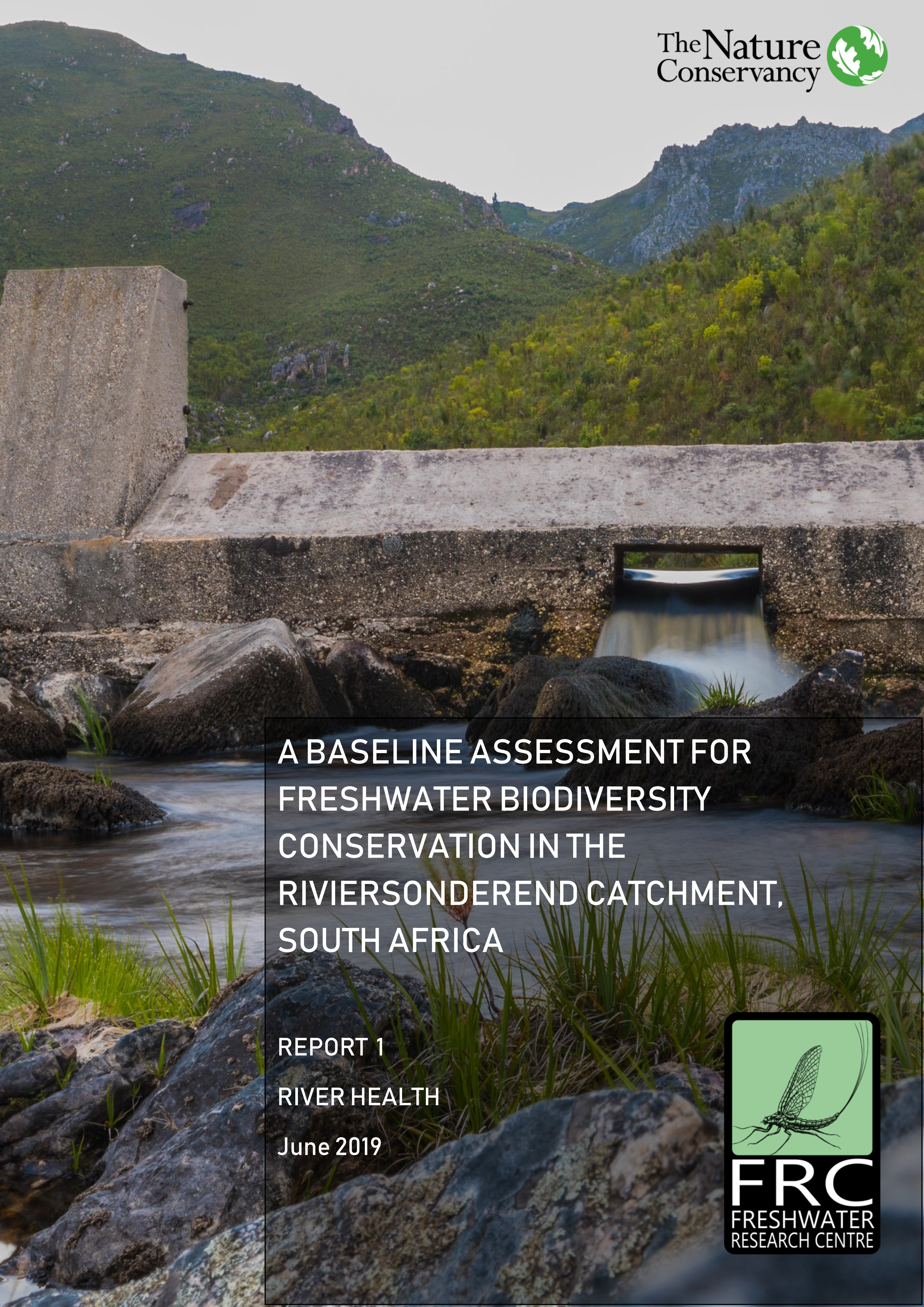

The Nature Conservancy

A BASELINE ASSESSMENT FOR FRESHWATER BIODIVERSITY CONSERVATION IN THE RIVIERSONDEREND CATCHMENT, SOUTH AFRICA

REPORT 1

RIVER HEALTH

June 2019

FRC FRESHWATER RESEARCH CENTRE

Report authors and citation

Snaddon K[1], Shelton JM[1], Frenzel P[1]. and Paxton BR[1]. 2019. *A Baseline Assessment for Freshwater Biodiversity Conservation in the Riviersonderend Catchment, South Africa. Report 1. River Health*. Prepared for The Nature Conservancy by the Freshwater Research Centre. Pp 67.

[1]Freshwater Research Centre,

A PROJECT FUNDED BY:

IN PARTNERSHIP WITH:

Acknowledgments

This study was made possible by funding from The Nature Conservancy. The FRC would also like to acknowledge the generosity of the landowners on whose farms some of the monitoring sites are located. Specifically, we would like to thank Tom Theron of Versoek Farm, Ken Kilpin of Boesmansrug, and the de Wets of Môreson Farm. Monique Ruthenberg of CapeNature also did not fail to offer her time and advice regarding work on the CapeNature reserves. FRC would like to acknowledge the groundwork and days of field work done by Christy Bragg – her ideas and passion are embedded in this project.

A baseline assessment for freshwater biodiversity conservation in the Riviersonderend catchment, South Africa

Report 1: River Health

Cape Town, South Africa

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LIST OF ACRONYMS

Acronym	Description
BGCMA	Breede-Gouritz Catchment Management Agency
CBA	Critical Biodiversity Area
CESA	Critical Ecological Support Area
CFR	Cape Floristic Region
CFE	Cape Fold Ecoregion
CoCT	City of Cape Town
CR	Critically Endangered (Threat Status)
CSIR	Council for Scientific and Industrial Research
DAFF	South African Department of Agriculture, Forestry and Fisheries
DEA	South African Department of Environmental Affairs
DEADP	Western Cape Department of Environmental Affairs and Development Planning
DRDLR	South African Department of Rural Development and Land Reform
DWS	South African Department of Water and Sanitation
E-Flows	Environmental Flows
EA	Environmental Authorisation
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EIS	Ecological Importance and Sensitivity
EMF	Environmental Management Framework
EMPr	Environmental Management Programme
EN	Endangered (Threat Status)
ESA	Ecological Support Area
EWR	Ecological Water Requirements
FEPA	Freshwater Ecosystem Priority Area
FRC	Freshwater Research Centre
GEF	Global Environmental Fund
GIS	Geographical Information Systems
ha	Hectare
IAP	Invasive Alien Plants
km	Kilometre
LT	Least Threatened (Threat Status)
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
NBSAP	National Biodiversity Strategies and Action Plans
NFEPA	National Freshwater Ecosystem Priority Areas
NGI	National Geo-Spatial Information
NT	Near Threatened (Threat Status)
NWA	South African National Water Act (1998)
NWP	New Water Programme
OESA	Other Ecological Support Area
PES	Present Ecological State
RQO	Resource Quality Objectives
RSE	Riviersonderend
SANBI	South African National Biodiversity Institute
SASS	South African Scoring System

Acronym	Description
SWSA	Strategic Water Source Area
TMGA	Table Mountain Group Aquifer
TNC	The Nature Conservancy
VU	Vulnerable (Threat Status)
WfWet	Working for Wetlands
WUA	Water Users Association
WWF-SA	Worldwide Fund for Nature – South Africa
ZWUA	Zonderend Water Users Association

Introduction and Context

In response to a call from the Water Fund (TNC) the Freshwater Research Centre (FRC) initiated biodiversity, social, and governance assessments to conserve indigenous freshwater fish and associated aquatic ecosystems of the Upper Riviersonderend, Amandels and Du Toits Rivers in the Theewaterskloof Catchment (Western Cape, South Africa). These assessments are to be aligned with the necessary awareness-raising, information collation, stakeholder engagement and identification of role players required to inform the framework for the development of robust, transparent and feasible conservation intervention options.

1.1 The catchments

The project area, much of which falls within Protected Areas, is located within quaternary catchments H60A and H60B in the Riviersonderend sub-Water Management Area (WMA) (Figure 1.1). The sub-quaternary catchments are the Upper Riviersonderend, Du Toits and Amandels River catchments, all of which supply water to the Theewaterskloof Dam, the largest supply reservoir in the Western Cape Water Supply System. The Upper Riviersonderend rises on the Groot Drakenstein Mountains and for its first 15km flows eastwards through the Riviersonderend Gorge within the Hottentots Holland Nature Reserve. As the river leaves the reserve it enters a 222 ha palmiet valley-bottom wetland on predominantly private land. The wetland flows into the Theewaterskloof Dam downstream of the agricultural settlement of Vyeboom. The farming communities of Dennebos and Morgenzon are located on farms close to the river.

The Upper Riviersonderend sub-catchment has been identified as a Freshwater Ecosystem Priority (FEPA) catchment, due to the good condition of the river, and presence of endemic freshwater species. These river reaches are known to provide sanctuary to the Endangered Giant Redfin, *Pseudobarbus skeltoni* (Chakona and Swartz 2013), which is endemic to the Breede River. Although this is one of the three last remaining populations of this newly-described species (Chakona and Swartz, 2013), the upper and lower distribution limits, population size, habitat requirements and threats have not yet been adequately quantified – information critical for effectively conserving the species. In addition to *P. skeltoni*, the river is also home to the Breede River redfin *Pseudobarbus* sp. 'burchelli Breede', the Cape kurper *Sandelia capensis* sp. "Riviersonderend" and three genetically-distinct lineages of Cape galaxias *Galaxias zebratus*, making the study area a hotspot for freshwater fish endemism and conservation in the CFR (Ellender *et al.* 2017).

Threats to the health of the Upper Riviersonderend (particularly the 5-km reach upstream of the Dam) that have already been identified include over-abstraction of water for irrigation, agricultural and residential pollution, invasive alien plant (IAP) encroachment, erosion of organic soils due to channelisation of inflows, loss of wetland vegetation, draining and desiccation of wetland areas, and head-cut erosion triggered by rapid changes in water level around the margins of Theewaterskloof Dam (Snaddon *et al.* 2018). It was not yet known before this study took place whether any non-native fish species occur in the river, but it is possible since non-native species like North American black bas *Micropterus* spp., common carp *Cyprinus carpio* and sharptooth catfish *Clarias gariepinus* are all present in the Theewaterskloof Dam.

The roughly 15-km long Du Toits River joins the Theewaterskloof Dam along its northern margin. The river rises on the Franschhoek Mountains, flowing southwards towards the dam through the Mont Rochelle Nature Reserve (managed by CapeNature). Like the Upper Riviersonderend, the Du Toits River exits the steep mountains and flows into an extensive 680 ha palmiet valley-bottom wetland before flowing into the dam. The river is inhabited by native Breede River redfin *Pseudobarbus* sp. 'burchelli Breede', the Cape kurper *Sandelia capensis* sp. "Riviersonderend" and at least two genetically-distinct lineages of Cape galaxias *Galaxias zebratus*. The upper distribution limits of these species are unknown and lower distribution limit appears to coincide with a gauging weir a few km upstream of the confluence with the dam (Lowe 2009 unpubl. data.). The weir marks the upper distribution limit of black bass *Micropterus* spp. and sharptooth catfish *C. gariepinus* which have invaded upstream from the dam (Lowe 2009, unpubl. data) and pose a major threat to native fishes in the system. In general, instream and riparian habitat condition both upstream and downstream of the gauging weir appears to be in good condition, and preliminary data (Lowe 2009, unpubl. data) suggest that, given the good habitat condition, native fish could re-colonise the invaded reach (between dam and gauging weir), should the non-native fish be removed). During the early 2000s, there was an erosion event in the catchment that led to the deposition of considerable sediment in the Du Toits River wetland (Kotze, 2015). The wetland has largely recovered from this impact, with a mixed plant community growing quite rapidly over the deposited sediment (Snaddon *et al.* 2018). As for the upper Riviersonderend wetland, head-cut erosion has been triggered in the wetland area adjacent to the dam as a result of rapid changes in water level. There has been extensive IAP removal over the past few years, and the vegetation now appears to be in good condition. There are no major human settlements in the Du Toits River catchment, but there may be impacts associated with VCSV Camp facility and other private accommodations adjacent to the upper river, as well as impacts associated with the nearby R45 Road pass.

The Amandels River is a ~8 km-long river rising to the southeast of the Du Toits River. The main threats to river health in this catchment are the intensive cultivation of orchards (and associated water quality and quantity impacts) in the lower 3 km of the river, the incision of channels in the wetlands just upstream of the river's confluence with Theewaterskloof Dam, and invasive alien plant (IAP) infestations in the upper catchment and encroachment into the riparian zone. The native fish community comprises Breede River redfin *Pseudobarbus* sp. 'burchelli Breede', the Cape kurper *Sandelia capensis* sp. "Riviersonderend" and at least two genetically-distinct lineages of Cape galaxias *Galaxias zebratus* (Chakona *et al.* 2013; Shelton *et al.* 2015). Native fish occur in the river adjacent to the orchards and extend at least two km upstream (Shelton *et al.* 2015), but the upper limit of the native fish is unknown. The main threat to fish and associated aquatic habitat in this river appears to be impacts on habitat quality resulting from dense infestations of IAP in the upper catchment, and it was not known whether non-native fish have invaded the river.

1.2 Baseline assessment

The value of catchment baseline monitoring and mapping allows the user to pinpoint the major drivers of degradation and threat (e.g., source(s) of pollution, habitat loss, flow alteration, invasive species) across the entire system at ecologically-meaningful spatial and temporal scales (such as where reduced flow in summer months could interact with increased temperatures to aggravate fish habitat loss).

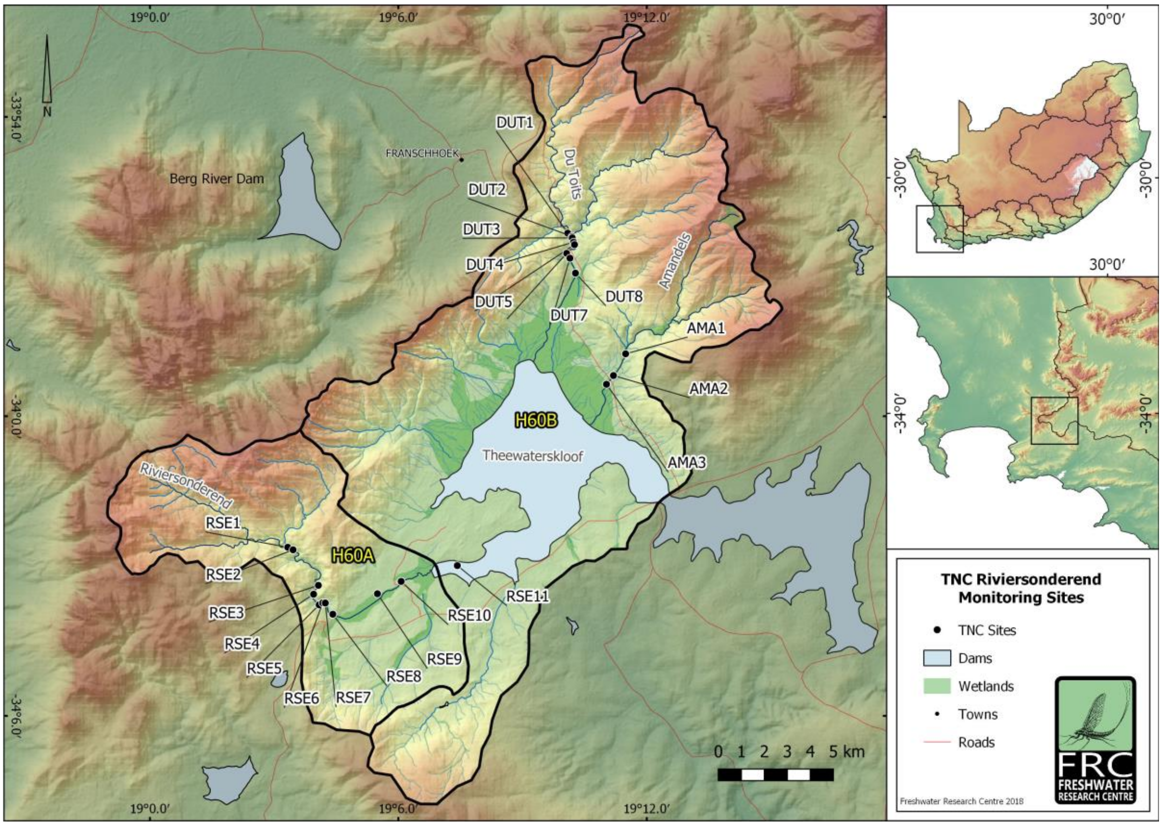


Figure 1.1 Map of the study area and monitoring sites sampled on the upper Riviersonderend, Du Toits and Amandels Rivers during the first baseline survey

We selected twenty-two river sites within the catchments, where we sampled biophysical conditions such as fish populations, aquatic invertebrates, instream and riparian health, aquatic habitat (e.g. depth, velocity, substratum) and water quality and quantity on two occasions: in early and late summer.

1.3 Permits and Ethics

The sampling protocols for the study meet the FRC's internal organisational ethics standards, and all data presented in this study were collected under CapeNature permit CN44-31-7921.

Water Quality

Good water quality is particularly important in the Riviersonderend catchment due to the livelihoods that depend on agriculture, and the fact that the rivers in this catchment feed into the largest impoundment supplying water to the City of Cape Town, the Theewaterskloof Dam.

2.1 Introduction

South Africa is regarded as a water scarce country, where the quality of its water resources is in decline. Inland aquatic systems, such as rivers and wetlands, are under increasing threat from increasing development (urban, agricultural and mining) and spread of alien invasive species (Kotze *et al.* 2009; West *et al.* 2016). These phenomena often have negative impacts on the water quality within catchments which is further exacerbated by the effects of climate change (Dallas & Rivers-Moore 2014).

The Western Cape is characteristically a nutrient-poor system (Lamont, 1983). With increasing rates of landscape alteration, particularly in the agricultural sector which dominates the Riviersonderend catchment, nitrogen and phosphorus levels are on the rise (Schulz and Peall, 2001), causing deterioration in water quality and the eutrophication of freshwater ecosystems and impoundments (Dallas & Day 2004; WWF-SA 2016). Sources of pollution are typically categorised as point-source (e.g. sewage treatment works) or non-point-source (e.g. agricultural runoff) (Dallas & Day 2004). Therefore, monitoring a range of different parameters can provide insight into the sources of pollution into these river systems, and provide a lens through which to zoom into the health of the rivers in this system.

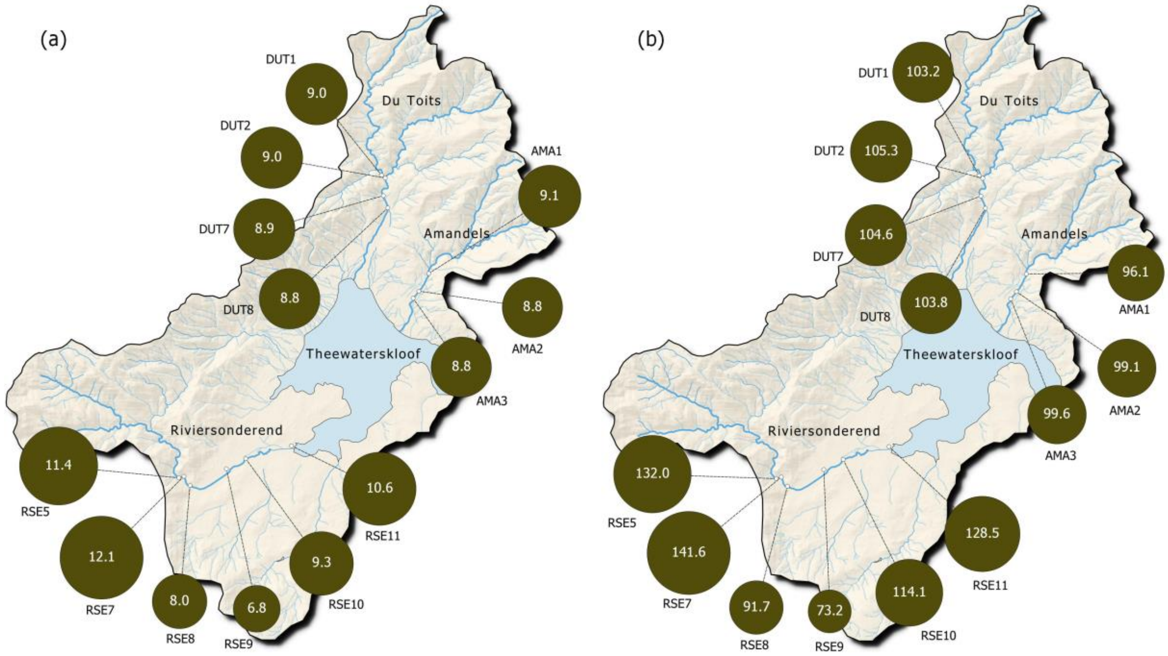


Figure 2.1 Dissolved oxygen (a) mg/l, and (b) percentage, concentrations recorded at the baseline monitoring sites during December 2018). Bubbles are scaled to parameter values.

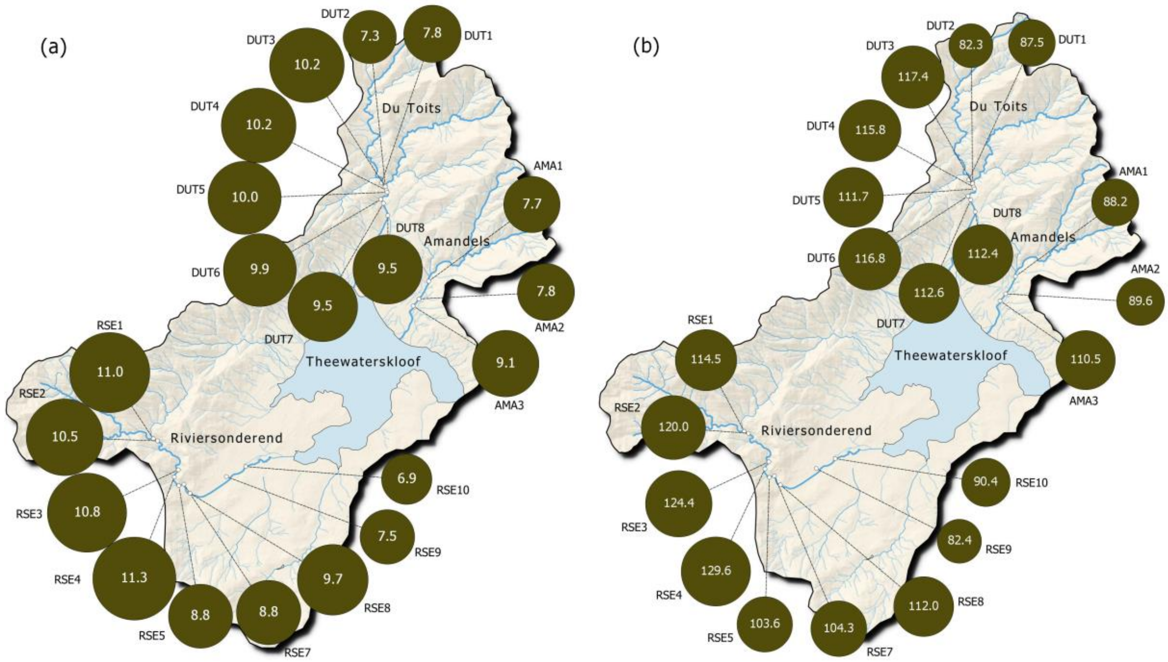


Figure 2.2 Dissolved oxygen (a) mg/l, and (b) percentage, concentrations recorded at the baseline monitoring sites during March 2019). Bubbles are scaled to parameter values.

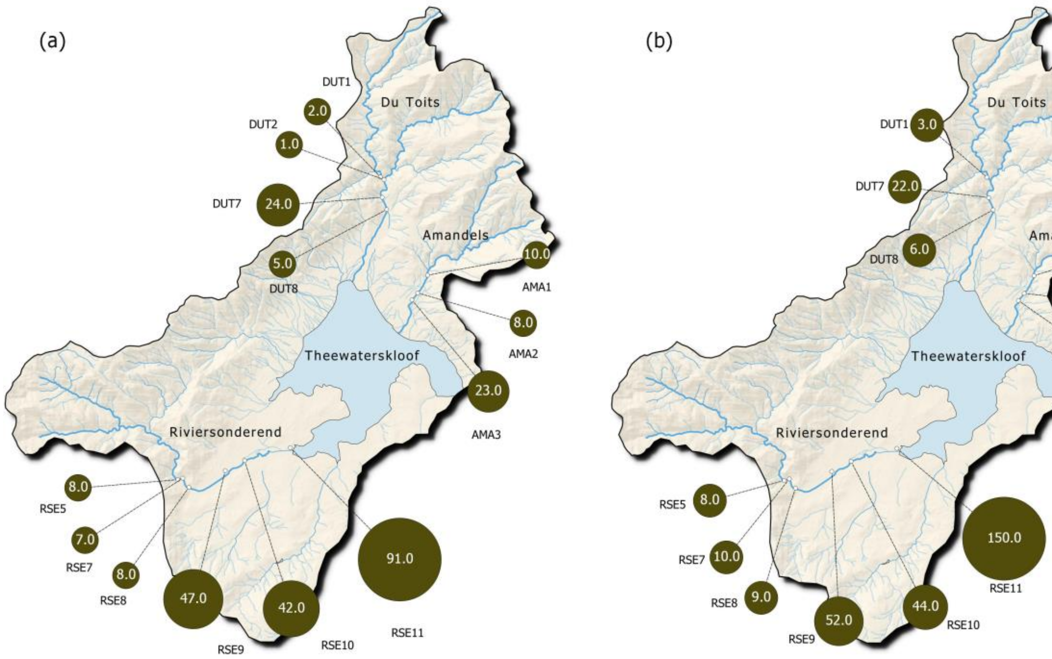


Figure 2.3 (a) E. coli and (b) Faecal coliform concentrations recorded at the baseline monitoring sites during December 2018). Bubbles are scaled to parameter values.

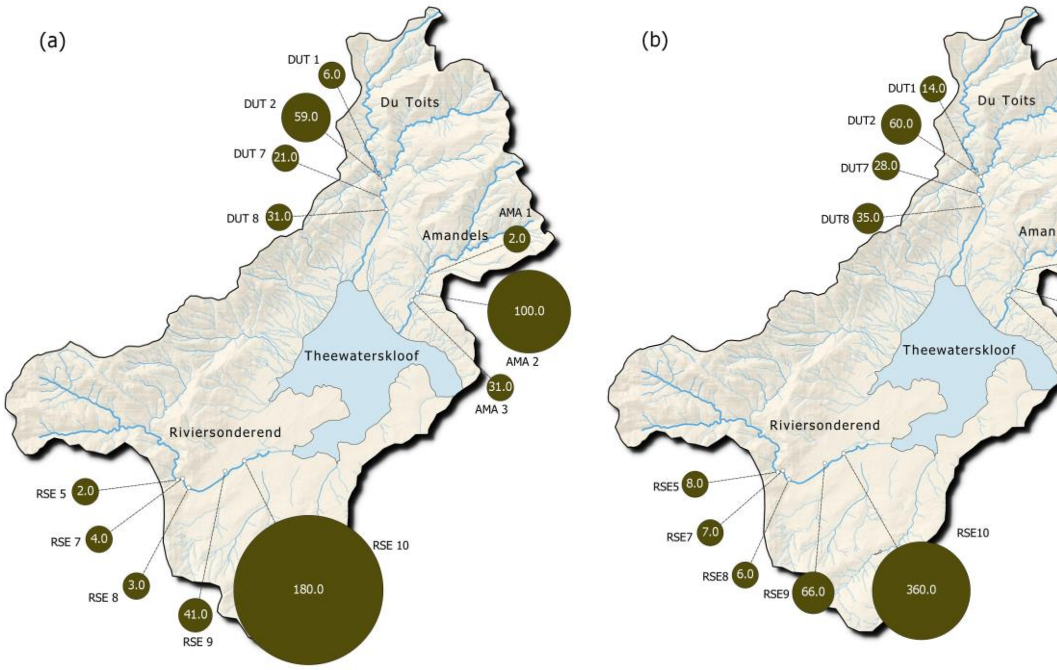


Figure 2.4 (a) E. coli and (b) Faecal coliform concentrations recorded at the baseline monitoring sites during March 2019). Bubbles are scaled to parameter values.

2.2 Methods

The following water quality analyses were done during the December 2018 and March 2019 field trips. *In situ* (using HANNA HI 98194 Multimeter instrument):

- pH
- Electrical conductivity
- Dissolved oxygen
- Total dissolved solids
- Water temperature

Laboratory analyses:

- Council for Scientific and Industrial Research: nitrates, nitrites, ammonia, orthophosphates and total phosphorus;
- Water Analytical LABoratory (WALAB): *E. coli* and total faecal coliforms.

2.3 Results

2.3.1 Dissolved oxygen

Dissolved oxygen is a measure of the amount of soluble oxygen in the water and is influenced by atmospheric re-aeration, temperature and salinity, photosynthesis and respiration by aquatic plants and animals (Dallas & Day 2004). High oxygenation levels are characteristically found in the upper reaches of rivers (due to high aeration in the fast flowing, boulder habitat) and decreases along the stretch of the river as it turns into slow flowing, sandy habitat (Dallas & Day 2004). This pattern is seen in most rivers in this study; however, sudden increases in oxygenation, as seen in the lower reach of the Riviersonderend (e.g. RSE 10 and 11), may be a result of some level of eutrophication due to increased human and agricultural influence (Dallas & Day 2004). Whilst oxygen saturation is interesting in terms of water quality, it is also important for aquatic invertebrates and fish populations and will be unpacked in greater detail in those discussions.

2.3.2 E. coli and faecal coliforms

In 1996, the Department of Water and Sanitation (previously known as Department of Water Affairs and Forestry) developed the South African Water Quality Guidelines for domestic- (Department of Water Affairs and Forestry 1996a), agricultural- (Department of Water Affairs and Forestry 1996b) and recreational use (Department of Water Affairs and Forestry 1996c). These guidelines stipulate the target water quality range for various water quality parameters – including *E. coli* and faecal coliform concentration range (Table 2.1).

Table 2.1 Target Water Quality Ranges, in terms of total faecal coliform and *E. coli* count, as expressed in the 1996 South African Water Quality Guidelines for various uses. These ranges are intended to be the minimum range which would minimise any risk to human or environmental health.

Target Water Quality Range (counts/100mL)		**Intended use**
Faecal coliform	***E. coli***	
0 – 130	0 – 130	Recreation: full contact
0 – 1000	-	Recreation: intermediate contact
-	<1[1]	Irrigation
-	0	Domestic: human consumption

[1] Fruit trees and grapes may be irrigated with water containing a concentration of up to 1000 E. coli counts/100mL provided that the fruits are not wetted. This maximum count in irrigated water coincides with the Global Gap certification which is needed for farmers to export agricultural produce.

Recording water quality measurements at a site on the upper Riviersonderend River (Photo by Jeremy Shelton)

The importance of these parameters in particular lies in that certain thresholds exist before they affect human health as well as limit the export of agricultural products. In this study, an increase in *E. coli* and faecal coliforms count trend was observed moving downstream along the upper Riviersonderend River – a pattern potentially linked to the relatively high human populations along the course of the river, which could increase the risk of contamination. This can clearly be seen at sites RSE10 and 11, where communities live adjacent to the river. An exponential spike in *E. coli* and faecal coliform count was observed at RSE10. This spike in count levels could be expected by the relatively slow flowing habitats, and warmer, interconnected pools resulting in a proliferation of coliforms.

Interestingly, a similar spike in *E. coli* and faecal coliform count levels at DUT7 (Du Toits River) in December 2018 was also observed. It is hypothesised that human excretion may be responsible for this trend as this point is the first safe location drivers can exit their vehicles after traversing the Franschhoek Pass. The count decreases drastically at DUT8 which highlights the potential of a healthy river to restore water quality. In the March 2019 sampling, the count levels doubled at DUT2. It is suspected that the increased contamination is a result of improved human access to this site after a fire that swept through the area in February 2019. During this sampling period, people were seen collecting water this site.

A spike in *E. coli* and faecal coliform count levels was also observed in the middle site along the Amandels River (AMA2) in the March sampling session. This site is located within the boundaries of the farm and it is suggested that the contamination originates from the households existing on the farm. The count levels decrease downstream the farm, at the AMA3 site, which suggests rapid recovery of water quality.

Very low levels of *E. coli* and faecal coliforms were measured at sampling sites upstream of major human activities e.g. RSE5, 7 and 8 in both December and March sampling periods. Unfortunately, no data exist on natural background *E. coli* concentrations in the Western Cape. However, despite this, any background levels may be attributed to hikers, wild animals (such as baboons) and a by-product of soil organisms higher in the catchments (Britz *et al.* 2012).

Overall, the *E. coli* and faecal coliform counts were low and far below the threshold required by farmers for irrigating their orchards to export their produce. However, these levels need to be monitored carefully to prevent human health issues and affect the farmers' ability to export their produce to the international market.

2.3.3 Other parameters

Various other physico-chemical variables and nutrient parameters are important to understand the dynamic and complex nature of water quality. Depending on the presence or magnitude of certain parameters, combinations of certain chemical substances can exacerbate toxicity in comparison to each on their own – as is the case for nickel and zinc (Dallas & Day 2004). Therefore, parameters need to be viewed in a holistic manner in order to understand their interactions and provide useful conclusions.

The sampling of nitrogen species (i.e. nitrates, ammonium and nitrite) and phosphorus species (i.e. phosphate) provides insight into the sources of fertiliser application, agricultural run-off and sewerage discharge. This study found very low nutrient concentrations, often below laboratory detection limits, for nitrogen and phosphorus species across the three rivers. This trend is expected as the Western Cape is characteristically a low nutrient region (Lamont 1983). This was particularly true for nitrates, ammonium and nitrites – except for December 2018 in the Riviersonderend. This was due to a high rainfall event before the December 2018 field trip causing a flushing of nutrients into the river. In general, higher concentrations of nutrients could be observed in the March sampling session as opposed to December as this relates to lower water volume in the rivers and less dilution, as the drier season progresses (Nilsson & Renöfält 2008).

Various spikes in phosphate pollution were measured (Table 2.3), such as relatively higher concentrations at RSE8 and DUT7 in March 2019. These levels did indicate a shift from oligotrophic to mesotrophic conditions, according to the DWAF (2002) guidelines (Table 2.2), but not according to the more recent work done by Malan and Day (2005). These spikes in phosphates would need to be verified with more data, but are not necessarily cause for concern. An increase in phosphate levels at the Amandels River sites in March 2019 compared with December 2018 may be attributed to inputs from fertiliser use on the adjacent orchards as well as some labourer houses near the river. As expected, pH readings were low at all sites, which is typical of south-western Cape rivers with a natural range fluctuating between 4.5 and 6 (Dallas & Day 2004) (Table 2.3). Interestingly, several pH readings in the Du Toits and Amandels Rivers fell below this range.

Table 2.2 Iterative reviews of benchmark ortho-phosphate category boundaries for trophic levels in inland aquatic systems (values in mg/l) (after Malan & Day 2005).

DWAF 1996	DWAF 2002	Malan and Day 2005
Ortho-phosphate or PO_4 (mg/l)		
	Natural- ≤ 0.005	
Oligo- ≤ 0.005	**Good-** 0.0051 - 0.025	**Oligo-** ≤0.02
Meso- 0.005-0.025	**Fair** 0.0251 - 0.125	**Meso-** 0.0201 - 0.125
Eutro- 0.02501 - 0.25	**Poor** > 0.125	**Eutro-** > 0.125

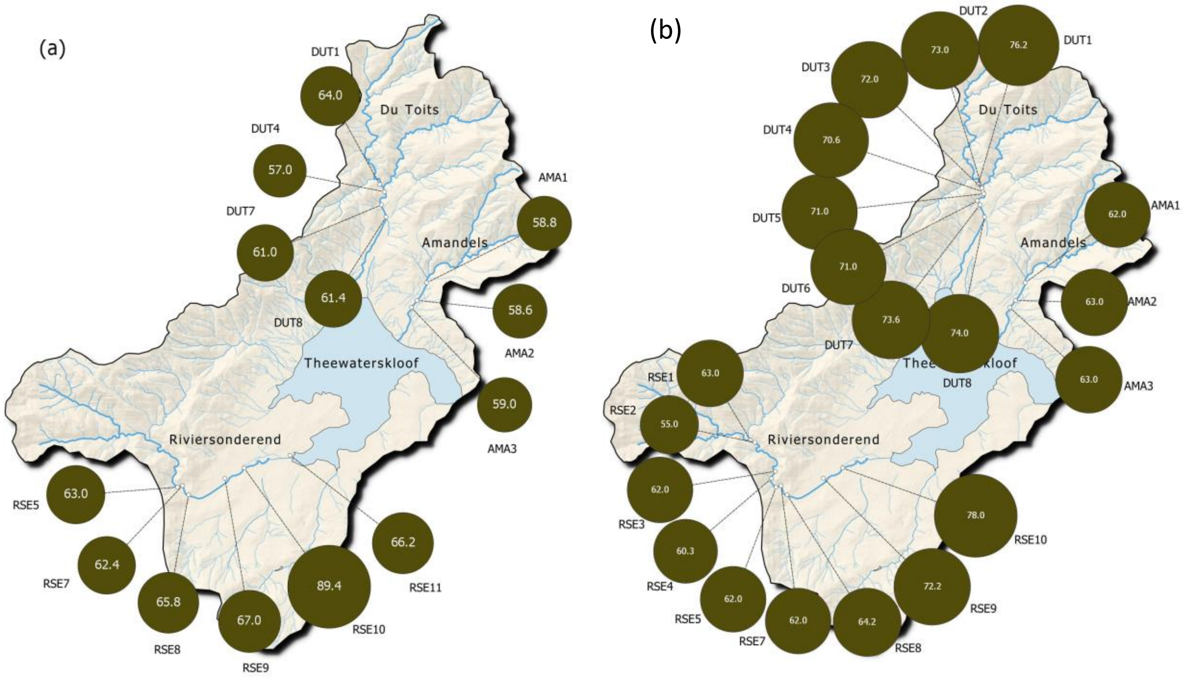


Figure 2.5 (a) Electrical conductivity values recorded in (a) December 2018, and (b) March 2019 at the baseline monitoring sites during March 2019). Bubbles are scaled to parameter values.

A few pH readings in the Riviersonderend were observed to be lower than the typical range.

In terms of Total Dissolved Solids (TDS), this represents the total quantity of dissolved material (organic and inorganic, ionised and unionised) in a water sample, gradually increased as one moves downstream (Dallas & Day 2004). TDS and electrical conductivity, which is a measure of the ability of a sample of water to conduct an electrical current, correlate closely with one another (Dallas & Day 2004). This general trend is typical of many rivers and can be explained by charged particles (or ions) as well as organic and inorganic material is being washed into the river as it traverses the landscape (Dallas & Day 2004).

2.4 Discussion

These data show that the overall water quality in these systems is good – particularly in the upper reaches of all three rivers. However, as these rivers leave their inaccessible, pristine headwater catchment areas, they are exposed to human activity and landscape alteration (primarily due to agricultural activities), and the water quality deteriorates. This needs to be monitored closely to ensure (1) that water quality entering Theewaterskloof Dam is as high as possible, (2) the sustainability of the freshwater biodiversity within the rivers and wetlands and (3) the good health and livelihoods of communities within the catchments

Table 2.3 Physico-chemical and nutrient parameters measured in the Upper Riviersonderend, Du Toits and Amandels rivers.

Month	**Dec '18**	**Mar '19**	**Dec '18**	**Mar '19**	**Dec '18**	**Mar '19**	**Dec '18**	**Mar '19**	**Dec '18**	**Mar '19**	**Dec '18**	**Mar '19**
Upper Riviersonderend	**RSE 5**		**RSE 7**		**RSE 8**		**RSE 9**		**RSE 10**		**RSE 11**	
Nitrate (µg/litre)	59	<5	48	<5	46	<5	43	<5	58	<5	25	
Nitrite (µg /litre)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	
Ammonium (µg /litre)	<5	<5	6	<5	12	<5	<5	<5	<5	<5	<5	
Phosphate (µg /litre)	<5	11	<5	8	5	14	<5	5	<5	7	6	
Total Phosphorus (mg/litre)	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	0.05	
pH (average of 5 measurements)	3.89	4.12	3.86	4.27	3.96	4.28	3.88	3.46	4.48	4.80	4.57	
Total Dissolved Solids (mg/litre) (average of 5 measurements)	31.20	31	31	31	33	32	33.6	36	44.8	39.2	32.2	
Temperature (average of 5 measurements)	21.36	21.91	21.45	21.93	18.48	20.76	17.51	18.40	24.03	27.72	23.4	
Du Toits	**DUT1**		**DUT2**		**DUT7**		**DUT8**					
Nitrate (µg/litre)	<5	<5	<5	<5	<5	<5	<5	<5				
Nitrite (µg /litre)	<5	<5	<5	<5	<5	<5	<5	<5				
Ammonium (µg /litre)	<5	<5	<5	<5	<5	<5	<5	<5				
Phosphate (µg /litre)	<5	7	<5	5	<5	13	5	7				
Total Phosphorus (mg/litre)	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05				
pH (average of 5 measurements)	4.23	4.41	4.37	4.40	4.32	4.50	4.31	4.51				
Total Dissolved Solids (mg/litre) (average of 5 measurements)	32	38	29	36	30.4	37	31	37				
Temperature (average of 5 measurements)	20.40	18.52	21	19.38	21.45	22.06	22.08	22.14				
Amandels	**AMA1**		**AMA2**		**AMA3**							
Nitrate (µg/litre)	<5	<5	<5	<5	<5	<5						
Nitrite (µg /litre)	<5	<5	<5	<5	<5	<5						
Ammonium (µg /litre)	<5	<5	<5	<5	<5	<5						
Phosphate (µg /litre)	<5	5	<5	6	<5	5						
Total Phosphorus (mg/litre)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05						
pH (average of 5 measurements)	4.53	4.22	4.66	5.05	4.53	4.70						
Total Dissolved Solids (mg/litre) (average of 5 measurements)	29.20	31	29	31	29	31						
Temperature (average of 5 measurements)	20.58	20.27	19.38	22.41	16.69	23.47						


Photo: Kate Snaddon

Invertebrates

Riverine invertebrates are important components of freshwater assemblages, playing a number of critical roles in order to maintain the ecological functionality of riverine systems. The objective of the collection of aquatic macroinvertebrate data was to document the diversity of these communities in the three rivers, and to use the data as an indication of ecological integrity or river health. The overall condition of the aquatic macroinvertebrate communities in the rivers also provides a snap-shot view of the condition of the riverine habitat available for the fish species, a major focus of this study. The data provide baseline information, against which future data may be evaluated and contextualised to track ecological change in these systems.

3.1 Introduction

Riverine invertebrates are important components of freshwater assemblages, playing a number of critical roles in maintaining the ecological functionality of riverine systems. These roles include:

- Provision of food to other faunal groups, both aquatic and terrestrial;
- Processing of organic matter, and
- Purification of water.

In addition to these important ecological services, riverine invertebrates make up a large proportion of the aquatic biodiversity supported by freshwater ecosystems. Riverine invertebrates occupy habitat niches, or ‘biotopes’, within a river, which have been selected in order to provide the optimal conditions, in space (i.e. quality and quantity) and time, for the survival of the individual and continuation of the species. Such habitat selection means that invertebrates are continually responding to their environment, and a shift in one environmental variable within a particular river reach, such as the concentration of suspended solids or of a particular nutrient, will produce a shift within the invertebrate assemblage supported by that reach.

It has been suggested that the four major components of a riverine system that influence the productivity of aquatic organisms are flow regime, physical habitat structure (e.g. channel form and nature of the substrate), water quality (e.g. temperature, dissolved oxygen), and energy inputs from the watershed (e.g. nutrients and organic matter) (Thirion, 2007). It can be assumed, then, that the effects of alterations in any of these system components can be tracked by monitoring riverine invertebrate assemblages. Importantly for this study, an assessment of the state of the invertebrate assemblages inhabiting river sites also provides an indication of the overall suitability of a site for fish species.

One of the charismatic macroinvertebrate taxa recorded during the SASS5 surveys – A water scorpion

3.2 Methods

The riverine macroinvertebrate communities were sampled at the same sub-set of river sites during both December 2018 and March 2018[2], using the SASS5 methodology (*sensu* Dickens and Graham, 2002). This method requires the *in situ* collection and identification (to family level) of the riverine macroinvertebrates inhabiting three main biotopes – stones and bedrock (in and out of current), gravel / sand / mud, and vegetation (instream and marginal) – where these biotopes are available.

The SASS5 protocol enables a rapid, on-site assessment of riverine invertebrate communities, using a non-destructive kick-sampling technique that disturbs the stream bed so that invertebrates are dislodged from the substrate and vegetation, and retained on a hand-held 950µm-mesh sieve (attached to a hand-held 300mm x 300mm frame). Each sample was placed in a basin and each taxon recorded, at the level of invertebrate family.

The SASS5 protocol allocates a predetermined score to each taxon according to its normal distribution and sensitivity to water quality perturbation. Sensitive taxa are allocated high scores (maximum of 15) while taxa more common to degraded/disturbed systems receive low scores.

The assessment yielded a total SASS5 score, the number of invertebrate families collected (a measure of taxonomic diversity), and an average score per taxon or 'ASPT' (total SASS5 score divided by the number of taxa) for each site. Additional data collected at each SASS5 site included the type of biotopes present, and a rating of how effectively the habitat could be sampled (rating of 1 to 5, with 5 being very good). Each biotope (see above) was sampled separately, and a combined score calculated for each site.

For the Upper Riviersonderend, Amandels and Du Toits rivers, the SASS5 data were used to determine the current health of each river site, specifically with regards to the sensitivity of the invertebrate assemblages to water quality. Dallas (2007) provides guidance on how to interpret the SASS5 data, in relation to scores from other sites from the same river type in the same Level 1 Ecoregion (Southern Folded Mountains). Thresholds of total SASS5 score and ASPT are provided as a means to determine the Present Ecological State (PES) of a site. In addition to the *in situ* identification to family level, the invertebrate samples were preserved in 96% ethanol for further taxonomic analysis in the future, or for archiving of type specimens at the Albany Museum.

Hand-held net used for the SASS5 sampling method. Each available biotope is sampled separately, and a combined score calculated for the river site (Photo taken by Jeremy Shelton).

[2] The lowest site on the Upper Riviersonderend, RSE11, was not sampled in March 2019, as there was no flowing water, and very little inundation.

3.3 Results

The total SASS5 and ASPT scores all indicate that water quality in the three rivers is generally good. This is particularly so for the Du Toits and Amandels Rivers, and the upper to middle sites on the Upper Riviersonderend (see

Figure 3.1 to Figure 3.4). High numbers of taxa (> 20) and high total SASS5 scores (> 140) were recorded at these sites, in both early (December 2018) and late summer (March 2019).

There were a few exceptions to this pattern, being:

- AMA2 (middle site on the Amandels River) in March 2019, where the total score was 131 in March 2019, and the number of taxa, 17, and
- RSE8 (middle site on the Upper Riviersonderend) in December 2018, with a total score of 123 and number of taxa, 18.

The ASPT scores showed a distinct downward trend in both months down the length of the Upper Riviersonderend, with no clear spatial patterns discernible from the ASPT data for the other two rivers. ASPT scores are the least sensitive to the quality and quantity of habitat available for invertebrates (Dickens and Graham, 2002), so this decreasing trend in the Upper Riviersonderend is most likely an indication of deterioration in water quality downstream. This finding is consistent with the water chemistry data, which show the same downstream deterioration in water quality (see Chapter 2).

There were always at least two biotopes available for sampling at all sites sampled during both months, and often three. The most common biotope available at all sites was the vegetation biotope. Most sites had a high diversity of instream and marginal plant species, which could generally be sampled for invertebrates. In late summer at AMA1 (and RSE11, but this site could not be sampled at all), the vegetation was not in contact with the water so was not sampled.

The gravel / sand / mud biotope was not always present at all sites, but was prevalent at the middle and lower Upper Riviersonderend sites, RSE8,RSE9, RSE10 and RSE11, and the lower Du Toits River sites, DUT7 and DUT8. This biotope generally supports the lowest diversity of invertebrates in rivers.

There appeared to be no obvious temporal trends in the invertebrate data between the two sampling trips, with some sites showing an increase from December 2018 to March 2019, and some a decrease in scores.

3.4 Discussion

In general, the state of the macroinvertebrate communities in all three rivers is good to natural. The PES Category for all sites did not fall below B in either December 2018 or March 2019, and the number of taxa recorded exceeded 15 at most sites. This is despite visible physical disturbance of the wetlands and rivers, and the high probability of polluted irrigation return flows entering the Upper Riviersonderend and Amandels River. This is an indication that water quality in the rivers is relatively good, as is the available aquatic habitat.

The total SASS5 scores did decrease down the length of the Upper Riviersonderend, as can be expected. In lower foothill and lowland rivers, there is usually a paucity of stones biotopes, which leads to a drop in diversity and a loss of taxa more sensitive to water quality.

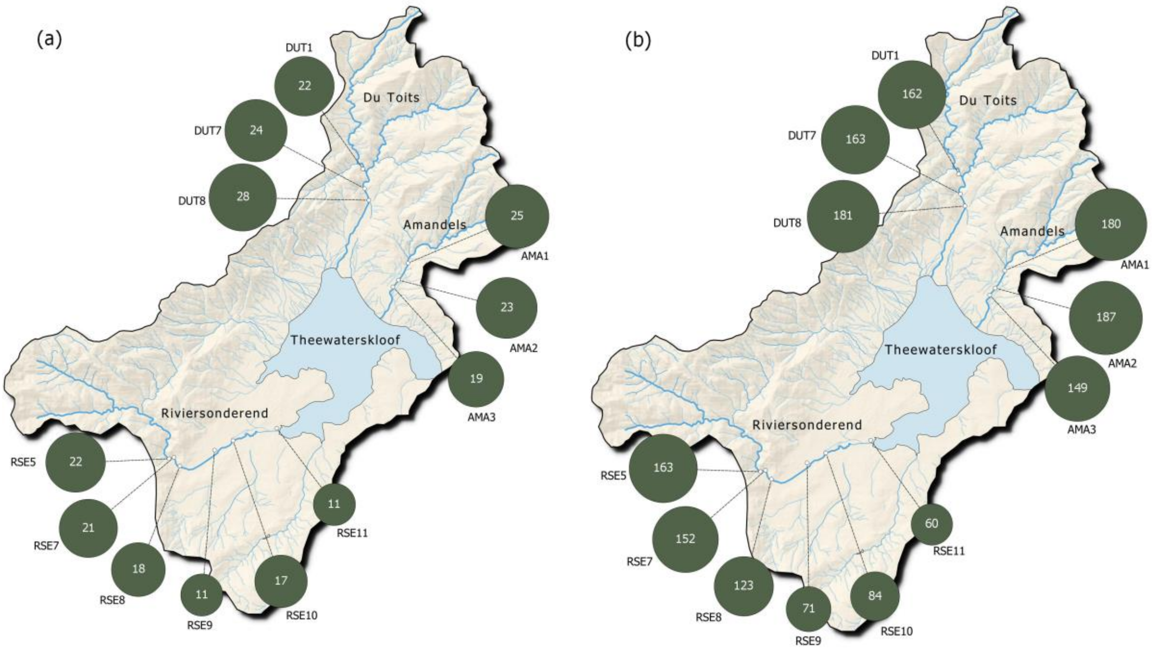


Figure 3.1 No. of invertebrate taxa (a) total SASS score (b) recorded at the baseline monitoring sites in December 2018.

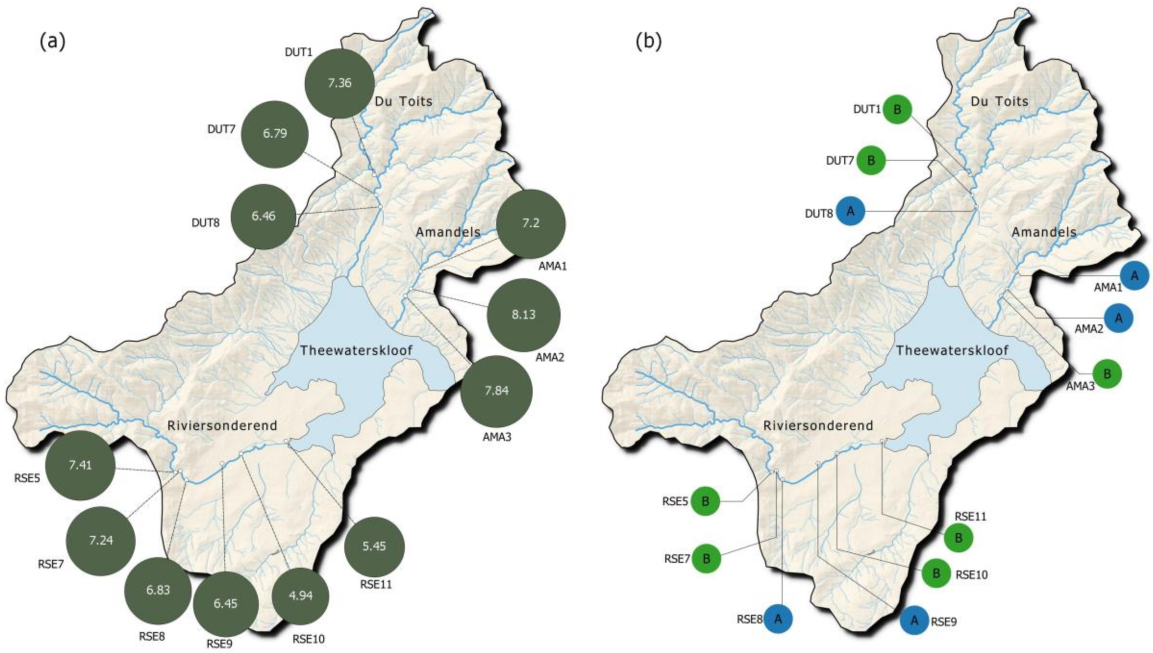


Figure 3.2 ASPT (a) and PES (b) scores recorded at the baseline monitoring sites in December 2018.

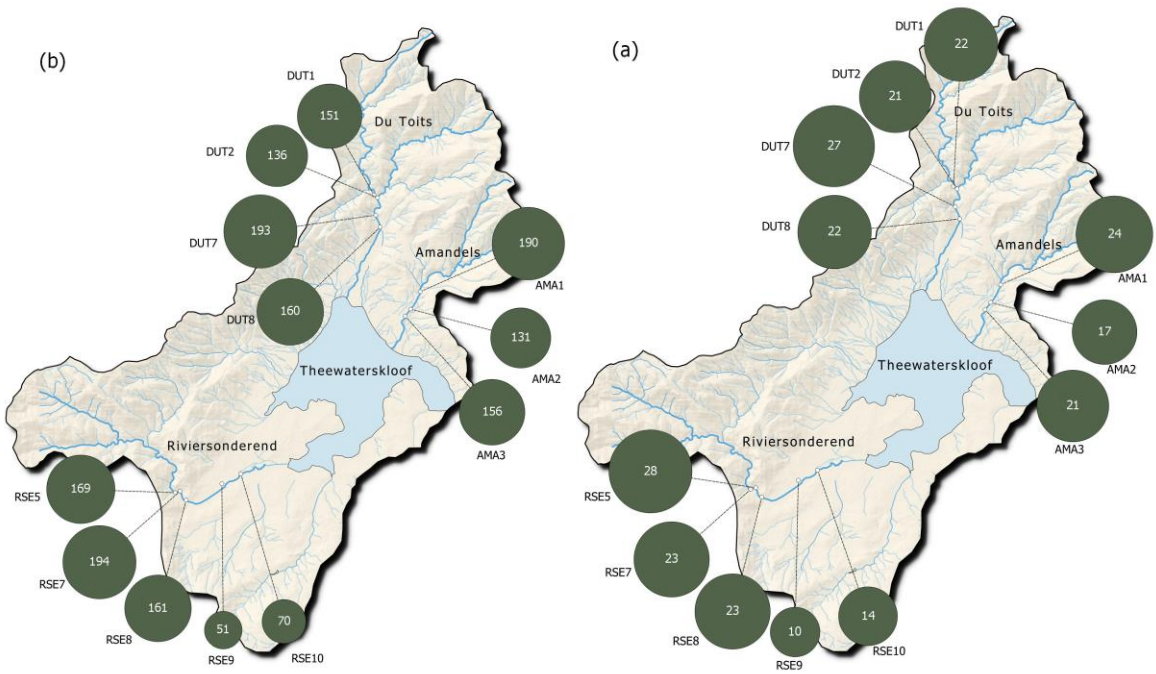


Figure 3.3 No. of invertebrate taxa (a) total SASS score (b) recorded at the baseline monitoring sites in March 2019.

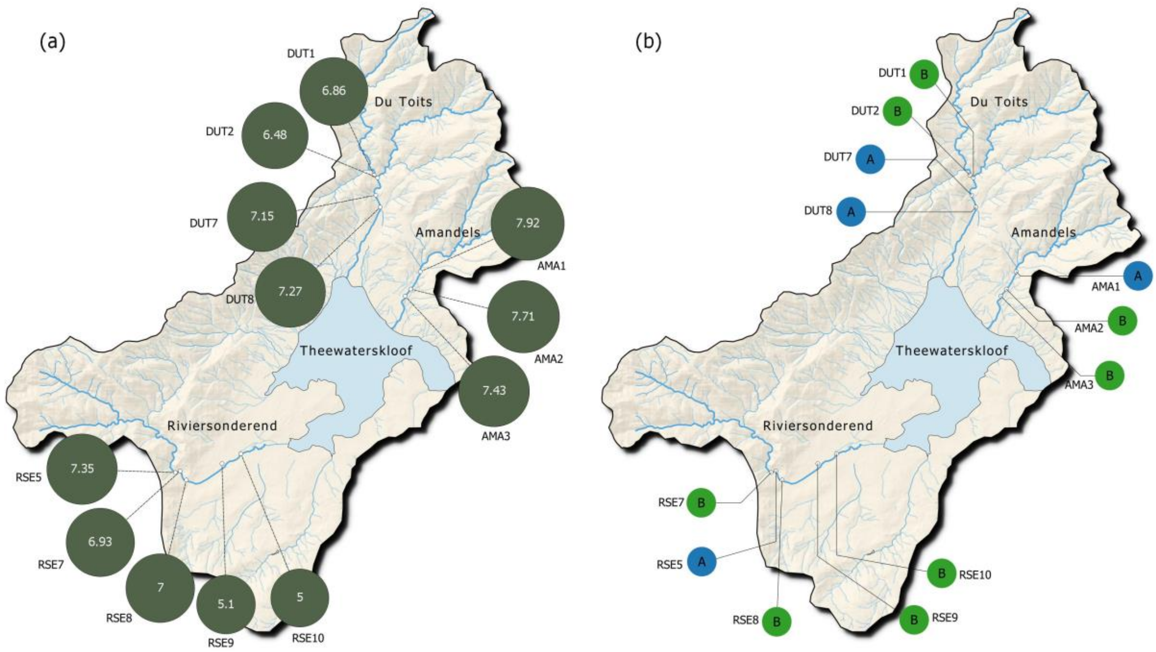


Figure 3.4 ASPT (a) and PES (b) scores recorded at the baseline monitoring sites in March 2019.

However, the lower foothill reaches of the Upper Riviersonderend do support quite a high diversity of macroinvertebrates (Figure 3.2), despite this section of the river being dominated by stands of palmiet, and having a predominantly sandy substrate.

It is likely that the palmiet plant, which dominates the middle to lower sections of both the Upper Riviersonderend and the Du Toits River, provides unique habitat for a variety of invertebrate taxa, in addition to playing an important role in both the hydrology and geomorphology of these ecosystems (see also Chapter 5). For instance, a Pisuliidae (cased caddis-fly) larva found at RSE8 appears to have built its case out of small sections of palmiet fronds (see photo below).

The uniqueness of the habitat provided by the palmiet plant has not been well-studied, and the data from this project may generate some interesting hypotheses in this regard. The invertebrates collected for this project should be identified to species level in order to further these lines of research.

In conclusion, the invertebrate fauna of the three rivers are in a good to natural condition. The main impacts on these assemblages include:

- Deterioration in water quality as a result of polluted return flows from irrigation agriculture, and from human faecal pollution, and
- Over-abstraction of surface water, which leads to drying out of river reaches.

Cased caddis-fly larva of the family Pisuliidae, found at RSE8. The case is constructed using leaf segments, likely to be from palmiet, and other species prevalent at the site.

Fish

The freshwater fish fauna of the Cape Fold Ecoregion (CFE) is characterized by low freshwater fish species diversity and high endemism. Human-linked degradation of aquatic habitats, including the introduction of non-native species and water abstraction, has resulted in dramatic decreases in the distribution, range and abundance of many of these species. This situation highlights the need for conservation projects that effectively address the threats facing these species and their freshwater habitats.

4.1 Introduction

4.1.1 The CFE hotspot and its fragile freshwater fish fauna

The freshwater fish fauna of the Cape Fold Ecoregion (CFE) is characterized by low species diversity (23 species), and high endemism (20 species), with several species restricted to very small geographic ranges (Ellender *et al.* 2017). Fourteen of the 20 fishes endemic to the CFE are currently evaluated as Vulnerable, Endangered or Critically Endangered using International Union for Conservation of Nature (IUCN) Red-List criteria. Human-linked degradation of aquatic habitats, including the introduction of non-native freshwater fishes and water abstraction, has resulted in dramatic decreases in the distribution, range and abundance of many of these species over the last century (Tweddle *et al.* 2009). This situation highlights the need for conservation projects that effectively address the threats facing these species and their freshwater habitats (Ellender *et al.* 2017). To add to this conservation challenge, recent biogeographic and taxonomic research using molecular techniques has revealed that the region's freshwater fish diversity has been severely underestimated. The consequence is that species previously thought of as widespread are now being split into species complexes consisting of a number of genetically unique lineages, many of which are limited to single catchments, streams or reaches within streams (Ellender *et al.* 2017).

4.1.2 Freshwater fishes of the upper Riviersonderend catchment

The native fish assemblage of the upper Riviersonderend catchment (including all rivers flowing into the Theewaterskloof Dam) comprises three families, namely the Cyprinidae (minnows and carps), the Anabantidae (labyrinth fishes) and the Galaxiidae (Table F1). Two cyprinids occur in the catchment, the Breede River redfin *Pseudobarbus* sp. 'burchelli Breede' and the recently-discovered Giant redfin *Pseudobarbus skeltoni*. Pseudobarbus sp. 'burchelli Breede', while relatively widespread in the upper Breede River catchment, is listed as Near Threatened in the IUCN Red List (Tweddle *et al.* 2009), but may soon be up-listed to Vulnerable, given its declining population trend (Jordaan and Chakona, in review). On the other hand, *Pseudobarbus skeltoni* is known from just three rivers, including the upper Riviersonderend, as well as the Krom and Tierkloof Rivers, which flow into the Molenaars River, and is listed as Endangered by the IUCN. The two redfins co-occur in the upper Riviersonderend, along with the anabantid Cape kurper *Sandelia capensis* sp. "Riviersonderend", and available information suggests that they occupy distinct trophic niches (Chakona and Swartz 2013, Kadye *et al.* 2016).

Pseudobarbus sp. 'burchelli Breede' generally favours deeper pool habitats (Chakona and Swartz 2012), but requires faster-flowing riffle habitats for spawning (Skelton 2001). Its sub-terminal (downward-facing) mouth position indicates that it is primarily a benthic feeder, and available data suggest that it is omnivorous, eating algae, detritus and invertebrates opportunistically, but appears to often favour invertebrate prey (Shelton *et al.* 2018). *Pseudobarbus skeltoni* inhabits both pools and riffles (Kadye *et al.* 2016), and has a terminal (forward-facing) mouth orientation, indicating that it is primarily a drift-feeder on aquatic invertebrates (Chakona and Swartz 2013). It is also possible that the Berg-Breede River Whitefish *Pseudobarbus capensis* (IUCN-listed as Endangered) a larger cyprinid species, once also occurred in the catchment (Shelton *et al.* 2017).

Only one species of anabantid, *Sandelia capensis* sp. "Riviersonderend", which is genetically-distinct from other Sandelia populations within the broader Breede River system, inhabits the upper Riviersonderend catchment. The conservation status of this lineage has not yet been assessed by the IUCN, but it appears to be relatively range-restricted, compared to the more widespread Breede River lineage. The species is known to be an ambush hunter that feeds primarily on aquatic invertebrates, but will also consume other animal prey including amphibians and fish (Skelton 2001, Shelton *et al.* 2018).

A giant redfin in the Upper Riviersonderend (Photo by Jeremy Shelton).

Breede River redfins still thrive in rivers where habitat conditions are favourable, and human-linked impacts minimal (Photo by Jeremy Shelton).

The Cape kurper population in the Riviersonderend catchment is genetically distinct from those elsewhere in the Breede system, and is currently being reclassified as a separate species (Photo by Jeremy Shelton).

Within the Galaxiidae, three genetically-distinct lineages are known to occur within the upper Riviersonderend catchment, namely *Galaxias* sp. “zebratus riviersonderend”, *Galaxias* sp. "zebratus rectognathus" and Galaxias sp. "zebratus nebula" (Ellender *et al.* 2017). Galaxias sp. “zebratus Riviersonderend” and *Galaxias* sp. "zebratus rectognathus" are considered highly range-restricted, while Galaxias sp. "zebratus nebula" is considered widespread in the region (Chakona *et al.* 2013). Neither *Galaxias* sp. "zebratus rectognathus" nor *Galaxias* sp. "zebratus nebula" have yet had their conservation status assessed by the IUCN. *Galaxias* sp. “zebratus Riviersonderend” is IUCN-listed as Vulnerable, and while the species remains poorly-studied, it appears to prefer moderate to slow-flowing, vegetated pool habitats, such as the marginal, palmiet-fringed areas around Theewaterskloof Dam – a behaviour that could render it especially vulnerable to predation by non-native fishes (Chakona 2017). All known sub-populations of this lineage are suspected to be small and isolated; there are currently eight known locations and the lineage is likely to be experiencing continuous decline due to the impacts of invasive alien fish and excessive water abstraction (Chakona 2017). *Galaxias* sp. "zebratus rectognathus" is likely to co-occur with Galaxias sp. “zebratus Riviersonderend” within the study area (CapeNature 2019). South African galaxiids are generally considered to be drift-feeders that prey on aquatic invertebrates and favour relatively fast-flowing stream habitats (Shelton *et al.* 2018), but the feeding and habitat preferences of the different lineages have not yet been studied.

Galaxias sp. "*zebratus rectognathus*", known only from the Amandel and Du Toits Rivers, is a small but stunning freshwater fish (Photo by Jeremy Shelton).

Table 4.1 Native freshwater fish present in the upper Riviersonderend catchment (Based on Ellender *et al.* 2017).

Species/lineage	IUCN Conservation status	Known distribution
Pseudobarbus sp. 'burchelli Breede'	Near Threatened	Headwater tributaries of the Breede, Duiwenhoks and Goukou River systems
Pseudobarbus skeltoni	Endangered	Limited to two localities within the Breede River system (upper Riviersonderend and Krom rivers)
Sandelia capensis sp. "riviersonderend"	Not Assessed	Tributaries of the Riviersonderend, Breede River system
Galaxias sp. "zebratus riviersonderend"	Vulnerable	Tributaries of the Riviersonderend and in the Keurbooms River, Breede River system. Also occurs in the Palmiet River system
Galaxias sp. "zebratus rectognathus"	Not Assessed	Amandel and Du Toit Rivers, Riviersonderend sub-catchment, Breede River system
Galaxias sp. "zebratus nebula"	Not Assessed	Widespread across the CFR from the Olifants River system in the west to the Bitou River system in the east

4.2 Methods

4.2.1 Fish distribution ranges and sampling sites

The presence/absence and upper/lower distribution limits of all fish species in all three rivers was assessed using a combination of snorkel surveys, fyke netting and electro-fishing (Appendix 1). Fish distribution ranges were used to select sites for sampling the fish populations and associated habitat conditions. A total of 22 sampling sites, covering the distribution ranges of the focal native species were identified in the upper Riviersonderend catchment: 11 in the Upper Riviersonderend, eight in the Du Toits River and three in the Amandels River. These were the 'main baseline monitoring sites' for sampling fish, habitat, water quality, physico-chemistry, invertebrates and river and riparian health.

4.2.2 Fish sampling

Fish sampling at all baseline monitoring sites was undertaken using a combination of sampling methods to assess fish populations and associated habitat conditions. Sampling protocols outlined in Shelton *et al.* (2018) were followed where possible. Fyke nets were set at each site overnight and the catch used to estimate relative abundance, community composition and size structure - an indicator of population health and recruitment success.

Snorkel surveys were used to estimate the densities and distribution limits of each fish species in the Du Toits River and Upper Riviersonderend. Single-pass snorkel surveys were undertaken at 3 sites along Upper Riviersonderend (Appendix 2a) and 39 sites along the Du Toits River (Appendix 2b). Each site was a randomly-selected 20m reach of river, and was surveyed by a single diver swimming upstream in a zigzag pattern and recording fish on an underwater slate (*sensu* Shelton *et al.* 2015a). Electrofishing was used as a complementary method for estimating species composition and relative abundance, as well as to evaluate fish micro-habitat selection at a subset of the baseline monitoring sites on all three rivers. Three or four 100-metre reaches were sampled on each river, using the point sampling method described in Dallas *et al.* 2016. A total of 129-229 random points were electro-fished in each river, and the total number of individuals from each species recorded. International best practices for electrofishing were followed (Beaumont *et al.* 2002, Bennett *et al.* 2016), and all fish were released back to the reach where they were collected unharmed.

4.2.3 Habitat sampling

A set of environmental variables of known importance to stream fish (based on McIntosh 2000), was measured at each baseline monitoring site (i.e. where fyke nets were set). Site length, and the wetted channel width at five evenly-spaced intervals were measured (m) along the length of the site with a tape measure. We then measured water depth (m), substrate length (mm), flow (m/s), and instream cover (%) at five equidistant points along each width transect. Dissolved oxygen (DO: mg/l), pH, conductivity (µS/cm), total dissolved solids (ppm), temperature (°C) were recorded at five random locations within each site. The spatial coordinates of each site were recorded with a GPS, and site elevation was ascertained from digitized topographic maps.

A more detailed fish 'microhabitat' investigation was undertaken at a subset of the main baseline monitoring sites. The following were measured at each point where electrofishing was undertaken: depth (m, with a calibrated depth rod), substrate particle length (mm, tape measure), flow (m/s, velocity head rod) and the presence of woody debris/aquatic vegetation were recorded at each point following electrofishing for relating back to fish abundance. These data, together with flow data will be used in conjunction with results from other studies (gleaned from our literature review and consultations with experts from partners including SAIAB and CapeNature), to ascertain microhabitat requirements for key species, to inform the Environmental Flows requirements of each species and for designing effective conservation interventions.

Electro-fishing sampling on the Amandels River (Photo by Jeremy Shelton).

A spotted bass *Micropterus punctulatus* recorded in a fyke net at site RSE10 (Photo by Jeremy Shelton).

Dr Bruce Paxton examines adult giant redfin sampled with a Fyke net at site RSE6 (Photo by Jeremy Shelton).

A native Cape kurper *Sandelia capensis* sp. "riviersonderend" (left) and invasive Sharptooth catfish *Clarias gariepinus* (right) from a fyke net set at site RSE11 (Photo by Jeremy Shelton).

4.2.4 Analysis

All fish caught in the fyke nets were enumerated and identified to species level, except for Galaxias sp. “zebratus riviersonderend” and Galaxias sp. "zebratus nebula" which were combined. Data are presented as CPUE per site, and size data visualized as frequency distributions (Upper Riviersonderend only), and compared between upstream and downstream of weir on RSE. Snorkel data are presented as number of fish per species recorded over each 20-m site surveyed. Used together with Fyke and shocking data to identify upper and lower distribution limits for each species in the RSE and DUT Rivers. Electrofishing data were used as a complementary measure of species distribution, abundance and assemblage composition, and to examine species-level microhabitat preferences. Fyke, snorkel and electrofishing data were combined to identify the upper and lower distribution of each species in each river.

Habitat data were analysed and related to fish data at two scales, meso-habitat and microhabitat. The meso-habitat analysis involves computing the mean ± SE of each environmental parameter for each baseline monitoring site. These data were subjected to PCA analysis to visualise differences in overall environmental conditions among sites and gradients in individual environmental parameters among sites. Gradients in environmental parameters were then related to the fyke net fish abundance data. PERMANOVA analyses were used to evaluate differences in environmental conditions at sites among the three rivers, and between sites upstream and downstream of the weir on the Upper Riviersonderend.

The microhabitat analyses were based on the environmental data collected during the electrofishing surveys. Depth, flow and substrate measurements recorded at all points where electrofishing was conducted were used to develop histograms of habitat availability. Histograms of habitat use for each species were generated using the habitat data from all points were each species was present. Differences in the distributions of the histograms of habitat availability and use were then used to make inferences about the flow, depth and substrate preferences of each species.

4.3 Results

4.3.1 Distribution and abundance

4.3.1.1 Upper Riviersonderend River

Eight species of freshwater fish were recorded in the Upper Riviersonderend, including two non-native species, and six native species. Figure 4.1 shows the distribution ranges of native fish species in the upper Riviersonderend and Du Toits Rivers based on all sampling methods. The fyke net (Figure 4.2) and snorkel (Figure 4.3) data indicated that the cyprinids *Pseudobarbus* sp. 'burchelli Breede’ and Pseudobarbus skeltoni were the most widespread native species, occurring from RSE1 through RSE8 (where the river transitions from foothill river to palmiet wetland). The upper limit of fish in the Riviersonderend River is marked by a waterfall 100m upstream of RSE1, and the snorkel surveys indicated that Pseudobarbus spp. were found up to the base of the waterfall (snorkel site R5).

Pseudobarbus sp. 'burchelli Breede’ dominated the native fish assemblage by number at most of the sites where it occurred (comprising ~70% of the fyke net catches; total fyke net catch across all sites = 814; Figure 4.1), while *Pseudobarbus skeltoni* was consistently less abundant (comprising ~25% of the native fish assemblage on average; total fyke net catch across all sites = 297). The highest abundances of both *Pseudobarbus* sp. 'burchelli Breede' and *Pseudobarbus skeltoni* were recorded at sites RSE7 (n=406 for *Pseudobarbus* sp. 'burchelli Breede' and n=129 for *Pseudobarbus skeltoni*) and RSE8 (n=104 for *Pseudobarbus* sp. 'burchelli Breede' and n=61 for *Pseudobarbus skeltoni*) – the two sites directly downstream of the gauging weir, but upstream of the palmiet wetland. The pattern of relatively high *Pseudobarbus* abundance downstream of the weir was corroborated by the snorkel surveys (Figure 4.3).

Sandelia capensis sp. "riviersonderend" was recorded from RSE3 through site RSE11 (total fyke net catch across all sites = 347; Figure 4.2), and was consistently more abundant at sites downstream of the weir that at sites upstream of it – a pattern corroborated by the snorkel surveys (Figure 4.3). Electrofishing also revealed that *Sandelia capensis* sp. "riviersonderend" was abundant downstream of the weir, in that 67 individuals were recorded from the 129 points sampled (Figure 4.4). All three of these species were consistently more abundant downstream of the weir than upstream of it (Figure 4.2 and Figure 4.3).

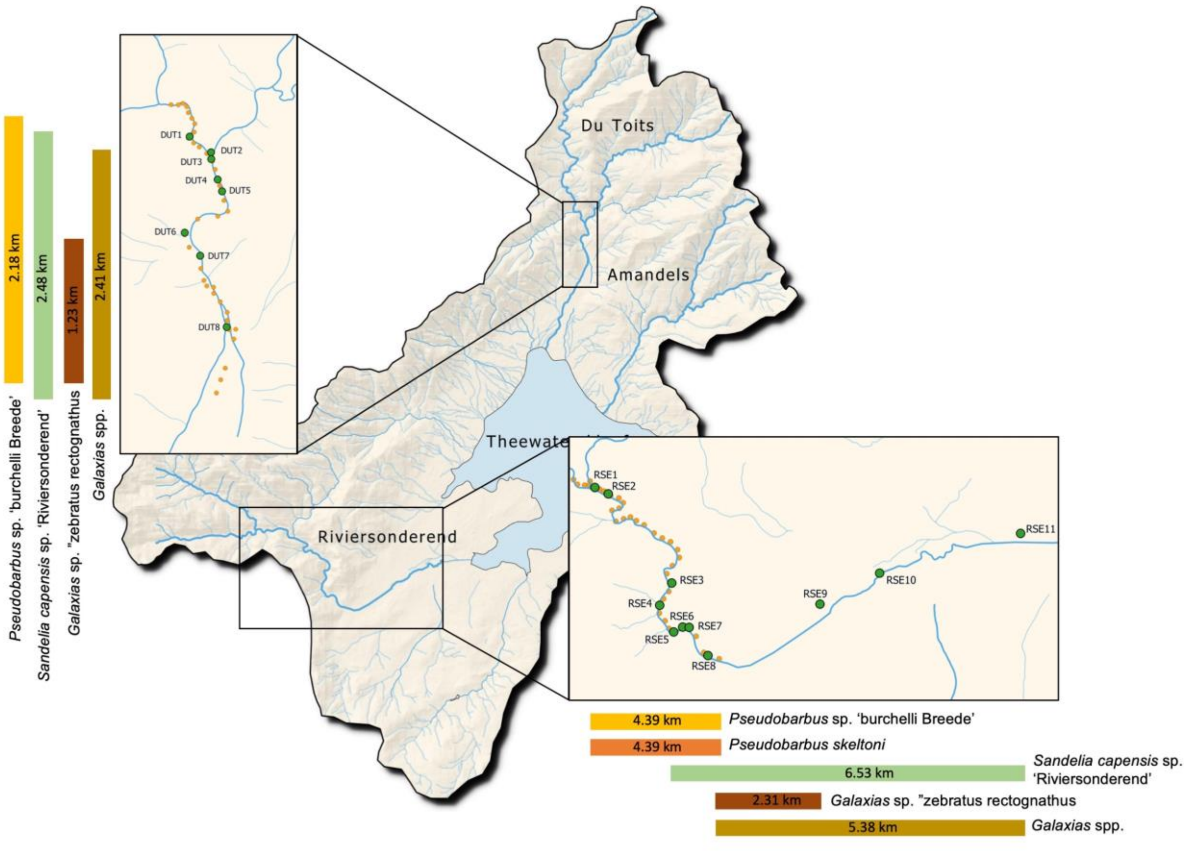


Figure 4.1 Fish distributions in the Upper Riviersonderend, Du Toits and Amandels Rivers based on fyke net (n=22 sites), snorkel (n= 77 sites) and electrofishing (n= 10 sites, 396 points). Coloured bars indicate upper and lower distribution limits for each species, and distances (km) indicate the length of river over which each species occurs.

Both *Galaxias* sp. "zebratus rectognathus" and Galaxias spp. were recorded at sites downstream, but not upstream, of the weir, and galaxiid catches in the fyke nets were relatively low (total fyke net catch across all sites = 10; Figure 4.2). The snorkel (n=45 fish recorded at 13 sites; Figure 4.3) and electrofishing (n=78; 129 points shocked; Figure 4.3) surveys recorded a higher abundance of galaxiids downstream of the weir. The non-native species *Micropterus punctulatus* (n=1) and *Clarias gariepinus* (n=1) were recorded in the fyke nets set at sites RSE10 and RSE11 respectively (Figure 4.2), but not recorded with the other sampling gears.

4.3.1.2 Du Toits River

Four native species, and no non-native species, of freshwater fish were recorded in the Du Toits River. The fyke net and snorkel data (Figure 4.2 and Figure 4.3) indicated that *Pseudobarbus* sp. 'burchelli Breede' was the most widespread fish species, occurring from DUT1 through DUT7 (where the river transitions from foothill river to palmiet wetland). The upper limit of fish in the Du Toits River is marked by a waterfall 400m upstream of DUT1, and the snorkel surveys indicated that *Pseudobarbus* sp. 'burchelli Breede' was found up to the base of the waterfall (snorkel site D3).

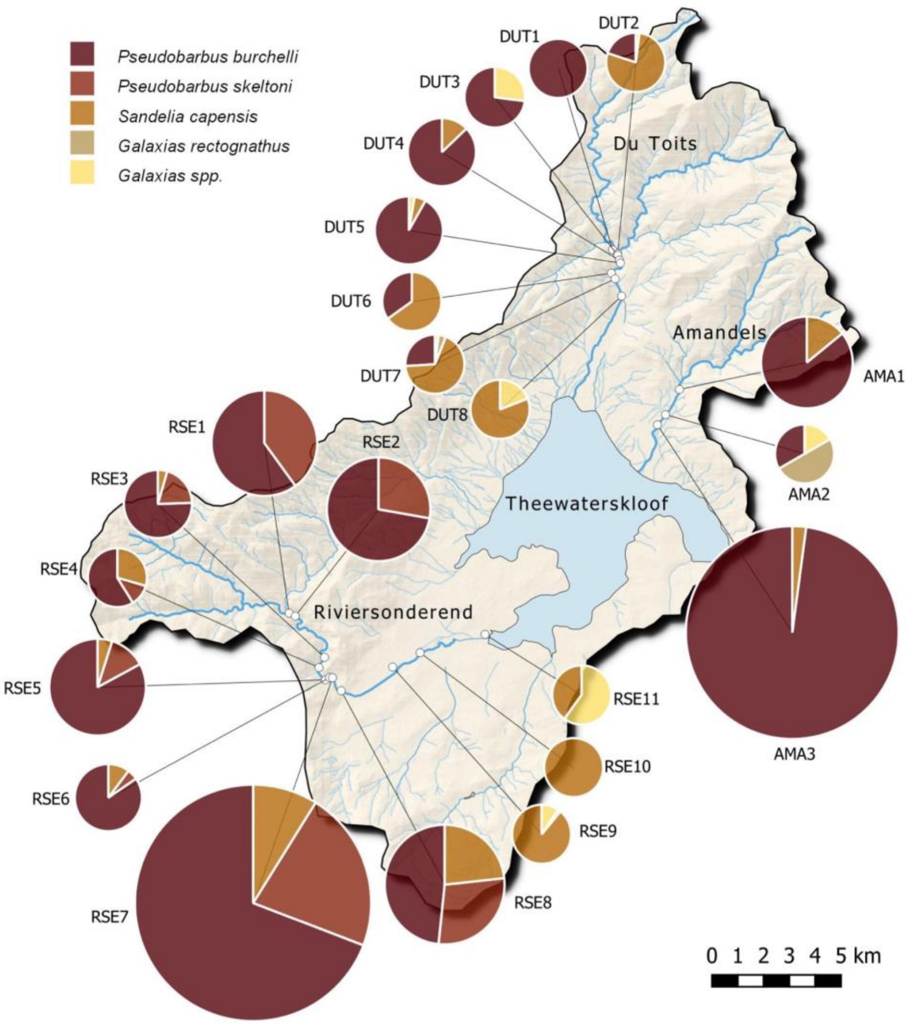


Figure 4.2 Fish assemblage composition based on fyke net data collected at the 22 baseline monitoring sites in the Upper Riviersonderend (n=11), Du Toits (n=8) and Amandel (n=3) Rivers. Bubble size scaled to total number of fish caught at each site.

The fyke net data indicate that *Pseudobarbus* sp. 'burchelli Breede' abundance was greatest at sites DUT3 to DUT5 (fyke net catches > 20 individuals), but that the species was relatively abundant (fyke net catches > 10 individuals) throughout its distribution range (Figure 4.2). The snorkel data, on the other hand, indicate that *Pseudobarbus* sp. 'burchelli Breede' abundance was highest upstream of the weir (several sites in this zone had abundances exceeding 50 fish seen/20m reach), but decreased steadily downstream to the lower-most site where the species was recorded (snorkel site D38) (Figure 4.3).

Sandelia capensis sp. "riviersonderend" was recorded in fyke nets from DUT2 through site DUT8 (total fyke net catch across all sites = 155), though its abundance was lower than that of *Pseudobarbus* sp. 'burchelli Breede' at the majority of the sampling sites (Figure 4.2). With the exception of site DUT2 (where its abundance was relatively high), *Sandelia capensis* sp. "riviersonderend" abundance increased steadily downstream, and both the fyke net and snorkel data agree that it was most abundant at the lower-most sites (Figure 4.2 and Figure 4.3).

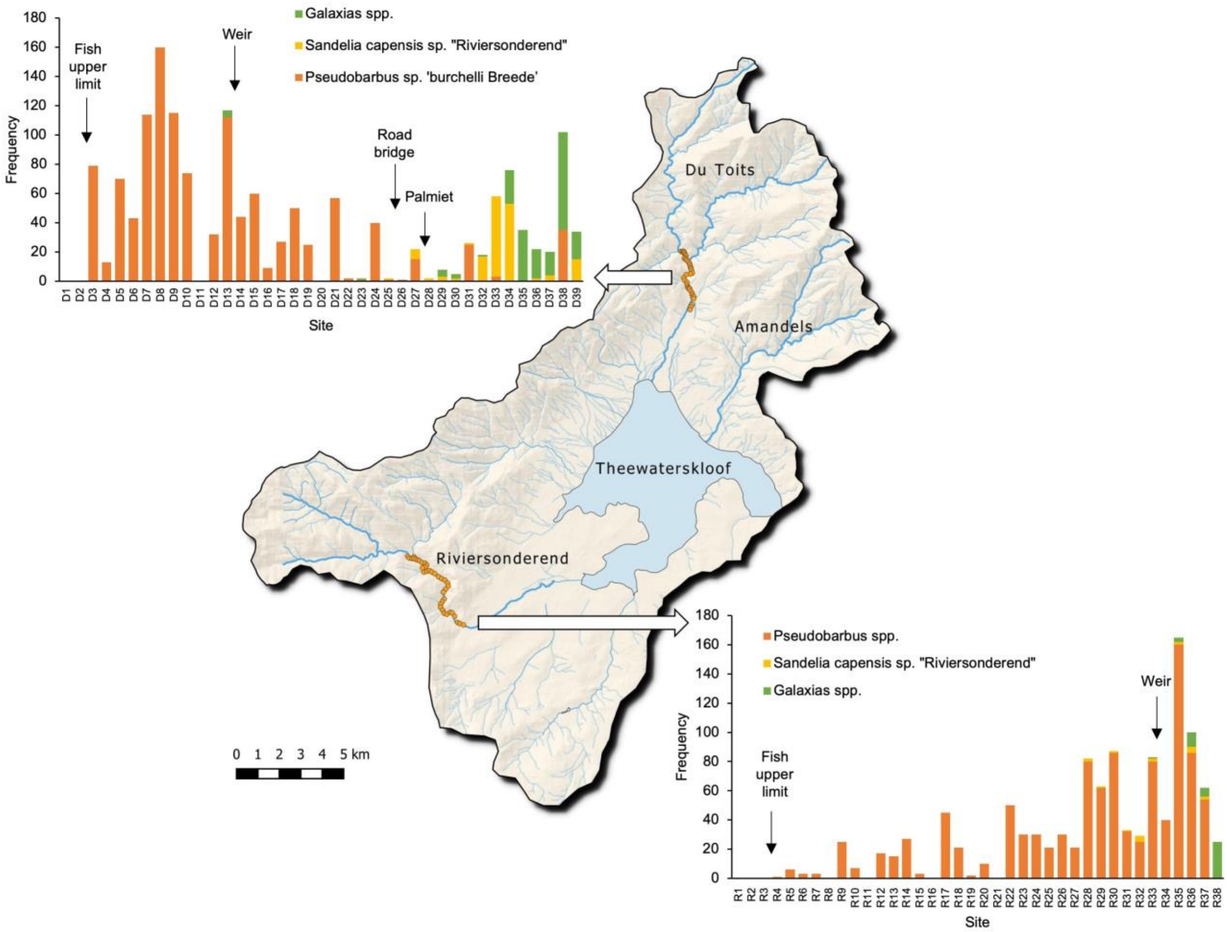


Figure 4.3 Fish abundance (number per 20m reach) and assemblage composition based on snorkel survey data collected at the 38 sites in the Upper Riviersonderend and 39 sites on the Du Toits River.

The snorkel surveys, however, recorded only 1 *Sandelia capensis* sp. "riviersonderend" upstream of the road bridge (where fyke net catches were relatively high; n > 30 at the majority of the sampling sites), but a total of 161 individuals downstream of it. Electrofishing confirmed that *Sandelia capensis* sp. "riviersonderend" was relatively abundant at the lower sites (DUT6-DUT9), in that 35 individuals were recorded from the 229 points sampled (Figure 4.4). Galaxias spp. was recorded in fyke net catches between site DUT2 and DUT8, but Galaxias spp. "zebratus rectognathus" was only recorded at site DUT7 (Figure 4.2). The snorkel surveys recorded *Galaxias* spp. at nine of the 14 sites surveyed downstream of the road bridge, and > 20 individuals were seen at the six lowermost survey sites (Figure 4.3). The electrofishing data indicate that both *Galaxias* spp. (40 individuals recorded from the 229 points electrofished) and *Galaxias* spp. "zebratus rectognathus" (45 individuals recorded from the 229 points electrofished) were abundant downstream of the road bridge (Figure 4.4).

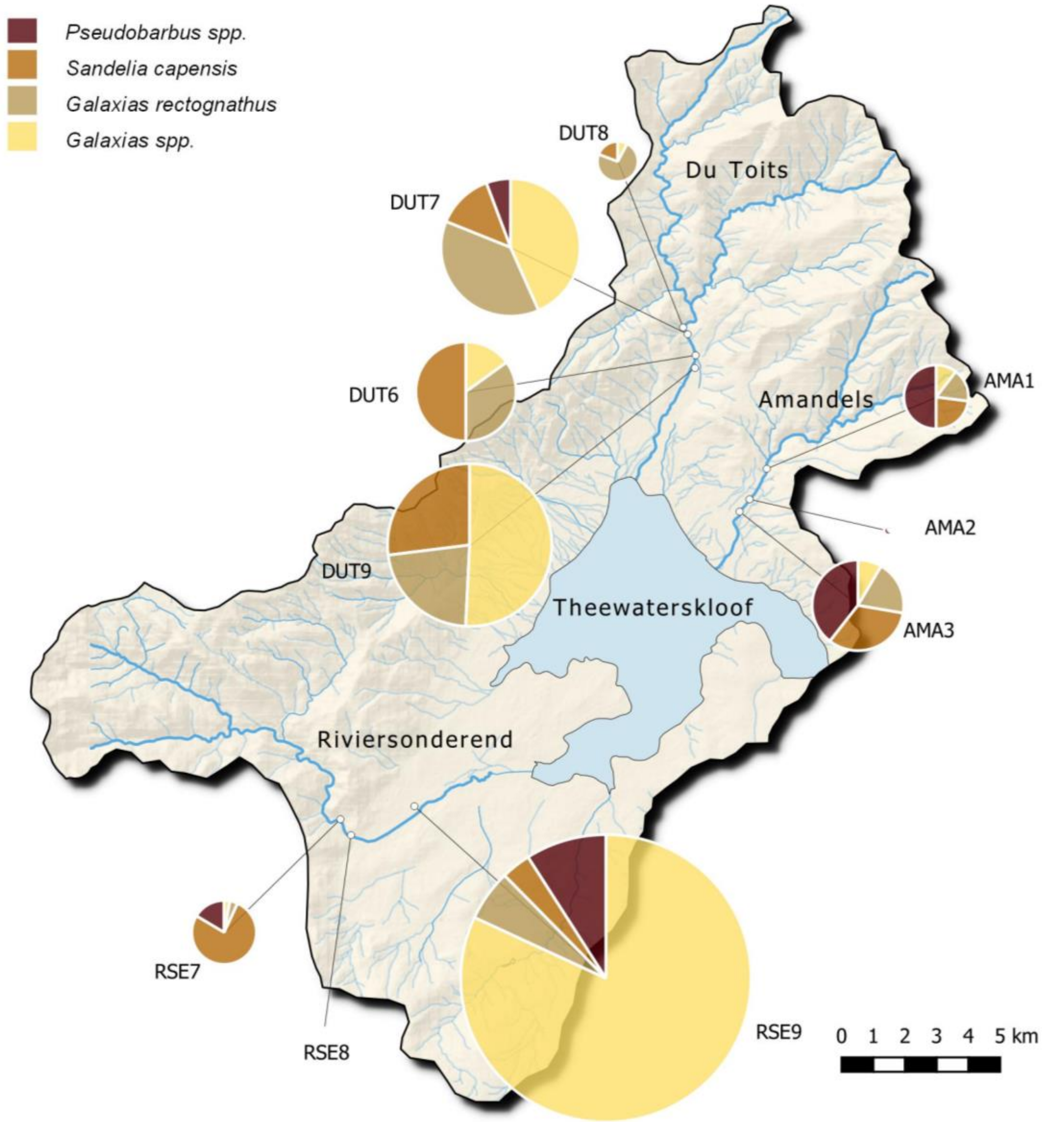


Figure 4.4 Fish assemblage composition based on electrofishing data collected at 10 of the baseline monitoring sites in the Upper Riviersonderend (n=3), Du Toits (n=4) and Amandel (n=3) Rivers. Bubble size scaled to total number of fish caught at each site.

4.3.1.1 Amandels River

Four native species (and no non-native species) of freshwater fish were recorded in the Du Toits River, including *Pseudobarbus* sp. 'burchelli Breede', *Sandelia capensis* sp. "riviersonderend", *Galaxias* spp. and *Galaxias* spp. "zebratus rectognathus". Fyke net data indicate that the fish assemblage was dominated by *Pseudobarbus* sp. 'burchelli Breede' – the only fish species recorded at all three sites (Figure 4.2). *Sandelia capensis* sp. "riviersonderend" was absent from the fyke net catch at AMA2, and, while the galaxiids were only recorded in the fyke net catch at AMA2. The Fyke data indicate that fish abundance was highest at AMA3 and lowest at AMA2. Electrofishing recorded all species at all three sites (except *Galaxias* spp. was not recorded at AMA2), and the electrofishing data were consistent with the trend that fish abundance was highest at AMA3 (Figure 4.4)

4.3.2 Population size structure

Size distributions for the Upper Riviersonderend revealed a wide range of size classes present within the native species *Pseudobarbus* sp. 'burchelli Breede', *Pseudobarbus skeltoni* and *Sandelia capensis* sp. "riviersonderend" (Figure 4.5). *Pseudobarbus* sp. 'burchelli Breede' sizes ranged between 30mm and 140mm, with a median size of 70mm (Figure 4.5a). *Pseudobarbus skeltoni* sizes ranged from 50mm to 190mm, with a median size of 70mm and secondary distribution peak at 110mm (Figure 4.5b). Both curves are skewed slightly to the right, indicating healthy populations with good numbers of both juvenile and adult size classes. The size curve for *Sandelia capensis* sp. "riviersonderend" indicated that the majority of fish fell between 50mm and 120mm, but that larger individuals up to 200m were also present at several of the sites (Figure 4.5c). The eight *Galaxias* spp. fell between 20-50mm, indicating recruitment, and just one 110mm (adult) *Galaxias* sp. 'zebratus rectognathus' was caught in the fyke nets (Figure 4.5d).

There were some subtle differences in the size frequency distributions of *Pseudobarbus* sp. 'burchelli Breede', Pseudobarbus skeltoni and *Sandelia capensis* sp. "riviersonderend" from sites upstream and downstream of the weir. In particular, the largest size classes of all three species were more abundant at sites below the weir than above it (Figure 4.6).

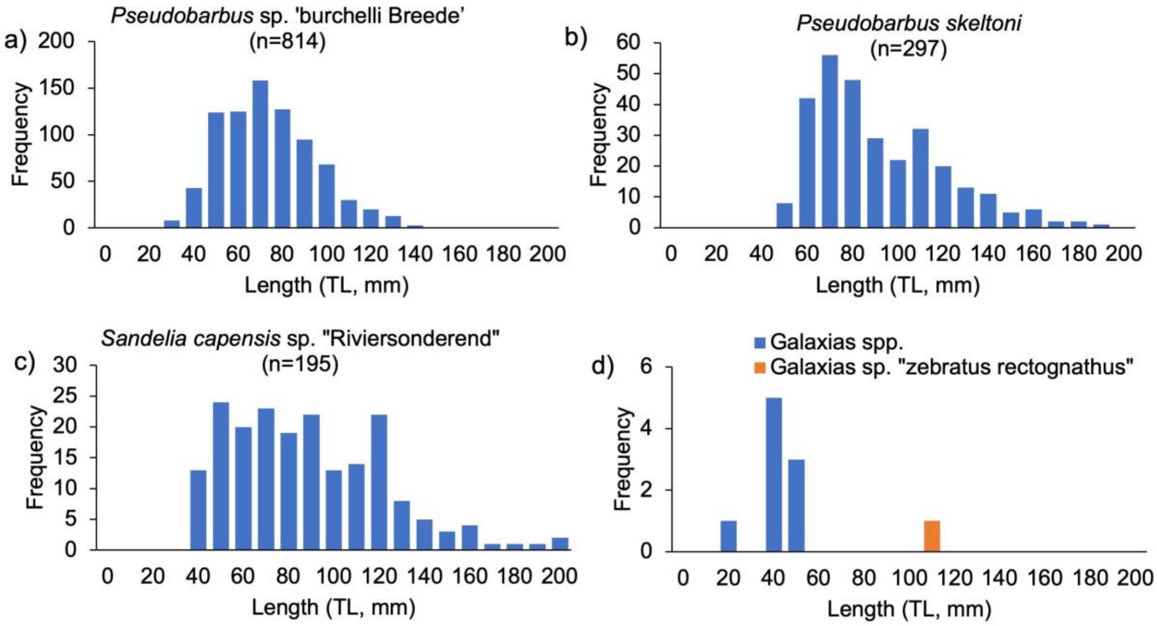


Figure 4.5 Size frequency distributions of native fish species recorded in the Upper Riviersonderend (data from all sampling sites combined).

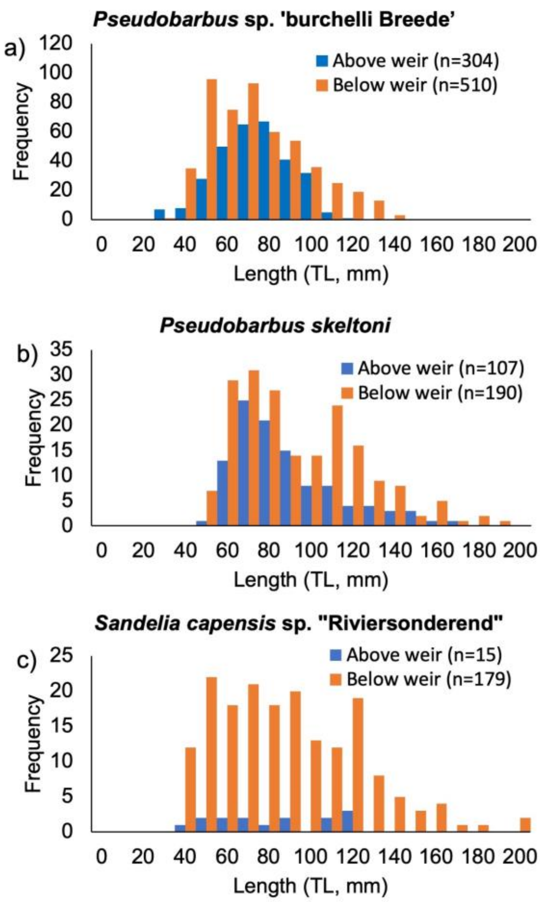


Figure 4.6 Size frequency distributions of native fish species upstream (blue bars) and downstream (orange bars) of the gauging weir on the Upper Riviersonderend.

4.3.3 Habitat associations

Appendices 3a and 3b show the mean ± SE of habitat variables and physico-chemical variables respectively. The PCA analysis revealed consistent differences in environmental conditions at sites on the three rivers surveyed, and PERMANOVA analysis confirmed that these differences were statistically significant ($F = 3.65$, $p < 0.002$; Figure 4.7). Sites on the Amandels River were more acidic, shallower, narrower and had less aquatic vegetation than sites in the other two rivers. In general, sites on the Upper Riviersonderend were characterised by swifter flows, more dissolved oxygen, larger substrata and lower TDS and conductivity than sites on the Amandel and Du Toits Rivers. Sites on the Du Toits River had consistently higher TDS and conductivity, and slower flows, smaller substrata and less dissolved oxygen than sites on the other two rivers.

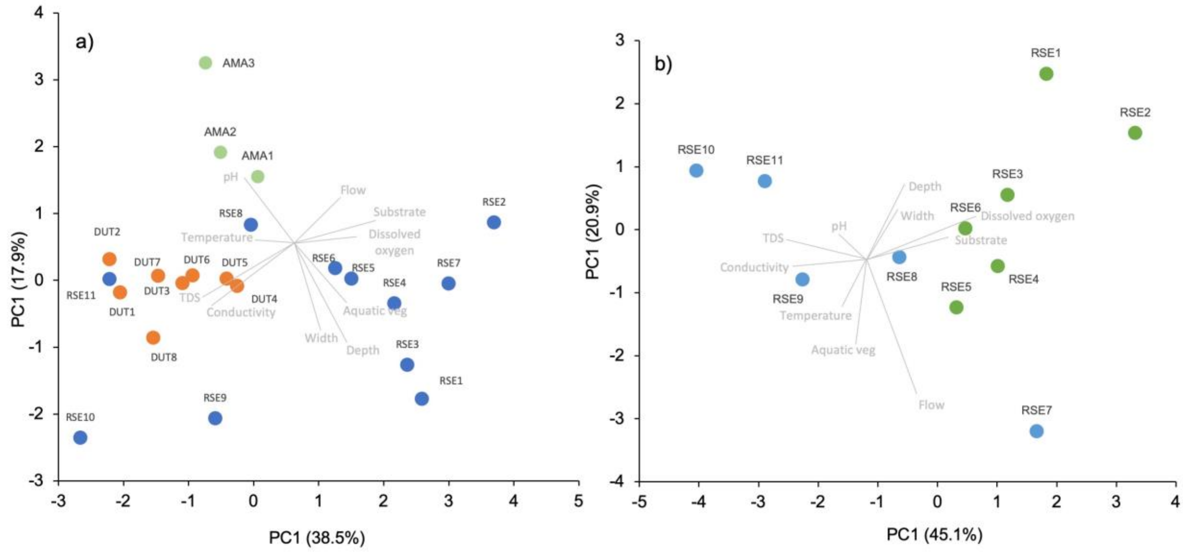


Figure 4.7 Principal Components Analyses showing groupings of sites and gradients in environmental conditions at (a) all baseline monitoring sites on the Upper Riviersonderend, Du Toits and Amandels Rivers, and (b) baseline monitoring sites upstream and downstream of the weir on the Upper Riviersonderend.

The PCA conducted on sites on the Upper Riviersonderend only revealed separation of sites upstream of the weir from those downstream of it, and the PERMANOVA analysis confirmed that this difference was statistically significant ($F = 3.17$, $p < 0.016$; Figure 4.7a). In general, sites upstream of the weir were characterised by having higher conductivity and TDS, more aquatic vegetation, lower levels of dissolved oxygen, finer substrata and narrower, shallower channels than sites upstream of the weir.

In total, 129 points were electrofished in the Upper Riviersonderend, 149 points in the and Amandels River and 229 points in the Du Toits River. A total of 76 *Pseudobarbus* sp. 'burchelli Breede', 131 *Sandelia capensis* sp. "riviersonderend", 77 *Galaxias* spp. and 116 *Galaxias* spp. "zebratus rectognathus" occurrences were recorded. The microhabitat analyses (Figure 4.8) showed that finer substrates (<400mm) were generally the more readily available than coarse substrates (with substrates >400mm comparatively scarce), and that patterns of habitat use for all four species generally mirrored patterns of habitat availability in the three rivers (Figure 4.7a). The most commonly-available depth class was 0.20-0.39m, followed by <0.20m and then 0.40-0.50m. This histogram of depth availability was closely mirrored by both *Galaxias* spp. "zebratus rectognathus" and *Sandelia capensis* sp. "riviersonderend", but *Galaxias* spp. and Pseudobarbus sp. 'burchelli Breede' used deeper (>0.40m) habitats more frequently (Figure 4.8b). The most commonly-available flow velocity class was <0.2m/s, followed by 0.6-0.79m/s, 0.8-0.99 m/s, 1.0-1.19m/s, 0.2-0.39m/s and >1.19m/s. With the exception of *Galaxias* spp. "zebratus rectognathus", all species were most frequently recorded in relatively slow-flowing (<0.2m/s) habitats. *Galaxias* spp. "zebratus rectognathus", on the other hand was most frequently recorded in higher flow velocities (>0.6m/s), likely indicating a preference for swifter-flowing habitats (Figure 4.8c).

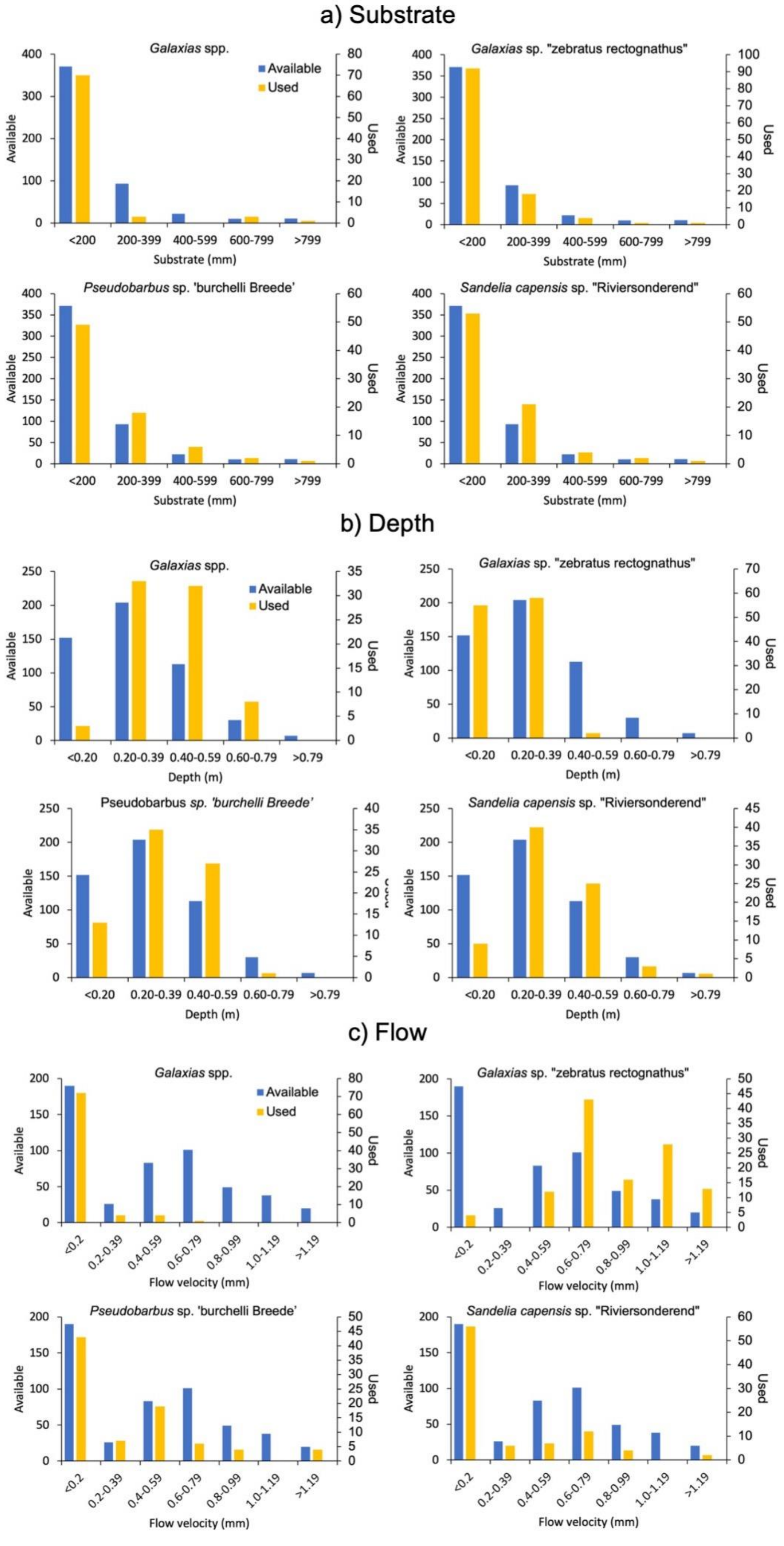


Figure 4.8 Microhabitat data for four native fish based on electrofishing data from 10 sites and 396 sampling points on the Upper Riviersonderend, Du Toits and Amandels Rivers. Yellow bars indicate habitat availability and blue bars indicate habitat occupied.

4.4 Discussion

4.4.1 Upper Riviersonderend

The Upper Riviersonderend had the highest fish diversity and was the only river where non-native fish species were recorded. The fish upper limit is marked by waterfalls, and the two *Pseudobarbus* species occur over a ~4km stretch of pristine river habitat (only ecotourism and non-native plant impacts occur upstream)**.** Their lower limit of these species is marked by a palmiet wetland, which may also act as an invasion barrier to non-native fish that have colonized the river downstream (likely from the Theewaterskloof Dam)**.**

The greater abundance of native fish (particularly large individuals of *Pseudobarbus* sp. 'burchelli Breede', *Pseudobarbus skeltoni* and *Sandelia capensis* sp. "riviersonderend") downstream of the weir suggests that habitat conditions in the short (<1km) stretch of river between the weir and the start of the palmiet wetland may be more favorable than that upstream of the weir. Indeed, our habitat analyses showed consistent differences in habitat conditions between these sections of river, notably finer substrates, gentler flows, warmer temperatures and more aquatic vegetation.

Two human-linked factors could potentially be impacting on the native fish in this zone. First, non-native plants including pines and black wattles are invading the riparian zone and, in some areas, have already replaced native riparian vegetation entirely, which appears to be causing sedimentation and substrate homogenization within the river channel, which has known negative impacts on native fish feeding, spawning and sheltering habitats. Moreover, the non-native plant species use more water than do the native plants that they replace, which is a cause for concern for species like the endemic, range-restricted *Galaxias* spp. "zebratus rectognathus" which appear to rely on swift-flowing (>0.6m/s) habitats (Figure 4.8). Second, the weir may be acting as a physical barrier to seasonal native fish migrations between spawning habitats, feeding habitats and over summering / wintering refugia.

Non-native fish impacts appear to be restricted to reaches downstream of the palmiet wetland (which appears to pose a physical barrier to upstream dispersal), and pose no obvious threat to the *Pseudobarbus* spp. in this system at present. However, these non-native fish, together with water quality and quantity impacts stemming from agriculture downstream may pose a threat to *Sandelia capensis* sp. "riviersonderend" and *Galaxias* spp. "zebratus rectognathus" and *Galaxias* spp. populations downstream of site RSE8. Options for conservation interventions addressing these two impacts are being in developed.

4.4.2 Du Toits River

Historic data indicate that while known to be abundant in the 600m stretch of river between the weir and the waterfall marking the upper limit of the fish distribution, native fish were scarce or absent downstream of the gauging weir (Lowe 2008). Their absence from this section was attributed to the presence and impacts of non-native fish like *Micropterus* spp. (Lowe 2008). Contrastingly, our surveys revealed good numbers of native fish at all sites sampled downstream of the weir, and no non-native were detected, despite our use of multiple sampling methods and periods. This finding may indicate recolonization and recovery of the native species in this section in response the disappearance of non-native fish.

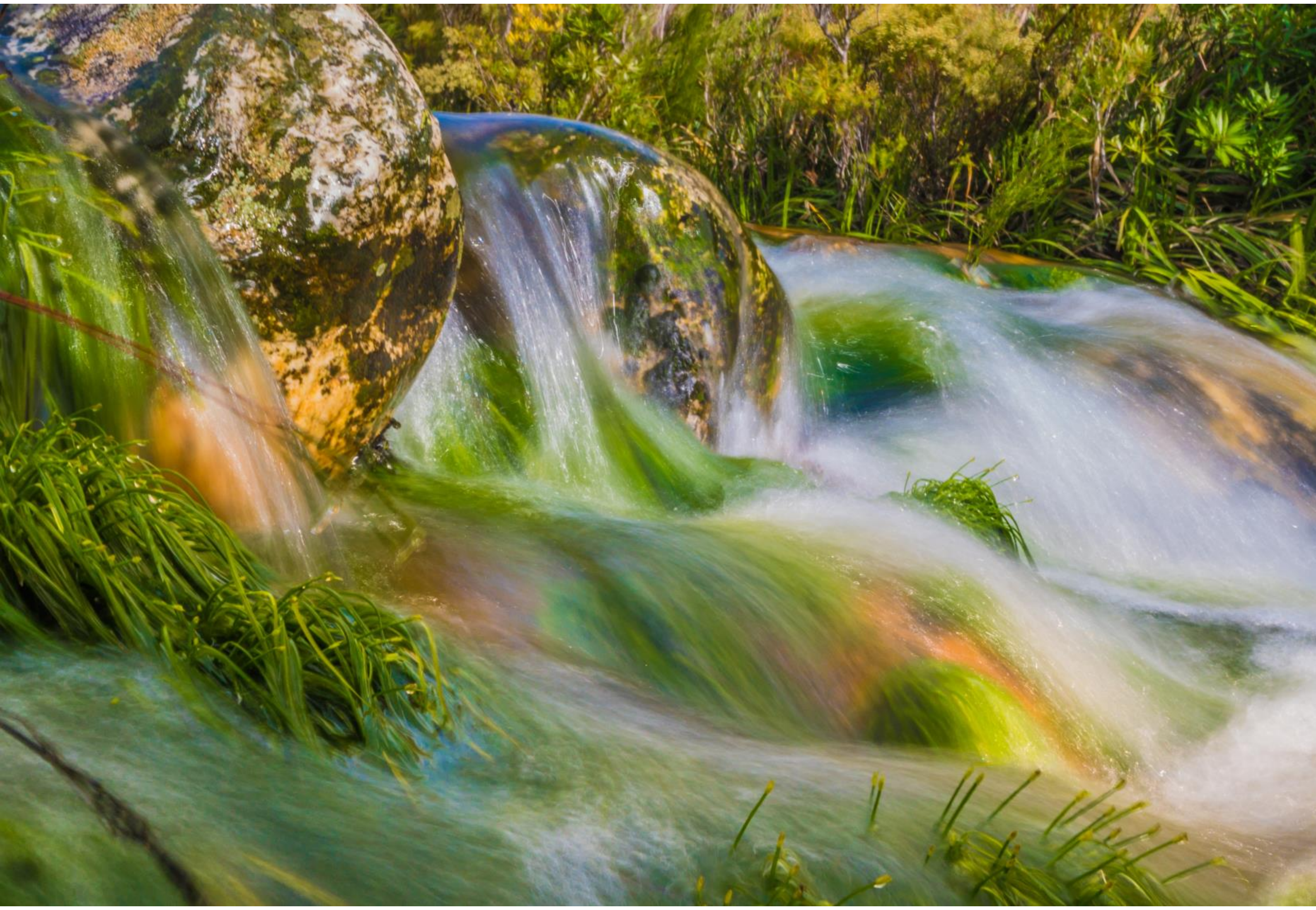
Possible reasons for the disappearance of non-native *Micropterus* spp. include impacts of drought (Shelton *et al.* 2018) and *Clarias* *gariepinus* predation (Skelton 2001). This reach has high conservation value and management options for maintaining high ecological integrity include removing non-native plants (like black wattle) that have started invading the riparian zone, and preventing new non-native fish invasions (perhaps through installing a physical fish barrier in the vicinity of DUT8) as conditions stabilize (and re-invasion likelihood increase) following the drought. The (re)introduction of Endangered Berg-Breede River whitefish, which almost certainly once occurred in this section of river (Shelton 2001), should also be considered.

Of special interest is the finding that *Galaxias* spp. "zebratus rectognathus", *Galaxias* spp. and *Sandelia capensis* sp. "riviersonderend" distribution ranges now extend all the way down to the lower-most sites where the river transitions from foothill zone to palmiet wetland (>2km downstream of the weir), emphasizing the conservation value of this area for freshwater fish, particularly for these endemic, highly range-restricted species.

4.4.3 Amandels River

Our surveys indicate that the Amandels River supports healthy populations of native of *Pseudobarbus* sp. 'burchelli Breede', and endemic, range-restricted *Sandelia capensis* sp. "riviersonderend"), *Galaxias* spp. "zebratus rectognathus" and *Galaxias* spp., and that this river is probably the least in need of a conservation intervention of the three. That said, thick pine invasions higher up in the catchment are a concern for flow and water quantity – particularly given the apparent reliance of *Galaxias* spp. "zebratus rectognathus" on swift (>0.6m/s) flows. The relatively low native fish abundance at site AMA2, adjacent to Amandel Farm, is likely a response to agriculture-linked impacts on water and habitat quality. However, the fish populations appear to recover downstream of the farm boundary, with site AMA3 showing very high native fish abundance.

No non-native fish were recorded in the Amandels River, despite the apparent lack of barriers to invasion from Theewaterskloof Dam. The upper and lower limits of native fish were not identified in this study, but this information would be useful for evaluating whether or not agricultural impacts are a cause for native fish concern in this river, and whether or not conservation interventions should be considered.



Wetland and River Health

The ecological health or integrity of an ecosystem is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on temporal and spatial scales that are comparable to the natural characteristics of ecosystems of the region.

5.1 Introduction

The ecological integrity of an ecosystem is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on temporal and spatial scales that are comparable to the natural characteristics of ecosystems of the region. The integrity of a system is directly influenced by its current state, and how much the system has been altered from the reference or unimpacted condition. The ecological importance of a freshwater ecosystem is an expression of its importance to the maintenance of ecological diversity (i.e. both species and habitat diversity) and functioning on local and wider scales.

A total of 40 wetlands have been mapped in the two study catchments, making up a total area of 2266 hectares. The wetlands are a mix of types – channelled and unchannelled valley-bottom wetlands, depressions and seeps. According the national wetland inventory, seeps cover by far the largest area, followed by unchannelled and then channelled valley-bottom wetlands. The wetlands within the two quaternary catchments are predominantly associated with rivers – starting as seeps at high altitude that feed into narrow valley-bottom wetlands located within valley floors between high mountains, and then flowing into wider valley-bottom wetlands lying on the flatter slopes on which the Theewaterskloof Reservoir lies. The mainstem rivers of the two quaternary catchments run for a total of 79 km, and all are perennial. The rivers are a mix of mountain streams, upper foothill and lower foothill rivers. Only the Upper Riviersonderend transitions from an upper foothill to a lower foothill river within the study area – this occurs at site RSE8.

Catchments H60A and H60B lie primarily within the Southern Folded Mountains ecoregion (sensu Kleynhans *et al.*, 2005), with a small overlap into the Southern Coastal Belt. In terms of vegetation bioregions, the study area lies entirely within the Southwest Fynbos bioregion (Rebelo *et al.*, 2006). This bioregion has been shown to support wetlands and rivers with a high diversity and density (number of wetland plants per hectare of wetland) of wetland and riparian plants, especially in those wetlands occurring at high altitudes (Sieben *et al.*, in prep.). The Southwest Fynbos bioregion also supports the highest level of endemism of wetland plant species in the whole country – the bioregion lies, after all, in the Cape Floristic Region (CFR), with 69% of the CFR's plant species endemic to the CFR (Linder *et al.*, 2010; de Moor and Day 2013), and 56% of all aquatic taxa, resulting in the CFR being classified as one of the World's 200 significant Freshwater Ecoregions (Thieme *et al.*, 2005).

The wetlands and rivers are fed by rainfall, with groundwater also playing an important role, either from shallow short return-time interflow in the vadose (unsaturated) zone, or from the deeper long return-time aquifers (Snaddon *et al.*, 2014; 2018). Sieben *et al.* (in prep.) found that the diversity and level of endemism of wetland plants are positively correlated with rainfall – thus, the wetlands that occur in South Africa's high rainfall/high runoff catchments tend also to be the most diverse, with the highest occurrence of range-limited plant species. A large proportion of wetland area is made up of palmiet (*Prionium serratum*) beds. This obligate wetland plant has been described as an "ecosystem engineer" due to its ability to block water flow where the plant proliferates, leading to the accumulation of organic material and the development of wetland conditions (Sieben, 2012; Job, 2014).

The organic content of the soils in the Upper Riviersonderend and Du Toits River wetlands has been sampled on a number of occasions in the past (Job and Reeler, 2013; Kotze, 2015), and has been estimated that the two wetlands contain over 350 000 and 1 000 000 m^3 respectively (Kotze, 2015). These organic soils below the palmiet are known to slow down water flow (thereby increasing flood attenuation), and to store water well into the drier months (thereby lengthening the duration of baseflows in downstream river reaches).

5.2 Methods

The health or condition of the wetlands and rivers was assessed both at a desktop level (Figure 5.1), and then in greater detail for a subset of sites during the March 2019 field trip.

5.2.1 Desktop assessment

The desktop assessment of **wetland** health was done by means of a Level 1A WET-Health assessment (Ollis *et al.* in prep.). The method is based on land-cover data, and provides an indication of the deviation of wetland condition from the natural reference state. This allows for the identification of current impacts on wetland integrity and overall catchment health. The desktop map of condition was ground-truthed at the field sites and refined during March 2019.

For the **rivers**, the DWS desktop Present Ecological State (PES) data were used (DWS, 2014). These data give an overall PES category for river reaches, based on a number of parameters – riparian and instream habitat integrity, flow, physico-chemical modifications. These data were also ground-truthed during March 2019.

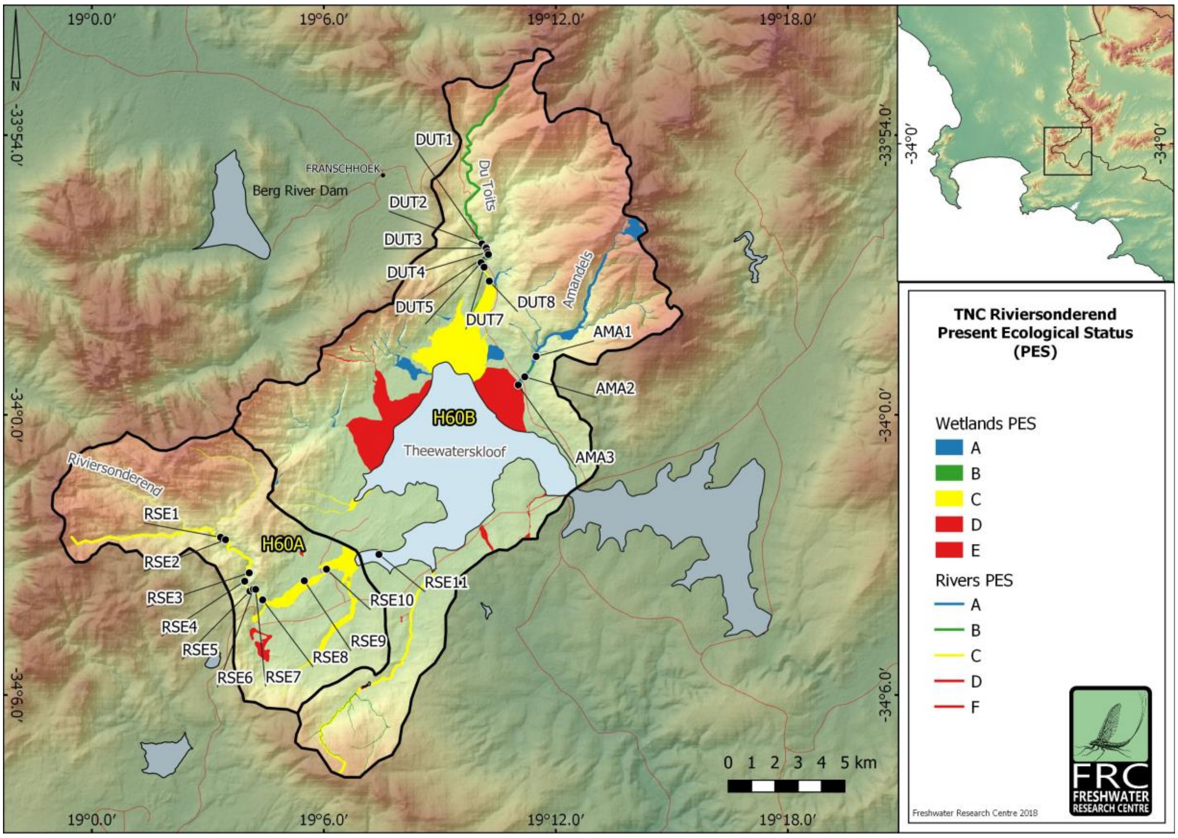


Figure 5.1 Desktop assessment of Present Ecological State (PES) of the wetlands and rivers in quaternary catchments H60A and H60B.

5.2.2 In-field assessment

Two key wetlands were selected for in-field assessment of wetland condition, using data collected in March 2019, and with reference to other work done by Snaddon *et al.* (2018). These were the weakly channelled valley-bottom wetland surrounding the middle and lower Upper Riviersonderend, and the unchannelled valley-bottom wetland surrounding the lower Du Toits River.

The Level 2 WET-Health protocol was followed for the assessment of condition (MacFarlane *et al.*, 2009). This method gives an indication of the deviation of a wetland system from its natural reference condition, through assessing the following biophysical drivers:

- Hydrology - defined as the distribution and movement of water through a wetland and its soils;
- Geomorphology - defined as the distribution and retention patterns of sediment within the wetland; and
- Vegetation - defined as the vegetation structural and compositional state.

All observed impacts on the assessed wetlands, determined by examining features of the wetlands and their catchments, were scored based on impact scores and then represented as Present Ecological State (PES) Categories (Table 5.1).

Table 5.1The scores for hydrology, geomorphology and vegetation were simplified into a composite impact score, using the predetermined ratio of 3:2:2 (MacFarlane *et al.*, 2009) respectively for the three components.

Table 5.1 Impact scores and present ecological state (PES) categories for describing the integrity of wetlands. (MacFarlane *et al.*, 2009).

Impact Category	Description	Impact Score (0-10)	Present Ecological State Category
None	Unmodified, natural.	0-0.9	**A**
Small	Largely natural with few modifications. A slight change in ecosystem processes is discernible and a small loss of natural habitats and biota may have taken place.	1-1.9	**B**
Moderate	Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact.	2-3.9	**C**
Large	Largely modified. A large change in ecosystem processes and loss of natural habitat and biota has occurred.	4-5.9	**D**
Serious	The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognizable.	6-7.9	**E**
Critical	Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	8-10	**F**

For the **rivers**, the Department of Water and Sanitation's (DWS) Resource Directed Measures (RDM) approach was used. This method is based on the assessment of existing impacts on two components of the river or watercourse - the riparian zone and the instream habitat. Assessments are made separately for both components, but data for the riparian zone are interpreted primarily in terms of their potential impact on the instream component. Criteria within each component (see Table 5.2) are pre-weighted according to the importance of each, and each criterion is scored between 0 and 25, with six descriptive categories ranging from 0 (no impact), 1 to 5 (small impact), 6 to 10 (moderate impact), 11 to 15 (large impact), 16 to 20 (serious impact) and 21 to 25 (critical impact). The scores for the instream and riparian zone components were used to place the site in a habitat integrity category (A – E/F) for both components (see Table 5.3). A full description of the method can be found in DWAF's RDM document (DWAF, 1999).

The Field Guide to Present Ecological State Scores (Southern Waters, 2001) was used to complete the assessment of PES.

Table 5.2 Criteria used in the assessment of Present Ecological Status (from Kleynhans, 1996).

Criterion	Relevance
Water abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.
Flow modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.
Bed modification	Regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment. Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the stream bed, e.g. the removal of rapids for navigation is also included.
Channel modification	May be the result of a change in flow, which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.
Water quality modification	Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments.
Exotic macrophytes	Alteration of habitat by obstruction of flow and may influence water quality. Dependent upon the species involved and scale of infestation.
Solid waste disposal	A direct anthropogenic impact which may alter habitat structurally. Also a general indication of the misuse and mismanagement of the river.
Indigenous vegetation removal	Impairment of the buffer the vegetation forms to the movement of sediment and other catchment runoff products into the river. Refers to physical removal for farming, firewood and overgrazing.
Exotic vegetation encroachment	Excludes natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochthonous organic matter input will also be changed. Riparian zone habitat diversity is also reduced.
Bank erosion	Decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment.

Table 5.3 Present Ecological State categories for watercourses (adapted from Kleynhans, 1996).

PES Category	Score (%)	Description
A	90-100	Unmodified, natural.
B	80-90	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	60-79	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.
D	40-59	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	20-39	The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	0	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

5.3 Results and Discussion

5.3.1 Wetlands

There is a total of 2266 hectares of wetland in the two quaternary catchments. According to the desktop assessment of wetland condition, 87% of the wetland area is in a C Category ("fair") or lower. Most of the wetland area is located on the slopes around the Theewaterskloof Reservoir, and so has been impacted over many years by agriculture, infrastructure development (roads, pipelines, sportsfields, etc.), residential and industrial activities. Two large wetlands were assessed in detail in the field, namely the Upper Riviersonderend and Du Toits River valley-bottom wetlands.

5.3.1.1 Upper Riviersonderend wetland

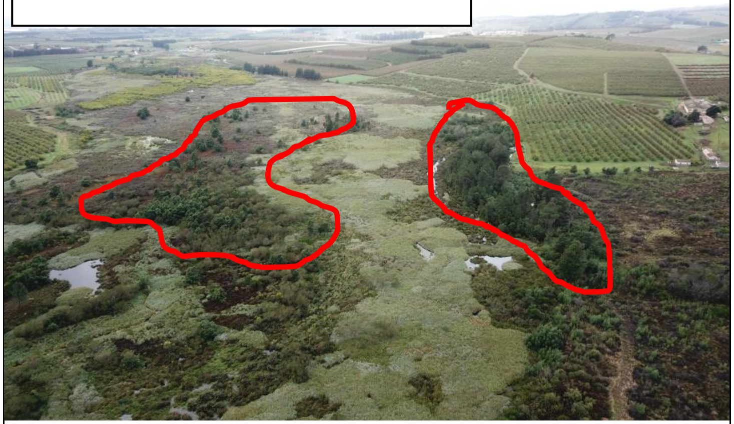
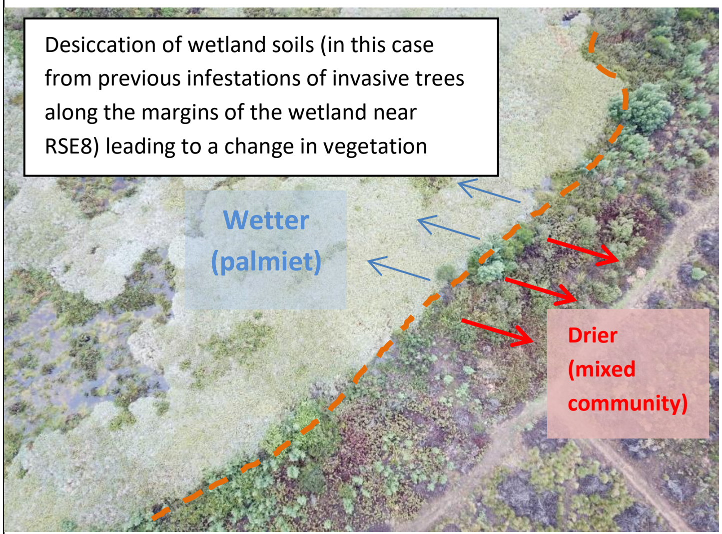
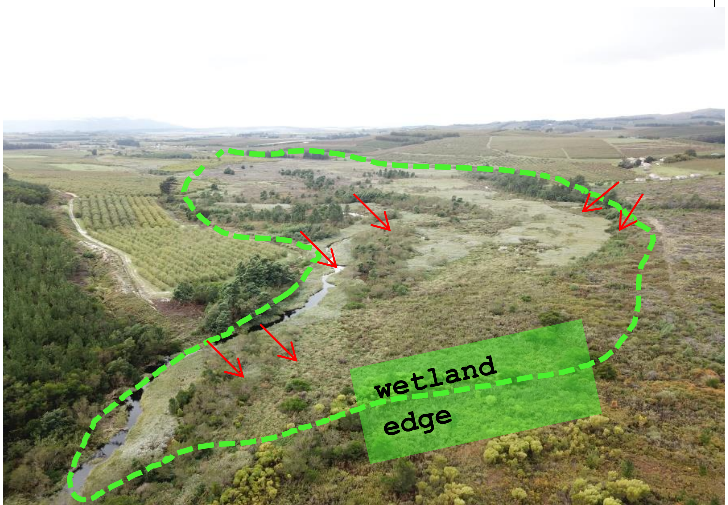
The Upper Riviersonderend wetland is in a largely modified state, primarily due to altered hydrology as a result of agricultural practices, invasive alien plant (IAP) encroachment (past and/or present) and afforestation. The Level 2 WET-Health assessment yielded a PES Category D for the wetland as a whole (Table 5.4). One of the major impacts that were evident from RSE8 downstream to the confluence with Theewaterskloof, is erosion. The erosion is linked to:

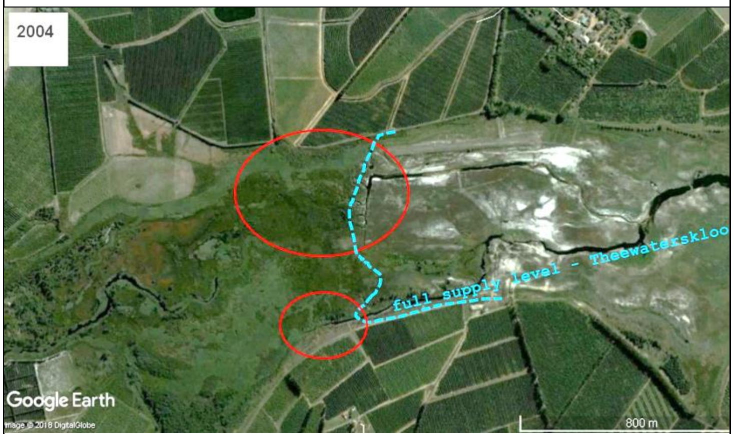
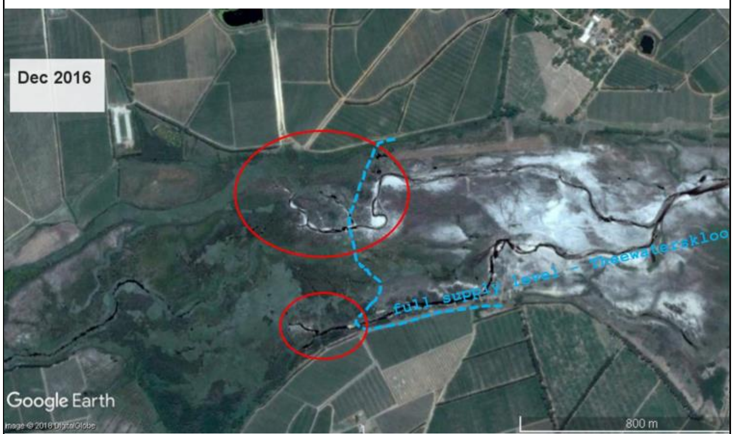
- IAP invasion, which alters soil morphology, causing destabilisation of soils;
- IAP clearing where cleared biomass is left in the wetland or river channel, blocking surface flows and causing head-cut erosion and incision;
- Rapid changes in water level around the margins of Theewaterskloof Dam (and drying out of soils during the recent dry period) trigger head-cut erosion into the wetlands feeding the dam. This erosion and loss of organic soils and wetland vegetation leads to channelisation of flows in erosion gullies. This leads to the draining and desiccation of wetland areas and further erosion.
- Agricultural channels carrying irrigation return flows and other surface flows into the wetland;
- Roads and bridges, which constrict and re-direct surface flows, causing head-cut erosion and channel incision, and
- Infilling of wetland area, directing surface flows into concentrated channels.

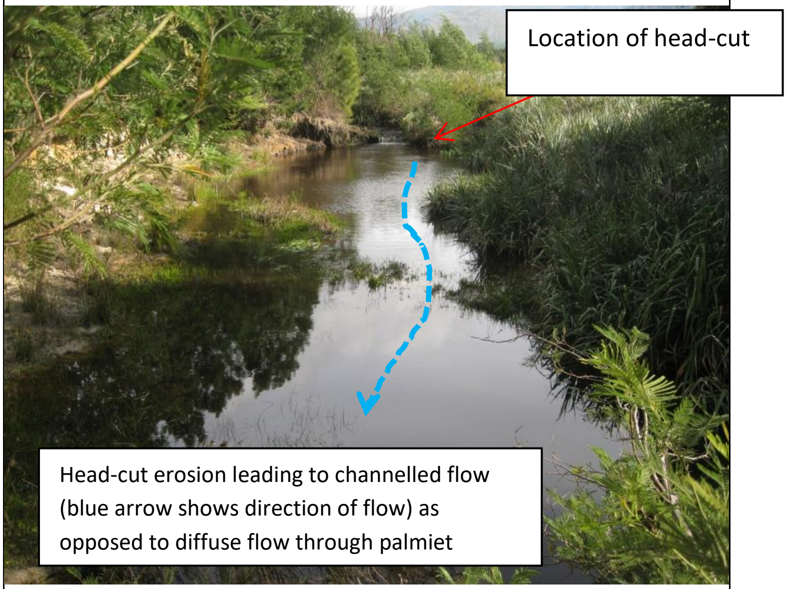
Table 5.4 Results of the Level 2 WET-Health assessment on the Upper Riviersonderend and Du Toits River wetlands (both valley-bottom wetlands).

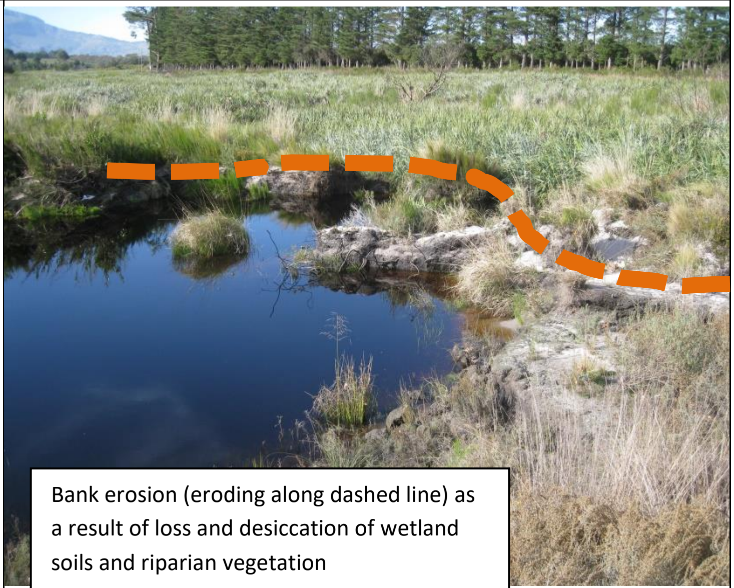
Wetland name		Upper Riviersonderend	Du Toits
Hydrology	Impact Score	6.0	6.5
	PES Category	**E**	**E**
Geomorphology	Impact Score	3.1	1.6
	PES Category	**C**	**B**
Vegetation	Impact Score	3.0	2.0
	PES Category	**C**	**C**
Overall	Impact Score	4.3	3.8
	PES Category	**D**	**C**

Table 5.5 Photographs of the impacts recorded in the Upper Riviersonderend wetland.

Wetland problem	Photos
IAP encroachment. Photo shows black wattle near RSE9. IAP encroachment alters soil morphology, causing destabilization, while elevated evapotranspiration rates from exotic species causes desiccation of soils	IAPs (mostly black wattle) in the Upper Riviersonderend wetland. (Photo courtesy of Heidi Nieuwoudt)  
IAP encroachment (red arrows) into the wetland area – leading to evapotranspiration losses that are higher than that attributed to indigenous vegetation (photo taken just downstream of RSE8)	

Wetland problem	Photos
Rapid changes in water level around the margins of Theewaterskloof Dam (and drying out of soils during the recent dry period) trigger head-cut erosion into the wetlands feeding the dam. This erosion and loss of organic soils and wetland vegetation leads to channelisation of flows in erosion gullies. This leads to the draining and desiccation of wetland areas and further erosion. The erosion in the photo to the right (top) is just upstream of RSE11. The aerial photographs show the advance of head-cuts upstream of full supply level of Theewaterskloof Dam. RSE11 is downstream of this erosion.	 Head-cut erosion leading to loss of stabilising organic soils and  

Wetland problem	Photos
Head-cut erosion which has changed the manner in which low flows move through the wetland – these now flow as channelled flow rather than diffuse flow through beds of palmiet (photo taken upstream of RSE11)	
Discharge of channelled flows into the wetland from agricultural drains, changing flow patterns and causing erosion (RSE9)	

Wetland problem	Photos
Bank erosion as a result of loss and desiccation of wetland soils and vegetation (RSE10)	 Bank erosion (eroding along dashed line) as a result of loss and desiccation of wetland soils and riparian vegetation
Infilling of wetland area leading to desiccation of soils, and concentration of flows in channels. The photo to the right is of RSE10, showing infilling of wetland to the left, and concentrated flow in the channel flowing under the road bridge.	

5.3.1.2 Du Toits River wetland

During the early 2000s, there was an erosion event in the Du Toits River catchment that led to the scouring of an erosion gully into the Du Toits River wetland, and the deposition of considerable sediment in the wetland (Kotze, 2015). The erosion gully has stabilised over the past few years, and the wetland has largely recovered from this impact, with a mixed plant community growing quite rapidly in the gully and over the deposited sediment (Snaddon *et al.* 2018). Unfortunately, the whole wetland burned in early March 2019, leading to a loss of vegetation cover and probably further erosion.

The WET-Health assessment indicated that the wetland lies in a PES Category C – moderately modified (Table 5.4). Most of the deterioration in condition can be attributed to the above erosion event, which has changed the way water flows through the wetland, and the geomorphological characteristics of the system.

Table 5.6 Photographs of the impacts recorded in the Du Toits River wetland.

Wetland problem	Photos
Erosion gully at DUT8, showing how the erosion has stabilized with indigenous vegetation (now burnt!)	
Scattered IAPs in the Du Toits River wetland, downstream of DUT8. Photo on the right (top) was taken in December 2018, while the one below was taken in March 2019, showing dust blowing through the wetland post-fire.	 

5.3.2 River sites

The results of the in-field assessment of PES for the river sites are shown in Table 5.7. River health deteriorated downstream for both the Upper Riviersonderend, and the Du Toits River, as the rivers flow from more natural areas into landscapes affected by human activities. The Amandels River showed a decrease in condition at the middle site, AMA2, with an improvement in condition once the river flows towards Theewaterskloof.

The impacts that collectively appear to influence river health include:

- Over-abstraction or surface water from the rivers;
- Constriction of flow around roads and bridges, which leads to channel incision through erosion;
- Presence of weirs, which have an impact on low flows;
- Loss of indigenous vegetation and encroachment of IAPs into the riparian zone;

Table 5.7 Results of PES assessment of river sites.

River	Geomorphological zone	Instream	Riparian	Overall	PES category
RSE5	Upper foothill	99	99	99	A
RSE7	Upper foothill	85	90	88	B
RSE8	Lower foothill	85	75	80	B
RSE9	Lower foothill	77	67	72	C
RSE10	Lower foothill	57	48	52	D
RSE11	Lower foothill	54	38	46	D
DUT1	Mountain stream	95	95	95	A
DUT2	Mountain stream	93	93	93	A
DUT7	Lower foothill	82	78	80	B
DUT8	Lower foothill	80	66	73	C
AMA1	Mountain stream	98	93	95	A
AMA2	Upper foothill	80	69	74	C
AMA3	Upper foothill	80	80	80	B

Table 5.8 Photographs of the impacts recorded at the baseline monitoring river sites.

Wetland problem	Photos
Abstraction of water from the river (top, RSE10; bottom, no flow at RSE11 in March 2019)	 
Weirs, affecting low flows (above RSE7)	

Wetland problem	Photos
Concentration of surface flow below road bridge (RSE10)	
Pine trees in the riparian zone, at AMA2.	

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Appendix 1 Summary of data collected at baseline monitoring sites

Latitude	Longitude	Site	Fyke net (fish)	Snorkelling (fish)	Electro (fish)	Invertebrates (SASS)	Fish Habitat	Physico-Chemistry	Nutrients
-34.043754	19.055466	RSE1	x	x			x		
-34.0446	19.057603	RSE2	x	x			x		
-34.056458	19.067791	RSE3	x	x			x		
-34.059417	19.065861	RSE4	x	x			x		
-34.062965	19.068102	RSE5	x	x		x	x	x	x
-34.062314	19.069544	RSE6	x	x			x		
-34.062354	19.070581	RSE7	x	x	x	x	x	x	x
-34.066096	19.073595	RSE8	x	x	x	x	x	x	x
-34.059259	19.091558	RSE9	x	x	x	x	x	x	x
-34.055142	19.101116	RSE10	x	x		x	x	x	x
-34.049857	19.123718	RSE11	x	x		x	x	x	x
-33.938857	19.168158	DUT1	x	x		x	x	x	x
-33.939964	19.169961	DUT2	x	x		x	x	x	x
-33.940434	19.169979	DUT3	x	x			x		
-33.941871	19.170521	DUT4	x	x			x		
-33.942699	19.170893	DUT5	x	x	x		x		
-33.945603	19.167739	DUT6	x	x	x		x		
-33.947221	19.169047	DUT7	x	x	x	x	x	x	x
-33.952222	19.171284	DUT8	x	x	x	x	x	x	x
-33.979161	19.191467	AMA1	x	x	x	x	x	x	x
-33.98642	19.186572	AMA2	x	x	x	x	x	x	x
-33.989338	19.183752	AMA3	x	x	x	x	x	x	x

Appendix 2a: Snorkel sampling sites on the upper Riviersonderend River and number of fish observed per 20-m reach

Lat	Long	Site	*Pseudobarbus* spp.	*Sandelia capensis* sp. "Riviersonderend"	*Galaxias* spp.
-34.042702	19.052023	R1	0	0	0
-34.043336	19.052639	R2	0	0	0
-34.043464	19.053822	R3	0	0	0
-34.042912	19.054697	R4	1	0	0
-34.043388	19.05457	R5	6	0	0
-34.043745	19.055338	R6	3	0	0
-34.043983	19.056229	R7	3	0	0
-34.04424	19.056933	R8	0	0	0
-34.044867	19.057984	R9	25	0	0
-34.045153	19.059315	R10	7	0	0
-34.045785	19.060003	R11	0	0	0
-34.046515	19.059374	R12	17	0	0
-34.046805	19.058207	R13	15	0	0
-34.048252	19.05882	R14	27	0	0
-34.047919	19.060086	R15	3	0	0
-34.047684	19.061167	R16	0	0	0
-34.048165	19.062105	R17	45	0	0
-34.048743	19.063357	R18	21	0	0
-34.049814	19.064946	R19	2	0	0
-34.050481	19.066266	R20	10	0	0
-34.050975	19.067601	R21	0	0	0
-34.052021	19.068718	R22	50	0	0
-34.053067	19.069004	R23	30	0	0
-34.05415	19.067911	R24	30	0	0
-34.055222	19.066979	R25	21	0	0
-34.057573	19.067309	R26	30	0	0
-34.058547	19.066479	R27	21	0	0
-34.059423	19.065821	R28	80	2	0
-34.060457	19.065796	R29	62	1	0
-34.061486	19.06671	R30	86	1	0
-34.062503	19.067343	R31	32	1	0
-34.062876	19.068448	R32	25	4	0
-34.062188	19.069852	R33	80	2	1
-34.062384	19.070669	R34	40	0	0
-34.063538	19.071693	R35	160	2	3
-34.065694	19.072936	R36	86	4	10
-34.066117	19.073908	R37	54	2	6
-34.066538	19.075394	R38	0	0	25

Appendix 2b: Snorkel sampling sites on the Du Toits River and number of fish observed per 20-m reach.

Lat	Long	Site	*Pseudobarbus* sp. 'burchelli Breede'	*Sandelia capensis* sp. "Riviersonderend"	*Galaxias* spp.
-33.936619	19.166591	D1	0	0	0
-33.936637	19.167204	D2	0	0	0
-33.936535	19.167595	D3	79	0	0
-33.936763	19.167911	D4	13	0	0
-33.937179	19.16804	D5	70	0	0
-33.937577	19.168343	D6	43	0	0
-33.937963	19.168594	D7	114	0	0
-33.93854	19.168542	D8	160	0	0
-33.938971	19.168035	D9	115	0	0
-33.939305	19.1685	D10	74	0	0
-33.93959	19.168968	D11	0	0	0
-33.940045	19.169601	D12	32	0	0
-33.940596	19.170077	D13	112	0	5
-33.941161	19.170311	D14	44	0	0
-33.941788	19.170464	D15	60	0	0
-33.9423	19.170685	D16	9	0	0
-33.942732	19.170867	D17	27	0	0
-33.943339	19.171048	D18	50	0	0
-33.944101	19.171382	D19	25	0	0
-33.944447	19.170532	D20	0	0	0
-33.944648	19.168835	D21	57	0	0
-33.945751	19.167727	D22	2	0	0
-33.946625	19.168122	D23	1	0	1
-33.947291	19.169052	D24	40	0	0
-33.948117	19.169103	D25	1	1	0
-33.948957	19.169363	D26	1	0	0
-33.949339	19.169606	D27	15	7	0
-33.949429	19.170171	D28	0	2	0
-33.949859	19.170185	D29	0	3	5
-33.950452	19.17074	D30	0	2	3
-33.951194	19.171324	D31	25	1	0
-33.951754	19.171318	D32	0	17	1
-33.95241	19.171495	D33	3	55	0
-33.952379	19.172046	D34	0	53	23
-33.953061	19.171892	D35	0	0	35
-33.955113	19.171162	D36	0	2	20
-33.955113	19.171162	D37	0	4	16
-33.955928	19.170779	D38	35	0	67
-33.956855	19.170419	D39	0	15	19

Appendix 3a: Mean ± SE for physical habitat parameters sampled at the baseline monitoring sites

Site	Width		Substrate (mm)		Flow (m/s)		Depth (m)		Aq veg (%)
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean
RSE1	8.88	0.73	692.50	110.38	0.17	0.03	0.81	0.12	0.05
RSE2	6.37	0.41	1318.00	302.20	0.30	0.07	0.50	0.08	0.05
RSE3	5.59	0.66	498.50	130.27	0.23	0.07	0.57	0.09	0.45
RSE4	4.24	0.52	220.00	26.14	0.33	0.01	0.35	0.03	0.45
RSE5	5.32	0.37	400.40	89.49	0.54	0.13	0.34	0.02	0.52
RSE6	7.28	0.73	461.60	97.50	0.43	0.04	0.36	0.04	0.20
RSE7	5.85	0.65	623.60	185.18	1.70	1.25	0.53	0.08	0.64
RSE8	3.83	0.27	22.40	1.94	0.50	0.07	0.30	0.07	0.12
RSE9	3.34	0.26	62.80	24.89	0.24	0.05	0.43	0.06	0.52
RSE10	6.73	1.40	24.00	15.01	0.01	0.01	0.50	0.09	0.48
RSE11	4.40	0.42	10.00	0.63	0.19	0.04	0.34	0.09	0.04
DUT1	4.48	0.26	303.60	55.61	0.24	0.02	0.31	0.04	0.00
DUT2	4.50	0.20	127.60	24.27	0.23	0.01	0.24	0.02	0.00
DUT3	4.64	0.18	134.40	18.37	0.28	0.09	0.29	0.04	0.05
DUT4	4.77	0.72	278.00	50.17	0.42	0.10	0.36	0.10	0.05
DUT5	4.93	0.35	361.50	73.20	0.42	0.08	0.35	0.06	0.10
DUT6	4.13	0.70	208.67	79.02	0.29	0.02	0.39	0.04	0.00
DUT7	4.21	0.53	183.20	45.76	0.34	0.08	0.31	0.06	0.05
DUT8	4.63	0.62	12.00	3.44	0.26	0.02	0.43	0.04	0.10
AMA1	3.69	0.76	306.00	65.11	0.41	0.05	0.21	0.02	0.10
AMA2	5.90	0.23	274.80	54.69	0.44	0.06	0.19	0.03	0.10
AMA3	0.06	0.00	292.50	45.20	0.29	0.02	0.27	0.04	0.05

Appendix 3b: Mean ± SE for physico-chemical habitat parameters sampled at the baseline monitoring sites

Site	pH		DO (%)		DO (mg/L)		Cond (µS/cm)		TDS (ppm)		Temperature (deg C)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
RSE1	4.03	0.09	114.53	3.38	10.96	0.56	63.00	1.00	31.00	0.00	19.31	0.01
RSE2	4.18	0.18	119.97	3.24	10.49	0.07	55.00	1.00	28.00	0.00	19.71	0.04
RSE3	3.92	0.16	124.43	2.19	10.81	0.23	62.00	0.00	31.00	0.00	19.92	0.02
RSE4	3.60	0.03	129.57	0.92	11.32	0.08	60.33	0.33	30.00	0.00	19.99	0.00
RSE5												
RSE6	4.12	0.10	103.64	0.93	8.76	0.07	62.00	0.00	31.00	0.00	21.91	0.01
RSE7	4.27	0.11	104.26	1.37	8.78	0.12	62.00	0.00	31.00	0.00	21.93	0.01
RSE8	4.29	0.03	112.04	3.02	9.66	0.25	64.20	0.20	32.00	0.00	20.76	0.01
RSE9	3.46	0.02	82.38	1.87	7.45	0.17	72.20	0.20	36.00	0.00	18.40	0.04
RSE10	4.80	0.09	90.38	2.87	6.86	0.18	78.00	0.71	39.20	0.37	27.72	0.51
RSE11												
DUT1	4.41	0.06	87.48	2.05	7.83	0.19	76.20	0.20	38.00	0.00	18.52	0.01
DUT2	4.40	0.02	82.34	0.33	7.27	0.03	73.00	0.00	36.00	0.00	19.38	0.00
DUT3	4.29	0.07	117.37	1.43	10.20	0.12	72.00	0.00	36.00	0.00	20.38	0.07
DUT4	4.21	0.04	115.78	0.92	10.19	0.09	70.60	0.24	35.00	0.00	19.85	0.07
DUT5	4.48	0.12	111.70	1.70	10.00	0.16	71.00	0.00	35.67	0.26	18.96	0.07
DUT6	4.50	0.04	116.77	1.42	9.92	0.13	71.00	0.00	35.67	0.00	21.61	0.03
DUT7	4.50	0.14	112.60	0.87	9.52	0.07	73.60	0.24	37.00	0.00	22.06	0.09
DUT8	4.41	0.15	112.40	1.26	9.46	0.11	74.00	0.00	37.00	0.00	22.14	0.02
AMA1	4.22	0.05	88.18	0.88	7.70	0.09	62.00	0.00	31.00	0.00	20.27	0.11
AMA2	5.05	0.05	89.58	1.76	7.78	0.15	63.00	0.00	31.00	0.00	22.41	1.99
AMA3	4.70	0.10	110.54	1.43	9.07	0.11	63.00	0.00	31.60	0.24	23.47	0.03