, it might cause the extinction of an invertebrate population. Rather consider downstream river rehabilitation.
- Translocations can do more damage than good if undesired genetic mixing occurs, since gene pools can be homogenised.
- Future conservation genetic planning is complicated, especially if the source and receiving locations and number of individuals are not accurately recorded.

Recommendations with regards to translocations.

- Assess the receiving system for indigenous aquatic fauna and flora to assess if anything will be threatened.
- Map all escape routes and the expected new distribution range of the species being translocated.
- Estimate expected population size after establishment and assess whether such a subpopulation will be viable long-term.
- Initially the focus should not be on genetic management of the translocated population, but rather on establishing the population in the first place.
- Augmentation should follow to increase the genetic diversity.
- All the steps and number of individuals including their origin and release points should be accurately documented and published.
- Preferably fin clips should be taken of all individuals so that genetic monitoring can be done.
- The actual number of specimens needed to establish a population that does not show a significant loss of genetic diversity, should be established through a population viability analysis.

7.3.5. What information is needed for efficient conservation genetic management?

The following information is needed for conservation genetic planning (related to PVA).

- Estimates of geographic distribution of genetic diversity.
- Estimates of genetic diversity within populations.
- Effective size of each of the populations.
- Knowledge of the breeding system.

- Sex ratio.
- Age of first breeding.
- Total average age.
- Fecundity.

7.3.6. Specific conservation genetic recommendations of A. gilli

Conservation genetic recommendations specifically for *A. gilli* include.

- Monitor contact points where aliens and indigenous populations meet. In cases were *A. gilli* occurs with aliens, the density of aliens should also be monitored to assess changes in population sizes.
- Prioritise populations for conservation actions as listed in Table 1. This will ensure that the most important populations for genetic diversity will receive attention first, and as resources become available other populations that contribute valuable but less significant diversity can be protected at a later stage.
- Keep each population size large enough to survive long-term. Typically a few thousand individuals need to be protected to give a population a significant chance of retaining most of its genetic diversity. If population size is not large enough, consider downstream rehabilitation of tributary streams and prevent re-invasion by aliens by constructing barriers.
- Protect habitats across the gradient of complex tributary streams, since they may carry morphological and genetic diversity across this relatively short range that is probably of adaptive significance.
- Keep local sub-population size large over short distances in the Jan Dissels River, typically at least 50 individuals per kilometre by eradicating alien fishes.
- Do further studies to better understand the morphological and genetic diversity within *A. gilli*. This will allow for more accurate prioritisation of conservation efforts to conserve genetic diversity. As a precautionary approach each population that carries suspected adaptive variation should receive special protection, such as the Biedou, Tra Tra and Jan Dissels populations.
- When river rehabilitation is planned, it should be kept in mind that fish poisons can often not be used because of the occurrence of *A. gilli*. Not only can they maintain significantly large populations despite the presence of alien fishes, but the loss of downstream sub-populations of this species can also cause a significant loss of genetic diversity. The downstream diversity may be significant for two reasons: 1) Adaptive variation is occurring due differences between upstream and downstream habitats such as the Jan Dissels River and 2) Genetic diversity is mostly higher downstream because of the accumulation of mutations that accumulate because migration downstream if often easier than upstream.

7.3.7. Specific conservation genetic recommendations for A. barnardi

The following conservation genetic recommendations should be incorporated into a species recovery program for *A. barnardi*.

- Conserve all three remaining populations in the following rank of priority: 1) Noordhoeks, 2) Heks and 3) Thee.
- Secure their population size by preventing further invasion through the construction of barriers.
- Eradicate existing populations of aliens in the Thee, Noordhoeks and Heks to allow an increase in population size.
- Establish the range of the Thee and Heks populations so that a better PVA assessment can be done.
- Monitoring is needed for the lower Noordhoeks and Thee Rivers to assess the threat of invasion, but a barrier should preferably be built before it is too late.

7.3.8. Specific conservation genetic recommendations for B. erubescens

Conservation genetic recommendations specifically for *B. erubescens* include the following.

- Effective population size is likely to be of more concern for conservation managers than intraspecific genetic differentiation, since negative effects of general inbreeding (not inbreeding depression at this stage) can be a problem in this species. Typically this can be an issue in species with less than 1000 individuals depending on the life history strategy.
- Monitoring efforts should focus on estimating effective population size and assess changes in it over time.
- The lack of information on gene flow patterns in the Twee River catchment will have to be addressed. A direct assessment of gene flow is not possible, since fragmentation has occurred due to alien fishes, but fine-scale diversity patterns can be assessed to guide conservation genetic management of this species.
- At a local scale (short river section) the aim should be to maintain at least 50 breeding adults to avoid the loss of unique genes due to inbreeding.
- There needs to be studies on annual population fluctuation in effective population size (this and other small populations).

7.4. Priority actions for conservation genetic management

Priorities for the conservation genetic management of Cederberg fishes depend on the following.

1) The value of the population for the overall genetic diversity of the unique genetic lineage or species.
2) Threat status of the species, genetic lineage or unique population.
3) Practicality of conservation actions.

In this section, the emphasis will be on 1 and 2 above and not on the practicality of actions. The latter will be dealt with in other sections of this document. Priory setting should follow the following framework in order of importance.

1) Prevent the extinction of unique genetic lineages, namely Olifants *A. gilli*, Doring *A. gilli*, *A. barnardi* and *B. erubescens*.
2) Ensure as much geographic representation of each of these lineages as possible by protecting as many populations as possible.
3) Maintain effective size of each population at least above inbreeding depression levels and preferably above levels where general effects of inbreeding can affect genetic diversity.

Priority actions towards effective conservation genetic management of each of the unique genetic lineage are listed in Table 7.1.

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8. A SURVEY OF THE AQUATIC MACROINVERTEBRATES OF SELECTED TRIBUTARY RIVERS OF THE OLIFANTS AND DORING RIVERS IN THE CEDERBERG, WESTERN CAPE TO HELP ASSESS CONSERVATION STATUS AND ASSIST CONSERVATION PLANNING OF THE BIODIVERSITY OF THESE RIVERS

FERDINAND C. DE MOOR[1] & HELEN M. BARBER-JAMES[2]

[1&2]SCIENTIFIC SERVICES, CAPENATURE, PRIVATE BAG X5014, STELLENBOSCH 7600.
[1](E-MAIL: f.demoor@ru.ac.za), [2](E-MAIL: h.james@ru.ac.za)

8.1 Introduction

The aquatic macroinvertebrates of the southern and south Western Cape have been studied in some detail by previous researchers (Barber-James and Lugo-Ortiz 2003; Barnard 1932, 1934, 1940; de Moor 1993, 1997, 1999; de Moor and Scott 2003; Endrody-Younga 1997; Griffiths 1981; Harrison and Elsworth 1958; Harrison and Agnew 1962; King 1981, 1983; McCafferty and de Moor 1995; McCafferty and Wang 1997; Picker and Stevens 1997; Scott 1955, 1958a, 1958b, 1961, 1983; Scott and de Moor 1993, Stevens and Picker 1999, 2003; Wood 1952; and recent work by Ractliffe, Wissard and many others). These studies have revealed a very rich, diverse aquatic macroinvertebrate fauna that is largely endemic to the Cape Floral Kingdom. Many of the species also indicate that there is a strong temperate Gondwana origin for this fauna. This suggests that these species are relict survivors of a once widespread temperate southern fauna dating back about 140 million years prior to the breakup of Gondwana.

The discovery of nymphs and larvae of aquatic macro-invertebrates in families and genera representing this Gondwana fauna in the rivers flowing off the Cederberg needs further study. Firstly to confirm how closely related to the rest of the southern and south-western Cape fauna this Cederberg group is, and secondly whether a broader based approach incorporating more aquatic faunal groups to conservation of aquatic ecosystems can be developed. The first aspect needs the collection of adult insects to confirm species identification. Most previous work has dealt mainly with the aquatic stages of insects and these can usually not be identified to species level. For the second the use of diverse assemblages of species, to identify distinct river signatures, can be used to evaluate uniqueness, this provides a broader based approach to biodiversity conservation of rivers than the use of only rare or endangered species. Because of the paucity of comprehensive information on distribution patterns of regional fauna the use of biophysical surrogates, in place of actual distribution data of species, has gained popularity in systematic conservation planning (Margules & Pressey 2000; Roux et al. 2003; Nel et al. 2006).

In addition to identifying species and getting to know their distribution patterns, a molecular-systematic assessment of the frequently found disjunct populations of many of these Gondwana species also needs to be conducted in future. Work with colleagues in the USA, Great Britain and Switzerland and with students at Rhodes University dealing with these aspects has commenced and should provide some further answers to unravel unique biodiversity patterns.

The current study to assess some of the distribution patterns and conservation status of selected macroinvertebrate species, however, only comprised a single 10-day survey of 11 selected rivers and was based on the morphotaxonomic status of the species collected. Most macroinvertebrate taxa encountered were collected but the assessment of species was confined to selected groups including Trichoptera, Ephemeroptera and Simuliidae. In addition identifications of many other taxa to family or generic level were made and selected taxa that were noted to be of value are also mentioned in the report. The data presented can be used to motivate for and propose further research as deemed necessary.

The rare species of fish fauna that previous studies have focused on have a well surveyed and recorded distribution pattern. The macroinvertebrate survey undertaken has covered some of the rivers where the rare fish were still recorded. One of the aims of the study was to assess what species of macroinvertebrates are usually associated with the fish or are to be found upstream of barriers to the indigenous fish. If unique associations between fish and macroinvertebrates can be shown to occur, they will enhance conservation decisions as they will focus conservation needs not only on the fish but on the aquatic ecosystem providing unique conditions for an assemblage of species.

8.2 Study Area and Methods

Figure 8.1 and Table 8.1 show the sampling stations used during the survey undertaken. Information on the topography, geology, rainfall and vegetation in the catchment is reported on in detail elsewhere (Bills pers. comm.).

During the ten-day collecting excursions, 12-22 April 2005, undertaken by Dr F C de Moor, Mrs. I J de Moor representing the Albany Museum and Mr. R Bills of SAIAB 13 sites on 11 rivers were sampled (Figure 8.1, Table 8.1). At each sampling station readings of pH, temperature at the time of sampling, electrical conductivity and total dissolved solid concentrations were recorded; a photographic record was made of the general aquatic environment giving a visual record of the aquatic biotopes and prevailing conditions at the time of sampling (see Digital photographic records held in Department of Freshwater Invertebrates, Albany Museum and at SAIAB). Aquatic invertebrates were sampled using a selection of various water and aerial hand nets ranging in net mesh size from 80 µm (0.08 mm) to 1000 µm (1 mm). Sampling of aquatic stages was done using a standard SASS net (mesh size 1 mm); a hand-net (mesh size 250 µm); a small D hand-net (mesh size 80 µm) for sampling bedrock in swift flowing cascades and hygropetric splash zones of waterfalls; Emergence traps to collect newly emerged winged adults and subimagoes of aquatic insects were set for several days at many sites; Malaise traps to collect insects flying next to streams were also set up where feasible; Drift nets left in the water round dusk to collect the nymphal and larval shucks of emerging insects and to measure organic drift activity. General hand-picking of stones, lodged branches and removable substrates was also carried out. As diversity of aquatic biotopes were sampled at each site and an abbreviated description of biotopes is given in Table 8.3. Light traps, to collect the adult stages of many aquatic insects, important for species identification, were set up at all major sites. Where time permitted, general collecting for flying adult insects using hand nets was also carried out.

The biotopes sampled included stones in and out of current, rooted and marginal vegetation and root stocks, filamentous and encrusted algae, sediments on substrata, the surface of water bodies, adult flying insects with aquatic nymphal and larval stages and insects attracted to light traps. A light trap using a super-actinic light source over a white tray was used in all instances and where conditions were suitable. Biotopes were sampled in a number of ways. Invertebrates associated with aquatic plants were collected by running a net through aquatic macrophytes and marginal vegetation. Where stony substrata were present, stones were lifted by hand and brushed by hand or washed into a collecting net. Aquatic animals were also picked off these stones with a fine pair of forceps or by hand. Sediments were stirred up and either a coarse or fine-meshed net was run through disturbed sediments and substrates. Where running water was found, stones in the flowing current were dislodged and kicked and invertebrates were carried by the current into a net suspended below the disturbed substrates. In a few instances invertebrates were also collected with a handnet held downstream of an electro-shocker.

Unsorted samples as well as selected animals collected were given a catalogue number for each site, date and biotope type. Samples were labelled and preserved in 80% ethanol. Samples were sorted in the laboratory by first picking out large animals and then passing each sample through a series of nets of different mesh sizes to separate large and small invertebrates. A final check of each sample with a dissecting microscope served to remove any smaller animals that could be missed in the coarse sorting.

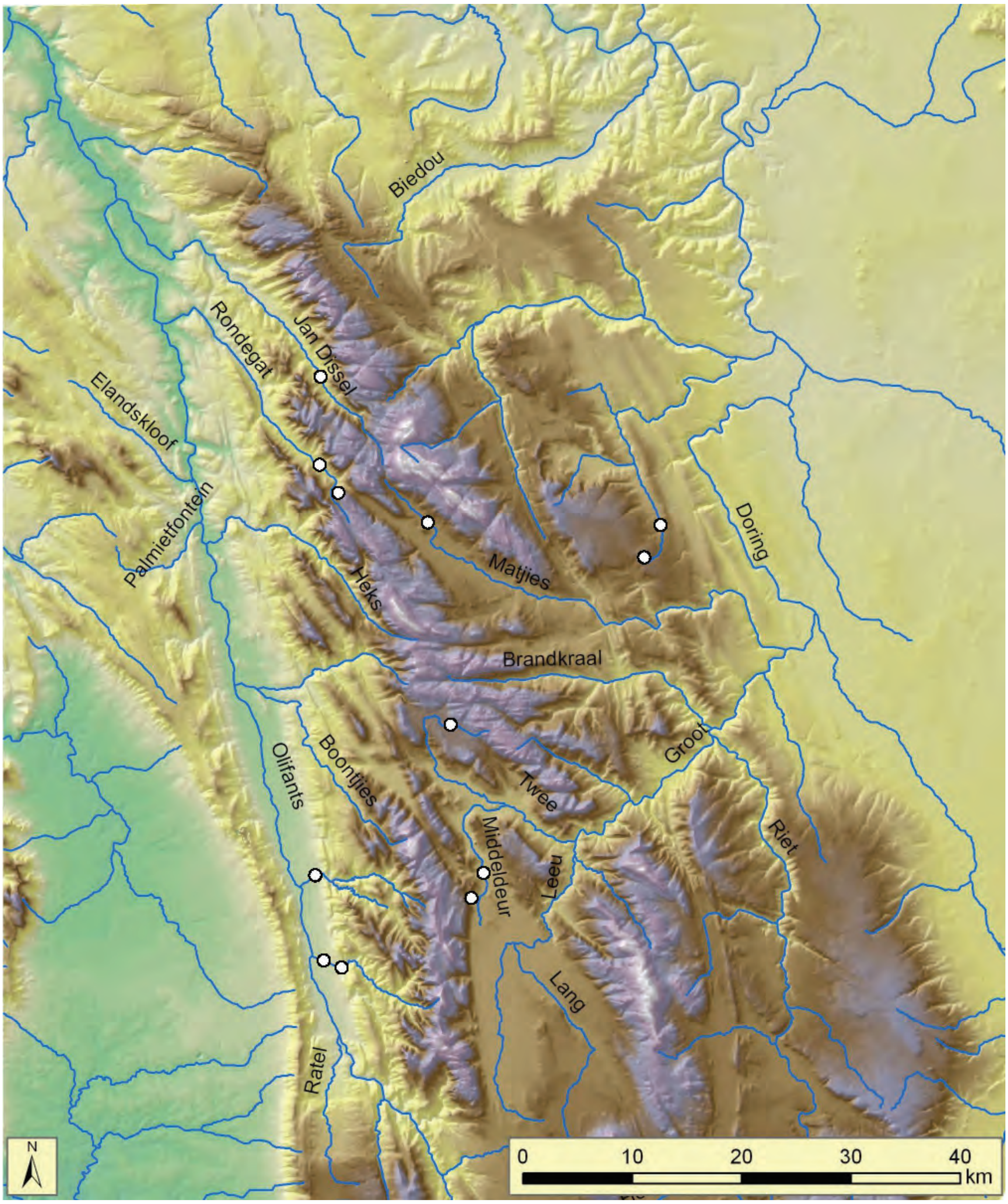

Figure 8.1. The river sites surveyed during the 12-22 April 2005 collecting excursion to the rivers of the Cederberg. For site details refer to Table 8.1.

Identification of animals was carried out using Wild M5 dissecting microcopes (6-50X magnification). The library of taxonomic papers and card index information held by the Albany Museum was used for identification. Museum-voucher specimen material was used for comparison and confirmation of identification. Although not all species were identified to specific or even generic level all material collected is stored and curated in the National Collection of Freshwater Invertebrates of the Makana Biodiversity Center, Albany Museum, Grahamstown. Material is recorded under the Cederberg Rivers catalogue (CED) for ease of retrieval and regional recognition of the collection. The collection contributed 92 separate CED catalogue entries. Samples that have been sorted were given individual species identification labels under the CED catalogue.

8.3 Results

Of the 92 biotopes sampled on the 11 rivers surveyed, 52 were completely analyzed and studied and all taxa were identified as far as possible (Table 8.1). Only a selection of taxa are however considered for this report and these are presented in Table 2. The abbreviations for biotopes sampled are listed in Table 8.3. The pH of all the rivers surveyed was acid ranging from 5.4 to 6.3 and all waters had low levels of TDS ranging from 15 to 57 mg $\ell^{-1}$and electrical conductivity from ranging from 4 to 66 µS cm^{-1} (Table 8.1).

(a) Ephemeroptera

A total of 32 mayfly species in five families were identified. Of these 22 belong to known described species. This means that 10 of the species were either of uncertain identity (due to, for example, small size or damage), or appeared to have differences to known species, which may mean that either they represent a morphological variation in a diverse group, or they are undescribed species. The results of this study indicate a slightly higher diversity of mayflies in the streams draining to the west (24 species) of the watershed directly into the Olifants River than those draining east (21 species) into the Doring River.

The family Teloganodidae has four genera and five species, all except one species are endemic to the southern and western Cape. The survey recorded three species in three separate genera in the rivers of the Cederberg. *Lestagella penicillata* the most widespread and only species extending its range beyond the south-western Cape, was relatively abundant and found in all rivers except the Hex-Middeldeur and Noordhoeks Rivers. *Lithogloea harrisoni* was found only in the Driehoeks River (quite abundant at the only site sampled). *Ephemerellina barnardi* was found in the Driehoeks, TraTra and upper Hex Rivers. All species of Teloganodidae were recorded from the rivers draining eastwards from the watershed but only *L. penicillata* was recorded in the west flowing rivers.

The Leptophlebiidae are well represented by eight species in the survey. The common *Adenophlebia auriculata* (widespread through South Africa) was found in rivers flowing east and west from the watershed. The rare *Adenophlebia peringueyella* was found in the Upper Thee and Driehoeks rivers. Three species of the western-Cape endemic genus *Aprionyx* were identified, with a fourth unnamed species which could be the undescribed nymph of one of several species currently known only in the adult stage. *Aprionyx intermedius* was found only in the Driehoeks River, where it was relatively abundant, while *A. tabularis* and *A. peterseni* were more widespread. The former species recorded from the Rondegat River draining west and in the Hex (Middeldeur), Tentskloof and TraTra Rivers draining east. The latter species also recorded from the Rondegat and Noordhoeks Rivers draining west and the Tra Tra River draining east into the Doring River. *Choroterpes nigrescens*, a relatively rare species, with a limited distribution countrywide, was found only in the Tentskloof River. *Castanophlebia calida* a widespread, common species, was recorded from the Noordhoeks, Jan Dissels and Upper Hex (Middeldeur) Rivers. *Euthraulus elegans* was found only in the Upper Thee River during this survey, but is a widespread species in South Africa.

Several interesting species were discovered in the family Baetidae. Of particular note are an undescribed species of *Acanthiops* from the Noordhoeks River, an undescribed species of *Afroptilum* from the Upper Thee and Jan Dissels Rivers, an undescribed species of *Demoulinia* from the Tra Tra River, a species of *Nigrobaetis* (possibly *bethunae*) from the Upper Hex (Middeldeur) River, an undescribed species of *Pseudopannota* which was abundant in the Upper Thee and Noordhoeks Rivers and an undescribed species of *Baetis* from the Rondegat River. The other listed described species are all relatively common and not worth further mention. One single specimen from the Tentskloof River, could not be placed even at generic level, but as this specimen was damaged (no legs), it cannot be declared a new genus without further material being examined. The unidentified *Cloeon* species is not particularly noteworthy as it was damaged, and is probably a known species.

Afronurus barnardi (Heptageniidae) was found in all of the west-draining rivers, but none of those draining to the east. Despite a revision of the *Afronurus* species by Schoonbee (1968), there is still uncertainty about the identification of *Afronurus* species. *A. peringueyi*, which is widespread in Natal and in countries to our north (Namibia and a possible record from the Democratic Republic of the Congo), and *A. barnardi*, are very similar morphologically.

The Caenidae as a family need revision, with the linking of nymphal and adult stages. The most common and abundant species in the western-Cape is *Caenis capensis.*

A *Prosopistoma* species collected previously from the Olifants River by Rebecca Tharme in the early 1990s, and by Elizabeth Filmalter from the Jan Dissels River, also during the early to mid-1990s, is noticeable absent from this survey, and has been specially sought since these earlier records. This is certainly a new species, and is under severe threat, if not already extinct.

Considering the rare, unusual or undescribed mayflies identified from this survey, the Driehoeks, TraTra and upper Hex (Middeldeur) Rivers support the rare teloganodid mayfly, *Ephemerellina barnardi*, with the Driehoeks also recording *Lithogloea harrisoni*, and the leptophlebiid *Aprionyx intermedius.* The Rondegat and Tra Tra Rivers both recorded two other species of *Aprionyx*, with the Rondegat River also producing an undescribed species of *Baetis.*

Conservation of the Upper Thee River would protect several undescribed and possibly endemic species of Baetidae, and the rare *Adenophlebia peringueyella.* The Noordhoeks River provided the only specimen of an undescribed species of *Acanthiops*, and the unnamed *Pseudopannota* species was only recorded but relatively abundant in both the Noordhoeks and Thee Rivers. This survey highlights that the Cederberg rivers studied have a high number of unusual, rare and in some cases possibly endemic mayflies.

(b) Trichoptera

A total of 45 species of caddisflies in ten families were recorded from the survey undertaken. Of these 20 species belong to known and described species. Of the 25 remaining genera that were recorded, 13 were collected only as larvae and could thus belong to presently known and described adults of species for which the correlation with larvae is not known, or they could represent larvae of undescribed species. The remaining twelve species could not be placed into known described species and may represent undescribed species or morphological variants of known species. They will be discussed in some detail below. The streams draining west directly into the Olifants River contributed 31 species and those draining east into the Doring River contributed 29 species of Trichoptera. The Thee and Noordhoeks Rivers produced the greatest diversity of Trichoptera species in the west draining rivers and the Hex – Middeldeur River the most in the east draining rivers.

The family Philopotamidae is represented by two genera and six known species in the western Cape. In the survey conducted it was represented by *Chimarra ambulans* in the Noordhoeks and Jan Dissels Rivers, the larvae of a *Dolophilodes* species in the Thee River and larvae of *Chimarra* species from the Jan Dissels, Tentskloof, Tra Tra and Dassiekloof Rivers.

The family Hydropsychidae is represented by four genera and 8 known species in the western Cape. The widespread species *Cheumatopsyche afra* was recorded only from the Thee and Noordhoeks Rivers and *Cheumatopsyche maculata* a species known from upper erosion reaches of streams was expectedly recorded in the Rondegat, Upper Hex (Middeldeur) and Tentskloof Rivers. *Macrostemum capense* was recorded from the Jan Dissels and Driehoek Rivers. The undescribed larvae of a *Cheumatopsyche* species were recorded in all the west flowing tributaries of the Olifants River and from the Driehoeks and Tra Tra Rivers. By far the most interesting find was the collection of females of an undescribed genus and species belonging in the tribe Polymorphanisini. This considerably extends the distributional range of the tribe, known previously only from the eastern sub-tropical regions of South Africa in KZN and along the western border of the Limpopo River. What is needed however are some males of this species to enable a proper description and selection of a type specimen to represent the species and genus. Material of the female of this species have been sent to colleagues in the USA who are undertaking a molecular systematic study of the world genera of hydropsychid Trichoptera. The placement of this species will hopefully reveal some very interesting phylogenetic relationships.

Dipseudopsidae were under-collected and would have been expectedly more common. The special burrowing behaviour of the larvae would mean that special collecting techniques would have been required to reflect true representation.

Eight species of *Ecnomus* and one species of *Parecnomina* are known from the western Cape. The present survey recorded *Ecnomus kimminsi* and *E. similis* from the Noordhoeks River and *Parecnomina resima* from the Rondegat, Hex (Middeldeur) and Driehoeks Rivers. Two undescribed species of *Ecnomus* were recorded from the Thee River.

Polycentropodidae have not been previously recorded from the western-Cape and larvae of a species of *Paranyctiophylax* from the Jan Dissels River will almost certainly represent an undescribed species.

Although ten possible species have been recorded from the western-Cape previously, the micro-caddisfly family Hydroptilidae has not been adequately studied in South Africa. Three of these were recorded during this survey. *Hydroptila cruciata* was recorded from both east and west flowing tributaries of the Olifants and Doring Rivers. *Orthotrichia barnardi* was found only in the swift flowing cobble-beds of the Noordhoeks and Jan Dissel Rivers. *Oxyethira velocipes* was most widespread and found in the Thee, Hex, Middeldeur and Tentskloof Rivers. An undescribed species of *Hydroptila* was found in the Thee River.

Of all the Trichoptera families recorded from South Africa, the Leptoceridae with more than 50 species in 10 genera attains its greatest diversity in the western Cape. At least 14 species were recorded in the present survey and six of these are undescribed species. The Thee River exclusively records one and the Rondegat, Hex, Driehoeks and Tra Tra Rivers record a second undescribed species of *Athripsodes*. The Middeldeur records three undescribed species of *Leptecho* and two of these are also found in the Tentskloof River. The remarkable *Leptecho helicotheca*, a leptocerid larva that constructs a helical snail-shell shaped case of sand grains was recorded from all of the west flowing tributaries of the Olifants River but none of the tributaries of the Doring River.

The family Sericostomatidae has four genera and 12 species recorded from the western Cape. The present study records *Petroplax caricis* from the Tentskloof River and *P. curvicosta* from Thee, Noordhoeks and Tra Tra Rivers. What may prove to be the undescribed larvae of *Cheimacheramus caudalis* were collected from a small seeping tributary of the Rondegat River.

Larvae of *Barbarochthon*, that would represent either morphological variation in the species *B. brunneum* or undescribed species in this genus, were collected the Hex, Tentskloof, Driehoeks and Tra Tra Rivers, notably only the east flowing tributaries of the Doring River. The variation observed in the so far only known species of *Barbarochthon* has cast doubt on its restricted species status. A student at Rhodes University is undertaking a molecular analysis to assess the relationship of the different isolated populations of this species.

Empty cases and some pupae of presumably *Petrothrincus circularis* were collected from the Rondegat, Jan Dissels, Hex, Tentskloof and Tra Tra Rivers. This represents a considerable range extension for this genus. The species identification will have to be confirmed from adults that need to be collected or reared through from larvae or pupae.

(c) Diptera (Simuliidae)

Although many families of aquatic Diptera were collected only the Simuliidae (blackflies) are studied in detail for this report. Eight species in the genus *Simulium* were recorded in the rivers surveyed and none of these were recognized, on morphological features used to identify them, as undescribed species.

All three known species of *Simulium* endemic to the southern and south-western Cape (*S. merops, S. hessei* and *S. harrisoni*) were recorded during the survey. *Simulium harrisoni* was widespread and occurred in both east-flowing tributaries of the Doring River and west-flowing tributaries of the Olifants River. *Simulium hessei* was recorded only from the Tentskloof River and *S. merops* only from the Tra-Tra River. Not one of the five species of *Paracnephia* endemic to the south-western Cape, was however collected. These five species are, however, known to be seasonal and have been recorded only during the spring to early summer, a period not covered during this ten-day survey (Palmer & de Moor 1998).

The recording of *S. bequaerti* from the Hex River and *S. hirsutum* from the Thee and Noordhoeks Rivers are range distribution extensions of these species that were previously considered to be restricted to the eastern half of southern Africa. *Simulium medusaeforme* one of the most widespread and common species of blackfly in South Africa was found in all the river systems surveyed where suitable flow conditions occurred. Strangely enough the other common and pollution tolerant species *S. nigritarse* was recorded only at the Tra Tra River in this survey. *Simulium impukane* a widespread, common species in temporary streams was recorded in the Thee and Noordhoeks Rivers. Simuliid larvae or pupae were not abundant in any of the rivers sampled.

(d) Plecoptera

Only the family Notonemouridae was represented and not all samples of species collected were identified to generic level.

(e) Coleoptera

The discovery of *Delevea bertrandi* (Torridincolidae) in the Tentskloof River extends the distribution of this species, previously restricted to the Hawaqas and Hottentots Holland Mountains, further north into the rivulets of the Cederberg. The other known species *Delevea namibensis* has been recorded near Calvinia and in the Namib Nauwkluft mountains and represents a wider but disjunct distribution pattern. The only other known species in the sub-family Deleveinae are from Japan (Endrody-Younga 1997). The sub-family Torridincolinae is well known from the eastern part of southern Africa and extends into Central Africa, Madagascar and South America (Endrody-Younga 1997).

The "hairy-headed" genus and species of Scirtidae (=Helodidae) is also an interesting find as nothing like this is recorded in Henri Bertrand's 1972 monograph of the larvae of world beetles nor in any of the many papers he published on larvae from Africa. This "species" was fairly common in the higher reaches of rivers in the Doring and Olifants catchments (Table 8.2).

Larvae in the family Ptilodactylidae (genus, and species undescribed) are fairly common in the rivers of the southern and south-western Cape and being found in the Cederberg further extends their distribution. The family is evidently endemic to this region in South Africa as it is not recorded anywhere else.

(f) Neuroptera and Megaloptera

The collection of adult Sisyridae genus *Sisyra* sp. from the Noordhoeks River indicates that there is a presence of freshwater sponges. Sisyridae are known from the Orange and Vaal Rivers and have been collected by Albany Museum researchers in rivers in KZN and the eastern Cape. The discovery of these animals in the Cederberg is therefore an interesting new range extension.

The larvae of Megaloptera belonging to the family Corydalidae were recorded in several streams where they were restricted to swift-flowing mountain stream reaches. These long-living larvae that take two to three years to complete a life cycle are thus indicative of permanently flowing conditions.

8.4 Discussion

The collection of 14 undescribed species incorporating two undescribed genera in two orders of aquatic insects, indicate that the biodiversity in the rivers of the Cederberg is only partially known and still needs further survey, collecting and study to become more comprehensively known. As already known for the Fishes, there is also some endemism evident in these two aquatic insect orders (Ephemeroptera and Trichoptera). The Noordhoeks and Thee Rivers in particular were either the only single or else the only two rivers to record undescribed species of *Acanthiops*, *Pseudopanota*, *Hydroptila* and

Athripsodes and two species of *Ecnomus*, as well as the new genus and species of Polymorphanisini. In addition these two rivers also contained a further two of the more widespread undescribed species (Table 8.2). The Middeldeur and Tentskloof Rivers also shared three undescribed species of *Leptecho*. The Tentskloof River furthermore produced an undescribed genus of baetid mayfly, and was the only river where *Simulium hessei* and the rare *Delevea bertrandi* were recorded. The upper reaches of the Driehoeks River produced four rare species of Ephemeroptera.

The recording of Prosopistomatidae in the Olifants River was a single rare events and it is to be expected that if the species survived it would have found refuge in the larger western flowing tributaries of the Olifants River. The periodic drying out of the main Olifants River and the spraying of pesticides for citrus orchard insect pest control would have almost certainly caused the local extinction of the unnamed species in this river.

The single survey of a few river sites has revealed a rich aquatic macroinvertebrate fauna with several undescribed species. More survey work is recommended covering more rivers and sampling selected rivers over several seasons.

Acknowledgements
Thanks to Roger Bills for organizing the field excursion and assisting with collecting: to Irene de Moor for assistance with the fieldwork and Mbongeni Baninzi for helping sort and clean up and pre-identify unsorted the collected samples. The WRC provided funding for the work and workshop. The Directorate of Museums and Heritage, Eastern Cape, are thanked for providing research facilities and encouraging this research.

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Table 8.1. The Cederberg rivers surveyed for macroinvertebrates between 12-22 April 2005. The names of the rivers, Albany Museum catalogue numbers designated to biotopes sampled, the date, description of biotope (refer to table 3 for explanation of abbreviations), latitude, longitude, numbers of digital photos taken at sites, pH, temperature (degrees celcius), Electrical conductivity (Microsemens per centimeter), Total dissolved solids (milligrams per litre) and time samples were collected and details were recorded.

Sample	**Date**	**Biotope and description**	**Latitude S**	**Longitude E**	**pH**	**Temp**	**EC**	**TDSmg/l**	**Time**
CED1	12/04/2005	SOP, ovipositing leptophlebiids c.10h00	32º 43’ 30”	19º 13’ 29”	5.5	15.9	24	15	
CED2	12/04/2005	Temp rock pools (two sites CED1 & CED2)	32° 43’ 19”	19º 12’ 43”					
CED3	12/04/2005	FNW Odonata on rocks	32° 43’ 17”	19º 12’ 41”					
CED4	12/04/2005	TVIC, TVOC Scirpus	32° 43’ 17”	19º 12’ 41”	5.5	15.5	43	27	12h30
CED5	12/04/2005	Bedrock pool away from river (flood water?)	32° 43’ 17”	19º 12’ 41”					
CED6	12/04/2005	SIC, Large boulder in slow-flowing water	32° 43’ 17”	19º 12’ 41”					
CED7	12/04/2005	SOC, Algal covered stone	32° 43’ 17”	19º 12’ 41”					
CED8	12/04/2005	MVIC Scirpus in swift current (Simuliidae)	32° 43’ 17”	19º 12’ 41”					
CED9	12/04/2005	SIC below overhang & covered with Scirpus	32° 43’ 17”	19º 12’ 41”					
CED10	12/04/2005	RIC, MIC, Roots & moss in trickling water	32° 43’ 17”	19º 12’ 41”					
CED11	12/04/2005	RMIC, Scirpus in swift current & waterfall	32° 43’ 17”	19º 12’ 41”					
CED12	13/04/2005	Light Trap, on bridge near camp site	32º 43’ 46”	19º 13’ 47”					
CED13	13/04/2005	Light Trap, upper Hex River	32° 43’ 17”	19º 12’ 41”					
CED14	13/04/2005	Light Trap, pool below new pump site	32º 43’ 30”	19º 13’ 29”					
CED15	13/04/2005	Light Trap, above fish barrier waterfall	32º 37’ 44”	19º 10’ 55”					
CED16	13/04/2005	FNW, Ephemeroptera & Odonata	32º 37’ 44”	19º 10’ 55”					
CED17	13/04/2005	BRIC, SIC above fish barrier waterfall	32º 37’ 44”	19º 10’ 55”	5.8	15.6	26	17	11h25
CED18	13/04/2005	Bedrock with vegetation in cracks	32º 37’ 44”	19º 10’ 55”					
CED19	13/04/2005	MVIC Scirpus in current	32º 37’ 44”	19º 10’ 55”					
CED20	13/04/2005	Waterfall seep with vegetation	32º 37’ 44”	19º 10’ 55”					

Sample	Date	Biotope and description	Latitude S	Longitude E	pH	Temp	EC	TDSmg/l	Time
CED21	13/04/2005	Rooted sedges & moss on vertical cliff face (Sericosomatidae)	32º 37' 44"	19º 10' 55"					
CED22	13/04/2005	Sediments below seep (Sericostomatidae)	32º 37' 44"	19º 10' 55"					
CED23	13/04/2005	MVIC (Palmiet) in dammed River where B. erubescens was translocated	?	?					
CED24	13/04/2005	SIC & BRIC Small trib of Suurvlei on Mountain	32º 37' 55"	19º 12' 09"	5.4	15.5	24	16	17h35
CED25	14/04/2005	Light trap, below confluence of Hex & Middeldeur	32° 43' 22"	19º 13' 43"					
CED26	14/04/2005	Light trap on bridge near camp site	32º 43' 46"	19º 13' 47"					
CED27	14/04/2005	Emergence Trap, below onion field	32º 43' 40"	19º 13' 43"					
CED28	14/04/2005	Emergence Trap, on upper Hex River	32° 43' 17"	19º 12' 41"					
CED29	14/04/2005	SIC, sampled run, cobbles & boulders	32º 48' 36"	19º 07' 02"					
CED30	15/04/2005	Light trap, broad run in river	32º 48' 14"	19º 06' 30"					
CED31	15/04/2005	Light trap, below upper camp site	32º 48' 36"	19º 07' 02"					
CED32	15/04/2005	SIC, electrofished into seine net	32º 48' 36"	19º 07' 02"	5.4	17.6	38	24	10h30
CED33	14/04/2005	Drift Sample	32º 48' 36"	19º 07' 02"					18h00-20h00
CED34	15/04/2005	SIC downstream of confluence with tributary							
CED35	15/04/2005	SIC upstream of confluence with tributary							
CED36	15/04/2005	SIC, leaf litter sampled for Simuliidae							
CED37	15/04/2005	Insects in spider web							
CED38	15/04/2005	Hand-picked stones							

CED39	15/04/2005	Moss from stones above tributary confluence							
CED40	15/04/2005	SIC, riffles & runs above confluence							
Sample	**Date**	**Biotope and description**	**Latitude S**	**Longitude E**	**pH**	**Temp**	**EC**	**TDSmg/l**	**Time**
CED41	15/04/2005	SOP, Coleoptera, Hemiptera in large pool	32º 48' 10"	19º 06' 29"					15h30
CED42	15/04/2005	Drift Sample 5 nets over 200 m of stream	32° 43' 18"	19° 04' 18"					18h00-22h30
CED43	16/04/2005	Light trap next to riffle	32° 43' 18"	19° 04' 18"					
CED44	16/04/2005	SIC, handpicked samples	32° 43' 18"	19° 04' 18"	5.7	19.8	35	23	11h26
CED45	16/04/2005	SIC, Kick sample with SASS net	32° 43' 18"	19° 04' 18"					
CED46	16/04/2005	SIC, with 300 micro m. net along 200 m of river	32° 43' 18"	19° 04' 18"					
CED47	16/04/2005	RMIC, Scirpus in current along 50 m river	32° 43' 18"	19° 04' 18"					
CED48	16/04/2005	Moss & MVIC in slow current	32° 43' 18"	19° 04' 18"					
CED49	16/04/2005	SOC, Backwater pools	32° 43' 18"	19° 04' 18"					
CED50	17/04/2005	Light trap below camp site	32° 48' 01"	19° 06' 27"		16.7	40	26	
CED51	17/04/2005	Emergence trap below camp site	32° 48' 01"	19° 06' 27"					
CED52	17/04/2005	Light trap below upper camp site	32° 48' 37"	19° 07' 04"					
CED52	17/04/2005	Emergence trap below upper camp site	32° 48' 37"	19° 07' 04"					
CED53	17/04/2005	FNW Empididae road crossing deep run	32° 48' 10"	19° 06' 29"					
CED54	17/04/2005	Emergence trap	32° 43' 18"	19° 04' 18"					
CED55	17/04/2005	Temp rock pool on rocky outcrop	32º 24' 28"	19º 06' 33"					
CED56	18/04/2005	Light trap top of catchment	32º 25' 53"	19º 08' 57"					
CED57	18/04/2005	FNW Ephemeroptera	32º 25' 53"	19º 08' 57"	5.8	15.9	20	17	10h05

CED58	18/04/2005	Hand-picked stones & detritus below seep	32º 24 23”	19º 05’ 04”	6	13.4	4	30	11h20
CED59	18/04/2005	Sediment & leaf litter below seep	32º 24 23”	19º 05’ 04”					

Sample	**Date**	**Biotope and description**	**Latitude S**	**Longitude E**	**pH**	**Temp**	**EC**	**TDSmg/l**	**Time**
CED60	18/04/2005	Moss & vegetation along splash zone in seep	32º 24 23”	19º 05’ 04”					
CED61	18/04/2005	Light trap above waterfall (fish barrier)							
CED62	18/04/2005	Light trap below road bridge							
CED63	18/04/2005	Reared heptageniid from Thee River	32º 48’ 36”	19º 07’ 02”					
CED64	18/04/2005	SIC, Main stream medium -swift flow	32º 22 24”	19° 03’ 37”	6	14.2	52	44	16h15
CED65	18/04/2005	MVIC,	32º 22 24”	19° 03’ 37”					
CED66	18/04/2005	FNW Adult Ephemeroptera	32º 22 24”	19° 03’ 37”					
CED67	19/04/2005	Malaise trap	32º 22 24”	19° 03’ 37”					
CED68	19/04/2005	Light trap at seep	32º 24 23”	19º 05’ 04”					
CED69	19/04/2005	Emergence trap upstream of barrier waterfall							
CED70	19/04/2005	Emergence trap below road bridge							
CED71	19/04/2005	Light trap at large tributary on footpath							
CED72	19/04/2005	SIC,MIC stones with & without moss	32º 25’ 53”	19º 08’ 57”					
CED73	19/04/2005	MVIC, RMIC	32º 25’ 53”	19º 08’ 57”					
CED74	20/04/2005	Light trap in front of NC cottage	32º 23’ 51”	19º 05’ 25”	6.1	14.1	33	28	08h22
CED75	20/04/2005	SIC, LPIC	32º 23’ 51”	19º 05’ 25”					
CED76	20/04/2005	SIC	32º 23’ 51”	19º 05’ 25”					
CED77	20/04/2005	Light trap at seep (2nd sample)	32º 24 23”	19º 05’ 04”					
CED78	20/04/2005	Emergence trap set 17/04	32º 25’ 53”	19º 08’ 57”					

CED79	20/04/2005	MVIC Scirpus below pool near NC cottage	32º 23’ 50”	19º 05’ 22”					
CED80	20/04/2005	MVIC after flood in swollen river	32º 16’ 59"	19º 12’ 40”					
CED81	21/04/2005	Light trap upstream of bridge rd to Esselbank	32º 16’ 47"	19º 13’ 03”					
CED82	21/04/2005	Light trap below barrier waterfall	32º 16’ 59"	19º 12’ 40”	6.2	9.4	66	57	11h50
CED83	21/04/2005	MVIC after subsided flood water	32º 16’ 59"	19º 12’ 40”					
Sample	**Date**	**Biotope and description**	**Latitude S**	**Longitude E**	**pH**	**Temp**	**EC**	**TDSmg/l**	**Time**
CED84	21/04/2005	Temporary rock pools	32º 16’ 58"	19º 12’ 39”					
CED85	21/04/2005	SIC hand-picked below bridge	32º 16’ 54"	19º 10’ 55”	6	13.3	41	35	15h25
CED86	21/04/2005	SIC kicked with SASS net	32º 16’ 54"	19º 10’ 55”					
CED87	21/04/2005	MVIC, TVIC Scirpus, Palmiet	32º 16’ 54"	19º 10’ 55”					
CED88	21/04/2005	SIC, MVIC	32º 17’ 43"	19º 11’ 56”					
CED89	21/04/2005	Crab released	32º 17’ 43"	19º 11’ 56”					
CED90	21/04/2005	SIC, MVIC Scirpus road crossing to village	32º 15’ 58"	19º 09’ 18”					17h50
CED91	21/04/2005	Ephemeroptera failed rearing sub-imagos	32º 25’ 53”	19º 08’ 57”					
CED92	22/04/2005	SIC, hand-picked, & kicked samples	32º 14’ 34”	19º 00’ 47”	6.3	16.6	37	31	13h30

Table 8.2. The taxa collected from 13 sites on 11 rivers in the Cederberg between 12 and 22 April 2005. Taxa recorded include Ephemeroptera, Trichoptera, Diptera (Simuliidae), Plecoptera and species of special interest from Coleoptera, Neuroptera and Megaloptera.

Taxa	Upper Thee	Lower Thee	Noord-hoeks	Ronde-gat	Ronde-gat Trib	Jan Dissels		Upper Hex	Lower Hex	Middel-deur	Tents-kloof	Drie-hoeks	Tra Tra	Dassie-kloof
EPHEMEROPTERA														
Teloganodidae														
Ephemerellina barnardi								17				4	4	
Lestagella penicillata	58			19		5					8	1	17	6
Lithogloea harrisoni												42		
Leptophlebiidae														
Adenophlebia auriculata				13				1			21		11	
Adenophlebia peringueyella	7													
Aprionix intermedius												27		
Aprionix tabularis				1				3			3		1	
Aprionix peterseni			1	5									3	
Aprionix sp.			1	13				2						
Castenophlebia calida			1			4		1						
Choroterpes nigrescens											15			
Euthraulus elegans	4													
Baetidae														
Acanthiops sp CED42F			1											
Pseudocloeon piscis	8		2	17				17						1
Pseudocloeon glaucum	5													

Pseudocloeon vinosum	28		33	15		7					2		5	
Afroptilum parvum			6											

Taxa	**Upper Thee**	**Lower Thee**	**Noord-hoeks**	**Ronde-gat**	**Ronde-gat Trib**	**Jan Dissels**		**Upper Hex**	**Lower Hex**	**Middel-deur**	**Tents-kloof**	**Drie-hoeks**	**Tra Tra**	**Dassie-kloof**
Afroptilum sudafricanum	19		8					2			20		3	2
Afroptilum sp.CED29D	2					37								
Demoulinia sp. CED80G													1	
Nigrobaetis sp.								5						
Demoreptus capensis				5							1			
Pseudopannota sp. CED36A	51		60											
Cheleocloeon excisum	2		42	5		3								
Baetis harrisoni	28		11	12		8					16		4	2
Baetis sp. CED76D				9										
Cloeon virgiliae											1			
Cloeon sp. CED47F			1											
Genus sp. CED23B											1			
Caenidae														
Caenis capensis	2			1									2	
Caenis sp.	1		11								1			
Heptageniidae														
Afronurus barnardi	43		3	2		11								
TOTAL Ephemeroptera sp.	**14**	**0**	**14**	**13**	**0**	**7**		**8**	**0**	**0**	**11**	**4**	**10**	

Taxa	**Upper Thee**	**Lower Thee**	**Noord-hoeks**	**Ronde-gat**	**Ronde-gat Trib**	**Jan Dissels**		**Upper Hex**	**Lower Hex**	**Middel-deur**	**Tents-kloof**	**Drie-hoeks**	**Tra Tra**	**Dassie-kloof**
TRICHOPTERA														
Philopotamidae														
Chimarra ambulans			2			1								
Chimarra spp. Larvae						4					13	2	17	
Dolophilodes spp. Larvae	1													
Hydropsychidae														
Cheumatopsyche afra	21		71											
Cheumatopsyche maculata				9				4			8			
Cheumatopsyche sp. CED42AA	80		108	16		48						2	4	
Genus Polymorhanisini CED31D	1		39											
Macrostemum capense						1						14		
Dipseudopsidae														
Dipseudopsis sp.													1	
Ecnomidae														
Parecnomina resima				2				4				3		
Ecnomus kimminsi			3											
Ecnomus similis			4											
Ecnomus sp. CED31P	1													

Taxa	Upper Thee	Lower Thee	Noord-hoeks	Ronde-gat	Ronde-gat Trib	Jan Dissels		Upper Hex	Lower Hex	Middel-deur	Tents-kloof	Drie-hoeks	Tra Tra	Dassie-kloof
Ecnomus spp.			11	4		6								
Polycentropodidae														
Paranyctiophylax sp.						1								
Hydroptilidae														
Hydroptila cruciata	26	2	28			2				9				
Hydroptila sp CED30G	10	2												
Ortthotrichia barnardi			3			2								
Orthotrichia sp.	1							1						
Oxyethira velocipes	25	5						2		13	1			
Oxyethira sp.								1	3			1		
Leptoceridae														
Athripsodes harrisoni	28		64							1				
Athripsodes prionii													8	
Athripsodes schoenobates										4				
Athripsodes sp. CED4X larvae				2				8			4		2	
Athripsodes sp. SCR164P	3													
Athripsodes spp.								1				100		
Leptecho bergensis	1		20	3	1						60	1	2	
Leptecho helicotheca	1		1	3		1								
Leptecho lupi								3						
Leptecho sp. CED12B adult										1	1			

Leptecho sp. CED13E adult								1		5	3			
Taxa	**Upper Thee**	**Lower Thee**	**Noord-hoeks**	**Ronde-gat**	**Ronde-gat Trib**	**Jan Dissels**		**Upper Hex**	**Lower Hex**	**Middel-deur**	**Tents-kloof**	**Drie-hoeks**	**Tra Tra**	**Dassie-kloof**
Leptecho sp. CED13G adult									1	9				
Leptecho sp. CED4Y larvae								69						
Leptecho spp.	6					9		2			36	1		
Oecetis modesta				4									2	
Oecetis sp.	4	1	1	1		25		25			2	6		
Sericostomatidae														
Petroplax caricis											1			
Petroplax curvicosta	5		4										5	
Petroplax sp.						4								
Cheimacheramus sp. Larvae					21									
Barbarochthonidae														
Barbarochthon spp.								3			29	1		
Barbarochthon sandgrain case											2		2	
Petrothrincidae														
Petrothrincus circularis				4		2		26			2		6	
TOTAL Trichoptera sp.	**17**	**4**	**14**	**10**	**2**	**13**		**14**	**2**	**7**	**13**	**10**	**10**	

DIPTERA														
Simuliidae														
Simulium bequaerti								2						

Taxa	**Upper Thee**	**Lower Thee**	**Noord-hoeks**	**Ronde-gat**	**Ronde-gat Trib**	**Jan Dissels**		**Upper Hex**	**Lower Hex**	**Middel-deur**	**Tents-kloof**	**Drie-hoeks**	**Tra Tra**	**Dassie-kloof**
DIPTERA														
Simulium harrisoni	20		47	1		4		1			9	5	4	
Simulium hessei											17			
Simulium hirsutum	3		12											
Simulium impukane	18		1									1		
Simulium medusaeforme	41		25	3		13		45			11	1	43	
Simulium merops													1	
Simulium nigritarse											2			
Simulium spp.	4			1										1
TOTAL Simuliidae sp	**5**	**0**	**4**	**3**	**0**	**2**		**3**	**0**	**0**	**4**	**3**	**3**	**1**
PLECOPTERA														
Notonemouridae														

Unidentified	4			2							2	100		
Aphanicercopsis sp.								5						
Aphanicerca sp.											12			
Aphanicercella sp.				17										

Taxa	**Upper Thee**	**Lower Thee**	**Noord-hoeks**	**Ronde-gat**	**Ronde-gat Trib**	**Jan Dissels**		**Upper Hex**	**Lower Hex**	**Middel-deur**	**Tents-kloof**	**Drie-hoeks**	**Tra Tra**	**Dassie-kloof**
SPECIAL INTEREST														
COLEOPTERA														
Torridincolidae														
Delevea bertrandi											3			
Helodidae = Scirtidae														
Hairy head genus CED29Q	9			2				3			9		8	1
non hairy species	4		5		12	6		6			7	25	4	2
Ptilodactylidae														
Undescribed genus	17		9			4		1					2	
NEUROPTERA														
Sisyridae														
Sisyra sp.			1											

MEGALOPTERA														
Corydalidae														
Unidentified larvae	3			2							4		2	

Table 8.3. Abbreviations for aquatic biotopes where macro-invertebrates were sampled.

BRIC	Bedrock in current
FNW	Flying near water
LPIC	Leaf pack in current
MIC	Moss in current
MVIC	Marginal vegetation in current
RIC	Roots in current
RMIC	Rooted macrophytes in current
SIC	Stones in current
SOC	Stones out of current
SOP	Surface of pool/pond
TVIC	Trailing vegetation in current
TVOC	Trailing vegetation out of current

9. POPULATION VIABILITY ANALYSIS OF *AUSTROGLANIS BARNARDI* IN THE CEDERBERG

MICHAEL CUNNINGHAM

UNIVERSITY OF THE FREE STATE, PRIVATE BAG X13, PHUTHADITJHABA 9866. E-MAIL: spookpadda@yahoo.com

Summary

This chapter uses the available biological data to explore the risk of extinction in *Austroglanis barnardi* (Skelton 1981), an endangered fish species from the Cederberg, using the population viability analysis software program VORTEX. This species was chosen for PVA analysis because it occurs in only three isolated populations, a relatively simple situation to model, and because there are good ecological and biological data available for *A. barnardi* on which to base estimates of extinction risk. Models were developed to address various scenarios incorporating environmental variation and uncertainty in our estimates of species ecology. These scenarios were designed in close collaboration with other project participants (Roger Bills, Ernst Swartz and Vusi Mthombeni), who provided the biological data on which the models are based. The results suggest that the small population in the Thee River may be at a high risk of extinction over the next century due to normal inter-annual fluctuations in population size, and may be a sink population that was formerly supported by dispersal from populations in the Olifants River and adjacent tributaries. Since the commencement of this project the Thee has been invaded by bass (*Micropterus* spp.), increasing the threats to this population. The comparison of similarly sized populations of *A. barnardi*, the Heks and Noordhoeks Rivers, with and without bass, suggest that even low levels of added predation have the potential to reduce populations to low density, dependent on the availability of refuges that are inaccessible to the predators. At these low densities the population would be vulnerable to extinction due to normal year to year fluctuations. These models may not match precisely the dynamics of these actual populations, due to uncertainty in ecological and environmental parameters, and more research is needed, particularly on the extent of year to year variability in population size. The current models, however, do give some useful guidance for conservation management. The overall results suggest that the Thee population has little to contribute, beyond genes, to the conservation of *A. barnardi*. The Heks population is at high risk of extinction but if bass were removed from this stream recovery of *A. barnardi* would substantially reduce the risk of extinction to this species, perhaps resulting in down-listing of the species conservation status. For the present, however, the survival of *A. barnardi* is dependent on management of the Noordhoeks River population to prevent habitat destruction and in particular to prevent the invasion of this system by bass and other predatory fishes.

Population Viability Analysis

Introduction: Estimating Extinction Risk with VORTEX

The aim of Population Viability Analysis is to use available environmental, ecological and demographic knowledge to estimate the risk of population extinction and to better understand the dynamics of a population. The immediate cause of extinction events is change in population size resulting from discrepancies between the number of individuals born and the survival of existing individuals in any time period. The risk that a population goes extinct depends on the current population size, the amplitude of size fluctuations, and the impact of any threatening processes that tend to reduce the population. Fluctuations in birth and survival rates result from random demographic events, such as chance differences in reproductive success that are unrelated to individual attributes. These critical demographic attributes are also affected by year to year differences in the environment, stemming from unpredictable variation in weather, through good years and bad. Although we cannot say with certainty how long a population will survive, given some ecological and environmental knowledge we can estimate the degree of fluctuations in size and from this estimate the probability that a population will become extinct within a set time frame. Simulation approaches are particularly suited to Population Viability Analysis because they replicate the fluctuations that occur in population. In addition, the process of constructing a population model is informative in itself as it forces us to evaluate what we know and to identify which ecological and environmental characteristics are likely to influence extinction risk. VORTEX is a copyrighted program developed by Bob Lacy of the Chicago Zoological Society that is distributed by the IUCN-SSC Conservation Breeding Specialist Group. VORTEX can be downloaded from: http://www.Vortex9.org/Vortex.html.

An overview of the modelling process

Extinction is a natural phenomenon but most species are remarkably persistent. Historical extinction rates for a range of species have been estimated from the fossil record and other sources as being on the order of one per million species per year (Pimm & Jenkins 2010). It seems reasonable to assume that a naturally occurring population, that has persisted through time and that is minimally subject to external threats is capable of surviving normal fluctuations, through good years and bad. The initial step in modelling was to develop a framework scenario of a species reproductive and survival characteristics, using available biological data and ignoring environmental factors that cause population fluctuations. The next step was to develop a standard scenario that included plausible levels of environmental variation, resulting in year to year fluctuations in population size. These initial scenarios modelled the natural state of each population and provided a check that under these circumstances extinction is an unlikely event. A third step in model development was to add population scenarios that include threatening processes, such as predation or habitat loss, either separately or through stepwise addition. The results of simulation under these scenarios were compared with the standard model to better understand the potential effects and timescales of change resulting from these threats. Finally, a range of scenarios were designed to explore the effects of uncertainty in our knowledge of the species ecology. These last models serve to distinguish ecological attributes that need more research from those that have little influence on the persistence of populations. I did not attempt to include effects of inbreeding in these models as in general these populations are at low risk of inbreeding depression, which occurs through persistence at a very small population size through several to many generations. Each model scenario developed through this process was run for 1000 simulations, each of 100 years. The results are expressed as the probability of extinction, the mean time of persistence for populations that go extinct and the mean population size of surviving model populations over the next century.

Austroglanis barnardi: A detailed example of model development

Austroglanis barnardi is a small rock catfish that lives in shallow pools and in the interstices between cobbles (rounded rocks 5-20 cm in diameter) in the lower sections of the Thee, Noordhoeks and Heks Rivers, which flow from short, steep mountain catchments in the Cederberg (Sneeuberg), Heksriverberg and Kouebokkeveldberg ranges, joining the Olifants River from the east around Citrusdal. Genetic differences between the Noordhoeks and Heks River populations of *A. barnardi*, based on sequencing and PCR – restriction fragment analysis of mitochondrial DNA, indicates that there is little or no dispersal among these populations (Cunningham, Swartz & Bills, unpublished data).

Table 9.1 summarises input parameters for the Standard model outlined below. The three populations represent alternate scenarios: a small stream without introduced predators (“Thee”), a larger stream, with abundant habitat and no impacts of invasive species (“Noordhoeks”), and a similarly large capacity habitat with an invasive predatory species (“Heks”). Although these models were intended to represent the actual populations, they can also be seen as labels attached to different scenarios, so that, for example, “Noordhoeks” represents the potential of the Heks population for rehabilitation after removal of bass, “Heks” represents the possible fate of the Noordhoeks if this population is invaded by bass, and “Thee” represents the impact on the Noordhoeks population if upstream water extraction, siltation or other habitat change results in a reduction in population size in that stream.

Thee River

The Thee River is a small tributary joining the Olifants River 24 km upstream of Citrusdal. A small population of *A. barnardi* occurs in shallow cobble runs and pools in this stream, along with its larger relative, *Austroglanis gilli* (Barnard 1943), and several species of minnows and *Galaxias*. Smallmouth bass, *Micropterus dolomieu* (Lacepède 1802), and spotted bass, *Micropterus punctulatus* (Rafinesque 1918), have invaded the lower sections of this river in the past five years, resulting in the loss of at least the minnows and *Galaxia zebratus* Castelnau 1861, which are still found upstream, above the bass. The simulation scenarios modelled here are based on observations prior to the invasion of this river by bass.

Capture – recapture electrofishing surveys of density and measurements of the extent of suitable habitat by Roger Bills (SAIAB) gave a population size estimate of 160 *A. barnardi* in this stream.

Table 9.1. Summary of standard input parameters.

Population / Parameter	**Thee**	**Noordhoeks**	**Heks**
Dispersal	None	None	None
Breeding system	Polygynous	Polygynous	Polygynous
Sex Ratio	M:F = 1:1	M:F = 1:1	M:F = 1:1
% females breeding	100 ± 10%	100 ± 10%	100 ± 10%
% males breeding	100%	100%	100%
Breeding age (A)	2-15 yrs	2-15 yrs	2-15 yrs
Fecundity	Age dependent $F_A = (600/e^{2/A}) \pm 0.25(600/e^{2/A})$	Age dependent $F_A = (600/e^{2/A}) \pm 0.25(600/e^{2/A})$	Age dependent $F_A = (600/e^{2/A}) \pm 0.25(600/e^{2/A})$
0-1 year mortality	99 ± 0.3%	99 ± 0.3%	99 ± 0.3%
1 -2 year mortality	75 ± 5%	75 ± 5%	75 ± 5%
Adult mortality	30 ± 5%	30 ± 5%	30 ± 5%
Initial size N	**160**	**2590**	**1860**
Carrying capacity K	**180 ± 60**	**2800 ± 180**	**2800 ± 180**
Predation	**0**	**0**	**Juv: 25(N/K) Adult: 75(N/K)**

Noordhoeks River

The Noordhoeks River is the next tributary downstream of the Thee, entering the Olifants 15 km upstream of Citrusdal. It is a larger, fast flowing stream with a wide fan of cobble at varying depths, forming shallow riffles, runs and deeper pools. *A. barnardi* is abundant in the Noordhoeks and co-occurs there with a complete complement of five other indigenous fishes including its larger relative, *A. gilli*, along with yellowfish, other minnows and *Galaxias*. A predatory introduced species, *Tilapia sparrmanii* A.Smith 1840, which is indigenous in the Orange River system, occurs at low density in the Noordhoeks and although it may have some impact it does not seem to be a major threat to the rock catfish. The population of *A. barnardi* was estimated at 2590 individuals (Bills, Chapter 2).

Heks River

Similar habitat occurs in the lower Heks River, 17 km downstream of Citrusdal, but the indigenous fish fauna here is comprised of the two Rock Catfish species alone, due to the presence of smallmouthed bass. *A. barnardi* and *A. gilli* occur at much lower densities in the Heks River, when compared with the Noordhoeks, and are restricted to cobble riffles. This river has a long stretch of suitable habitat, however, and the population was estimated to include 1860 *A. barnardi*.

Population carrying capacity (K)

The observed size of a population will rarely be a good estimate of the carrying capacity, which is the potential population size based on the extent and quality of suitable habitat. In each of the two non-invaded populations I assumed that the estimated size differed from the carrying capacity of that site due only to natural inter-annual fluctuations in population size. Preliminary simulations suggested that the average size of a population may be up to 30% below the carrying capacity, depending on the extent of environmental variance. I made the conservative assumption that estimated population size is around 90% of the carrying capacity, setting this to 2800 for the Noordhoeks and 180 in the Thee. For the Heks River, where population size may be depressed by the presence of Bass, I assumed that carrying capacity is also 2800 individuals, as in the Noordhoeks site. This allowed the comparison of a similarly sized site with and without predation by Bass. The carrying capacity is not a critical feature of these models. Essentially, these model scenarios compare one population with a limited area of suitable habitat and two populations with more extensive habitat.

Reproduction

Analysis of age structure based on otolith ring counts from 154 individuals, found individuals breeding from age two years onwards and surviving up to 14 years of age (Mthombeni & Weyl, unpublished, see the associated project report). Males and females are similarly abundant. The reproductive system is presumed to be polygynous, with males competing to fertilize the eggs of spawning females. This means that reproduction is not limited by the availability of unpaired males. Females are capable of spawning two to three times in a season and counts of ovarian follicles gave an average of 240 eggs, with a range from 60 up to 540 eggs, depending on the female body size (Mthombeni, unpublished data, the range of 28-238 vitellogenic oocytes per fish reported in that report section relates to a single clutch, the figure used here includes vitellogenic and developing eggs). Size increases with age but with a wide variance among individuals (Mthombeni, Chapter 6). In order to model this aspect of fecundity I fitted these data on age, size and ovarian follicles to a curve, assuming that fecundity is normally distributed within age classes, giving the formula:

$$F_A = (600/e^{2/A}) \pm 0.25(600/e^{2/A})$$

where F_A is the fecundity of age class A. The first term ($600/e^{2/A}$) gives the mean fecundity for this age class and the second term the standard deviation, which is one quarter of the mean. This relationship is graphed in Fig. 1, which represents the increase with age in both fecundity and in the variance among females in fecundity, as there is greater body size variation in older age classes.

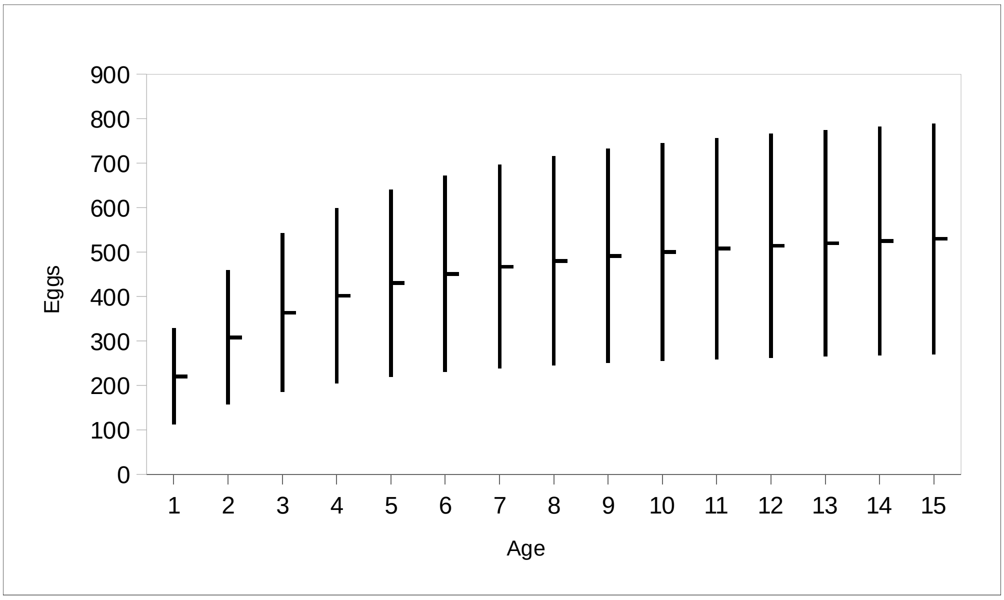

Figure 9.1. Model of fecundity in *Austroglanis barnardi.* Horizontal lines show the average fecundity in each age class, vertical lines show the 95% range of individual variation (1.96 standard deviations).

Age is a strong determinant of fecundity in the first five years of life, a period of rapid growth, and is less important after this when individual growth is likely to be determined by environmental opportunity. In this model the mean fecundity is asymptotic at 600 eggs but exceptionally large individuals may approach up to 800 eggs. Such individuals would be rare in any unbiased population sample because only around 10% of the population are females older than 8 years (see below) and only 16% of these, around one in sixty individuals, would be more than one standard deviation above the average size (with > 600 eggs).

Survival rates and age structure

Mortality tables were designed assuming a stable age structure in the Noordhoeks population, using data from Mthombeni (Chapter 6). This required an extremely high mortality rate of 99% in the first year, from egg to juvenile, a high mortality rate of 75% for second year juveniles and a relatively low rate of 30% adult mortality per year. A very high rate of first year mortality was necessary to approximate the observed age structure and avoid a model population dominated by juveniles. This mortality may be justified by considering factors such as direct predation of eggs, failure of fertilization and resorbtion of vitellogenic ovules, reducing the effective clutch size. The low annual mortality rate of 30%

for adults compares with 39% estimated from age / growth curves by Mthombeni (Chapter 6). The lower rate was required in the models to better match the observed age structure, with some older individuals surviving in the population, and is not substantially different from that estimated from growth curves, when environmental variance is taken into account. This combination of fertility and mortality rates differs somewhat from the sampled age structure, in which 26% of individuals are immature and 30% are more than six years old (versus 55% and 7% in the model). This may partly be due to under-sampling of first year individuals in the otilith-based ageing study.

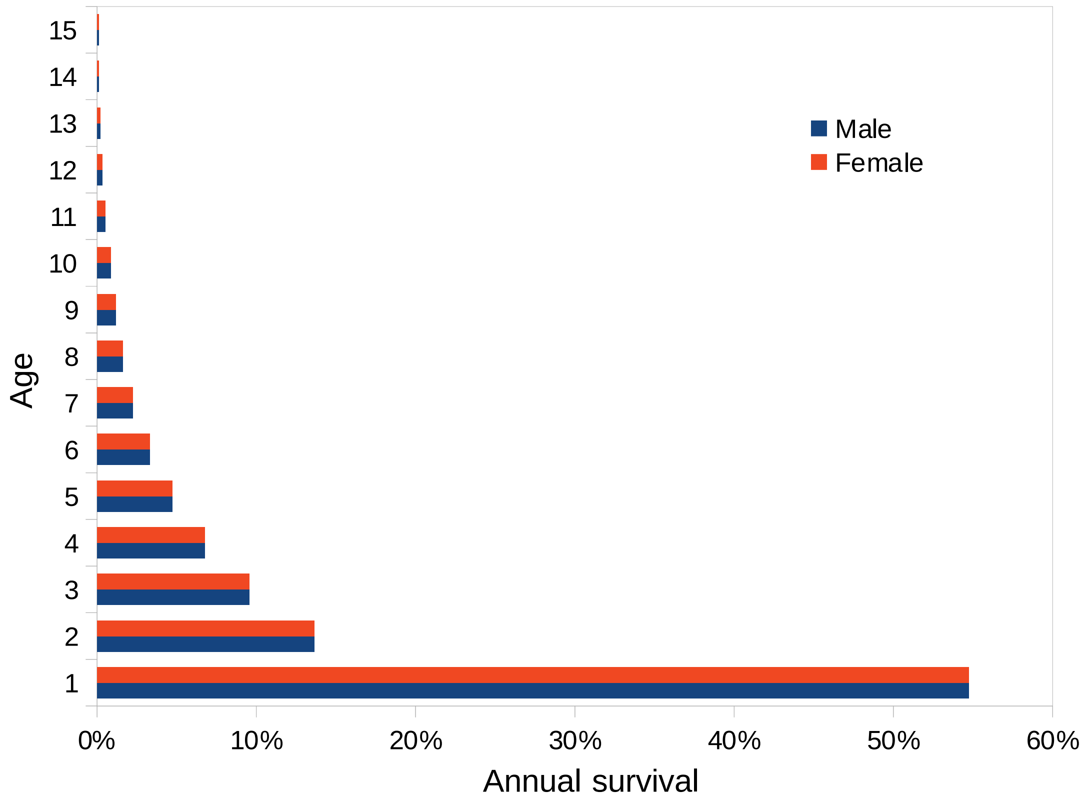

Figure 9.2. Model age structure in *A. barnardi.*

Environmental variance

Environmental variance determines the amplitude of fluctuations in population size and can be input into three aspects of VORTEX models: variation in the carrying capacity of the population, variation in the percentage of females that breed in a particular year, and variation in survival rates within different age classes. We have no biological information on year to year fluctuations in population size and the long term time-series required for reliable estimates are difficult to obtain. This aspect must therefore be added to the models by exploration of plausible values (guesses!). These three streams are all in the same area, on the same versant of the mountains, and it was assumed that environmental variation is highly correlated across these sites (that a wet year in the Heks catchment is similarly wet in the Noordhoeks and Thee). This correlation of environmental variation across sites was set at 90% in models.

Rainfall and stream flows in this part of the Cederberg are highly seasonal but relatively consistent and predictable across years, with an inter-annual coefficient of variation in rainfall and stream-flows of around 30% (Shultze 2006). Fluctuations in species demography are unlikely to be this severe, however, as variations in the availability of food, shelter and suitable breeding sites will not be proportional consequences of stream volume. In the models here all mature females were capable of breeding every year, with a standard deviation of 10%, due to environmental variation, in the percentage of females that actually did breed. Environmental variation in carrying capacity was modelled slightly differently, varying by 60 individuals (±33%) in the Thee River and by 180 individuals (±6%) in the Noordhoeks and Heks Rivers. My intention here was to reflect the disproportionate impact in small streams of variability in the extent of habitat, where sections may actually dry out, as opposed to larger streams where the absolute numbers of individuals affected may be greater but where there is generally greater habitat heterogeneity and a lower proportional impact of low flow, high temperature or other environmental variation.

Environmental variance in survival

Preliminary simulations showed that results are insensitive to modest year to year fluctuations in the proportion of reproductive females. These results were more sensitive to variation in carrying capacity and are strongly influenced by environmental variation in age specific mortality rates. The standard deviation in percentage mortality must be set in relation to the average percentage mortality such that complete reproductive failure of the population is a rare event or that successive reproductive failures are unlikely to exceed the expected life-span of adults. Based on the preliminary simulations mortality rates were set at 99 ± 0.3% for first years, 75 ± 5.0% for second year juveniles, and 30 ± 5% for adult mortality. These values reflect the need to consider fluctuations due to environmental variance, the expectation that undisturbed populations will persist given sufficient habitat, such as in the Noordhoeks, and the need to match the sampled age structure of this species. With these values complete reproductive failure would result from juvenile mortality more than three standard deviations above the mean, which would occur around one in a thousand years. If the variance in first year mortality was raised from 0.3% to 1% then reproductive failure would occur around one in every six years, with successive failures occurring every 36 years or so. These higher values were found to be unrealistic in that model populations were unlikely to persist for the next century.

Predation by Bass

Predation was modelled in the Heks River as a deterministic process in which up to 150 adults and up to 50 juveniles are predated per year, with the actual number taken declining with population size, using the formulae: Juveniles predated = 25 (N/K) for each sex; Adults predated = 75 (N/K) for each sex. This models a situation in which as population size declines more or better refuges become available and fewer individuals are at risk of predation. The low level of predation explored here, around one victim every two days across the Heks River populations of *A. barnardi* and Bass, indicates a situation where the predators are not dependent on this source of prey.

Additional scenarios and sensitivity testing

A number of additional model scenarios were developed in order to explore the effects of uncertainty in population parameters and the effects of additional processes that may increase population instability and risks of extinction. These include the scenarios with higher environmental variance in juvenile and adult mortality rates and also the scenarios with higher carrying capacity, described above. Table 9.2 summarises these additional scenarios.

Uncertainty in carrying capacity

To test the sensitivity of modelling to underestimates of carrying capacity I compared the results with an alternate scenario in which carrying capacity was double that in the standard scenario (Thee, 360; Noordhoeks, 5600; Heks, 5600 *A. barnardi*).

Uncertainty in environmental variance in survival rates

In order to gauge the effect of these variables two additional model scenarios were explored. One of these was a high juvenile mortality model in which first year mortality was raised from 99 ± 0.3% to 99 ± 0.5% for first years and from 75 ± 5% to 75 ± 25% for second year juveniles. These very high rates of variance would result in extreme year to year fluctuations in the number of juveniles surviving through to maturity. In a second scenario rates of juvenile mortality were retained from the Standard model but adult mortality was increased from 30 ± 5% to 30 ± 15% (which would result in adult survival varying from 40-100% in most years).

Table 9.2. Additional Model Scenarios

Scenario	**Objective**
Double Carrying Capacity (K)	Determine the effect of uncertainty in carrying capacity on extinction risk
High Juvenile Mortality	Determine the effect of uncertainty in juvenile mortality rates on extinction risk
High Adult Mortality	Determine the effect of uncertainty in adult mortality rates on extinction risk
Density Dependence	Explore the effects of density dependence on population fluctuations, average size and extinction risk
Catastrophes	Explore the impact of occasional extreme events on extinction risk
Occasional Otter Predation	Explore the effect of an occasional heavy harvest on population persistence

Density dependence

Population density is likely to influence breeding success. At very high densities there may be competition for optimal egg laying sites, at very low densities individuals may experience difficulty in finding mates (Allee effects). These effects could introduce additional instability and increase the risks of population extinction. In order to explore the contribution of density effects to extinction risk I used the formula provided in VORTEX, with Allee parameter of 2, Steepness parameter of 16 and 80% of females breeding at carrying capacity. This effect is in addition to the 10% environmental variance across years in females breeding. The resulting curve, depicted in Figure 9.3, models a situation where the proportion of females breeding is insensitive to population density across a wide range of population sizes, but declines sharply at very low and at very high densities. All the above scenarios were modelled with and without the effects of density dependence.

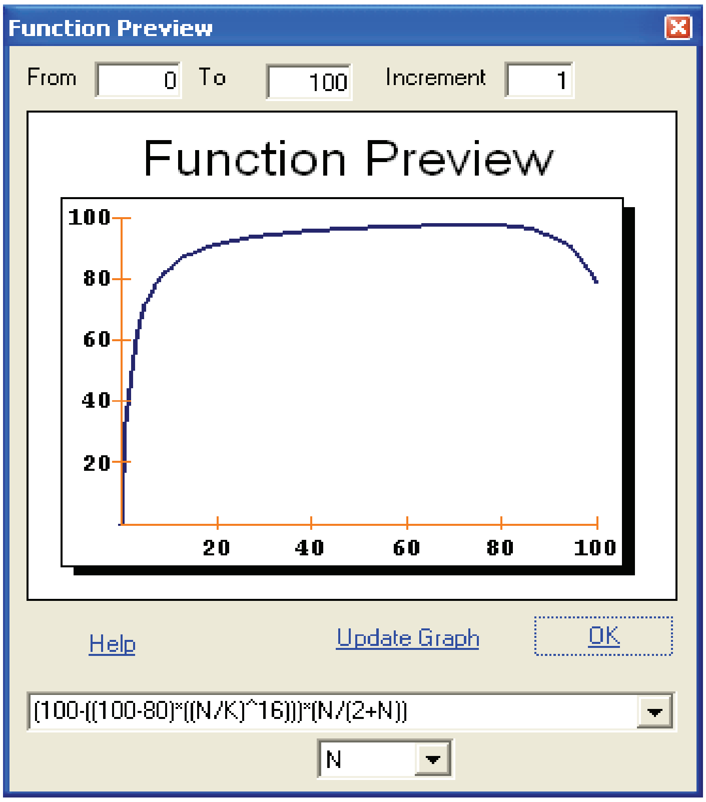

Figure 9.3. Percentage of females breeding (y-axis) and population size (x-axis, as a percentage of carrying capacity) under the model of density dependence.

Catastrophes

In addition to year to year environmental variation there may be occasional extreme events that impact severely on individual reproduction and / or survival. I included a model with three forms of catastrophe.

- "Drought" was an occasional event, occurring every ten years on average and affecting all populations simultaneously, causing moderate (30%) suppression of reproduction and a modest (10%) reduction in survival
- "Disease" was a rare event, occurring, on average, once per century and impacting on a single population, in which both reproduction and survival were reduced by 40%
- "Otter" was an uncommon event, occurring every twenty-five years, on average, and impacting on a single population, in which reproduction was unaffected but survival was reduced by 40%

Predation by otters

Cape Clawless Otters are wide-ranging predators that may move up to 20 km in a day, crossing between different stream catchments (M. Somers, University of Pretoria, pers. comm.). Otters feed mainly on River Crabs, *Potamonautes* spp., but also hunt fish, including *A. barnardi* and *A. gilli* (I.R. Bills, SAIAB, pers. comm.). Otters typically create a holt in a suitable site and may reside in an area for some time if food is plentiful. As an alternate way of modelling the potential impacts of occasional intense predation on populations by otters an additional scenario was created modelling predation by otters as a periodic harvest, rather than as an environmental catastrophe. This harvest occurred every ten years on average, and took up to 100 individuals, depending on population density. This was modelled using the formula Harvest = 50(N/K) for adults of each sex (assuming that Otters differentially target adult individuals that they can hold) with the criterion RAND < 0.1 to specify that the event occurs randomly, with an expected occurrence once in every ten years.

Results: *A. barnardi*

Figure 4 shows a single simulation result under the Standard model, which compares the three population scenarios using the reproductive and survival parameters above and includes environmental variation in reproductive success, mortality and carrying capacity.

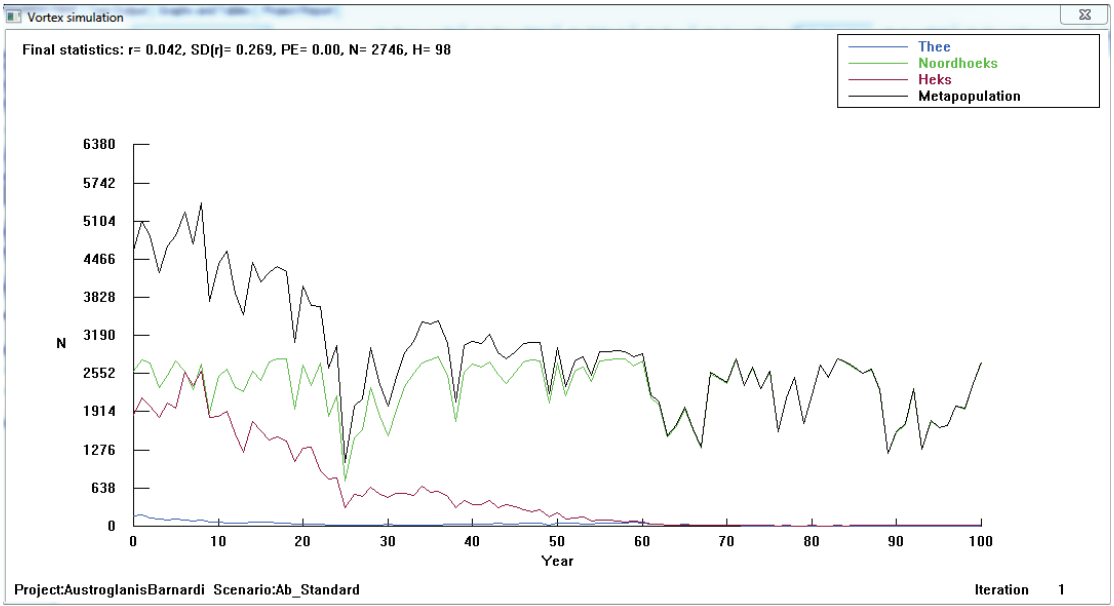

Figure 9.4. Screenshot of a single simulation under the Standard model.

In this particular run the small Thee population (blue line) starts with a population size slightly below carrying capacity (N = 160, K = 180) and declines over the first two decades to around 20 individuals, then fluctuates between 10 and 60 individuals for a half century before becoming extinct. The much larger Noordhoeks population (green line; N = 2600, K = 2800) survives through the century but shows erratic fluctuations, with population size typically varying by several hundred individuals from year to year, reaching a low point below 1000 individuals in the 25th year and a high point around the carrying capacity at several other times.

The Heks population (red line; N = 1860, K = 2800), which is subject to bass predation, also shows fluctuations, with an initial increase in population size to around 2600 individuals followed by an irregular decrease to very low numbers, such that in the last thirty years the population never exceeds 20 individuals and would be at very high risk of extinction due to demographic and environmental variance, despite reduced predation at such low densities. The combined metapopulation (black line) tracks the total species population size and converges on the Noordhoeks as other populations decline.

Several results are consistent results across this table. The “Thee” model shows moderate to high extinction risk across all models that include environmental variance in carrying capacity. The time to extinction is generally around 50 years, indicating that despite its small size the population may persist for a long time, in the absence of additional threats such as the current invasion by bass. There is a large variance in population size among simulations, which is correlated with year to year variance within simulations, showing that the risk of extinction in these models is due to excessive fluctuations.

The “Noordhoeks” model shows a high probability of persistence in all scenarios except in number 9, the scenario with increased environmental variance in juvenile mortality (where it shows a 26% chance of extinction). This scenario can therefore be rejected as unrealistic. Generally, the standard deviation of population size across simulations is less than one third of the average population size, suggesting that under these various scenarios year to year fluctuations would not threaten this population.

The “Heks” model shows dramatic declines to very low population size in most scenarios, with large fluctuations in all scenarios and moderate to high risk of extinction. Although the mean time to extinction of this population was quite long, averaging around 80 years across scenarios, the decline in population size happened in the first two decades in most simulations, with the population typically fluctuating at low levels for many more decades. Interestingly, the three scenarios that resulted in decreased extinction risk in this population were increased carrying capacity, the presence of environmental catastrophes and occasional large predation events (Hungry Otter). The carrying capacity of the population may be larger than estimated here, based on the mark – recapture results, and this may be more consistent with the current size of this population (see below). Counter-intuitively, the presence of randomly occurring catastrophes, including severe episodic predation events, seems to reduce the risk of extinction by creating pulses of successful reproduction upon recovery.

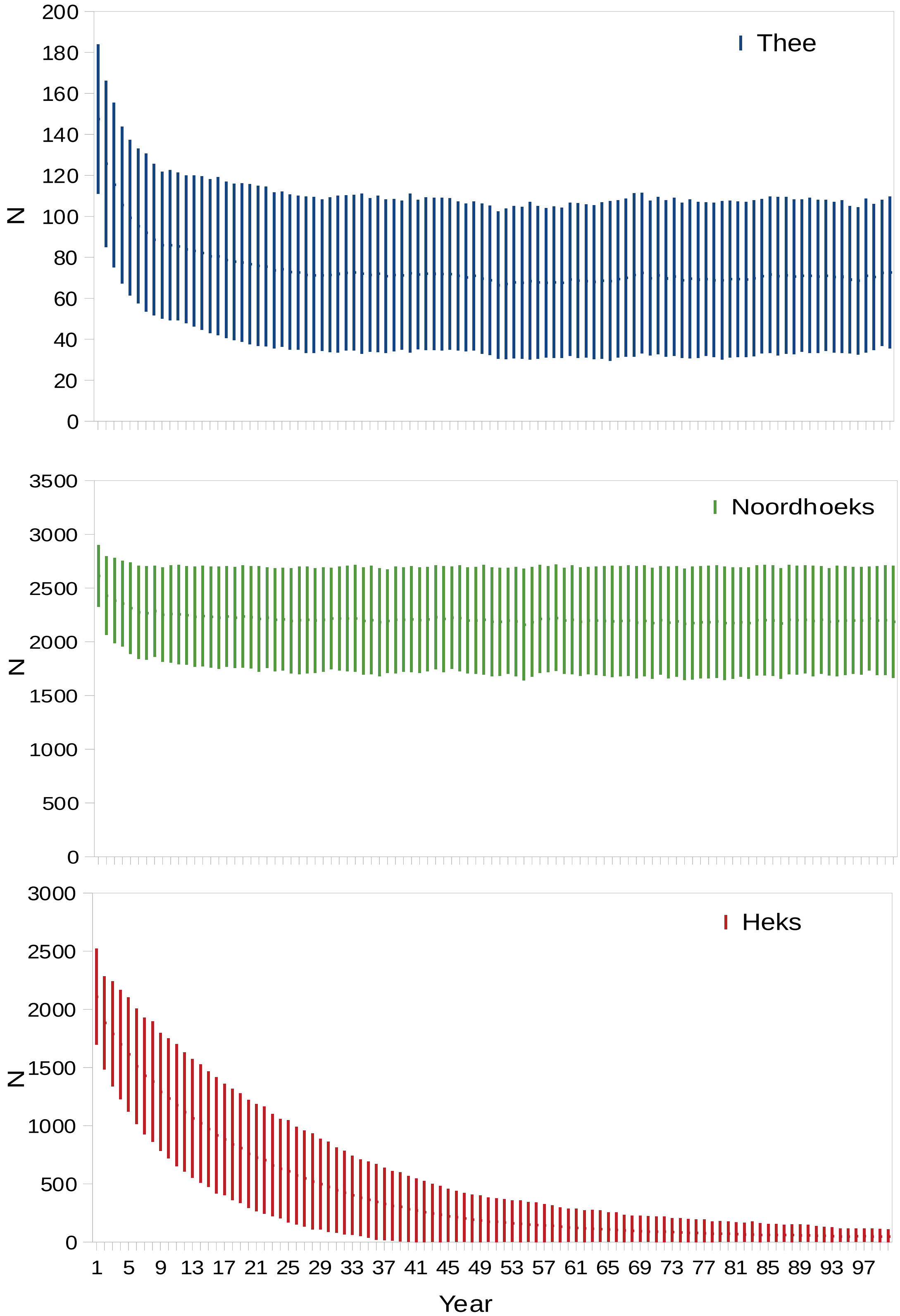

Figure 9.5. Simulation results (N ± SD) from the Standard model for *A. barnardi*

Several aspects of these simulations results seem surprising considering ecological knowledge and field experience. The low average size of the Thee population, well below the ecological estimate of population size may suggest a carrying capacity that is higher than that modelled. The frequent extinction of this population suggests that under the model parameters it would not survive over longer time scales and could only persist as a sink population, supported by dispersal. Both these discrepancies could result from over-estimates of environmental variance, perhaps the proportionally higher environmental variance in carrying capacity in this site, although it is reasonable to expect proportionally greater fluctuations in smaller populations due to sampling error around survival and reproduction rates. In addition, the isolation of *A. barnardi* as a small population in the Thee may have occurred in the past 50 years. The Olifants River has been extensively modified, with water-flow greatly reduced by extraction for agriculture, leaving large areas of dry cobble along the river, loss of water quality, and invasion by bass, bluegill (*Lepomis macrochirus* Rafinesque 1918) and other predatory fishes, which are now abundant in the mainstream. Where now the Thee flows into the Olifants only in winter floods there would previously have been waterflow throughout the year. *A. barnardi* may have lived in cobble beds along the Olifants and there may have been no barriers to movement between the Thee, Olifants and the adjacent Noordhoeks River. In contrast to the Heks River, the Thee River population of *A. barnardi* has not been assayed for genetic variability and so we do not know whether this population is distinct from the Noordhoeks.

The extent of fluctuations in the Noordhoeks population may also appear excessive, especially when considering individual simulations such as in Figure 9.4, which show shifts of up to 1000 individuals from one year to the next. The coefficient of variance in model population size is less than inter-annual variance in rainfall, however, and this may be more an issue of perception than a problem with the model.

Dramatic changes in population size are rare in the simulations, occurring once or twice per century, and the error in field estimates of population size may exceed average inter-annual differences in the model, making this variance difficult to observe (for example, we may not be able to consistently distinguish a population with 2800 individuals from one which has only 2300 or fewer individuals).

Finally, the steep decline in the Heks River population seems inconsistent with the persistence and moderately large size of this population, given that bass were introduced into the Olifants system in the 1940s and have probably been in the Heks for several decades. The modelled level of predation causing this decline was low in terms of the number of fish predated (200 predated out of 2800 individuals at carrying capacity) and also low as a proportion of the population (being set at 7% loss). This is much less than the average inter-annual variation due to environmental variance and suggests that predation could be a surprisingly effective threat.

Table 9.3. Summary of *A. barnardi* simulations under various scenarios.

Model / Population	**"Thee"**			**"Noordhoeks"**			**"Heks"**		
	%PE	TE	N	%PE	TE	N	%PE	TE	N
1. Framework	0	-	173 ±13	0	-	2800 ±15	26	89	38 ±30
2. Framework + EV in reproduction	0	-	175 ±11	0	-	2800 ±14	27	90	37 ±31
3. Framework + EV in carrying capacity	27	50	102 ±48	0	-	2763 ±158	26	88	38 ±32
4. Framework + EV in mortality	3	66	138 ±43	0	-	2336 ±521	58	76	58 ±135
5. Standard Model	45	53	73 ±37	0	-	2185 ±523	59	76	46 ±65
6. Standard with reduced EV in K	4	68	122 ±40	0	-	2060 ±512	60	77	41 ±60
7. Standard with density dependence	40	52	81 ±41	0	-	2189 ±513	69	76	46 ±59
8. Double K (carrying capacity)	21	53	165 ±79	0	-	4428 ±978	0	-	2198 ±1519
9. High EV in juvenile mortality	93	37	48 ±28	26	66	912 ±857	97	45	72 ±142
10. High EV in adult mortality	65	53	71 ±43	0	-	1768 ±729	81	70	62 ±88
11. Catastrophes	25	50	94 ±57	0	-	1814 ±713	1	79	1203 ±783
12. Hungry Otter	94	33	64 ±54	0	-	1770 ±709	3	78	995 ±724

Rather than an excessive rate of predation the discrepancy between the model and observed abundance in the Heks may be explained by an underestimate of carrying capacity.

In conclusion, this project is the first attempt to develop population viability models for fish in the Cederberg and has provided some guidance to conservation management priorities for

A. barnardi. This analysis leaves many questions unanswered, however, which are dependent on biological data to improve the models. Perhaps the greatest needs are for more information on the extent of year to year changes in population size and on survival in the field. As mentioned above, this information is difficult to obtain and may include a wide error margin in estimation. There are three independent sites and the models provide a basis for comparison, in the form of the distribution of differences in population size at different sampling times. Additional field estimates would give a better estimate of the magnitude of fluctuations, particularly if they were replicated over two or more years with permanently marked individuals to estimate survival rates. This information is critical as the level of fluctuations determines the risk of extinction in small populations.

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10. AMPHIBIAN DIVERSITY AND CONSERVATION IN THE CEDERBERG

MICHAEL CUNNINGHAM

UNIVERSITY OF THE FREE STATE, PRIVATE BAG X13, PHUTHADITJHABA 9866. (E-MAIL: CUNNINGHAMMJ@QWA.UFS.AC.ZA)

Summary

This chapter analyses the occurrence of frog species within the Greater Cederberg area and considers the likely impacts on these frogs of measures taken to secure threatened indigenous fish populations, in particular the eradication of alien fish from three critical headwater-stream segments using the piscicide rotenone.

The amphibian fauna of the Greater Cederberg, the catchment of the Olifants River System in the Western Cape and Northern Cape Provinces of South Africa, comprises a moderately diverse assemblage of 18 frog species. None of these frog species are endemic to this area but most are regional or biome endemics within fynbos or succulent karoo. There are no threatened frog species in this relatively well known fauna. The faunal composition and interdigitating species distributions are typical of a transitional area, showing attenuation of species richness within biomes and somewhat elevated richness at a landscape level due to the meeting of distinct habitats and faunas. This contrasts with the fish and aquatic invertebrate faunas which show high endemism to the Olifants River System. Frog species diversity within sites (α-diversity) is generally less than ten species and is highest in the foothills and valley basins on the western side of the mountains. Frog diversity is lowest in the dry Tankwa Karoo basin, to the northeast, and is also low along the major rivers and in montane areas above 1000 m. Around seven frog species occur in the vicinity of sites that are targeted for the conservation of endangered indigenous fishes. It is unlikely, however, that actions taken to secure populations of indigenous fishes will have any substantial impact on Cederberg frog populations because (i) most frog species use different biotypes to those occupied by fishes, (ii) stream living frogs have abundant habitat in tributaries and seepages above and beyond those occupied by fish, (iii) dispersal of these species occurs predominantly through movement of adults over land rather than by transport in streams, and (iv) the impacts of proposed actions to eradicate alien fishes, using local weirs and rotenone, are likely to be transient as this treatment will affect a small minority of individuals and will be mediated by ongoing dispersal from immediately adjacent areas. Despite these positive general considerations, the proposed treatment may have localised impacts on populations of the Cederberg Ghost Frog, *Helophryne* depressa, which should be monitored before and after treatment.

Diversity and Distribution of Frog species in the Cederberg

Distributional data

The data underlying this chapter are point locality records of species occurrence. These are largely unpublished records collected by the author and associates in herpetofaunal surveys of the Cape Fold Mountains (WWF-Table Mountain Fund project#1256, 2002-2006), in our trips for the South African Frog Atlas Project (SAFAP1 – 1995-2004; Minter *et al.* 2004) or records collected opportunistically during fish surveys of Cederberg streams. All records have been submitted to the provincial conservation authority, CapeNature, for inclusion in their biodiversity database and the analyzed dataset is included as an appendix to this chapter. For this project I defined a broad study domain bounded by 31.0-33.5^{o}S, and extending from the west coast, ~17.8^{o}E, to 20.0^{o}E. This domain captured records from a broad region, helping to minimise sampling biases in distributional analyses and to avoid overemphasis of peripheral species that are rare within the study area but widespread beyond. This domain includes areas beyond the Cederberg, such as the Knersvlakte, Giffberg, Oorlogskloof and Bokkeveld escarpment north of the Olifants River; the Saldanha peninsula, Piketberg range, and sub-coastal sandveld to the west; the Tankwa Karoo to the east; and the Warmbokkeveld, Matroosberg and Klein Berg River valley to the south. In total 578 frog species records from 182 sites in the Greater Cederberg were used in analysis, including 268 unique species x locality records of which 250 were separated by at least 0.25 km and can be considered independent samples. Of these data, 444 records from 105 sites, were from the central Cederberg and Kouebokkeveld, bounded by 32.0-33.0^{o}S, 18.8-19.5^{o}E (Fig. 10.1).

Taxonomic changes affecting names of Cederberg frogs

The Cederberg frog fauna is relatively well known and recent taxonomic changes reflect uncertainty in the correct use of names, rather than uncertainty in the validity of species. Names used in this report follow those in the Amphibian Species of the World Online database version 5.5 (Frost 2011) and Du Preez & Carruthers (2009). In a global review of frog taxonomy and systematics Frost *et al.* (2006) transformed the number, names and content of frog families and some large genera within families. The most substantial change for this study is the recognition of Pyxicephalidae, a morphologically diverse family found predominantly in southern Africa. Pyxicephalid genera in the Cederberg are *Amietia*, *Strongylopus*, *Tomopterna* and *Cacosternum*. These were previously placed in separate families, Ranidae and Petropedetidae, each of which was considered to be much more widespread. Another substantial change was the recognition of several new genus names for African toads, of which *Amietophrynus* and *Vandijkophrynus* occur in the Cederberg (with *Bufo* now restricted to Eurasia and North Africa). Frost *et al.* (2006) also determined that the correct genus for River Frogs is *Amietia*, relegating *Afrana* as a junior synonym (the earlier name *Rana* is now restricted to a group of temperate northern Hemisphere species), and recognized Brevicepitidae as a distinct family for *Breviceps* and relatives.

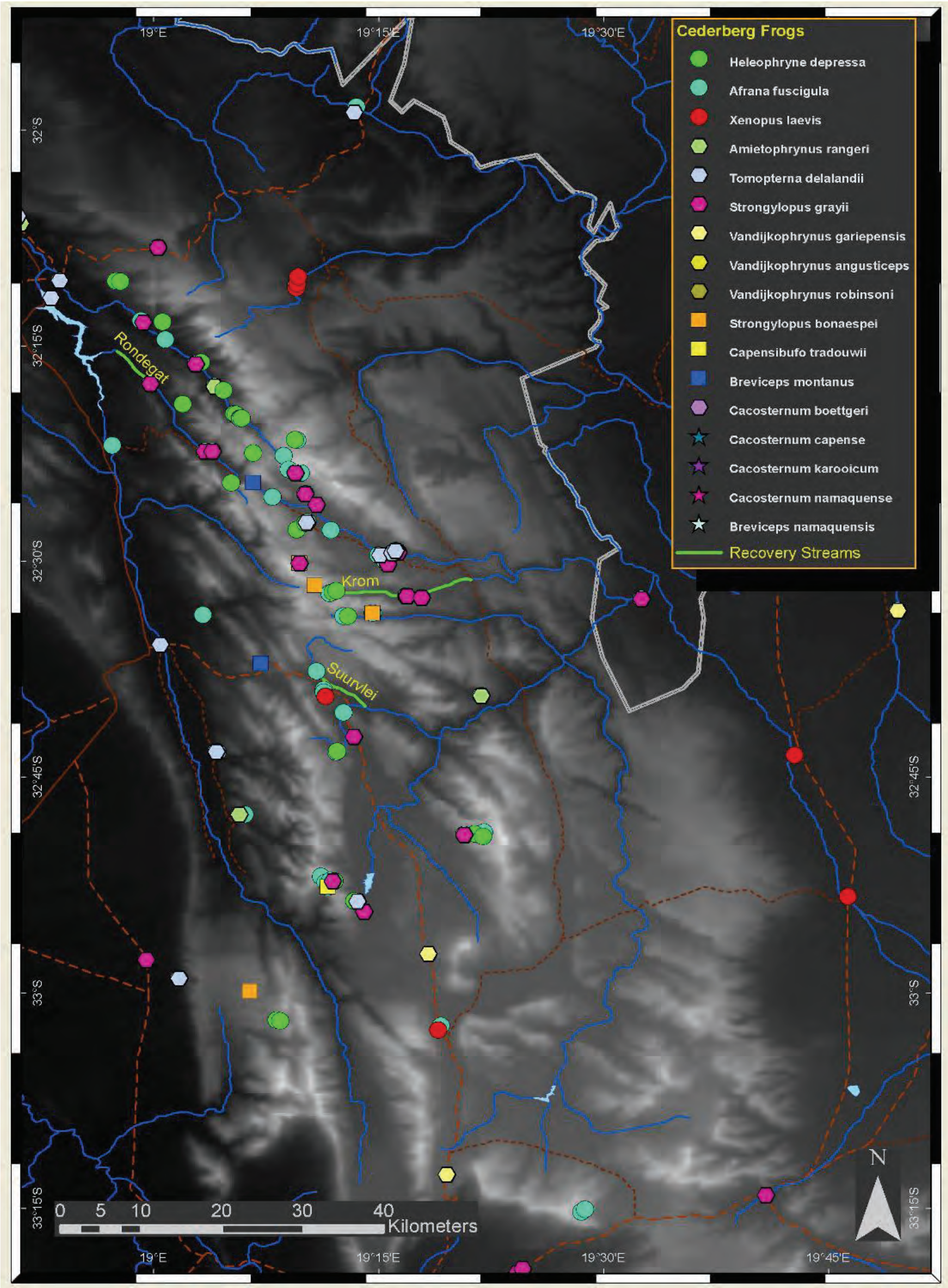

Fig. 10.1. The dataset: 444 frog species records from 105 sites in the central Cederberg. Data were available for 13 of the 18 species occurring in the Greater Cederberg area. The remaining species are peripheral to this area and do not occur in the stream catchments targeted for conservation of threatened fishes (these species are indicated by stars in the legend, *Breviceps rosei* is not shown).

These changes have been widely adopted but there remains debate over the content and names for Ranoid and Bufonoid genera. Other recent changes are the use of *Cacosternum platys* for Cederberg populations formerly assigned to *Cacosternum boettgeri,* which is now restricted to related populations further east (Channing 2001), and the recognition of *Heleophryne depressa* for Ghost Frogs in this area (Du Preez & Carruthers 2009). The correct species names of River Frogs (*Amietia* spp.) are under review due to the presence of cryptic species, numerous available names and difficulties of species diagnosis in this hyper-variable group (A. Channing pers. comm., Jan 2011).

Modelling species distributions and diversity – methodology

Species distributions were modelled using the simple bioclimatic envelope approach pioneered by Nix (1986). The purpose of this modelling is to extend beyond sparse occurrence data to a more complete picture of spatial patterns in species diversity and distributions. In short, estimates were obtained for a range of climatic variables at known sites and the distribution was then extrapolated to unsampled sites with similar climates. These calculations were done in ArcView 3.1 using the BIOCLIMav 1.2 extension (Moussalli 2004). Distributions were modelled on a one minute grid (1' latitude x 1' longitude grid; roughly 1.9 km x 1.6 km = 3 km^2 at this latitude). Eight climatic variables were used, comprising mean temperature and total rainfall in the driest, wettest, hottest and coldest quarter, calculated within each grid cell. These derived variables were compiled by Adnan Moussalli (Museum of Victoria, Australia) using the Bioclim software (Hutchinson 2009) on average monthly temperature and rainfall data from the Southern African Atlas of Agrohydrology and Climatology (Schulze 1997). A quarter is defined as any consecutive three month period of the year and these measures are calculated independently in each grid cell (e.g. the wettest quarter in one cell is not necessarily the same three month period as that in other cells on the map). In this reliably Mediterranean climate region, however, there is an almost absolute correlation across the map in the months assigned to each quarter in each cell, between rainfall and temperature in the coldest and wettest quarters, and between rainfall and temperature in hottest and driest quarters. Effectively, this reduces the number of variables considered to four – average rainfall and temperature in summer and in winter. This correlation does not otherwise affect predicted distributions. The benefit of using these derived climatic variables is that they summarise seasonal climatic factors that are more likely than monthly or annual averages to determine limits to species distributions.

The quality of a bioclimatic distributional model depends on sampling across the range of environmental conditions inhabited by a species and is limited by biases in the available distributional data. In general, the Bioclim approach tends to produce “tight” models for habitat specialists and restricted range species, in which potential occurrences beyond the sampled area are underpredicted, but tends to over-predict the local occurrence of habitat generalists (Finch *et al*. 2006). In this project I constructed a distributional model for all species with more than five locality records, while recognizing that the results provide less reliable maps for poorly sampled species. Sufficient data were available for modelling the distributions of 13 of the 18 species occurring within the study area. Species diversity was estimated, on the same spatial scale, as the sum of predicted species occurrences within each cell for these 13 species (Fig. 10.2). Locality data were filtered to exclude records within 250 m of another record of the same species. This left 250 species x locality records for the greater Cederberg Region and a total of 936 records for these species from across the entire Cape Floristic Region (CFR), excluding 50 records from around the coastline that were not covered by available climatic data. Where possible, distributional models were calculated using only records from the Greater Cederberg to reduce over-prediction effects due to local adaptation beyond this area. Species modelled from these records are: *Amietia fuscigula* (85 independent locality records within the study domain, 263 records from across the Cape Floristic Region), *Strongylopus grayii* (51, 212), *Heleophryne depressa* (32, 39), *Tomopterna delalandii* (28, 75), *Amietophrynus rangeri* (15, 83), *Vandijkophrynus gariepensis* (7, 20), *Xenopus laevis* (7, 16) and *Vandijkophrynus angusticeps* (6, 12). For other species there were insufficient locality records from the Cederberg but modelling could be achieved by including records from across the Cape Floristic Region. These species are *Cacosternum platys* (5, 58), *Strongylopus bonaespei* (4, 34), *Cacosternum capense* (4, 12), *Capensibufo tradouwi* (3, 10) and *Breviceps montanus* (2, 102). The data set did not include locality records of *Breviceps namaquensis*, *Breviceps rosei*, *Cacosternum namaquense, Cacosternum karooicum* and *Vandijkophrynus robinsoni* and I did not model their range. These species occur on the edge of the study area and are peripheral to this project as they are not dependent on permanent streams or rivers, they do not co-occur with fish and they will not be affected by management actions to protect endangered fish.

Species diversity and distributions – results

Figure 10.2 presents estimated species diversity across the study area, Figures 10.3-10.20 present the distribution of each species, created by superimposing point locality records from the project database, and the quarter-degree range for each species from the South African frog atlas (Minter *et al.* 2004), over the predicted distribution. Grid cells that fall within the middle 90% observed range on all climatic variables (5-95% percentiles) were considered as "predicted distribution" sites and used in the spatial estimate of species richness (Fig. 10.2.). Cells that fall just outside this climatic range, between the 2.5-97.5% percentiles, were considered "relaxed model" sites and further cells on the edge of the observed bioclimatic envelope (0-100% percentiles) were identified as "peripheral bioclimates" for each species. These are shown in Figs. 10.3-10.20 as red, olive and khaki cells, respectively (the colour scheme varies slightly among cells and differs from the red, orange and yellow given in the figure legends, due to the visual effect of overlaying a partially transparent distribution model over a shaded topography). Cells outside the species climatic range are left transparent.

Patterns of diversity

Predicted frog species richness on a 1 minute grid scale varies from 0-10 species, for those 13 species with sufficient data for distributional modelling (Fig. 10.2). Additional information on the 5 peripheral species that were not modelled would have little impact on this map beyond perhaps boosting diversity by 1-2 species in valley basins on the western side. When the distributions of all 18 species from the region are considered, a maximum of 10 species have been recorded from any single quarter degree cell (Minter *et al.* 2004). This compares with 22 species occurring in the quarter degree cell around Betty's Bay, the highest frog diversity in the fynbos biome, and similar or higher diversity, up to 35 species in a quarter degree cell, in subtropical north-eastern KwaZulu-Natal, which has the highest frog species diversity in Southern Africa. The total of 18 species from the Greater Cederberg similarly contrasts with adjacent bioregions of much lower diversity, such as the western Nama Karoo, with 6 species, and Namaqualand, with 8 species, although these potential totals have not been recorded in any single quarter degree cell. Diversity increases from east to west across the study area and is highest among the foothill ranges, lower slopes and valley basins west of the Olifants valley. Further west, in the subcoastal sandveld beyond the mountains, diversity decreases again slightly. Low diversity was predicted for the Tankwa Karoo to the northeast, montane areas of the central Cederberg (>1000 m, including the Krakadouw – Tafelberg – Wolfberg range, Uitkyk Pass, the Sneeuberg – Breekkrans – Suurvlakte range, the Kouebokkeveld, Skurweberg, Witsenberg and Groot Winterhoek mountains), and for the larger river courses (the mainstream Olifants R. below Citrusdal, lower Jan Dissels, Doring and Tankwa Rivers).

Patterns of distribution

The 18 species of frogs in the Cederberg are typical species of southwest winter rainfall zone of South Africa, with 13 species endemic to fynbos, succulent karoo or the combined area of these two biomes. This fauna species shows at least four distinct patterns of distribution. Firstly, there are five generalist Afrotemperate species (*Xenopus laevis, Amietia fuscigula, Tomopterna delalandii, Amietophrynus rangeri* and *Strongylopus grayii*) that occur from lowlands to lower mountain plateaus and extend north and south of the Cederberg, and to varying degrees, east into the karoo as well. These are mainly endemic to South Africa, Lesotho and Swaziland, with only *X. laevis* beyond southern Africa. All of these species are widespread across the fynbos biome and are abundant in the south of the Cederberg, in the catchment of the Berg River. *A. rangeri* and *S. grayii*, reach their northwestern limit in the Cederberg. *Vandijkophrynus gariepensis* is a similarly widespread Afrotemperate species but in contrast to those above it enters the Cederberg peripherally from the Karoo, in the east. A second distributional pattern is shown by Four Cape lowland endemics (*Vandijkophrynus angusticeps*, *Cacosternum platys*, *Cacosternum capense* and *Breviceps rosei*). These are endemic to the Cape Floristic Region and enter the study area from the south but they are peripheral in the central Cederberg, occurring mainly in the Swartland, sandveld and lower Olifants River Valley.

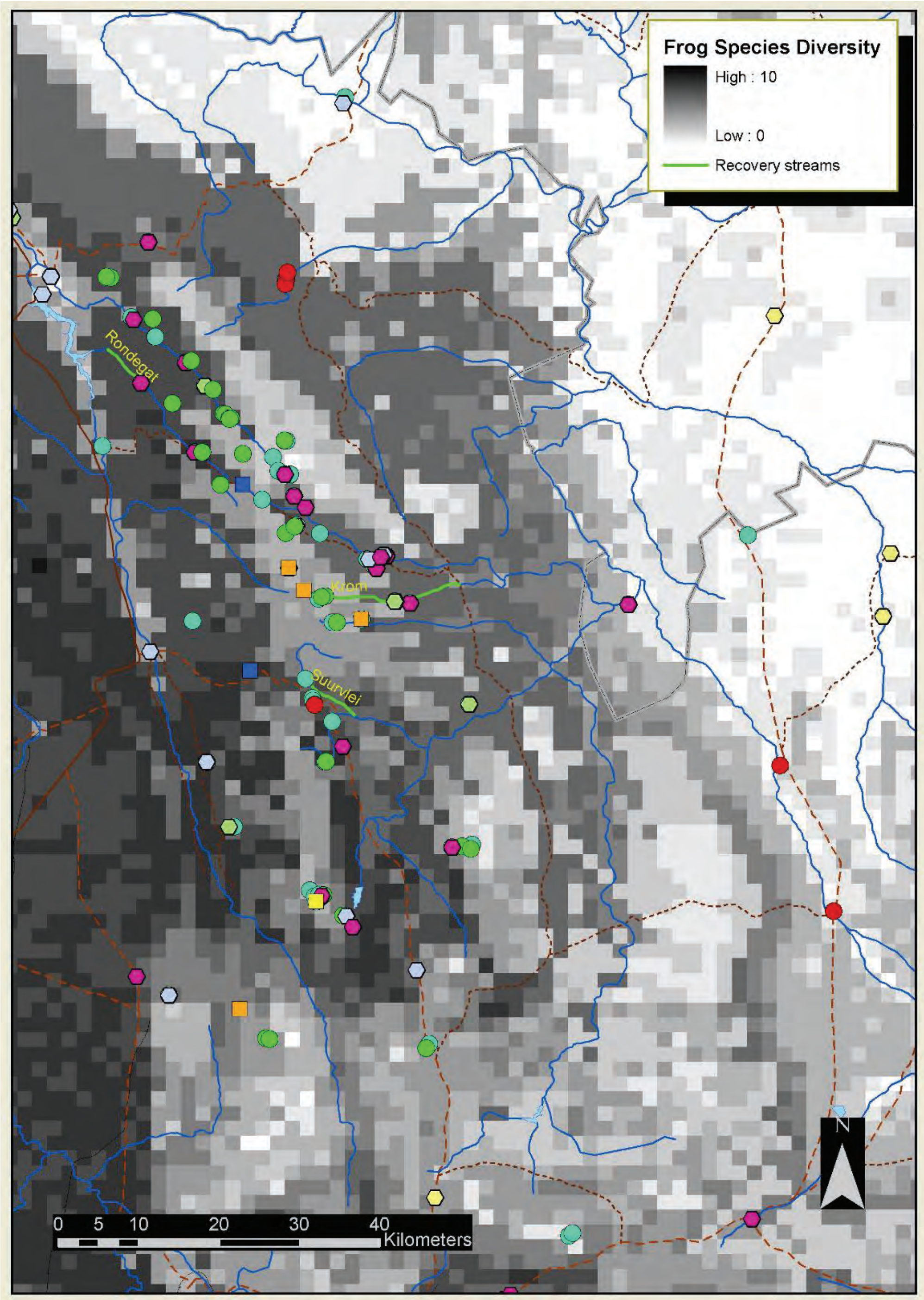

Fig. 10.2. Predicted species richness of frogs in the Cederberg based on the occurrence of 13 "core" species from this region. Diversity in one minute cells varies from 0-10 species. The remaining five species in the Greater Cederberg are peripheral to this central area, occurring to the north and west. These species would marginally increase local species richness in the valley basins on the western side, although the maximum diversity for any single one minute cell is unlikely to exceed 11 species.

Four Cape Fold Mountain endemics show a third distributional pattern (*Heleophryne depressa*, *Strongylopus bonaespei*, *Capensibufo tradouwi* and *Breviceps montanus*). These montane fynbos specialists extend in a fragmented series of populations along the mountain chain and reach their northern limit in the central Cederberg. These northernmost populations appear as relicts, isolated from more extensive populations further south and are likely vulnerable to climate change. A fourth pattern of distribution are Succulent Karoo endemics (*Breviceps namaquensis*, Vandijkophrynus *robinsoni*, *Cacosternum namaquense* and *Cacosternum karooicum*). These are generally distributed in Namaqualand and enter the Cederberg peripherally in the arid north, although *C. karooicum* is more generally distributed to the east, along the inland escarpment. In summary, the diversity of species in this area is boosted by the junction of the fynbos and succulent karoo biomes, with half the species recorded restricted to the periphery of the Cederberg.

Gaps in the available data

The dataset for this project was biased towards the Cape Fold Mountains and adjacent areas, particularly around streams with endangered fish. Records were collected opportunistically elsewhere, generally when driving between sites or on short, road based atlassing trips, rather than longer walking surveys, which generate more records but these are clustered over a small area. The details of distributional ranges are important and meaningful for interpreting and managing the impacts of environmental change. A more complete picture of species occurrence and local patterns of diversity, at a management relevant scale, will require frog atlas style surveys in the lower Olifants valley and among the ranges to the west, in the Olifants River mountains that border the river gorge upstream of Citrusdal, in the Groot Winterhoek wilderness area, from the western side of the Kouebokkeveld, around the Riet and Leeu Rivers, and from the arid north, around the Doring River valley.

Fish, frogs and conservation

The focal streams for this project are in moderate diversity sites, with 6-7 frog species, but these could not be considered as key locations for frog conservation because most frogs in this area are not stream dependent and none of these species thrive in streams that carry fish. These interactions are summarised in Table 10.1.

Table 10.1. Impacts of alien fish eradication on frogs of the Greater Cederberg

Scientific Name	Common Name	Olifants system	Stream living	With Fish	Impact
Heleophryne depressa	FitzSimon's Ghost Frog			~	~
Amietia fuscigula	Cape River Frog				X
Xenopus laevis	Common Platanna				X
Amietophrynus rangeri	Raucous Toad		~	~	X
Tomopterna delalandii	Cape Sand Frog		~	~	X
Vandijkophrynus gariepensis	Karoo Toad		X	~	X
Vandijkophrynus angusticeps	Cape Sand-Toad		X	X	X
Vandijkophrynus robinsoni	Paradise Toad		X	X	X
Strongylopus grayii	Clicking Stream Frog		~	~	X
Strongylopus bonaespei	Banded Stream Frog		X	X	X
Capensibufo tradouwi	Tradouw Mountain-Toad		X	X	X
Breviceps montanus	Cape Mountain Rain Frog		X	X	X
Breviceps namaquensis	Namaqua Rain Frog		X	X	X
Breviceps rosei	Rose's Rain Frog	?	X	X	X
Cacosternum platys	Common Caco		~	~	X
Cacosternum karooicum	Karoo Caco		X	X	X
Cacosternum namaquense	Namaqua Caco	-	X	X	X
Cacosternum capense	Cape Caco		X	X	X

All species except *Breviceps rosei* and *Cacosternum namaquense* are known to occur within the catchment of the Olifants River system. Populations of the former species may potentially be discovered in this system, in the poorly surveyed sandveld area around the

Olifants River mouth. Only three species (*Heleophryne depressa*, *Amietia fuscigula* and *Xenopus laevis*) can be considered to be stream dwelling. Streams are an occasional or peripheral biotype for an additional five species (indicated by '~') and the remaining species do not occur in streams. Only two species (*Amietia fuscigula* and *Xenopus laevis*) occur frequently with fish. All other stream-occurring species, including *Heleophryne depressa*, show a negative association with fish. The program to extend the distribution of indigenous fishes and eradicate alien fish is only likely to impact on *Heleophryne depressa* as this is the only stream-dwelling species that shows strong avoidance of fish in its occurrence. These impacts will be restricted to the localities where new fish populations are established but there is no reason to expect that they will have any substantial effect on regional or local catchment populations of frogs because the area affected by these translocations is relatively small, in relation to catchment size, and is bounded by additional barriers to fish, but not to frogs, higher up in the stream. The construction of weirs on these streams, to prevent reinvasion by alien fish, will have minimal impact as these weirs will occur in sites that are probably already sink populations for frogs, due to fish predation. The removal of alien vegetation may have local, transient impacts due to habitat disturbance of stream side habitat but this may also have slight medium term benefits from increased water availability in these habitats. Local impacts of rotenone treatment on these frogs can be mediated by removal of tadpoles and frogs to streamside buckets before and during treatment, for release after neutralisation of the piscicide.

Species accounts

The accounts tabulate the following information for each Cederberg frog species:

Total Range:	A verbal description of the global species distribution and an estimate of its minimum range size calculated from the number of Quarter Degree Cells (QDCs) occupied, based on the South African Frog Atlas data (Minter *et al.* 2004). (Range = QDCs x 675 km^2 ; this rough calculation tends to underestimate the Extent of Occurrence (EOO) and overestimate the Area of Occupancy (AOO) measures used in IUCN conservation status assessments. It is useful to rank species according to their known occurrence and as a minimum estimate of EOO)
Endemicity:	A summary of the smallest region enclosing this species (in terms of national and provincial borders or bioregional boundaries)
Biome:	The occurrence of this species across vegetation biomes as described in the SANBI vegetation map of South Africa (Mucina *et al.* 2007)
Habitats:	Descriptive aquatic microhabitats within which the species lives and breeds
Status:	IUCN Red List species conservation status from Measey *et al.* (2011)

Records:	The number of species records and the number of sites recorded for this species from the study domain (filtered for proximity of sites)
Rarity:	A simple categorisation indicating the likelihood of encountering this species in suitable habitat within the study domain
Occurrence:	A description of the predicted occurrence within the study domain
Range limits:	Any distributional boundaries that occur in the study domain
Elevation:	The altitudinal range of species records in the study domain
Substrate:	Major geological substrates on which the species occurs in the study domain. TMS = Table Mountain Sandstones of the Cape supergroup.
Taxonomy:	Any known issues of taxonomic relevance that may affect the species identification and its conservation status in the study domain
Fishes:	A note on the co-occurrence of this species with fishes
Impacts:	An assessment of likely impacts on this species from rehabilitation of indigenous fish populations in the headwaters of Cederberg streams (such as the upper Suurvlei, Noordhoeks, Thee, Heks, Rondegat, Jan Dissels or Krom Rivers). In this assessment I make the conservative assumption that eradication of introduced fish will result in the complete loss of tadpoles and most aquatic frogs over 2-10 km segments within the river channel.
Comments:	Additional notes on the data and assessment

Note that the first five of these fields refer to species-wide characteristics. The remaining eight fields, below the dividing line, apply to populations within the study area only.

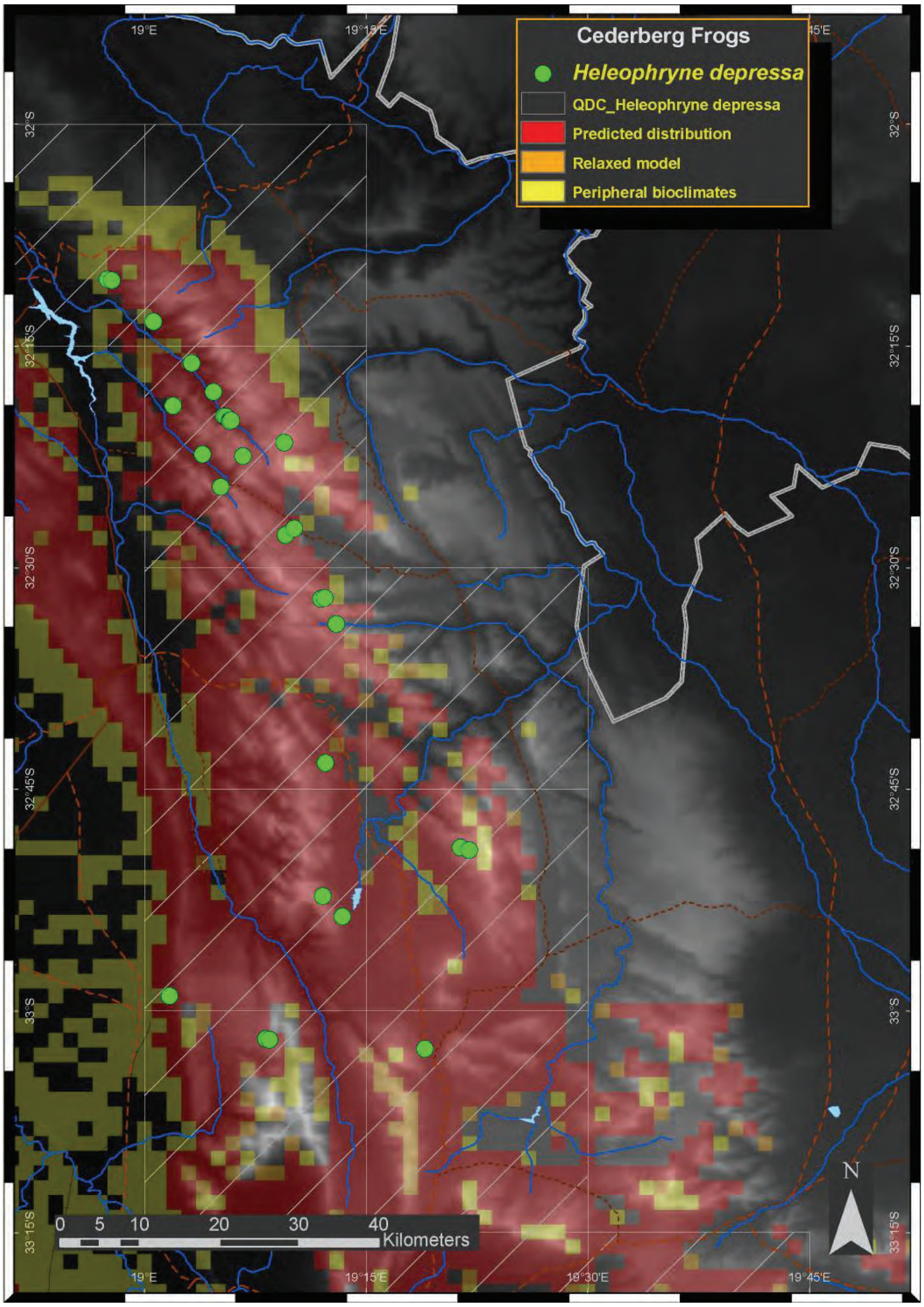

Fig. 10.3. Observed and predicted distribution of FitzSimon's Ghost Frog, *Heleophryne depressa*, in the Cederberg. This is a regionally endemic species, restricted to the northwestern Cape Fold Mountains. Ghost Frogs inhabit mountain fynbos streams but are capable of overland dispersal between adjacent stream catchments. The predicted distribution is a fair summary of the species range in the study area. Surveys are needed of predicted areas in the ranges west of the Olifants valley and in the south and southeast, around the source of Olifants, Doring and Klein Berg rivers.

Heleophryne depressa **FitzSimons, 1946 – FitzSimon's Ghost Frog**

Total Range:	From Taaiboskraal River (a tributary of the Jan Dissels River) through the Southern Cederberg, Kouebokkeveld, Hexrivierberg, Keeromsberg and western Langeberg as far as Dassiehoek NR near Robertson. Range Size > 10800 km^2 (16 QDCs)
Endemicity:	Regionally endemic to the NW Cape Fold Mountains
Biomes:	Fynbos
Habitats:	Clear, fast flowing mountain streams with riffles and cascades
Status:	Not Evaluated (likely Least Concern)

Records:	303 records / 32 sites within the study domain
Rarity:	Common and abundant within its restricted montane stream habitat
Occurrence:	Found only in the upper reaches of montane streams
Range limits:	Northern limit near Clanwilliam (as indicated on the map)
Elevation:	300-1702 m
Substrate:	Found only on Table Mountain Sandstone
Taxonomy:	Described by FitzSimons in 1946 from Boskloof (Keeromsberg) near Worcester. Poynton (1964) considered it a subspecies of *H. purcelli* Sclater, 1898. Subsequent authors considered it synonymous with *H. purcelli* (e.g. Boycott, Pp. 95-105 *in* Minter *et al.* 2004). Mitochondrial DNA sequences show that this is a distinct species that is regionally endemic to the mountains northwest of the Breede and Berg Rivers (M. Cunningham, unpublished data).
Fishes:	In many streams this species shows limited co-occurrence with indigenous fishes, particularly *Pseudobarbus*, *Barbus* and *Galaxias,* but it is unlikely that these are stable or self-sustaining populations. Generally, fish seem to be the major determinant of distributional limits along streams. Overlap occurs only at the upper limit of fish distribution where there is a low density of both fish and tadpoles. The density of tadpoles increases dramatically above barriers that exclude fish. This is probably a source-sink situation with tadpoles washing downstream and minimal reproductive success of frogs in the overlap zone. The proximal mechanism for this pattern is unknown but it is probably due to predation by fish of tadpoles and eggs (which are sometimes laid on wet rocks above the water level).
Impacts:	There will be localised impacts on *Heleophryne* populations where translocations are used to extend the fish population to sites above waterfalls or where this results in an increase in fish density in the overlap zone.

This species will be minimally affected by the building of weirs and the use of piscicide because it is generally absent from sites where alien fish occur, despite its abundance in surrounding tributaries. It is unlikely to benefit from the removal of alien fishes if these are replaced by indigenous fishes.

Comments: This species was targeted in surveys for this report. It has only recently been recognised as a valid taxon and its conservation status was not evaluated in Minter et al. (2004) or Measey (2011). It does not overlap with its sister species, *H. purcelli*, which occurs SW of the Breede and Berg Rivers. Du Preez & Carruthers (2009) refer to it as the Cederberg Ghost Frog but this is misleading as it extends beyond the Cederberg.

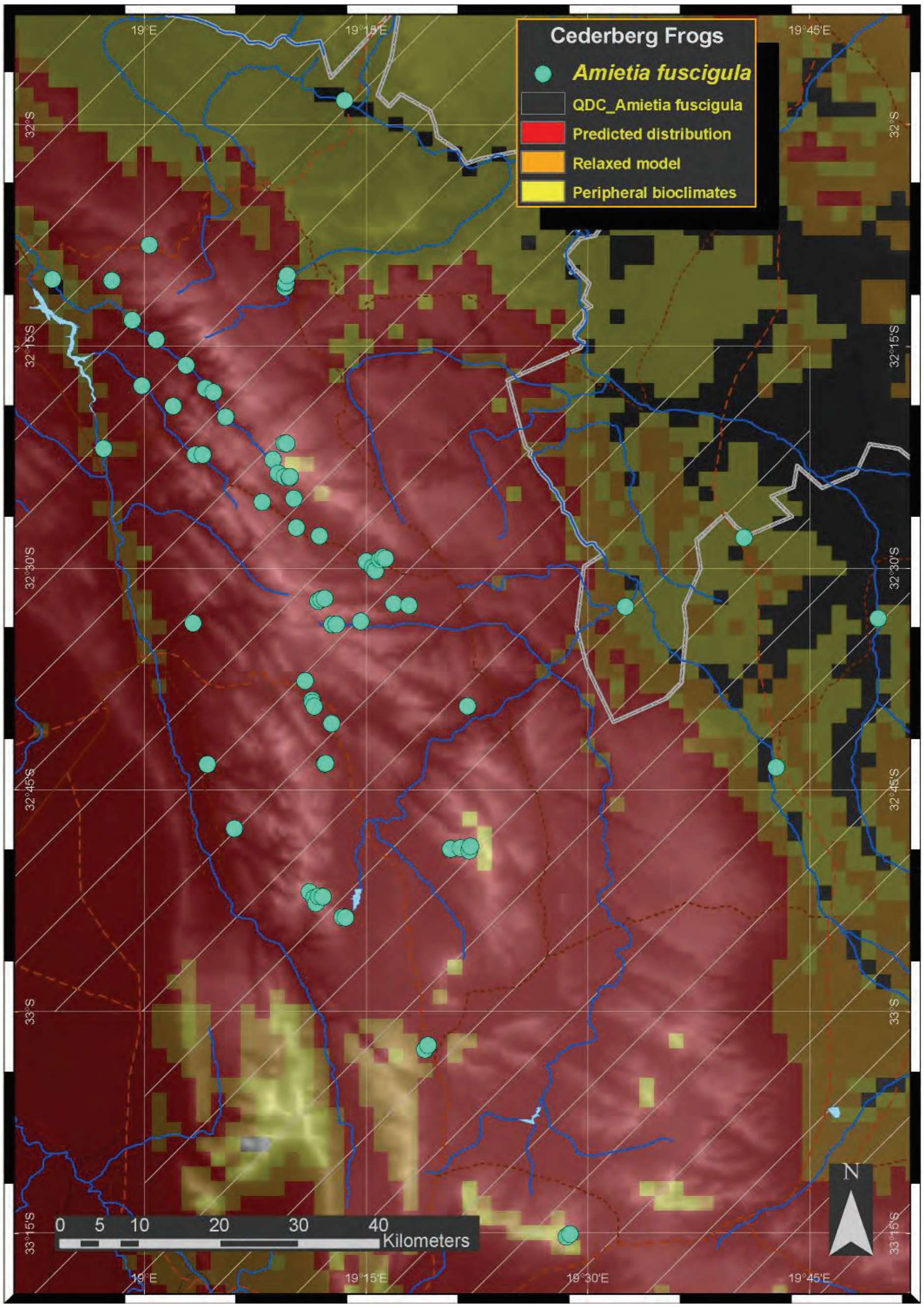

Fig. 10.4. Observed and predicted distribution of Cape River Frog, *Amietia fuscigula*, in the Cederberg. This appears to be a compound of two distinct taxa, a mountain stream form and a “lowland” pond form. The montane form predominates in this dataset such that valley basin records are predicted as being in suboptimal climates (105 montane records from 76 sites vs. 9 “lowland” records from 9 sites). Both forms are widespread but taxonomic confusion probably results in a somewhat overly extensive prediction, especially in the under-surveyed west.

***Amietia fuscigula* (Dumeríl & Bibron, 1841) – Cape River Frog**

Total Range:	Widespread coastally and inland from the Cape Peninsula to Port Elizabeth, northwest to around Springbok and through the central karoo and highveld to the Orange – Vaal river system, the KwaZulu-Natal midlands and the north-eastern escarpment of Mpumalanga. An isolated population occurs in the Naukluft mountains of Namibia. Range Size > 470 000 km^2 (> 700 QDCs)
Endemicity:	Endemic to South Africa, Lesotho & Namibia
Biomes:	Fynbos, Succulent Karoo, Nama Karoo, Grassland, Forest. Peripherally in Thicket and Savanna
Habitats:	Ponds, river pools and streams both in mountains and valley floors
Status:	Least Concern (unlikely to be affected by taxonomic changes)

Records:	114 records / 85 sites within the study domain
Rarity:	Very common and abundant
Occurrence:	The most commonly encountered and widely occurring species in the study domain, living almost anywhere where there are pools of water, from the river valleys up to the headwaters of mountain streams. The distributional model predicts a more patchy distribution east of the mountains, in the Tankwa Karoo, consistent with survey results.
Range limits:	None in this region, although the distinct gap between the Cederberg and Namaqualand records, spanning the Knersvlakte, may be significant when taxonomic problems with this taxon are resolved.
Elevation:	110-1750 m
Substrate:	Table Mountain Sandstone to Bokkeveld and Karoo shales
Taxonomy:	As currently recognised this taxon appears to be compound, with two morphologically, vocally and genetically distinct forms occurring in separate habitats throughout the western Cape, including the Cederberg. Montane populations may be endemic to the Cape Fold Mountains, whereas valley basin populations may be a widespread Cape lowlands – Karoo – Grassland form. The correct names for these forms are currently under review.
Fishes:	Commonly occurs with fishes, breeding mainly in fish-free side-pools. There may be differences in tolerance of fishes between “lowland” and montane forms. These should be investigated for behavioural or chemical (distastefulness) adaptations to life with fishes.
Impacts:	No significant or lasting impacts are expected, irrespective of the taxonomic problems with delimitation of this species. Actions to ensure conservation of endangered fish species will mainly affect the montane form. These frogs are abundant in side-streams and are likely to re-invade after piscicidal treatment to remove of alien fishes.
Comments:	Cape Fold Mountain populations of this species were well sampled in surveys for this project.

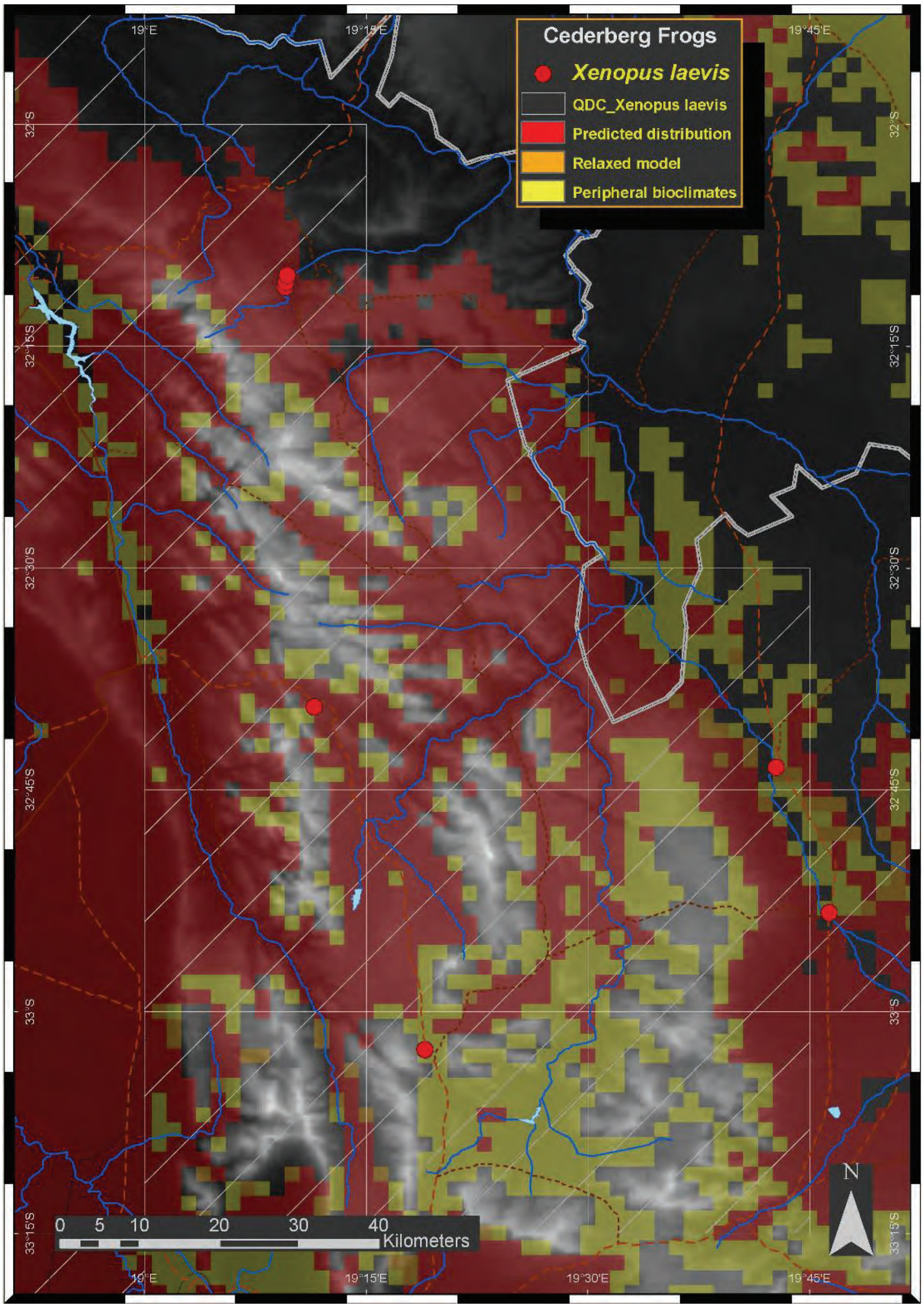

Fig. 10.5. Observed and predicted distribution of the Common Platanna, *Xenopus laevis,* in the Cederberg. This model is based on relatively poor sampling but is a fair representation of the species distribution, with the exception of the Tankwa Karoo and Doring River valley in the northeast, where the species occurs along intermittent river courses and is undoubtably more common than indicated here.

Xenopus laevis (Daudin, 1802) – Common Platanna

Total Range:	Southern Africa, south of the Zambezi River catchment, including southern parts of Malawi, Angola and Zambia. Range Size > 2 200 000 km^2
Endemicity:	Southern and South-Central Africa (10 countries: South Africa, Lesotho, Swaziland, Namibia, Botswana, Zimbabwe, Mozambique, Malawi, Zambia, Angola)
Biomes:	Fynbos, Nama Karoo, Succulent Karoo, Grassland, Forest, Savanna
Habitats:	Stream pools, dams, pans and slow-flowing river pools in valleys.
Status:	Least Concern

Records:	8 records / 7 sites within the study domain
Rarity:	Common but under sampled due to aquatic habits
Occurrence:	Widely occurring but absent from the mountain headwater streams and sparse in the central Tankwa Karoo to the north-east.
Range limits:	None in this area, although it occurs sparsely in the Knersvlakte and there are few known localities in Namaqualand, to the north. Measey & Channing (2003) found a genetic disjunction between populations in the Western Cape and those in Namaqualand.
Elevation:	380-981 m (highest on the Kouebokkeveld plateau)
Substrate:	Karoo and Bokkeveld sediments through to TMS. Tolerant of turbid, de-oxygenated and even slightly saline conditions.
Taxonomy:	Winter and summer rainfall populations are genetically distinct , reflecting differences in the main breeding season in each area (Measey & Channing 2003).
Fishes:	Frequently co-occurring with fish, including alien fish species, particularly in disturbed, eutrophied and turbid systems
Impacts:	No significant or lasting project impacts are expected
Comments:	This species was underrepresented in the surveys upon which this report is based, which targeted mountain streams where they are only occasionally encountered.

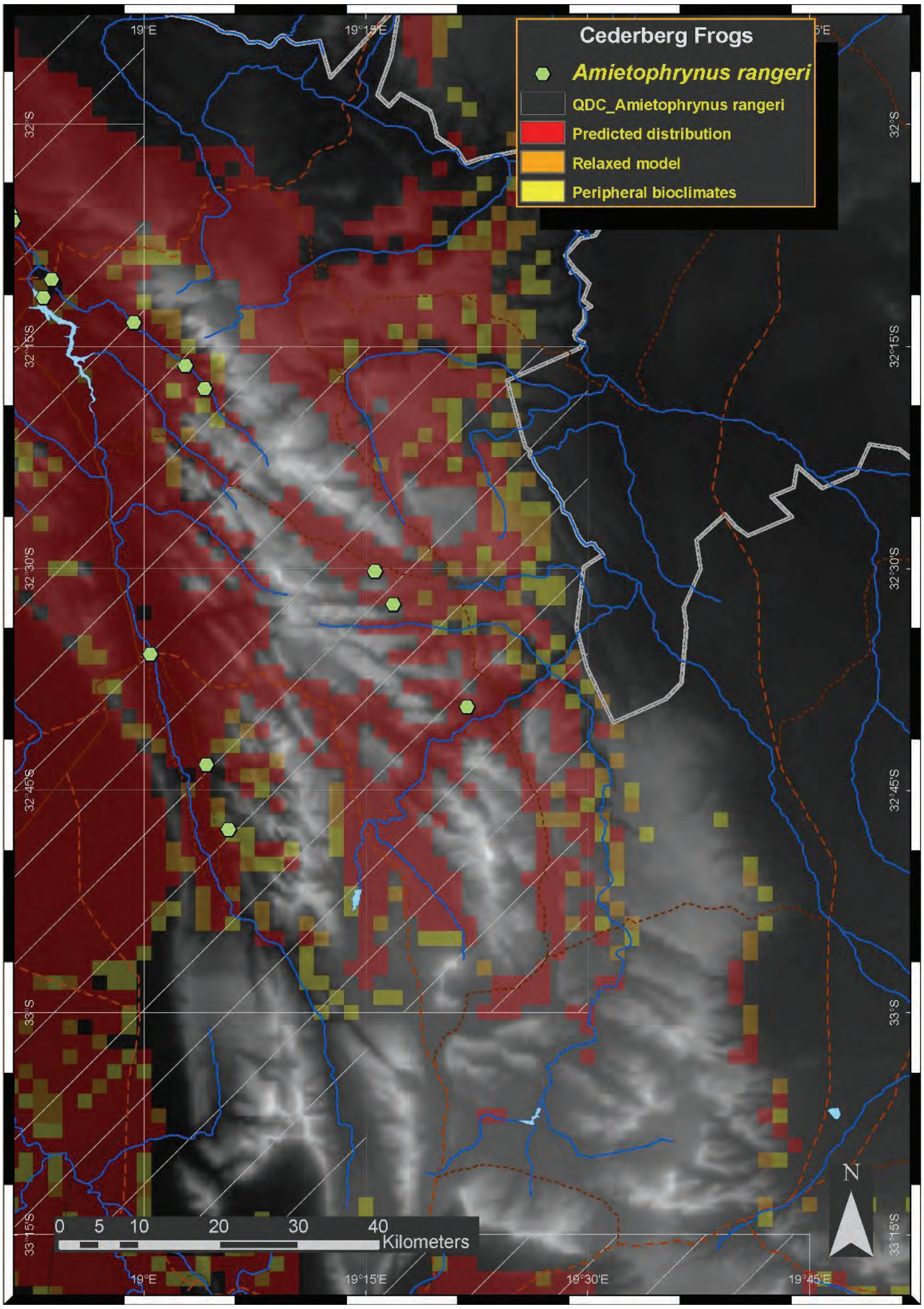

Fig. 10.6. Observed and predicted distribution of the Raucous Toad, *Amietophrynus rangeri*, in the Cederberg. The model is a good representation of the known distribution of this species, despite limited sampling. Surveys are needed in the north and northeast to better determine the limits to this species distribution.

***Amietophrynus rangeri* (Hewitt, 1935) – Raucous Toad**

Total Range:	Widespread; from the Olifants river mouth along the Cape Fold mountains and around the southern and eastern coastal areas to Richards Bay in KwaZulu-Natal, extending north from around Addo through the highveld and eastern escarpment to the Soutpansberg Mountains of Limpopo, and following the Orange River west to Namaqualand. Range Size > 500 000 km^2
Endemicity:	South Africa, Lesotho & Swaziland
Biomes:	Fynbos, Grassland, Thicket, peripherally in Forest and Savanna
Habitats:	Ponds, dams, channels and slow flowing river pools, valley floors and plateaux, generally not breeding in the mountains
Status:	Least Concern

Records:	22 records / 15 sites within the study domain
Rarity:	Common
Occurrence:	River valleys and areas around the base of the mountains. Extending across the Swartland to the south-west. Absent from rugged mountain areas, the Tankwa Karoo to the north-east and much of the Kouebokkeveld to the south.
Range limits:	The northern limit of this species is around the Olifants River mouth, it does not appear to extend east of the Cederberg into the Tankwa Karoo
Elevation:	170-830 m
Substrate:	TMS to Bokkeveld and Karoo shales
Taxonomy:	Cederberg populations fall within one of three historically isolated, genetically distinct lineages; the Cederberg lineage extends from this area south to Stellenbosch
Fishes:	Generally breeding in fish-free side pools and ponds; adults are mainly terrestrial and would encounter fish during the breeding season only. Tadpoles and eggs may sometimes develop in the presence of fish. Adults, larvae and eggs have chemical defences (bufotoxins) against vertebrates that deter many potential predators. These toxins are believed to be an evolutionary response to fish predation, arising early in the history of the family Bufonidae.
Impacts:	No significant or lasting project impacts
Comments:	Adequately represented in the survey records given here

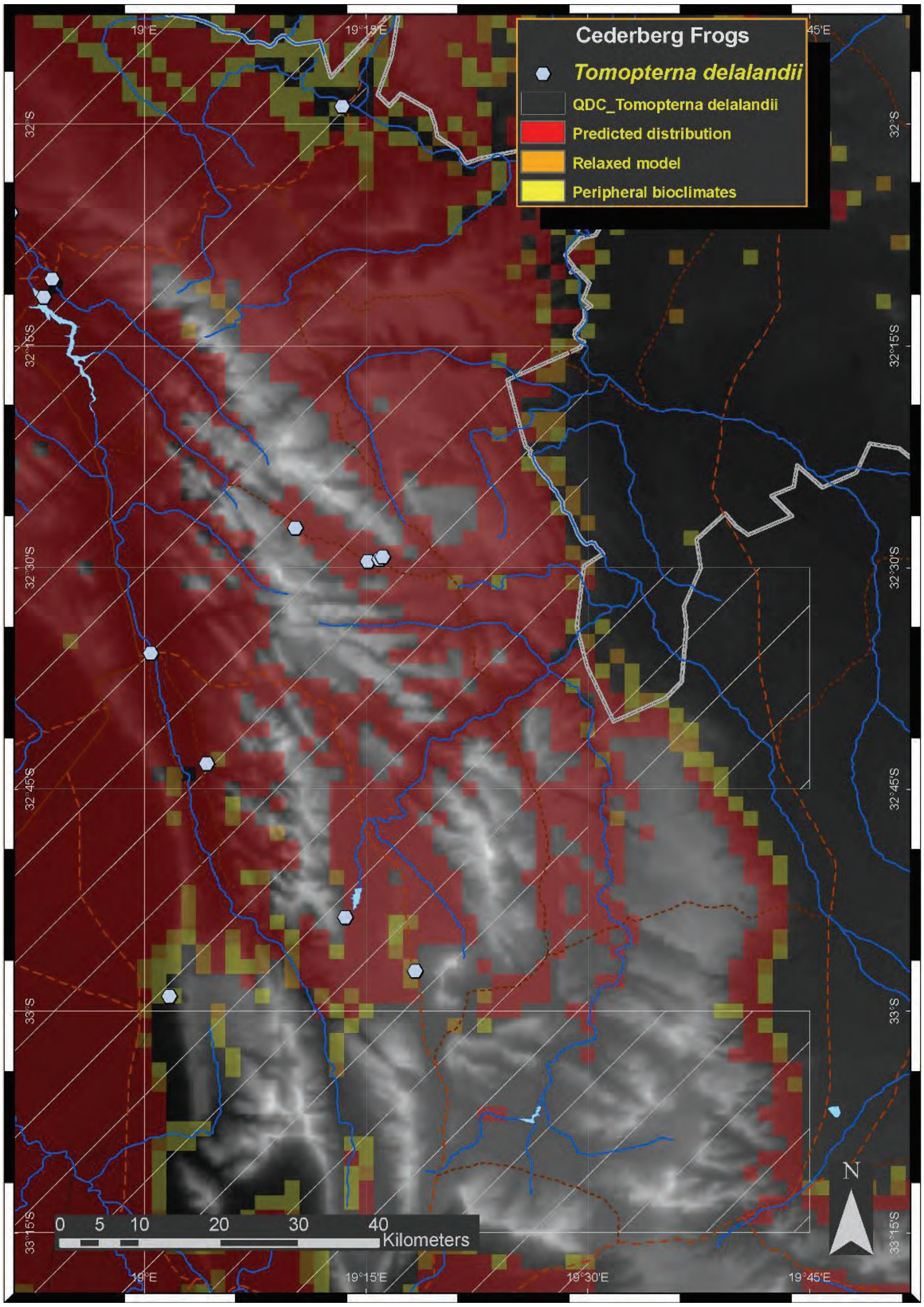

Fig. 10.7. Observed and predicted distribution of the Cape Sand Frog, *Tomopterna delalandii,* in the Cederberg. The model is a good representation of the species distribution in this area, although it may be more extensive than indicated along river courses in the Tankwa Karoo to the east.

***Tomopterna delalandii* (Tschudi, 1848) – Cape Sand Frog**

Total Range:	From the Orange River in Namaqualand around the coast and inland to the Karoo escarpment through to Port Alfred and Grahamstown. Range Size > 120 000 km^2
Endemicity:	Endemic to South Africa
Biomes:	Fynbos, Succulent Karoo, Nama Karoo
Habitats:	Ponds, pans and river side-pools on sandy flats
Status:	Least Concern

Records:	29 records / 28 sites within the study domain
Rarity:	Common
Occurrence:	Around valley basins and areas around the base of the mountains including the Swartland to the south-west and the sandveld to the west. Generally absent from rugged mountain areas, sparse in the arid areas of the east and the Kouebokkeveld to the south.
Range limits:	Reaches an inland range limit in the northeast of the study area
Elevation:	49-998 m
Substrate:	Sandy areas on TMS, Karoo and Bokkeveld sediments and alluvium
Taxonomy:	A well resolved taxon within the study area. Elsewhere historical hybridisation with a related diploid species, *T. cryptotis*, has resulted in polyploid populations assigned to *T. tandyi*, which may have arisen multiple times. These populations confound diagnosis of the parent species.
Fishes:	Generally doesn't co-occur with fishes
Impacts:	None, this species generally breeds in still water in ponds or river side pools.
Comments:	Sampling of this species is adequate

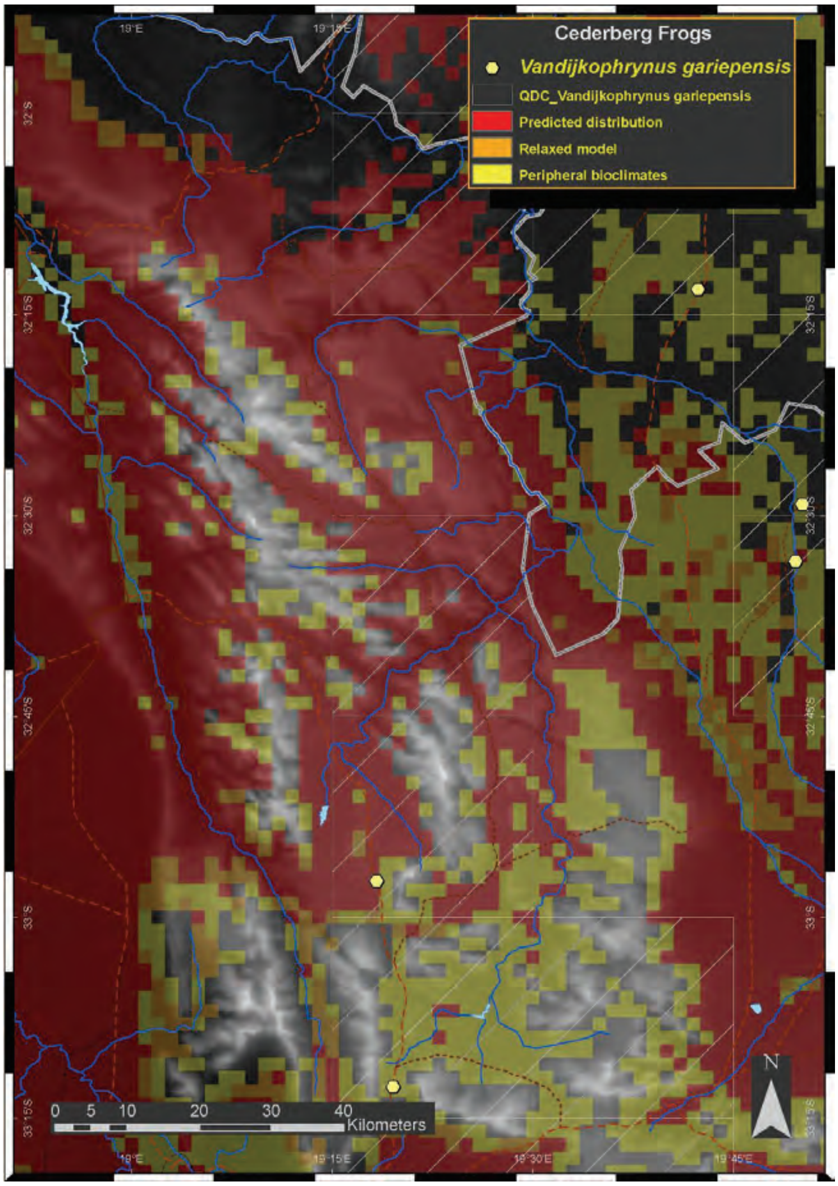

Fig. 10.8. Observed and predicted distribution of the Karoo Toad, *Vandijkophrynus gariepensis,* in the Cederberg. The model is a fair representation of the distribution of this species in the west but overpredicts the occurrence of this species in the east, where it is replaced by the Cape Sand Toad, *V. angusticeps*. The limited locality data on this species is a reflection of its absence from montane areas and the Olifants valley. Further surveys are needed in the Doring Valley and along the eastern side of the mountains.

Vandijkophrynus gariepensis **(Smith, 1848) – Karoo Toad**

Total Range:	From around Ceres and the Kouebokkeveld north to the Tankwa, Bokkeveld, Hantam and Boesmanland as far as the Orange River, and east across the inland Cape Fold Mountains and Karoo to the montane grasslands of the Eastern Cape and the Maluti-Drakensberg, extending north along the eastern escarpment to the vicinity of Lydenburg in Mpumalanga. Range Size > 270 000 km^2 (> 400 QDCs)
Endemicity:	South Africa, Lesotho and Swaziland
Biomes:	Nama Karoo and Grassland. Peripherally in Fynbos
Habitats:	Shallow temporary pans and pools, intermittent stream pools and seepage wetland ponds in montane grassland
Status:	Least Concern

Records:	13 records / 7 sites within the study domain
Rarity:	Moderately common in Nama Karoo, elsewhere sparse or absent
Occurrence:	Occurring predominantly in the Kouebokkeveld and Tankwa Karoo, along the eastern side of the mountains, south and east of the Cederberg. The predicted distribution overstates the actual occurrence of this species (see below).
Range limits:	The Cederberg range is the western limit for this species
Elevation:	341-1044 m
Substrate:	Karoo and Bokkeveld sediments
Taxonomy:	Three species of *Vandijkophrynus* meet around the Greater Cederberg and Poynton (1964) suggested that some specimens form this area may be hybrids. The boundary between *V. gariepensis* and *V. robinsoni*, around the Knersvlakte in particular, is poorly resolved. Beyond the study domain *V. gariepensis* shows considerable geographical variation in morphology with several montane dwarf forms occurring in the eastern part of its range. Resolution of the status of these forms may require changes to the scientific name for this species.
Fishes:	Generally doesn’t co-occur with fishes
Impacts:	None. This species does not occur in the area targeted for conservation of endangered fishes
Comments:	The distribution of this species contrasts with most other frogs in the study area. The model suggests that it could occur widely on the western side of the mountains, in the Swartland and Olifants River valley but there are no records from this relatively well surveyed area. This may be due to historical, ecological and evolutionary interactions between *V. gariepensis* and two related species that come into close proximity in the Greater Cederberg, *V. angusticeps* and *V. robinsoni*.

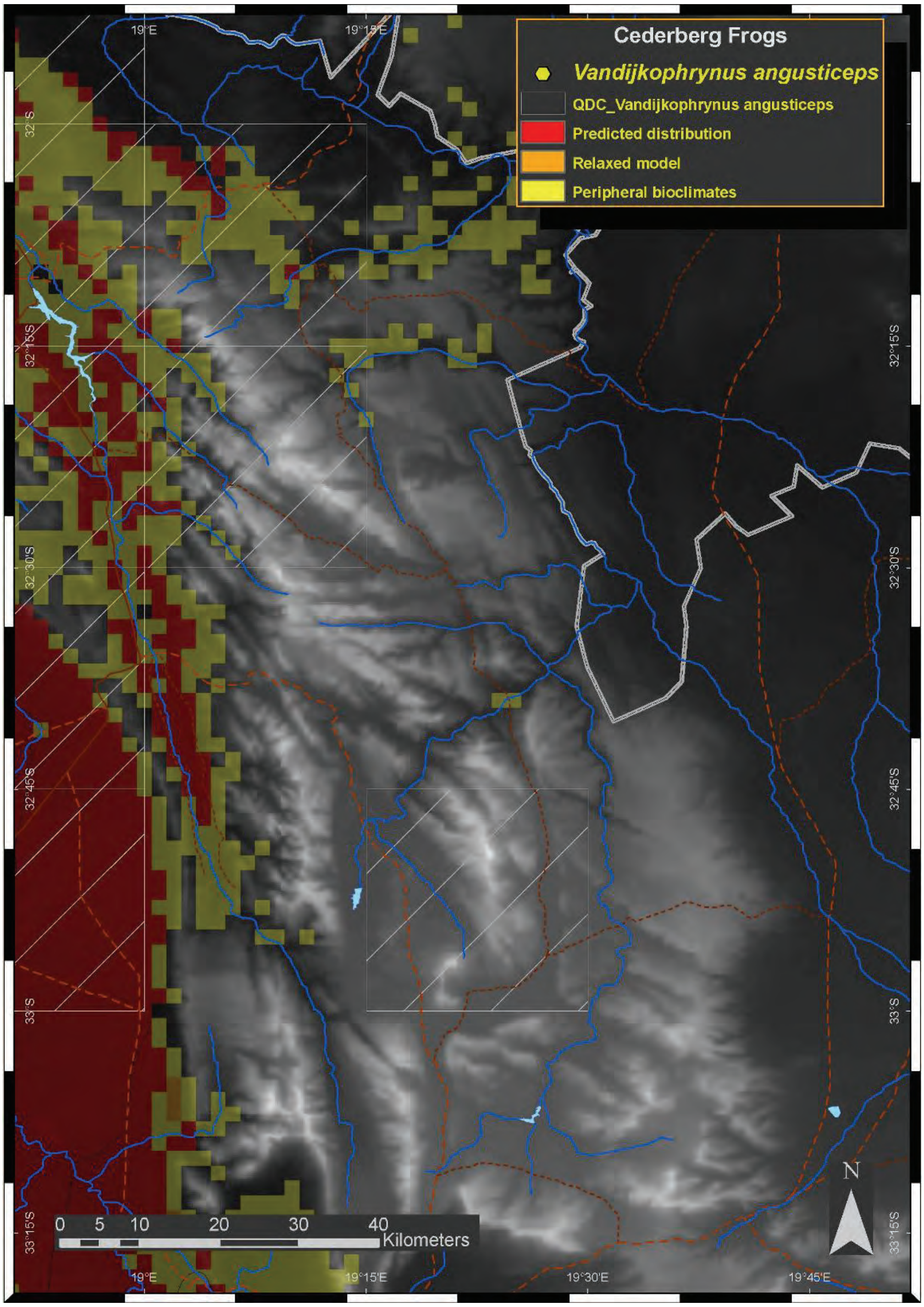

Fig. 10.9. Observed and predicted distribution of the Cape Sand Toad, *Vandijkophrynus angusticeps,* in the Cederberg. The map is a fair prediction of the distribution of this species, which is largely restricted to the Olifants river valley, Swartland and sandveld to the west of the study area.

***Vandijkophrynus angusticeps* (Smith, 1848) – Cape Sand-Toad**

Total Range:	Bokkeveld escarpment edge near Nieuwoudtville, and Gifberg, around the Cape coastal sandflats to Mossel Bay. Also occurring high in the Hex, Swartberg and Kammanassie Mountains and on coastal sands around Cape St Francis in the Eastern Cape. Range Size > 45 000 km^2 (67 QDCs)
Endemicity:	Cape Floristic Region
Biomes:	Fynbos
Habitats:	Temporary rain pools and coastal wetlands on deep sand, small pools in sandy mountain seepages
Status:	Least Concern

Records:	10 records / 6 sites within the study domain
Rarity:	uncommon within the study area
Occurrence:	Occurring in the sandveld west of the mountains and in sandy areas on elevated plateaus within the mountains
Range limits:	Reaches its northern and northeastern limits of distribution within the Greater Cederberg area
Elevation:	49-670 m
Substrate:	Deep sand
Taxonomy:	A well resolved species but hybridisation may occur with closely related species, *V. robinsoni* and *V. gariepensis* where they meet
Fishes:	This species breeds in temporary pools formed in winter on sandy flats. It does not co-occur with fishes.
Impacts:	None. This species does not occur around the lower montane streams targeted for conservation of endangered fishes
Comments:	This species is common in suitable habitat to the southwest and west of this area, including the lower Olifants valley around Klawer. It is surprisingly rare in sandy areas of the central Cederberg and Kouebokkeveld

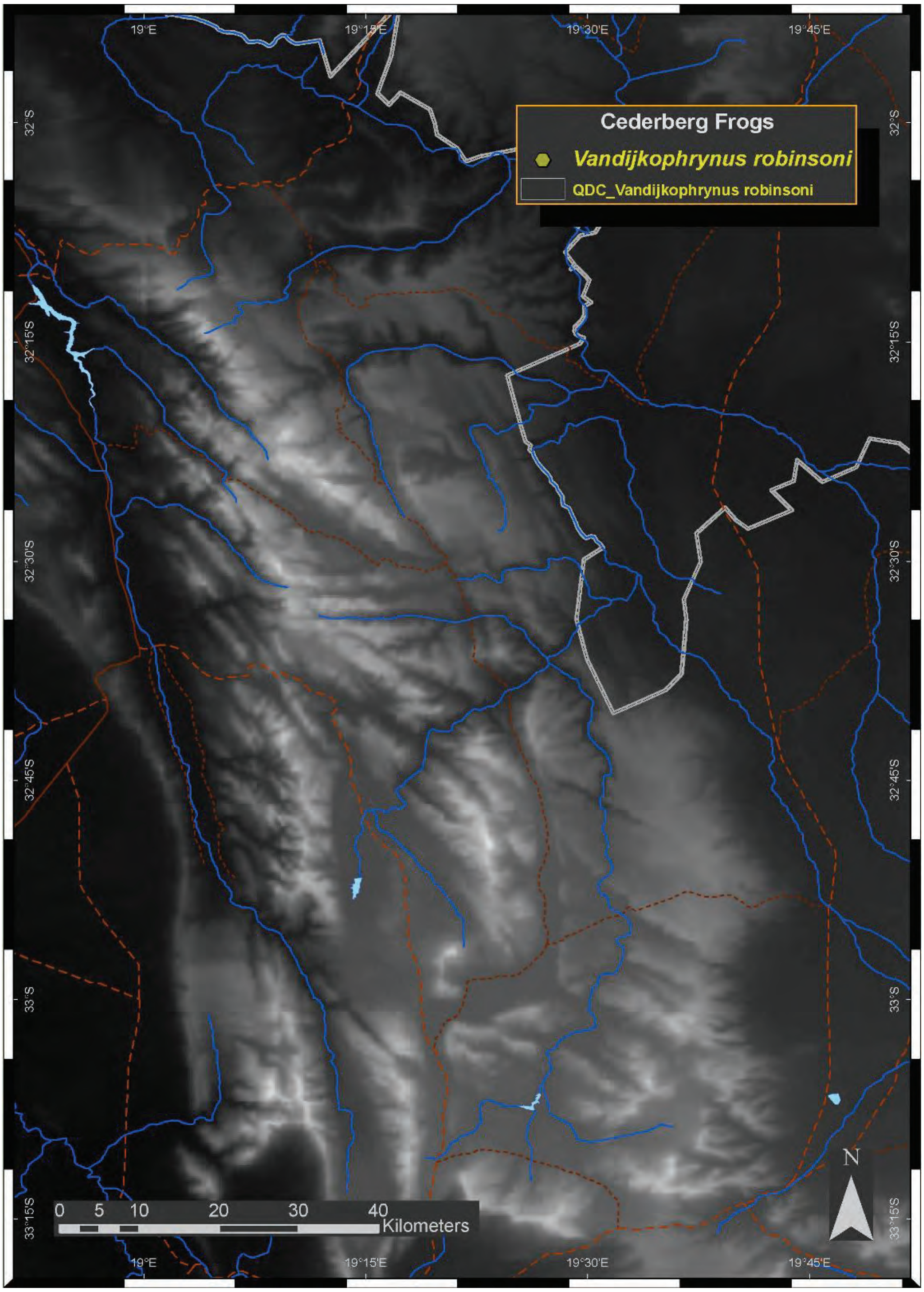

Fig. 10.10. The Paradise Toad, *Vandijkophrynus robinsoni*, is a poorly delimited Namaqualand endemic that extends south to the Knersvlakte around Vanrhynsdorp. This species has not been recorded from the central Cederberg (the area mapped) although further surveys are needed of potential habitat in the lower Doring valley.

***Vandijkophrynus robinsoni* (Branch & Braack, 1996) – Paradise Toad**

Total Range:	From Rosh Pinah in southern Namibia and the adjacent Richtersveld of South Africa, east to around Aggeneys and south through Namaqualand to around Vanrhynsdorp in the Knersvlakte Range Size > 34 425 km^2 (51 QDCs, including those northwest of 32^{o}S, 19^{o}E assigned to *Bufo gariepensis* in Minter *et al.* (2004) and the single record from southern Namibia)
Endemicity:	Namaqualand – NW South Africa and extreme SW Namibia
Biomes:	Succulent Karoo
Habitats:	Streamlines in arid, rocky areas
Status:	Least Concern

Records:	1 record / 1 site within the study domain
Rarity:	Rare within the study area
Occurrence:	Found only in the extreme north of the Greater Cederberg, in the Knersvlakte, where it is rarely encountered.
Range limits:	Southern limit around Vanrhynsdorp
Elevation:	155 m for the single record.
Substrate:	Quartz gravel beds, karoo shales, weathered granite and gneiss
Taxonomy:	This species was originally described, based on colouration and calls, as a very localised endemic within the Richtersveld. Surveys for the SA Frog Atlas Project (Minter et al. 2004) found toads elsewhere in Namaqualand that resembled *V. gariepensis* in pattern and colouration but gave the distinctive call of *V. robinsoni*. At the same time, Mitochondrial DNA sequence analysis (Cunningham & Cherry 2000, 2004; and ongoing research by the author) indicates that these populations are conspecific, that *V. robinsoni* is more closely related to *V. angusticeps* than to *V. gariepensis*, and suggest that the latter species may not occur in Namaqualand. The delimitation of these three species in this area requires further study.
Fishes:	This species breeds in temporary pools along rocky stream lines in arid areas. It does not co-occur with fishes.
Impacts:	None
Comments:	Poynton (1964) suggested the possibility of hybridisation in this group around Vanrhynsdorp. The single record in the dataset, a male from near Vanrhynsdorp found in August 2002, may possibly be a hybrid. This specimen showed the distinct features and markings of *V. robinsoni* (a relatively smooth dorsum with tan blotches outlined and highlighted with successive dark and light edging, on a grey-green background, without yellow feet). This differed from similarly sized males of *V. angusticeps* found in nearby sites, around Klawer and Giffberg Pass, at the same time (these had a highly

tubercular dorsum with indistinct markings without edging or highlighting, and with yellow tinted feet). Analysis of mitochondrial DNA from this individual, however, found a sequence typical of *V. angusticeps*, rather than *V. robinsoni* (an alternative explanation could be that this specimen is merely a peripheral variant or aberrant form of *V. angusticeps* although other specimens assigned to *V. robinsoni* have been collected in the same area.)

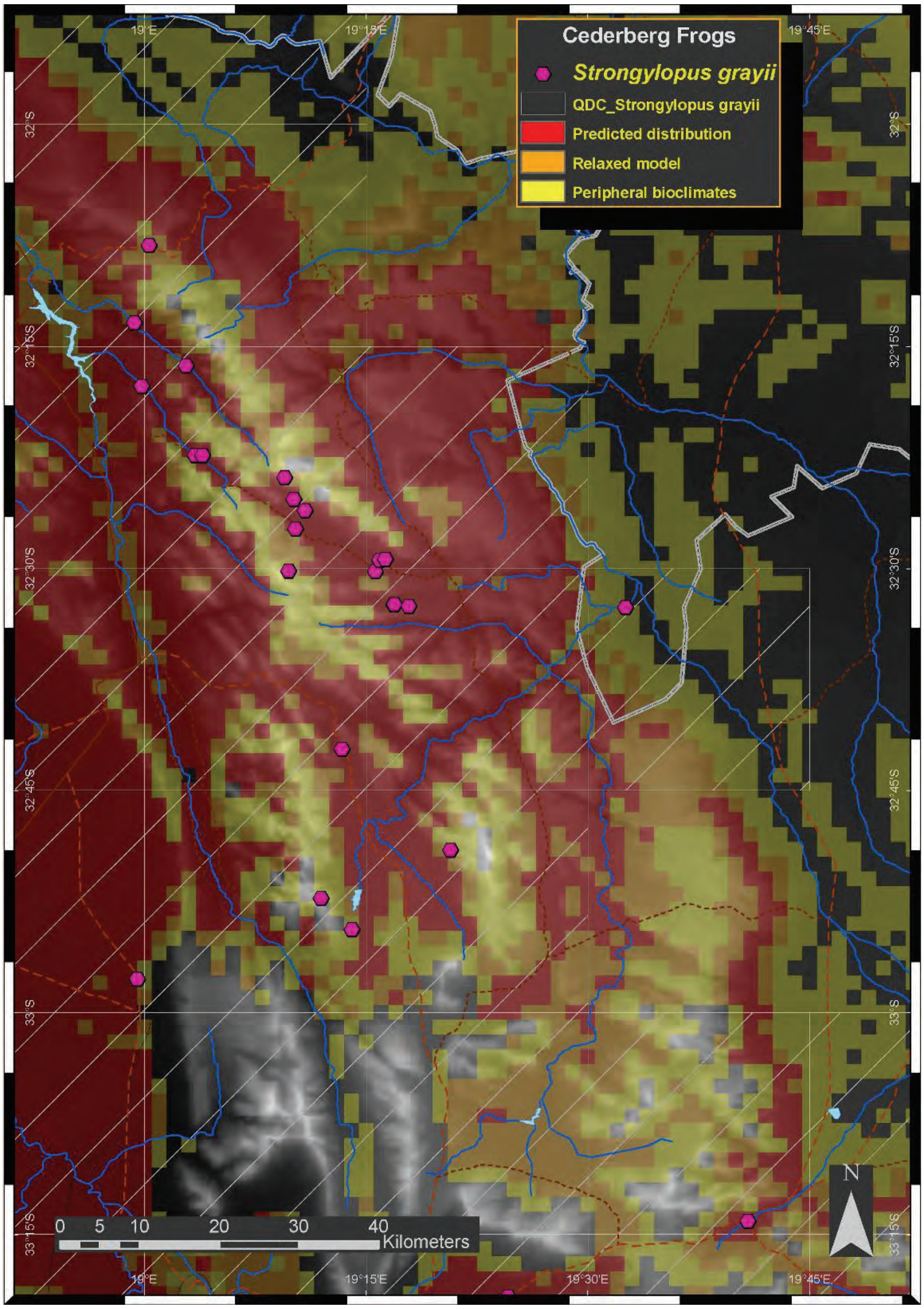

Fig. 10.11. Observed and predicted distribution of the Clicking Stream Frog, *Strongylopus grayii*, in the Cederberg. The map is a good representation of this species distribution in the area although further surveys are needed in around the Groot Winterhoek mountains and Klein Berg River valley in the South.

Strongylopus grayii **(Smith, 1849) – Clicking Stream Frog**

Total Range:	Widespread; from the Olifants river mouth inland to the karoo escarpment, south and east around the coast and midlands to the vicinity of Richards Bay, extending along the north-eastern escarpment to the Waterberg and Soutpansberg mountains. Isolated populations also occur in sheltered inland valleys across the Karoo escarpment. Range Size > 260 000 km^2
Endemicity:	South Africa, Lesotho & Swaziland (but see taxonomy)
Biomes:	Fynbos, Nama Karoo, Grassland, Forest and Thicket; peripherally in Succulent Karoo and Savanna
Habitats:	Temporary rain puddles and vegetated roadside ditches, inundated grassland and fynbos, small pools along intermittent drainage lines, vegetated overflow from farm dams, small pools in wetlands and seepages, side pools and backwaters with vegetated edges along streams, including modified and ecologically disturbed sites.
Status:	Least Concern

Records:	59 records / 51 sites within the study domain
Rarity:	Common and abundant
Occurrence:	Widespread across the study area, particularly around the lower slopes, foothills and mid-altitude plateaus. Rarely encountered or absent from the high mountain ridges and the arid west
Range limits:	Reaches limits in the north and northeast of the study area
Elevation:	15-1537 m
Substrate:	TMS to Bokkeveld and Karoo shales
Taxonomy:	This is a well-defined species in the study area. Populations from eastern South Africa are genetically distinct and may deserve separate recognition (Tolley *et al.* 2010) but this will not affect the conservation status of this species which would be restricted to populations from the Cederberg to the Amathole Mountains of the Eastern Cape.
Fishes:	Tadpoles and adults of this species are occasionally found with fishes, although they are generally separated by habitat, with this species tending to breed around shallow, vegetated temporary pools along stream banks
Impacts:	Some individuals within the treatment areas will be affected by piscicidal treatment to remove alien fishes, but this will not have negligible impacts on local populations of this species. The re-introduction of indigenous fishes to these sites will not affect this species. Clearing of alien vegetation along streams may have minor impacts on this species habitat but will not affect regional populations.
Comments:	This is perhaps the most abundant and adaptable species in this area. Eggs are laid on moist soil, usually sheltered by vegetation, and the emerging tadpoles wriggle into adjacent rain pools. Breeding may occur at virtually any time of the year that water is available – with calling occurring throughout the year.

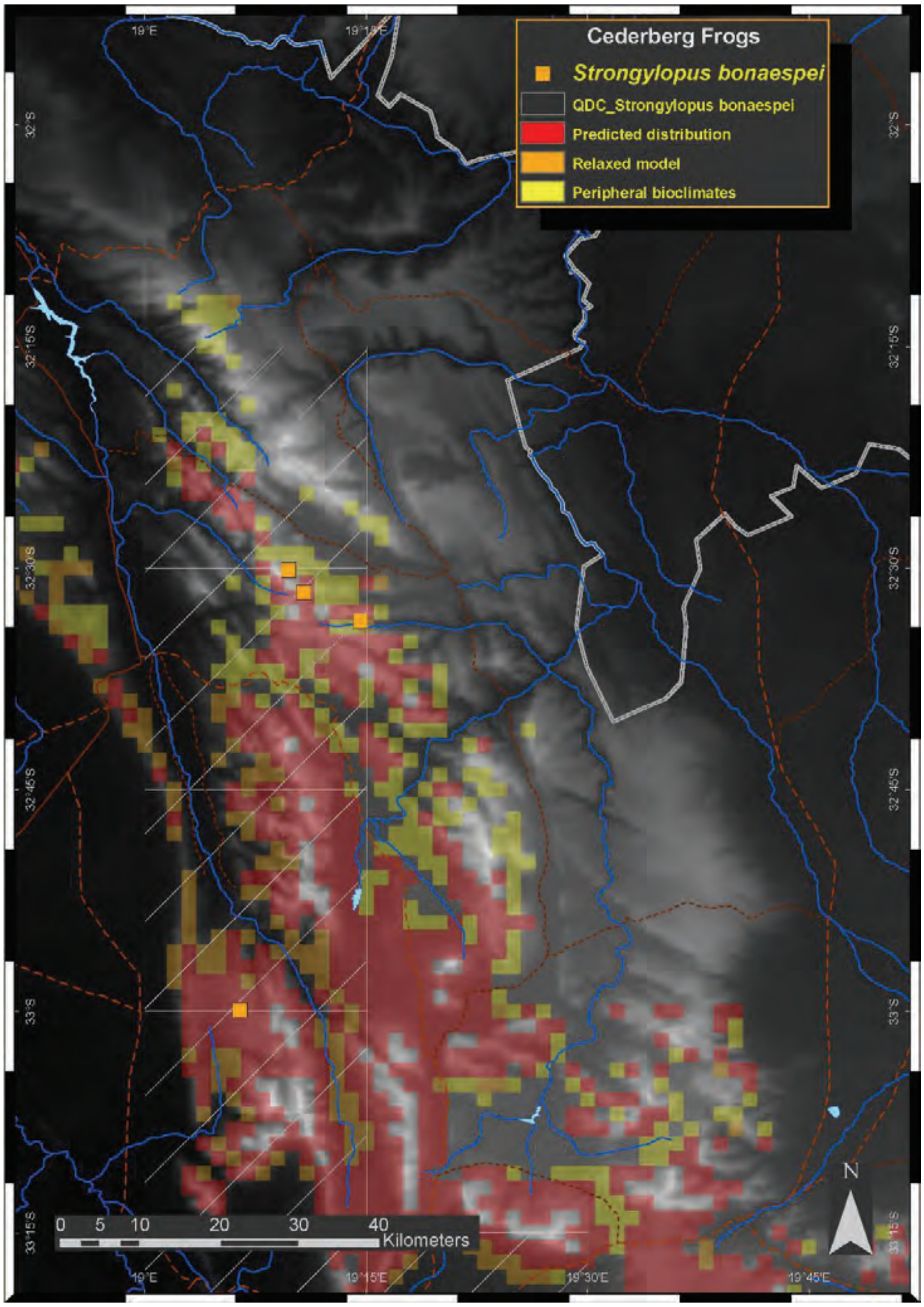

Fig. 10.12. Observed and predicted distribution of the Banded Stream Frog, *Strongylopus bonaespei,* in the Cederberg. The model, based on 34 records from across the Cape Floristic Region, is a good representation of the occurrence of this montane fynbos specialist and indicates a need for further surveys in the ranges west of the Olifants River valley and in the Kouebokkeveld mountains to the south, to confirm that this species occurs in these predicted areas.

Strongylopus bonaespei **(Dubois, 1981) – Banded Stream Frog**

Total Range:	From Hoogvertoon in the central Cederberg south to the Boland and Cape Peninsula, southeast around the coast to the western side of Cape Agulhas, and east along the Cape Fold Mountains to Joubertina and Witelsbos in the Eastern Cape. Range Size > 25 000 km^2
Endemicity:	Cape Fold Mountains, within the Cape Floristic Region
Biomes:	Fynbos
Habitats:	Thickly vegetated small seepage wetlands in mesic montane fynbos
Status:	Least Concern

Records:	5 records / 4 sites within the study domain
Rarity:	Very rare and restricted here
Occurrence:	Restricted to seepages high plateaux along the central backbone of the Cederberg mountains
Range limits:	This species does not extend north of the central Cederberg. It does not occur in the lower altitude areas to the east or west of the mountains.
Elevation:	970-1400 m within the Greater Cederberg
Substrate:	Table Mountain Sandstone
Taxonomy:	A well delimited species
Fishes:	Does not occur in streams and does not co-occur with fishes
Impacts:	None
Comments:	This species is reasonably easy to detect from calls, especially from July to February. This species pattern of occurrence, as summits, where there is little suitable habitat, but is found on high plateaus slightly further down. Further surveys of seepage wetlands on extensive mountain plateaux such as the Kouebokkeveld mountains, the Hexberg and the Suurvlakte would better delimit this species occurrence. Surveys of the Krakadouw – Tafelberg – Wolfberg range may extend the known distribution of this species slightly to the north.

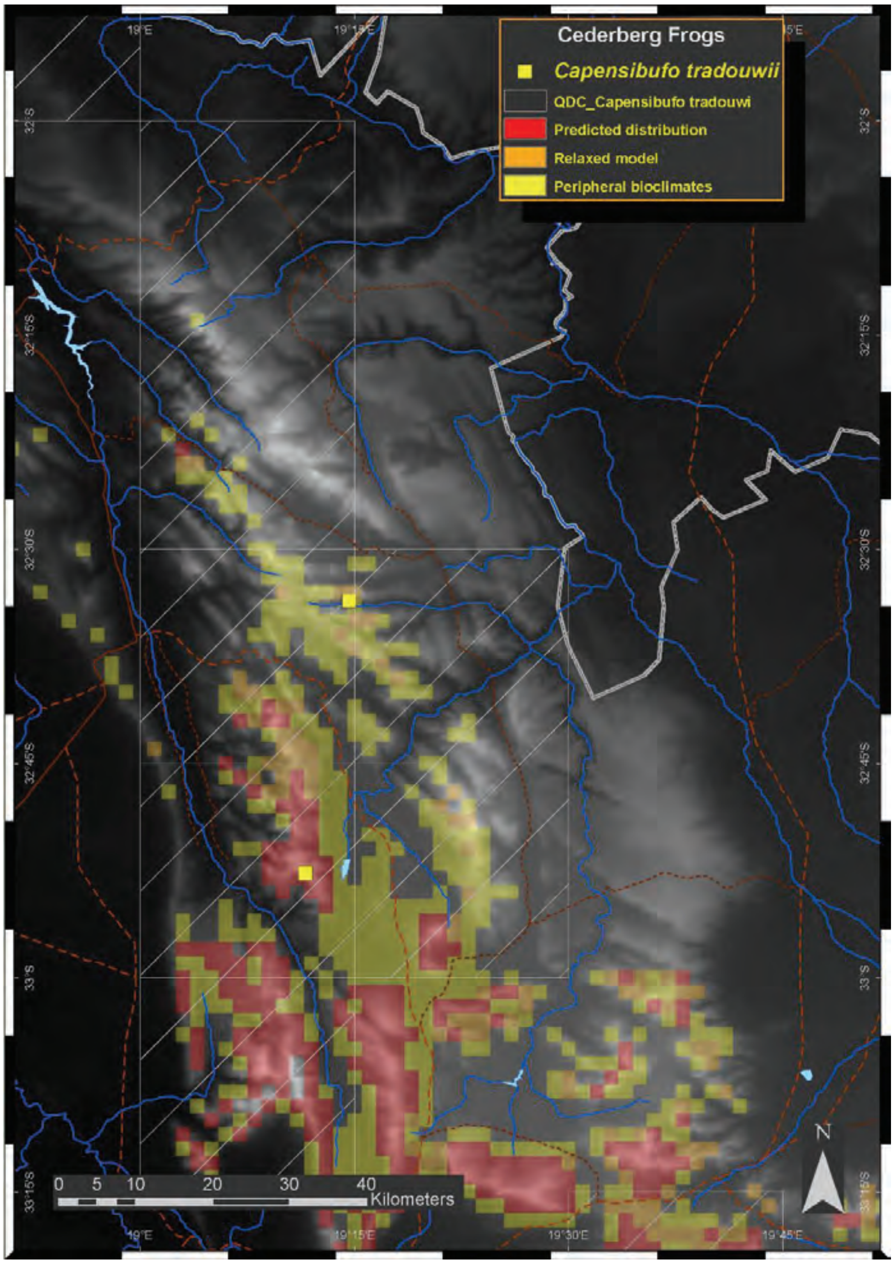

Fig. 10.13. Observed and predicted distribution of the Tradouw Mountain Toad, *Capensibufo tradouwi,* in the Cederberg based on 10 locality records from across the Cape Floristic Region. The model is a fair representation of the patchy occurrence of this montane fynbos wetland specialist although frog atlas records indicate that this species occurs in the north beyond the area predicted by the model. The addition of sites from these areas would result in a slightly more extensive distribution prediction.

Capensibufo tradouwi **(Hewitt, 1926) – Tradouw Mountain-Toad**

Total Range:	From the Bokkeveld escarpment south and east along the Cape Fold Mountains, north and east of the Breede and Berg Rivers, including the central Cederberg, Kouebokkeveld, Hex River, Langeberg, Swartberg, Kammanassie, Kouga and Tsitsikamma Mountains to the eastern Cape border. Range Size = 8775 km^2 (13 QDCs)
Endemicity:	Cape Fold Mountains, within the Cape Floristic Region, also endemic to the Western Cape Province
Biomes:	Fynbos
Habitats:	Thickly vegetated, mossy seepage wetlands in mesic montane fynbos
Status:	Least Concern

Records:	3 records / 3 sites within the study domain
Rarity:	Very rare and restricted here, difficult to detect
Occurrence:	Found only in montane fynbos seepage wetlands along the central backbone of the Cederberg mountains
Range limits:	This species reaches its northern limit in the central Cederberg and is not found in the lowlands to the east or west of here
Elevation:	970-1496 m for the three records from the study area
Substrate:	Sand from Table Mountain Sandstone
Taxonomy:	This species comprises several isolated mountain top populations. Molecular systematic studies of this genus indicate that some of these populations have been historically isolated over long time periods and may deserve species status. This could potentially affect the conservation status of this species.
Fishes:	Does not occur in streams, does not co-occur with fishes
Impacts:	None
Comments:	This species has a very similar distribution and habitat preferences to *Strongylopus bonaespei*, and similar comments apply, except that this species is more difficult to detect as it seems to have a shorter breeding season, around October, and has a less obvious call. Most individuals are encountered by chance while moving through wetlands. Despite a patchy distribution there are considerable areas of predicted occurrence that are poorly surveyed.

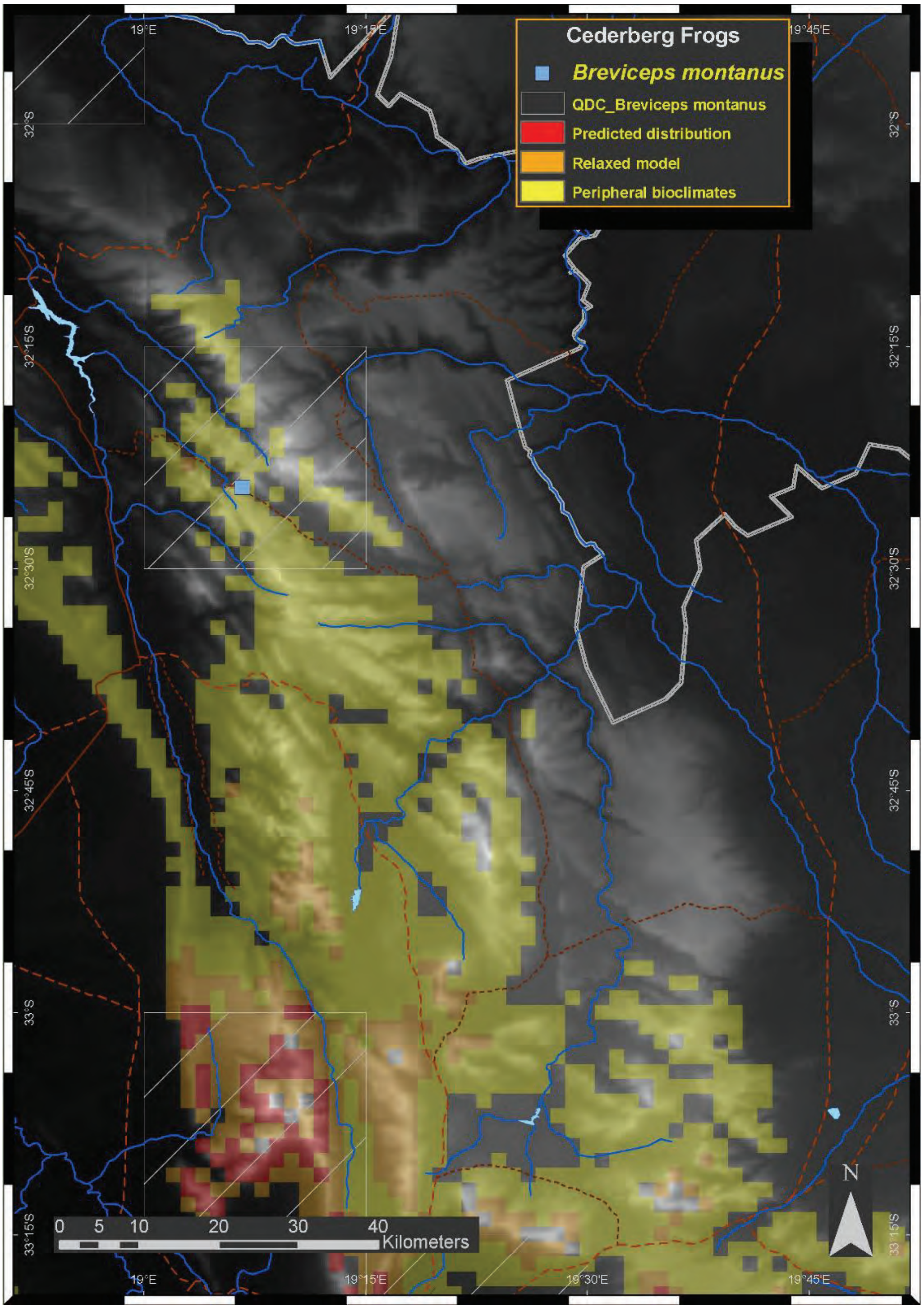

Fig. 10.14. Observed and predicted distribution of the Cape Mountain Rain Frog, *Breviceps montanus*, in the Cederberg, based on 102 locality records from across the Cape Floristic Region. The model suggests that most of this area is peripheral to this species climate niche. The species is rare in this area, with only two records in the dataset, although it probably occurs in more sites than are indicated by the model.

***Breviceps montanus* Power, 1926 – Cape Mountain Rain Frog**

Total Range:	From Gifberg northeast of Clanwilliam south to the Boland Mountains and Cape Peninsula, southeast to around Bredasdorp and east across the Langeberg, Rooiberg, Gamka, Outeniqua and Tsitsikamma Mountains behind Plettenberg Bay. Range Size > 28 000 km^2 (41 QDCs)
Endemicity:	Cape Fold Mountains, within the Cape Floristic Region, also endemic to the Western Cape Province
Biomes:	Fynbos
Habitats:	Mesic montane fynbos
Status:	Least Concern

Records:	2 records / 2 sites in the dataset (with an additional site, in a new quarter degree, discovered at Middeldeur Pass near Citrusdal since these maps were produced)
Rarity:	Rare within the study area
Occurrence:	Within the study area it has only been detected at the top of Uitkyk Pass near Algeria, in Middeldeur Pass near Citrusdal, in the Groot Winterhoek mountains and around Ceres. It likely occurs sparsely in other mesic montane fynbos sites in this area. The northernmost record in the SA Frog Atlas (Minter *et al.* 2004) requires validation. This is a lower altitude record, around 10 km N of Clanwilliam, from the CapeNature database.
Range limits:	This species reaches its northern limit in the central Cederberg and is not found in the lowlands to the east or west of here
Elevation:	531-1336 m in the study domain (with the lower altitude record from near Ceres in the south)
Substrate:	Sand from Table Mountain Sandstone
Taxonomy:	This is a well delimited species
Fishes:	This is a terrestrial breeding, direct developing species that would never encounter fishes
Impacts:	None
Comments:	This species is similar to other montane fynbos specialists at the northern limits of their distribution, *Strongylopus bonaespei* and *Capensibufo tradouwi*. In other areas this species is easily detected from calls and has a calling season that extends throughout the year, suggesting that the apparent rarity of this species in the Cederberg is not simply an artefact of limited surveys. Occasional monitoring of known sites is needed to gauge the impacts of climate change on these montane fynbos endemics at the northern limit to their distribution. The area between the summit of Uitkyk Pass and Hoogvertoon, where all three species have been recorded, would be a suitable and easily accessible location for a monitoring site.

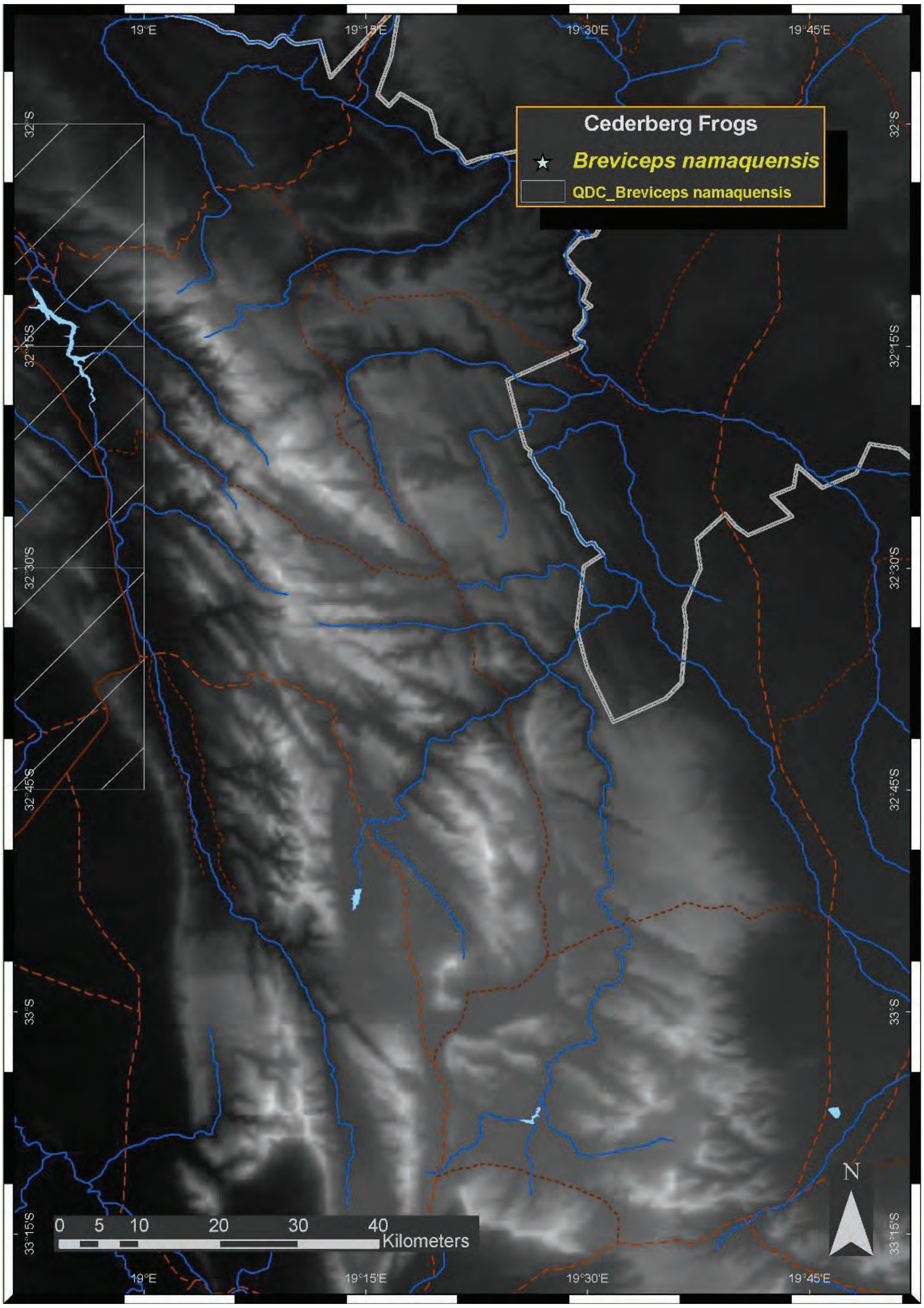

Fig. 10.15. Distribution of the Namaqua Rain Frog, *Breviceps namaquensis,* in the Cederberg. This species occurs to the north and west in the sandveld, coastal strandveld and subcoastal Namaqualand. This species does not occur around the lower montane streams surveyed in this study.

***Breviceps namaquensis* Power, 1926 – Namaqua Rain Frog**

Total Range:	From the northwest suburbs of Cape Town (Melkbosstrand) north along the coast and subcoastal interior through to the Richtersveld
Endemicity:	Western Cape and Northern Cape Provinces, or more narrowly to the western coastal area of South Africa
Biomes:	Fynbos, Succulent Karoo
Habitats:	Deep sands stabilised in strandveld and lowland succulent karoo
Status:	Least Concern

Records:	0 records / 0 sites within the study domain
Rarity:	Uncommon and poorly surveyed in this area. It is regularly encountered to the west of the study area.
Occurrence:	Restricted to succulent karoo in the lower Olifants valley basin and coastal strandveld further west
Range limits:	The Olifants River valley is the eastern limit to this species
Elevation:	±0-220 m (the altitude of Clanwilliam)
Substrate:	Deep red sands
Taxonomy:	This is a well delimited species
Fishes:	This is a terrestrial breeding, direct developing species
Impacts:	None
Comments:	Current survey data and biological information on this species is inadequate for effective conservation planning

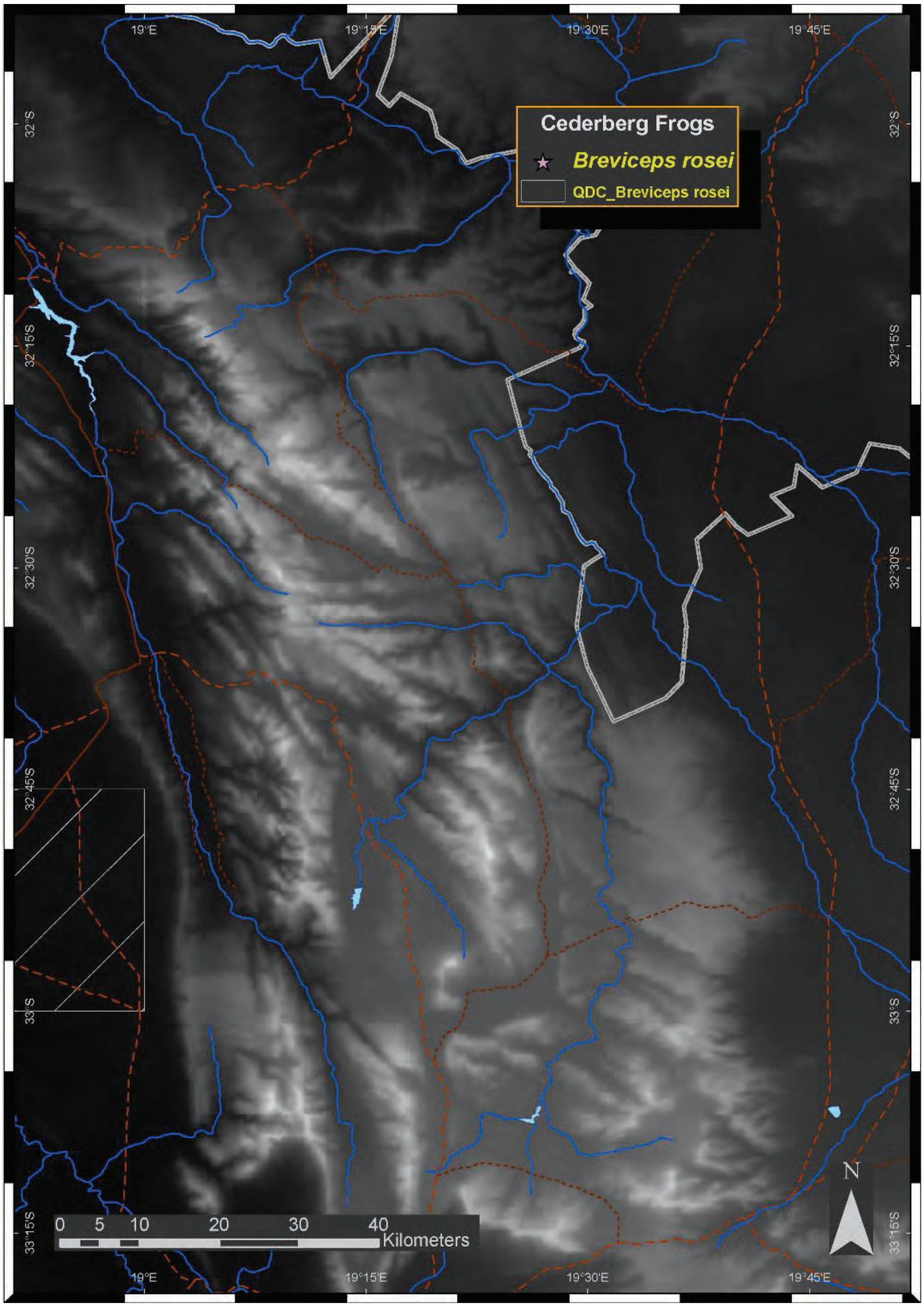

Fig. 10.16. Distribution of the Sand Rain Frog, *Breviceps rosei,* in the Cederberg. This species is peripheral to the study area and was not encountered in the surveys for this project.

***Breviceps rosei* Power, 1926 – Sand Rain Frog**

Total Range:	Coastal sandveld from the vicinity of Lamberts Bay south to Cape Town and from Hermanus around the Agulhas Peninsula to Goukamma near Knysna
Endemicity:	Cape Floristic Region, Western Cape
Biomes:	Fynbos, Thicket
Habitats:	Dune thicket and limestone fynbos
Status:	Least Concern

Records:	0 records / 0 sites within the study domain
Rarity:	Peripheral and poorly surveyed in the study area
Occurrence:	Restricted to the sandveld to the west of this area
Range limits:	Reaches its eastern limit near Eendekuil in the study area
Elevation:	±10- 120 m
Substrate:	Stable, vegetated deep sandy areas in strandveld and coastal fynbos
Taxonomy:	The west coast and south coast populations of this species are assigned to different subspecies based on inconsistent differences in colour pattern. These populations require comparisons of calls and DNA sequence analysis to determine whether these should be retained within a single species.
Fishes:	This is a terrestrial breeding, direct developing species
Impacts:	None
Comments:	This species is likely to occur more extensively in the south-western part of the study area

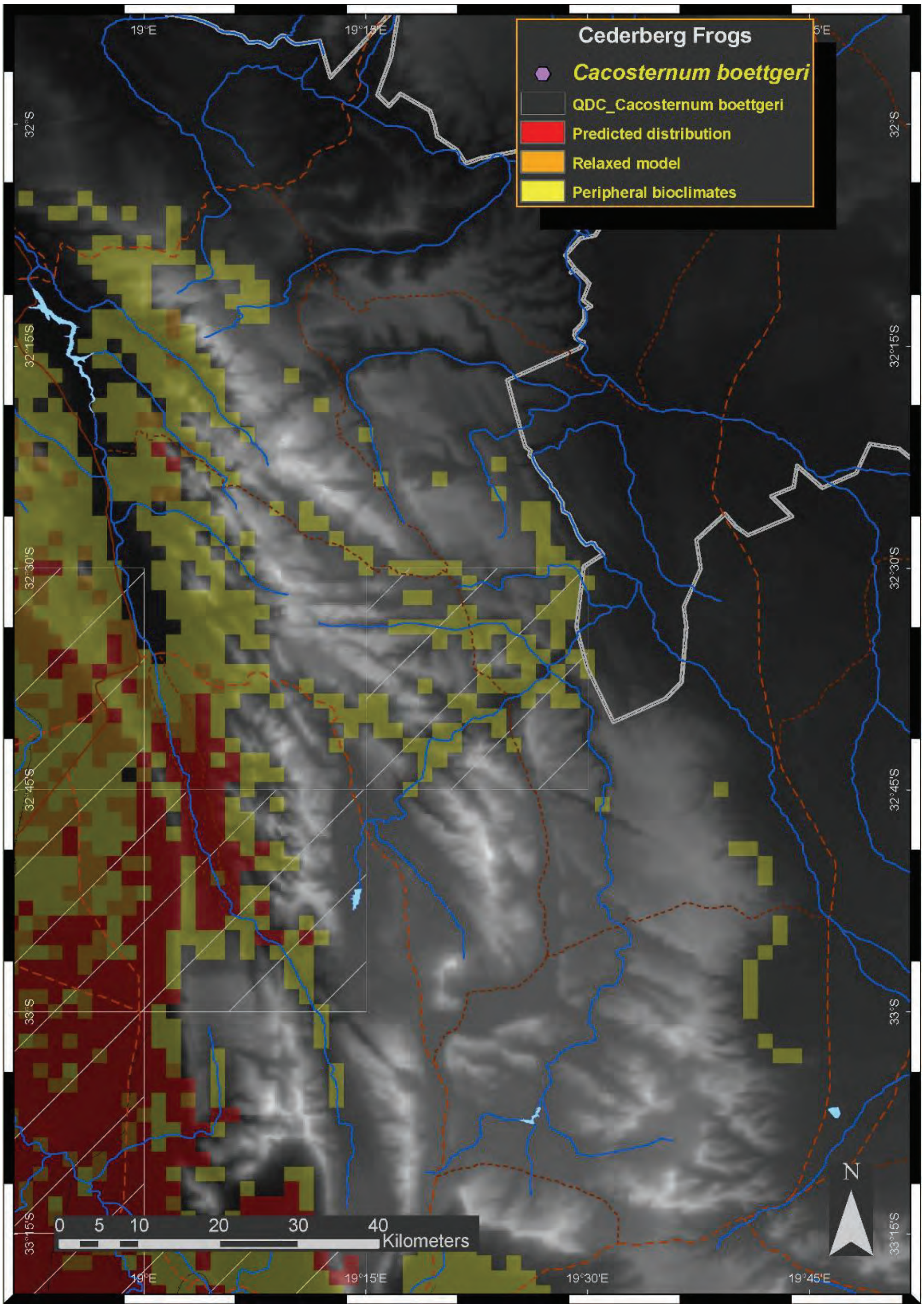

Fig. 10.17. Observed and predicted distribution of the Flat Caco, *Cacosternum platys* (as *Cacosternum boettgeri*) in the Cederberg. This is one of the most abundant vertebrate species in the Western Cape but occurs sparsely around the central Cederberg. The model is based on 58 locality records from across the range of this species, 5 of which are in sandveld to the southwest but none within the mapped area. This is a fair representation of the occurrence of this species in the area.

Cacosternum platys **Rose, 1950 – Flat Caco**

Total Range: From sandveld around Eendekuil south to the Cape Peninsula and east across the Agulhas plain and inland through the Little Karoo and Swartberg at least as far as Mossel Bay. The eastern limit of this species is uncertain (see taxonomy)

Range Size > 50 000 km^2 (74 QDCs)

Endemicity: Cape Floristic Region, Western Cape

Biomes: Fynbos, Succulent Karoo

Habitats: Seepages in coastal fynbos, inundated fynbos and rhenosterveld, disturbed areas, agricultural fields, vegetated seepages around drainage lines

Status: Least Concern

Records: 5 records / 5 sites within the study domain

Rarity: Uncommon in this area, although abundant where it occurs

Occurrence: Mainly in the Swartland but with an isolated occurrence around the Leeu River crossing below the Blinkberg

Range limits: Northern and northeastern range limit in the central Cederberg

Elevation: 15-88 m in this area

Substrate: Malmesbury and Bokkeveld shale

Taxonomy: The delimitation of this species with regards to *Cacosternum boettgeri* requires justification. These species are separated on call differences but there has not been any published analyses of call differences or variation within each species. There have been no published morphological comparisons and each species shows considerable variation in colouration. There is a gap in distribution between Cederberg populations and *C. boettgeri* populations to the northeast, in the upper Nama Karoo. The boundary between these species in the east is unclear. There are likely to be other distinct forms within *Cacosternum boettgeri* and a revision of this genus is long overdue. Taxonomic changes are unlikely to affect the conservation status of this species.

Fishes: This species is generally found in small seepages where there are no fishes. It may occasionally occur in shallow, vegetated stream side pools with fish (such as *Galaxias* and *Pseudobarbus* in the Verlorenvlei system)

Impacts: None, as it does not occur in the streams considered for rehabilitation and has only limited overlap in occurrence with fishes.

Comments: The distributional model matches well to the SA Frog Atlas (Minter *et al.* 2004) distribution and suggests that future surveys should look for this species in the Olifants Valley above Citrusdal and the tributary valleys between Citrusdal and Clanwilliam.

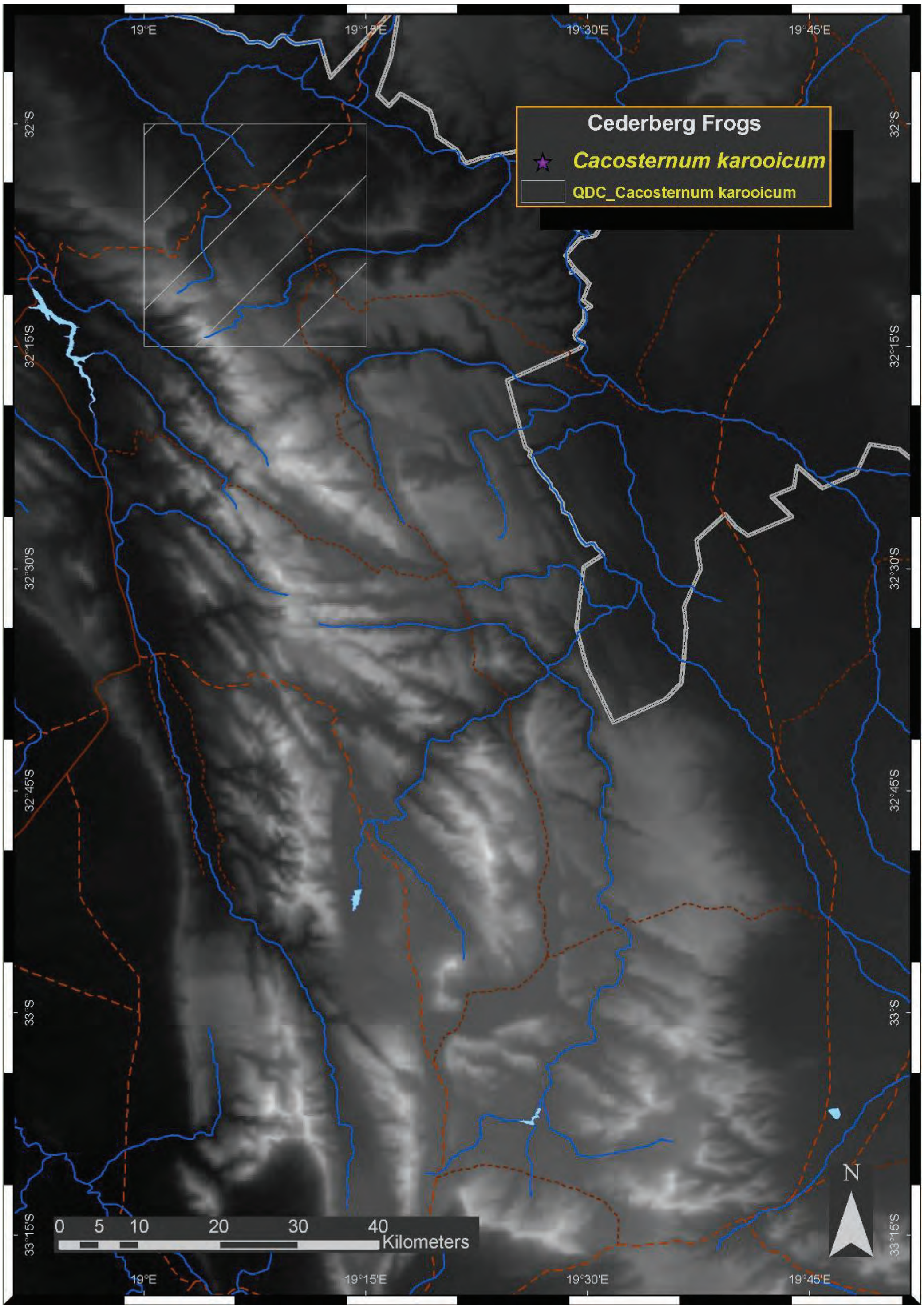

Fig. 10.18. Distribution of the Karoo Caco, *Cacosternum karooicum*, in the Cederberg. The single known location from the central Cederberg is in the Doring River Valley but this species may occur along the eastern edge of the mountains and across the Tankwa Karoo.

***Cacosternum karooicum* Boycott, De Villiers & Scott, 2002 – Karoo Caco**

Total Range:	From the Knersvlakte near Vanrhyns Pass south to the Doring Valley and southeast to the little Karoo around Robertson and around the Karoo escarpment, including the Komsberg and Nuweveldberg, to Beaufort West. Range Size > 7 500 km^2 (7 QDCs, although this species is likely to occur elsewhere within this range)
Endemicity:	Near endemic to the Western Cape, occurring just over the border with the Northern Cape
Biomes:	Succulent Karoo, Nama Karoo
Habitats:	Intermittent stream lines on shale in arid areas at the base of escarpment mountains
Status:	Least Concern

Records:	0 records / 0 sites within the study domain
Rarity:	Rare within the greater Cederberg and peripheral to the study area
Occurrence:	The two records within the Greater Cederberg are from the Knersvlakte and the Doring River valley. It was not encountered in the surveys contributing data to this project.
Range limits:	Its northern and western limits are within the Greater Cederberg
Elevation:	± 250 m within the study area
Substrate:	Karoo and Bokkeveld shales
Taxonomy:	This species was diagnosed from *C. namaquensis* on slight differences in calls and habitat preferences. These species overlap in distribution, however, and occur in the same area around Vanrhyns Pass. Better information on the distribution and habitat preferences of these species in that area would improve their identification.
Fishes:	This species is a temporary pool breeder and does not co-occur with endangered fishes
Impacts:	None
Comments:	Surveys in the northeast of the Greater Cederberg are needed to fill the large gaps between the few known populations of this species.

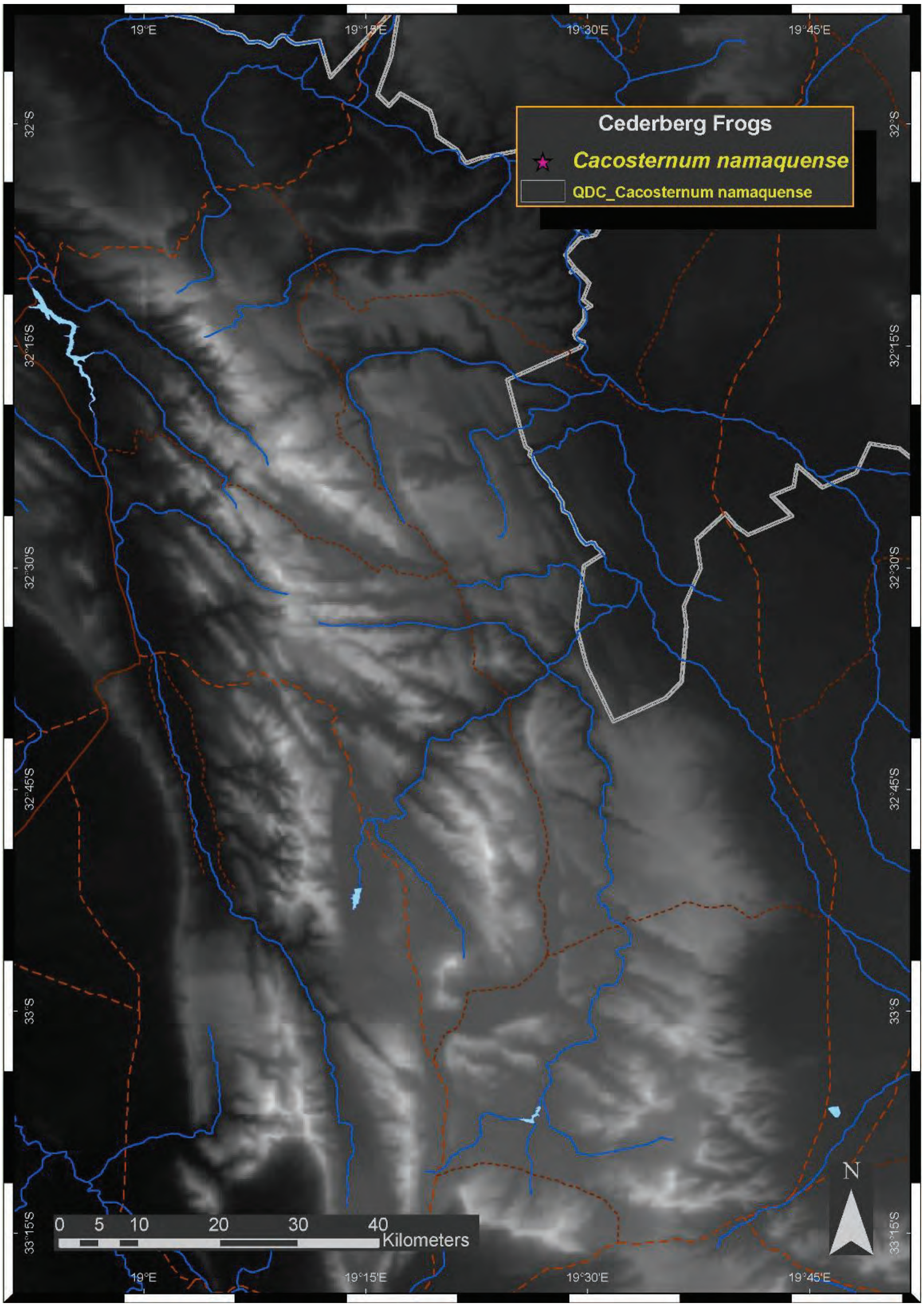

Fig. 10.19. Distribution of the Namaqua Caco, *Cacosternum namaquense*, in the Cederberg. There are no known sites for this species in the central Cederberg, with the closest sites being on the northern periphery of the region around Vanrhyns Pass.

***Cacosternum namaquense* Werner, 1910 – Namaqua Caco**

Total Range: From the southeastern Knersvlakte, at the base of the Bokkeveld escarpment, north through Namaqualand to the Richtersveld, including just over the Orange River into Namibia and east to the Hantam Karoo and Boesmanland around Pofadder.

Endemicity: Namaqualand, Succulent Karoo (including extreme southern Namibia)

Biomes: Succulent Karoo

Habitats: Around ephemeral pools, stream lines and seepages on granite koppies and shale, also breeds in man-made ponds and dams (Scott pp. 230-231 in Minter *et al.* 2004)

Status: Least Concern

Records: 0 records / 0 sites within the study domain

Rarity: Rare and peripheral in this area.

Occurrence: It is not known to occur in the central Cederberg but does occur just to the north in the Knersvlakte

Range limits: Reaches a southern limit just south of Vanrhyns Pass

Elevation: < 250 m here

Substrate: Bokkeveld shale, granite

Taxonomy: The relationship of this species to *C. karooicum* requires further investigation, including DNA sequencing.

Fishes: This species does not co-occur with endangered fishes

Impacts: None

Comments: Further visits to the poorly surveyed northeastern area, around the western side of the Gifberg and Oorlogskloof could discover additional populations of this species.

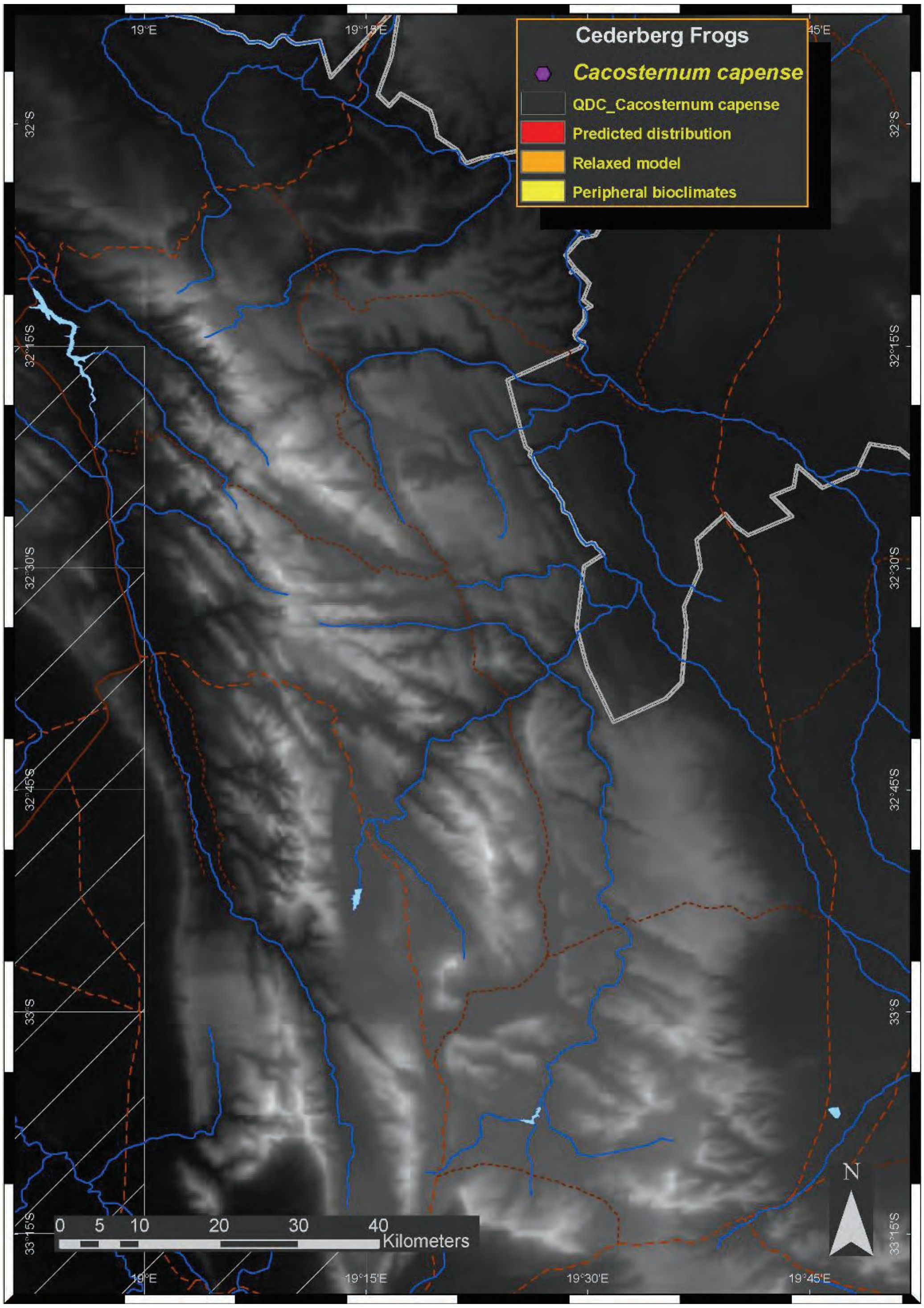

Fig. 10.20. Distribution of the Cape Caco, *Cacosternum capense*, in the central Cederberg. This species occurs peripherally in lowland areas to the west. The distributional model for this species was based on 12 localities, including 4 records from around Malmesbury, Darling and Morreesburg. This model did not include sites from the northern third of the distribution and failed to predict any sites within the mapped area.

***Cacosternum capense* Hewitt, 1925 – Cape Caco**

Total Range:	From Graafwater south to the northern suburbs of Cape Town and east to Somerset West and Worcester around the base of the mountains
Endemicity:	South-western Cape within the Cape Floristic Region and Western Cape Province
Biomes:	Fynbos
Habitats:	Inundated areas and temporary pools in areas with poorly drained clay soils, including modified areas such as ploughed paddocks, especially in rhenosterveld vegetation
Status:	Near Threatened

Records:	4 records / 4 sites within the study domain
Rarity:	Uncommon to Rare
Occurrence:	In rhenosterveld patches around Eendekuil, Graafwater and in the lower Olifants valley
Range limits:	Reaches its northern limit at Graafwater and does not extend east of here
Elevation:	58-126 m
Substrate:	Clay soils from Malmesbury shales
Taxonomy:	A well resolved species, although similar to *C. namaquense*.
Fishes:	Generally breeds in ephemeral pools and does not occur with fishes
Impacts:	None
Comments:	The known distribution of this species has increased significantly in recent years due to increased search effort. Most of this increase has been through discovery of new sites in this area (De Villiers pp. 224-227 in Minter *et al.* 2004). It is likely that additional sites will be found around the lower Olifants valley and further.

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11. DEVELOPING A CONSERVATION ACTIONPLAN FOR AUSTROGLANIS ROCK CATFISH AND TWEE RIVER REDFIN IN THE OLIFANTS-DORING RIVER SYSTEM

DEAN IMPSON[1] & ROGER BILLS[2]

[1]SCIENTIFIC SERVICES, CAPENATURE, PRIVATE BAG X5014, STELLENBOSCH 7600. (E-MAIL: dimpson@capenature.co.za)

[2]SOUTH AFRICAN INSTITUTE FOR AQUATIC BIODIVERSITY (SAIAB), PRIVATE BAG 1015, GRAHAMSTOWN 6140. (E-MAIL: r.bills@saiab.ac.za)

Introduction

The Olifants-Doring River System (ODRS) is a notable hotspot for conserving threatened endemic freshwater fishes (Skelton *et al*. 1995) and is arguably South Africa's most important river for freshwater fish conservation. It has long been a conservation priority of the then Cape Department of Nature and Environmental Conservation (van Rensburg 1966; Gaigher 1973; Scott 1982) and now CapeNature (Impson *et al*. 2002), the provincial conservation agency of the Western Cape Province. The Northern Cape Department of Nature and Environmental Conservation has identified the Oorlogskloof-Kobee River, with its large populations of Critically Endangered Clanwilliam sandfish (*Labeo seeberi* Gilchrist & Thompson 1911*)* and Endangered Clanwilliam sawfin (*Barbus serra* Peters 1864*)*, as a priority for fish monitoring work and has conducted two intensive surveys of the system since 1998 (Abie Abrahams pers. comm.).

The importance of the system for biodiversity conservation is acknowledged in existing protected area networks, private conservation initiatives, and conservation planning at both the national and regional scale. The ODRS has been allocated several National Freshwater Ecosystem Protected Areas (NFEPA) and includes several fish Critical Biodiversity Areas (CBAs)

This chapter describes the effectiveness of existing conservation initiatives in conserving *Austroglanis* rock catfish and the Twee River redfin in the ODRS, and highlights actions still necessary to more effectively conserve these highly threatened species and associated indigenous aquatic biota.

National and regional conservation planning

Conservation planning is now a priority conservation objective in South Africa. The Cape Floristic Region (CFR), which makes up nearly half of the terrestrial landscape of the ODRS, was the focal area of South Africa's first proper landscape level conservation planning process, the Cape Action Plan for the Environment (CAPE), which later evolved into Cape Action for People and the Environment (CAPE) to acknowledge societies role in conservation and the need for implementation projects to encourage "conservation on the ground" (Ashwell *et al*. 2006).

Part of the initial CAPE plan was an aquatic assessment of conservation priorities (van Niewenhuizen & Day 2000), which included a fish component (Impson *et al*. 1999). The latter was the first attempt to identify priority areas for freshwater fish conservation in the CFR. Not surprisingly, the river system with the majority of priority fish areas was the ODRS with 14. An important aspect of CAPE was the identification of “mega-reserves”, such as the Greater Cederberg Biodiversity Corridor (Figure 11.1) launched by CapeNature in 2004. A key goal of these areas is that they be large enough to sustain biodiversity patterns and processes in the CFR, even in the face of global climate change (Ashwell *et al*. 2006). These Corridors hence are sizeable enough to include several large CapeNature reserves.

Later, to more effectively manage water resources in the Olifants-Doring Water Management Area, preferably away from areas of high biodiversity value, the CSIR and partner organizations developed an aquatic conservation plan for this area (Nel *et al*. 2006). This plan identified priority aquatic areas based on river type, river condition, special features and threatened endemic biota and also recommended conservation actions to better conserve priority areas and species.

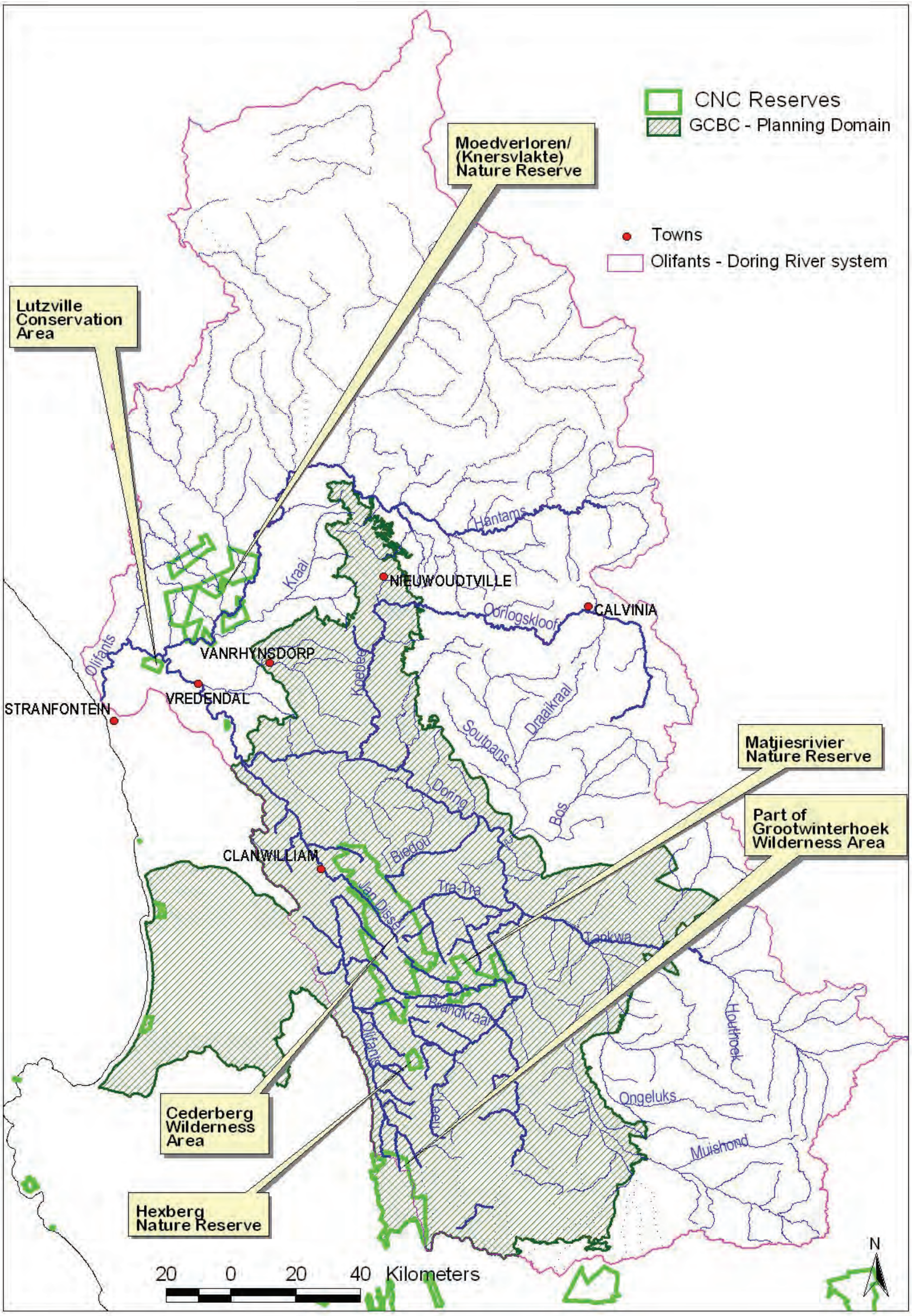

Figure 11.1: Location of the Greater Cederberg Biodiversity Corridor (GCBC) and CapeNature reserves in the Olifants-Doring River System (map Riki de Villiers).

The international recognition of the CAPE programme, and the advent of the National Environmental Management: Protected Areas (NEM:PAA) Act 57 of 2003 lead to a national focus on conservation planning, culminating from a freshwater perspective in the identification of NFEPA's as well as national CBA's for freshwater fish (Nel *et al*. in press [a,b]). The location of NFEPA's (which include fish CBA's) in the ODRS, which included most of the areas proposed by Nel *et al*. (2006) are shown in Figure 11.2. It is encouraging to note that all priority populations of *A. barnardi*, *A. gilli* and *B. erubescens* have been included in this nationally recognised map.

Included in the NFEPA initiative are priority river areas for rehabilitation, focusing on control programmes for invasive alien fishes (Figure 11.2). Most of NFEPA / CBA rehabilitation areas are in the CFR because of the severity of alien fish invasions here and the high numbers of threatened endemic fishes present.

Formally Protected Areas

It is good for conservation that a substantial portion of Fish CBAs in the ODRS are included in the formal nature reserves, notably Cederberg, Groot Winterhoek, Matjies River and Oorlogskloof Nature Reserves (Figure 11.2). In nature reserves, we do not expect to observe other impacts on rivers (e.g. weirs, dams, bulldozing, pollution, excessive abstraction), which are often so noticeable in privately owned areas. Rivers arising and flowing through protected areas should therefore have good to excellent habitat and water quality for aquatic species. The only major threats to rivers in such areas are invasive alien fishes and plants which can move freely across reserve boundaries. It is fortunately easier to eradicate alien species from nature reserves than private land, as there is usually one land-owner (the state) and it is a legal requirement in terms of Section 21 of the National Environmental Management Act 107 of 1998 to reduce or eliminate the threat of invasive alien species in such areas.

If one examines the formal reserve network and current distribution of rock catfish and Twee River redfin, then only *Austroglanis gilli* appears to be reasonably well conserved of the three species (Figure 11.3).

Associated protected areas and conservation initiatives

The ODRS has a number of other protected areas and conservation initiatives of relevance to a conservation plan for the three fish species. Because of the rugged natural splendor and biodiversity richness of the area, there is a strong focus on eco-tourism and obvious land-owner conservation awareness. This has lead to the formation of several active conservancies (Figure 11.4)

From the perspective of this study, the most significant action has been the identification and promotion of the Greater Cederberg Aquatic Corridor (Figure 11.5), thanks to substantial funding from the Table Mountain Fund. CapeNature's aim is secure this corridor as a Protected Area under the NEM:PAA, which will link the upper Olifants River from the Olifants gorge, through to the Noordhoeks River and across to the Twee River (Figure 11.5). The future establishment of this area will secure most of the prime rivers for the conservation of the three species.

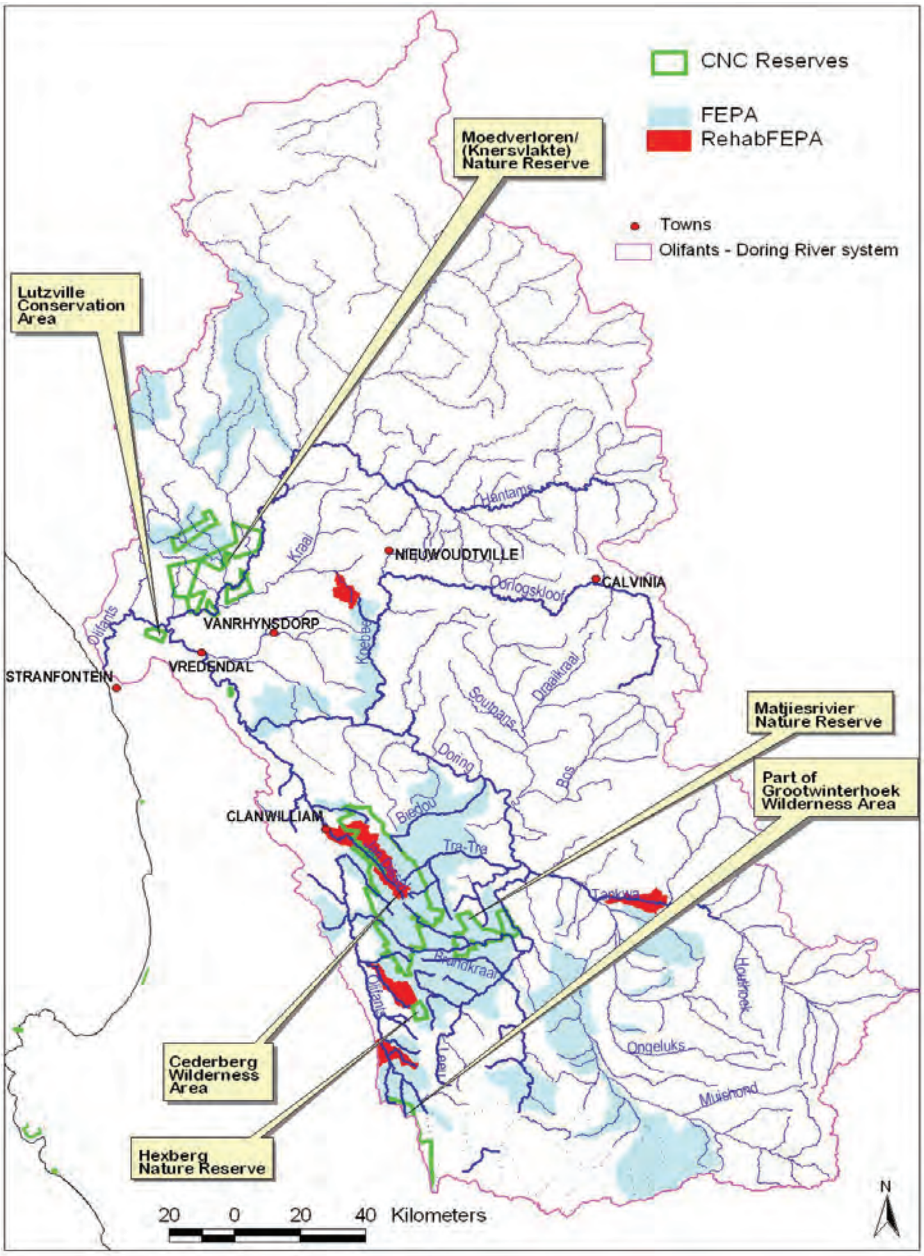

Figure 11.2: Location of National Freshwater Ecosystem Priority Areas and CapeNature reserves in the Olifants-Doring River system.

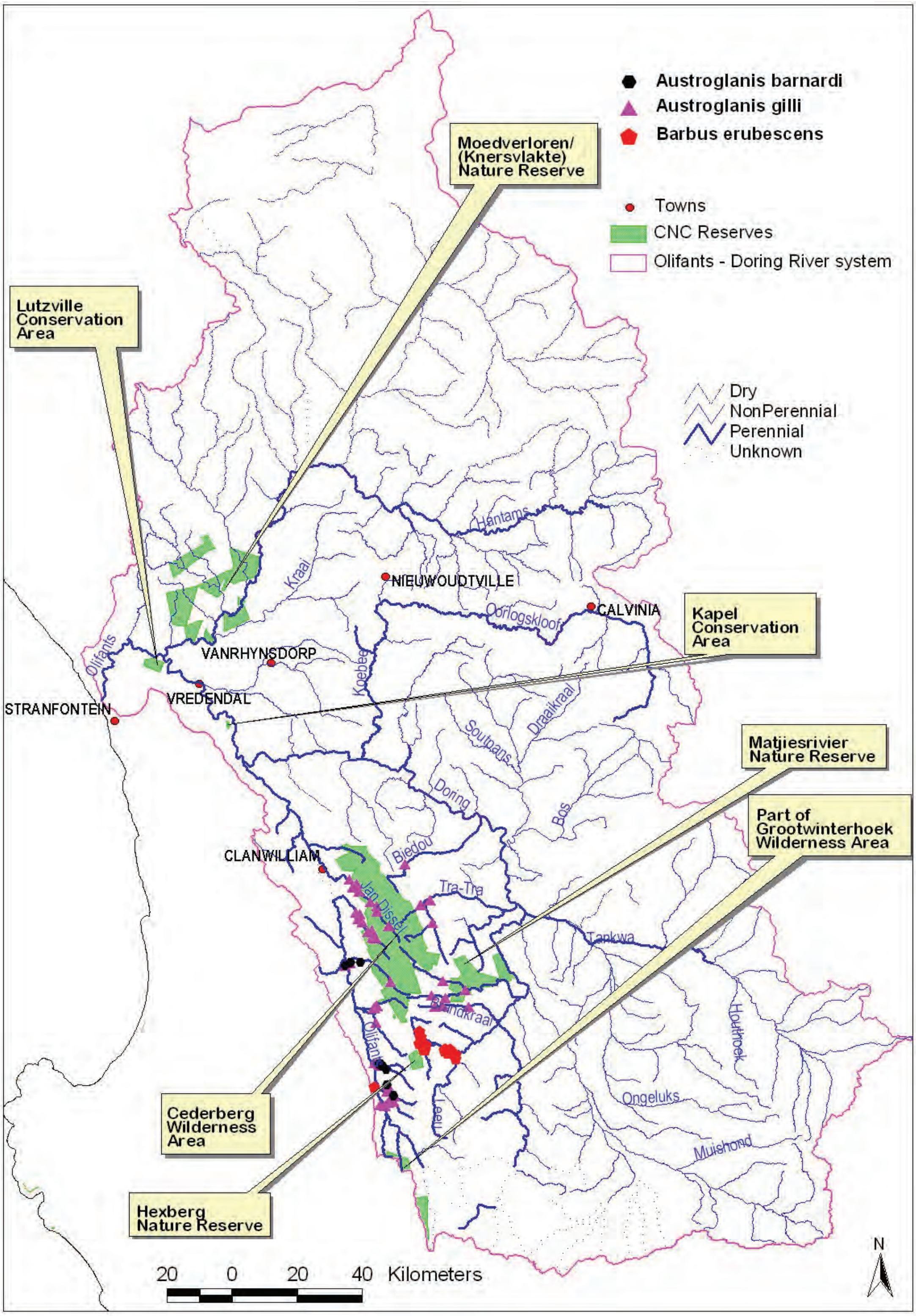

Figure 11.3: Distribution records for *Austroglanis barnardi, A. gilli* and *Barbus erubescens* in relation to CapeNature reserves. Only *A. gilli* appears to be well conserved.

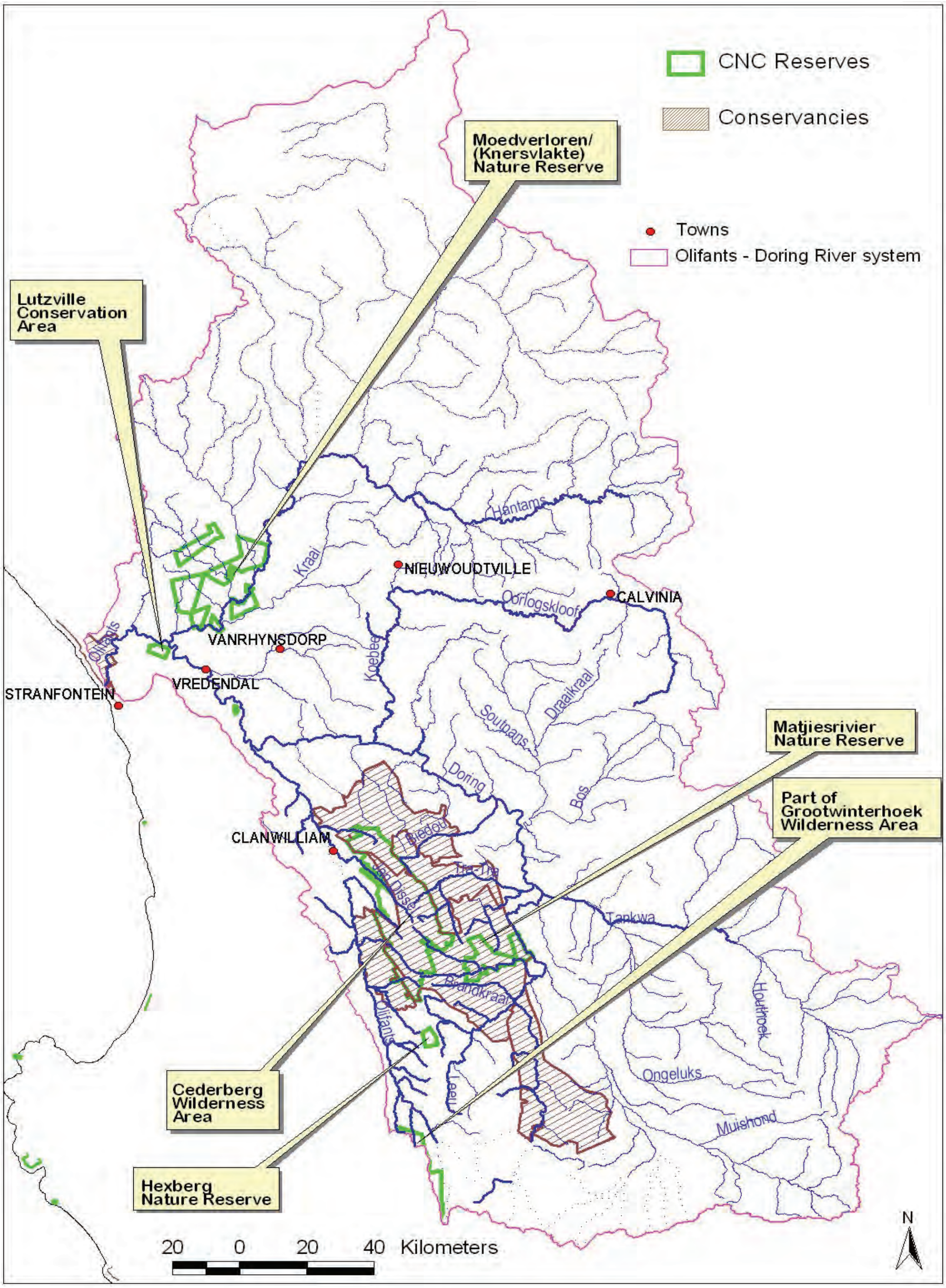

Figure 11.4: Location of five conservancies and CapeNature reserves in the Olifants-Doring River system. Most conservancies are located in or alongside the mountainous Cederberg region.

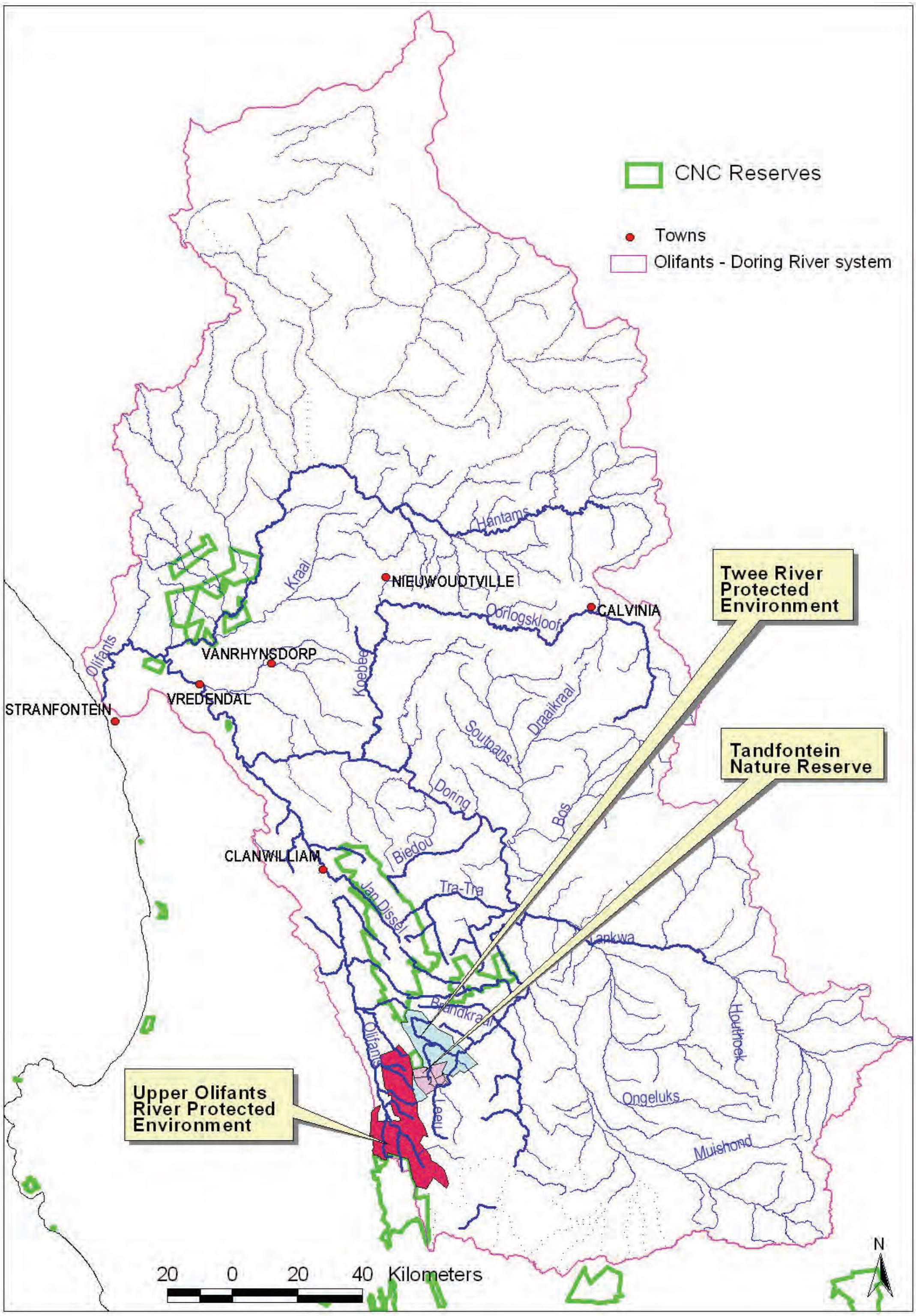

Figure 11.5: Location of the Greater Cederberg Aquatic Corridor and proposed Protected Environment and Tandfontein stewardship site in the Olifants-Doring River System

Invasive alien species affecting rivers of the ODRS

Most rivers, especially the mainstems (Olifants and Doring rivers), of the ODRS are unfortunately not pristine, with the biggest impact being that of invasive alien fish species. Rivers in several protected areas have also been invaded. Impson (this report, Study Areas chapter) describes that several invasive alien fish species have been in the system, including protected areas, for over 50 years with severe impacts on aquatic biota. Woodford et al. (2005) confirmed that where smallmouth bass are found, small indigenous fishes and juveniles of the large species are usually absent. The only exception to this rule are both rock catfish species which co-exist with bass, often in high numbers, probably because of their morphology (dorsal and pectoral spines make them difficult for bass to eat) and behaviour (hiding under rocks during day, active at night when bass sleep).

Invasive plants are a problem in the riparian zones of several rivers, including rivers containing the three focal species such as the lower Jan Dissels River, middle and lower Rondegat River, middle Krom River and middle Breekkrans River.

The impacts of invasive alien plants and fishes are fortunately receiving urgent national attention through Regulations currently being developed for alien species under the National Environmental Management: Biodiversity Act of 2004 as well as the national Working for Water programme. This programme has been very active in parts of the ODRS, especially the Olifants mainstem, since 2000. Working for Water spent R8.5 Million on alien plant clearing in the Olifants River and its tributaries above Clanwilliam in 2010/2011 and have budgeted R5.3 million for clearing and follow-up for the 2011/2012 financial year (Cobus Smit, WfW, pers. comm.)

CapeNature has developed a river rehabilitation project involving alien fish eradication in four priority fynbos rivers that includes the use of piscicides containing rotenone (Impson 2007; Tweddle 2009) One of the key aims of the project is to eradicate alien fishes from designated parts of the four rivers to allow highly threatened indigenous fishes to reclaim habitat in their natural distribution ranges. By increasing the distribution ranges and population numbers of threatened species through such measures, conservation authorities should be able to down-list the conservation status of the affected species. The project has been subjected to a comprehensive EIA (Tweddle 2009) and CapeNature intends treating the Rondegat River in February 2012. This will be the first project of its kind on a river in South Africa.

Priority Actions to improve conservation status of the three species.

Twee River Redfin (Barbus erubescens Skelton 1974)

Bills (this report) describes what we know about the conservation biology of *B. erubescens*. In Skelton (1974, 1987), Marriott (1984), Impson *et al*. (2007) and Marr *et al.* (2009), recommendations are provided to more effectively conserve the Twee catchment and its two endemic fishes, which includes the Twee River Galaxias. In summary, these recommendations embrace four aims: secure key remaining sub-populations, rehabilitate the invaded parts of the system starting at the Suurvlei River, get farmers to improve farming practices especially in the riparian zone and establish a conservancy in the river. We have identified the following key objectives to more effectively conserve *B. erubescens* within its natural distribution range in the Twee catchment.

<u>Key objectives</u>

1. Develop guiding management document

- CapeNature must take responsibility with partner organizations to use the information in this report as the basis for developing a BMP-S for *B. erubescens* by 2012. This will provide a framework for conservation action by all relevant stakeholders for this Critically Endangered species.

2. Research and Monitoring

- CapeNature and SAIAB to identify monitoring sites on Heks, Middeldeur, Suurvlei and Twee rivers, as well as stocked dams that are monitored by CapeNature for three days each summer.
- At each site, take fixed point photos, sample fish using over-night fyke nets, undertake SASS and IHAS, and take water quality measurements (pH, conductivity, water temperature, phosphates, nitrates, TDS, DO).
- Determine effect of agro-chemicals on fish and aquatic inverts in Twee System.
- Determine response of aquatic biota to rotenone use, when the Twee River rehabilitation project, involving alien fish eradication is implemented.
- CapeNature to compile report every five years on status of Twee river redfin and Twee Galaxias.

3. Establish stewardship agreements with key land-owners

- Determine key riparian landowners and contact details in 2011.
- CapeNature is negotiating a stewardship agreement with the land-owner of Tandfontein farm, which includes a substantial part of the upper Middeldeurs River. Once declared, a management plan for the property must be drawn up.
- CapeNature has identified the entire Twee catchment as a Protected Environment under the PAA. From 2011, CapeNature will enter into stewardship agreements with key land-

owners to more effectively conserve terrestrial and aquatic environments in the Twee River valley.

- Establish a forum for land-owners within the Protected Area and hold regular meetings (quarterly to twice yearly), with CapeNature support.

Plate 11.1: Male Twee River redfin and typical bedrock dominated habitat for the species in summer in a tributary (Tentskloof stream) in the Twee River catchment, Cederberg.

4. Rehabilitate dams to serve as refuges for the two fish species

- As part of BMP-S determine which dams have alien fishes.
- As part of BMP-S eradicate all alien fishes from the Twee catchment using rotenone with support of land owners.
- Identify dams ecologically suitable to serve as fish refuges.
- Determine stocking requirements (no. fish, source of fish, repeat stockings).
- Introduce the two indigenous fishes into suitable dams with support of land-owners.

5. Rehabilitate river areas in a phased approach

- The focus will be on alien fish eradication, alien plant eradication from riparian zones, and rehabilitation of the riparian zone which includes a suitable buffer area (10 m on Suurvlei, 35 m on all other rivers) in which no development is allowed (especially in the Suurvlei River).
- Alien fish eradication will focus on bluegill sunfish (*Lepomis macrochirus*), Clanwilliam yellowfish (*Labeobarbus capensis*) and Cape kurper (*Sandelia capensis*) with valuable yellowfish to be relocated to suitable dams outside this catchment but within their natural distribution range under permit. The Western Cape Yellowfish Working Group can assist with these relocations.
- Use the Environmental Management Plan of the EIA for the CAPE River rehabilitation project to guide initial alien fish eradication projects on the Suurvlei River.

6. Awareness and education

- Improve awareness of fish conservation issues in the Twee River valley.
- CapeNature and partner organizations to give presentations during the development of BMP-S and to conservancy partners.
- Develop posters and pamphlets in English and Afrikaans by 2012.
- Develop signage at appropriate points on the river by 2013.

7. Improve Farming Practices

- Get riparian farmers by 2013 to maintain or establish a 10 m buffer along smaller rivers (e.g. Suurvlei) and 35 m along bigger rivers (e.g. Twee).
- Get farmers to use approved pesticides according to best practice, and reduce or stop pesticide use within 35 m of rivers. Organic agriculture should be encouraged.
- Farmers are required by CARA to clear invasive alien vegetation from riparian zones and within their properties. This must be enforced by 2015, if land-owners are not willing to comply.
- Determine, with DWA assistance, a minimum dry season (October to March) base flow by 2015 for the Suurvlei, Middeldeur and Twee rivers, which must remain in the river at this time.
- Install a gauging station in the middle Twee River above the first waterfall by 2015 to ensure compliance.

- Through DWA, ensure compulsory water use licensing in the river by 2013.

Spotted rock catfish (Austroglanis barnardi Skelton 1981)

Bills (this report) and Bills (1999) describe what is known about the conservation biology of *A. barnardi* which is restricted to three rivers in the ODRS. With its small natural distribution area and specific habitat requirements, it is essential to conserve / secure all remaining habitat as effectively as possible. The focal area for conservation action is thus the Hex, Noordhoeks and Thee rivers, whilst trying to improve connectivity between the three rivers through an ecologically healthier middle Olifants River. We have identified the following key objectives to more effectively conserve *A. barnardi* within its natural distribution range in these three rivers.

Key objectives

1. Develop guiding management document

- CapeNature must take responsibility with partner organizations to use the information in this report as the basis for developing a BMP-S for *A. barnardi* by 2013. This will provide a framework for conservation action by all relevant stakeholders for this Endangered species.

2. Research and Monitoring

- CapeNature and SAIAB to identify monitoring sites on Hex, Noordhoeks and Thee rivers that are monitored by CapeNature for three days each summer.
- At each site, take fixed point photos, sample fish using electro-shocker, undertake SASS and IHAS, and take water quality measurements (Ph, conductivity, water temperature, phosphates, nitrates, TDS, DO).
- Detailed surveys of these three rivers are required to locate upper fish limits and estimate population sizes.
- Determine biology and ecology of *A. barnardi* in relation to *A. gilli*
- Determine whether the current manual control project (using shockers, gill nets, spearfishing) to eradicate spotted bass from the Thee River has been a success.
- The response of aquatic biota to rotenone use must be monitored if the project to eradicate smallmouth bass from the Hex River is implemented (next 10-20 years).
- CapeNature to compile report every five years on status of *A. barnardi*.

3. Establish stewardship agreements with key land-owners

- Determine key landowners and their contact details in 2011.
- CapeNature has identified the Thee and Noordhoeks catchments as a part of a wider Protected Environment under the NEM:PAA. From 2011, CapeNature will enter into stewardship agreements with key land-owners to more effectively conserve terrestrial and aquatic environments in these two catchments.

- CapeNature should enter into a stewardship agreement with the land-owner of Hex River as soon as possible.
- Establish forum for land-owners within Protected Area and hold regular meetings (quarterly to twice yearly), with CapeNature support.

4. Rehabilitate river areas in a phased approach

- Working for Wetlands (W. Cape region) have authorized the building of a barrier structure on the Noodhoeks River just upstream of the road bridge to keep invasive alien fishes out of the highly sensitive middle and upper reaches of this river. Once this is done manual removal (using nets) of the small banded tilapia (*Tilapia sparrmanii*) population that exists upstream of the barrier can be considered.
- CapeNature and partner organizations (UCT Freshwater Research Unit, Craig Garrow), through the Greater Cederberg Aquatic Corridor project are currently removing spotted bass (*Micropterus punctulatus*) from the Thee River using manual methods. The methods involve the use of temporary gabion barriers to isolate invading bass and preventing further upstream invasion. Bass are then subsequently removed using nets and electro-shockers. The success of this method, which has a poor track record of achieving 100% eradication elsewhere, needs to be quantified by a thorough survey of the invaded area by 2012.
- CapeNature has a long-term aim of rehabilitating the Hex River, but piscicide use to eradicate the widely spread smallmouth bass population will have to be carefully considered because of the high numbers of *A. barnardi* in the invaded area. This project cannot be implemented unless it is seen as a priority action in the BMP-S for *A. barnardi*. The project also requires a barrier weir to be built just upstream of the farmers water off-take point, to prevent re-invasion of bass from the nearby Olifants River.
- The three rivers with *A. barnardi* fortunately have a low incidence of invasive alien plants in their catchments and riparian zones. Riparian land-owners must take responsibility to remove category 1 and 2 plants on their properties (especially from the riparian zone).

5. Awareness and education

- Improve awareness of fish conservation issues in Hex, Noordhoeks and Thee valleys. This process has already started thanks to the dedicated TMF project and the appointment of an aquatic conservator in 2010.
- CapeNature and partner organizations to give presentations during development of BMP-S and to conservancy.
- Develop posters and pamphlets in English and Afrikaans during the BMP-S.
- Develop signage at appropriate points on the river after approval of the BMP-S.

Plate 11.2: Spotted rock catfish and typical riffle dominated habitat for the species in summer in the Hex River, Cederberg.

6. Improve land-use practices

- The three rivers are fortunately un-impacted by agriculture above key abstraction points on each river. The prime reason for this is that each river flows through a narrow valley that is unsuitable for commercial scale agriculture.
- It is essential that no agriculture or resort development be allowed above these water off-take points. This needs to be secured in stewardship agreements with the key landowners.

- Each of the three rivers has off-stream dams in their lower catchments. These dams all have alien fishes and some indigenous fishes. The BMP-S should investigate the eradication of alien fishes from the dams, and then stocking them with local indigenous fishes to enable them to act as refuges for these fishes.
- Some indigenous fishes are still found in the lower reaches of each river, especially in Spring when flows are still below off-take points. In particular, the Noordhoeks River has a good *Austroglanis* habitat in its lower reaches and good numbers of rock catfish when flow is acceptable. Consideration should be given to allowing at least 50% of summer base flow to pass over key abstraction points to sustain downstream environments.
- There should be a minimum 35 m no development buffer strip along each river bank in the agricultural areas.
- Get farmers to use approved pesticides according to best practice, and reduce or stop pesticide use within 35 m of rivers. Organic agriculture should be encouraged.
- Through DWA, ensure compulsory water use licensing in each river by 2015.

Clanwilliam rock catfish (Austroglanis gilli Barnard 1943)

Bills (this report) and Bills (1999) describe what is known about the conservation biology of *A. gilli*. *Austroglanis gilli* is known from at least 16 tributary streams in the Olifants River system draining both eastwards towards the Doring River and westwards towards the Olifants River. Anecdotal reports indicate that this species, prior to introduction of alien fishes and commercial farming in the system, was far more widespread and likely found in good numbers in both main-stems which allowed tributary populations to genetically connect with each other. The rivers with the strongest populations on the Olifants catchment are the Boskloof, Jan Dissels, Noordhoeks, Oudste, Rondegat and Thee, whereas on the Doring catchment they are the Breekkrans and Krom-Maatjies. It is likely that any historical connection between the Olifants and Doring populations will never be naturally restored because of anthropogenic impacts including dam walls. We have identified the following key objectives to more effectively conserve *A. gilli* within its natural distribution range.

<u>Key objectives</u>

1. Develop guiding management document

- CapeNature must take responsibility with partner organizations to use the information in this report as the basis for developing a BMP-S for *A. gilli* by 2014. This will provide a framework for conservation action by all relevant stakeholders for this Vulnerable species.

2. Research and Monitoring

- CapeNature and SAIAB to identify monitoring sites on priority rivers that are monitored by CapeNature in a dedicated survey every three years.
    - Upper & middle Heks River north of Citrusdal
    - Upper Noordhoeks
    - Lower end of Dwars River (upper Olifants tributary)

- o Diepkloof (upper Olifants tributary)
- o Lower Matjies valley
- o Oorlogskloof River
- o Main-stem sites – Olifants River at various points (e.g. below Canwilliam Dam, below Bullshoek Dam, below Doring confluence, Doring river below Matjies confluence

- At each site, take fixed point photos, sample fish using electro-shocker, undertake SASS and IHAS, and take water quality measurements (Ph, conductivity, water temperature, phosphates, nitrates, TDS, DO).
- Detailed surveys of these rivers are required to locate upper fish limits and assess population sizes.
- Determine the biology and ecology of *A. gilli* in relation to *A. barnardi*.
- Determine whether the current manual control project (using shockers, gill nets, spear-fishing) to eradicate spotted bass from the Thee River has been a success.
- Monitor the response of aquatic biota to rotenone use, when the project to eradicate smallmouth bass from Rondegat Project (scheduled for 2012) using rotenone is implemented. Monitor the response of aquatic biota in other rivers with *A. gilli* that are earmarked for rehabilitation (e.g. Krom River) if treated with piscicides.
- CapeNature to compile report every 10 years on status of *A. gilli*.

3. Establish stewardship agreements with key land-owners

- Determine key landowners and their contact details in 2011.
- CapeNature has identified the Dwars, Oudste, Ratels, Noordhoeks and Thee catchments as a part of a wider Protected Environment under the PAA. From 2011, CapeNature will enter into stewardship agreements with key land-owners to more effectively conserve terrestrial and aquatic environments in these two catchments.
- CapeNature should enter into stewardship agreements with key land-owners on the Breekkrans, Jan Dissels and Krom rivers as soon as possible.
- Establish a forum for land-owners within Protected Area and hold regular meetings (quarterly to twice yearly), with CapeNature support.
- Use existing conservancies to improve land-owner awareness of *A. gilli* and associated fish species.

4. Rehabilitate river areas in a phased approach

- Working for Wetlands (W. Cape region) have authorized the building of a barrier structure on the Noodhoeks River just upstream of the road bridge to keep invasive alien fishes out of the highly sensitive middle and upper reaches of this river. Once this is done manual removal (using nets and electro-fishing) of the small banded tilapia population that exists upstream of the barrier can be considered.
- CapeNature and partner organizations (UCT Freshwater Research Unit, Craig Garrow), through the Greater Cederberg Aquatic Corridor project are currently removing spotted

bass from the Thee River using manual methods. The methods involve the use of temporary gabion barriers to isolate invading bass and preventing further upstream invasion. Bass are then subsequently removed using nets and electro-shockers.

- CapeNature has earmarked two rivers (Rondegat, Krom) with strong *A. gilli* populations for river rehabilitation involving alien fish eradication. Each eradication exercise will be managed by an already developed Environmental Management Plan, developed as part of the EIA. The lower Rondegat River will be the first river to be cleared of alien fishes using an approved piscicide. There are few *Austroglanis* in the treatment area, and long term monitoring here after treatment will determine the recovery of this species. A concern for the recovery of *A. gilli* is the level of sedimentation in the treatment section, with few fully exposed rocks outside of riffles and rapids. Successful implementation of the Rondegat project will lead to full implementation of the Krom rehabilitation project. This river has high numbers of *A. gilli* in the treatment area, and a genetically recommended number of fish will be caught prior to treatment for re-introduction after treatment.
- Several other rivers with *A. gilli* are priorities for medium to long term alien fish eradication using piscicides including the Breekkrans, Tra Tra and Eselbank rivers. Following successful completion of phase 1 of the alien fish eradication project in the fynbos biome (i.e. Rondegat, Suurvlei, Krom, Kromme rivers), CapeNature and partner organizations will develop a short, medium and long term implementation list of rivers already identified as priorities for alien fish eradication.
- Due to the uniqueness and size of the Jan Dissels River population, it is recommended that bass are physically removed with nets and electro-shockers. This will be done slowly in a phased approach, by using a gabion barrier 500 m below the upper limit for bass, clearing this stretch over a 12-24 month period and then adding another gabion barrier 500 m downstream of this.
- River rehabilitation must include alien plant control where appropriate (e.g. Rondegat River), and Working for Water and riparian land-owners must be informed which rivers are priorities for such actions. Riparian land-owners must take responsibility to remove category 1 and 2 plants on their properties (especially from the riparian zone).
- Improving other land-use practices, in particular conservation of riparian buffer strips, by riparian owners should also be an aim for conservancy agreements.

5. Awareness and education

- CapeNature is required to improve awareness of fish conservation issues in priority catchments with *A. gilli*. This process has already started in the Noordhoeks, Oudste and Thee rivers thanks to the dedicated TMF project and the appointment of the aquatic conservator in 2010.
- CapeNature and partner organizations to give presentations during development of BMP-S and to conservancy and Protected Area forums.
- Develop posters and pamphlets in English and Afrikaans during the BMP-S process.

- Develop signage at appropriate points on the river after the approval of BMP-S.

Plate 11.3: Clanwilliam rock catfish and typical riffle dominated habitat for the species in summer in the Rondegat River, Cederberg.

6. Improve land-use practices

- The three rivers are fortunately un-impacted by agriculture above key water abstraction points. The prime reason is that each river flows through a narrow valley that is unsuitable for commercial scale agriculture.

- It is essential that no agriculture or resort development be allowed above these water off-take points. This needs to be secured in stewardship agreements with the key landowners.
- Each of the three rivers has off-stream dams in their lower catchments. These dams all have alien fishes and some indigenous fishes. The BMP-S should investigate the eradication of alien fishes from the dams to enable them to act as refuges for indigenous fish species of the valley.
- Some indigenous fishes are still found in the lower reaches of each river, especially in spring when flows are still below off-take points. In particular, the Noordhoeks River has a good *Austroglanis* habitat in its lower reaches and good numbers of rock catfish when flow is acceptable. Consideration should be given to allowing at least 50% of summer base flow to pass over abstraction points to sustain downstream environments.
- There should be no development buffer strips, a minimum of 35 m, along each river in the agricultural areas.
- Get farmers to use approved pesticides according to best practice, and reduce or stop pesticide use within 35 m of rivers. Organic agriculture should be encouraged.
- Through DWA, ensure compulsory water use licensing in each river by 2015.

Capacity requirements to implement the conservation plan

Substantial resources are required to accomplish the above conservation actions. Resources refer to people and funds dedicated to these needs.

The importance of the ODRS for river conservation at a national level makes it essential that permanent scientific and technical capacity in river ecosystem management be established at CapeNature at the regional level and within the Olifants-Doring Catchment Management Agency once this is operational.

At present, CapeNature has two aquatic scientists and one aquatic technician at their Scientific Services section. These staff work across the province undertaking river and fish surveys, regulatory issues (permits), land-use comments and conservation action projects (e.g. Rondegat River rehabilitation). This is insufficient capacity to be effective at a local level. Thanks to funds from the Table Mountain Fund, a contract conservator has been appointed for a three year period from 2010 to focus on the Groot Winterhoek Aquatic Corridor.

The conservator enjoys field work, land-owner engagement and conservation action projects, and his appointment has shown what can be achieved with a motivated trained person at a local level.

It is recommended that a minimum of one scientist and one technician is appointed at CapeNature in their regional offices in Porterville that focus solely on the Olifants-Doring Water Management Area.

The Olifants-Doring Catchment Management Agency is in the process of being developed and should be fully operational by 2015. At this time, it needs to be capacitated with several staff at scientific and technical level that focus on resource protection issues. This development will greatly assist better water resource management in the WMA.

Substantial funds are needed for conservation action. The implementation of the Rondegat River rehabilitation programme, for example, will cost at least R1 million to eradicate smallmouth bass. Working for Water spent R8.5 million on alien plant clearing in the Olifants River and its tributaries above Clanwilliam in 2010/2011.

Not all river rehabilitation will cost as much. There are several priority rivers, some in conservation areas, that have barrier weirs in place and have few or no alien plants. Eradicating the alien fishes from them will cost relatively little compared to the Rondegat project.

CapeNature and partner stakeholders will need to communicate and collaborate to see how scarce funds can be most wisely spent in the ODRS. The contents of this chapter and the forthcoming BMP-S for the three species should provide an excellent guide on how best to use available capacity to better conserve the three species and their habitat.

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