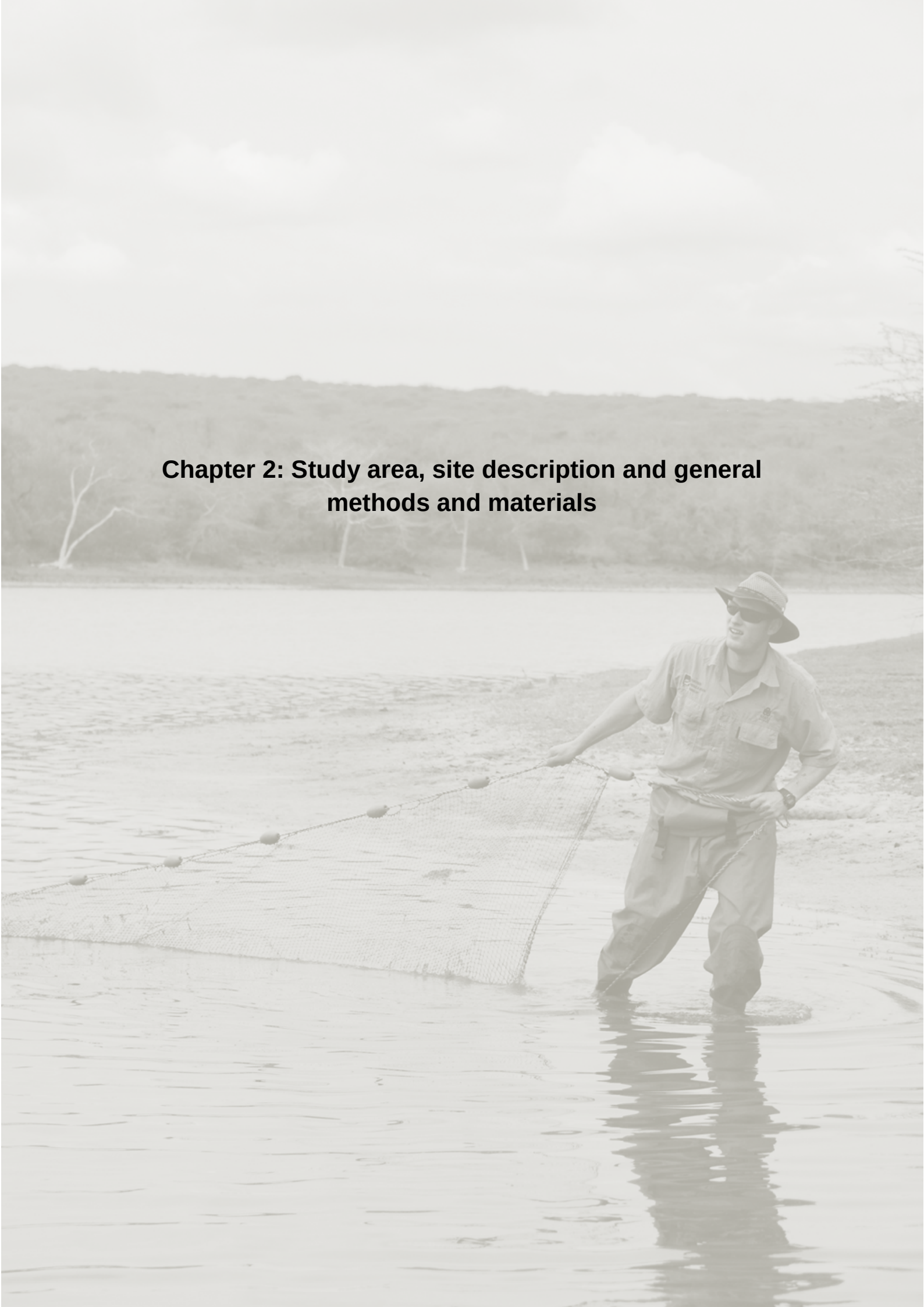
Chapter 2: Study area, site description and general methods and materials



2.1 Study area and site selection.

The focus area of this study is the river, the floodplain and its associated pans immediately downstream of the Pongolapoort Dam wall, all the way in a north-eastern direction along the length of the river towards the Usutu River that forms the border between South Africa and Mozambique. Ndumo Game Reserve and one of the tributaries of the Ngwavuma River, form part of the study area. A map of the sites used in this study is shown in Figure 2.1.

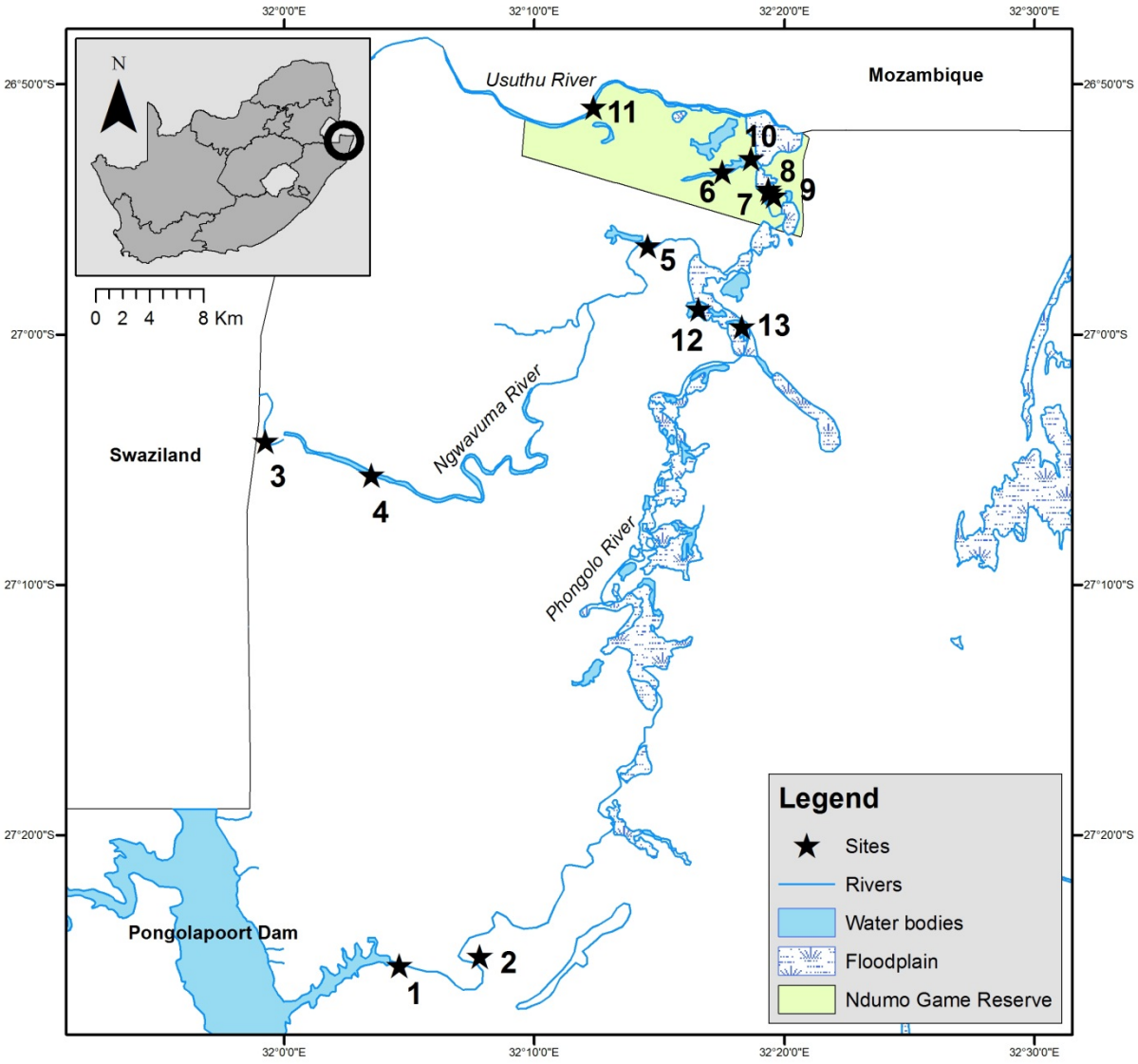


Figure 2.1: A map of the study area indicating the selected sites for this study.

The site selection process for this study was based on available historic data, current impacts and representation of the ecoregions. The initial selection process was followed by a ground truth survey in 2012 during which the suitability of the sites was investigated. As a result of this exercise 13 study sites were selected in total. It is important to note that these sites lie within two ecoregions, namely the Lebombo Upland (Ecoregion 12) and Lowveld (Ecoregion 3) regions (Figure 2.2).

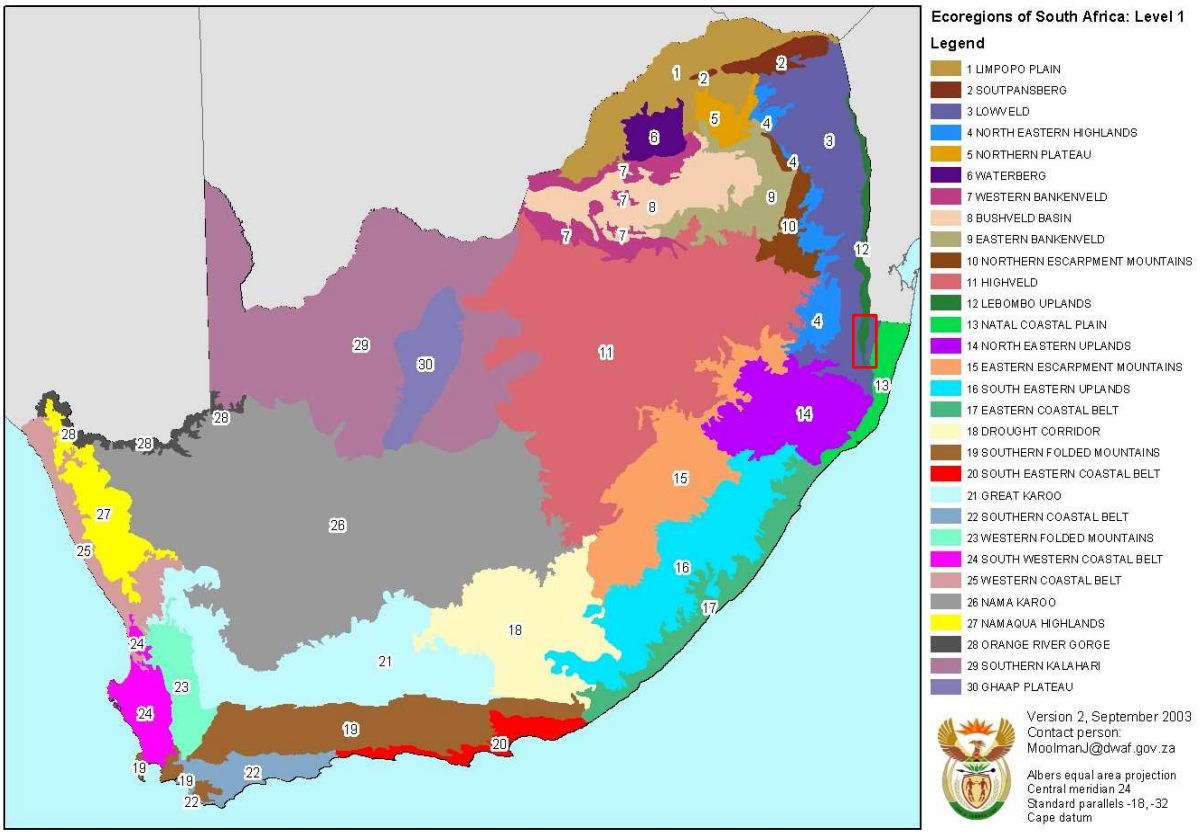


Figure 2.2: Map of ecoregions within South Africa (Department of Water Affairs and Forestry, 2003). The red rectangle indicates the ecoregions of this study.

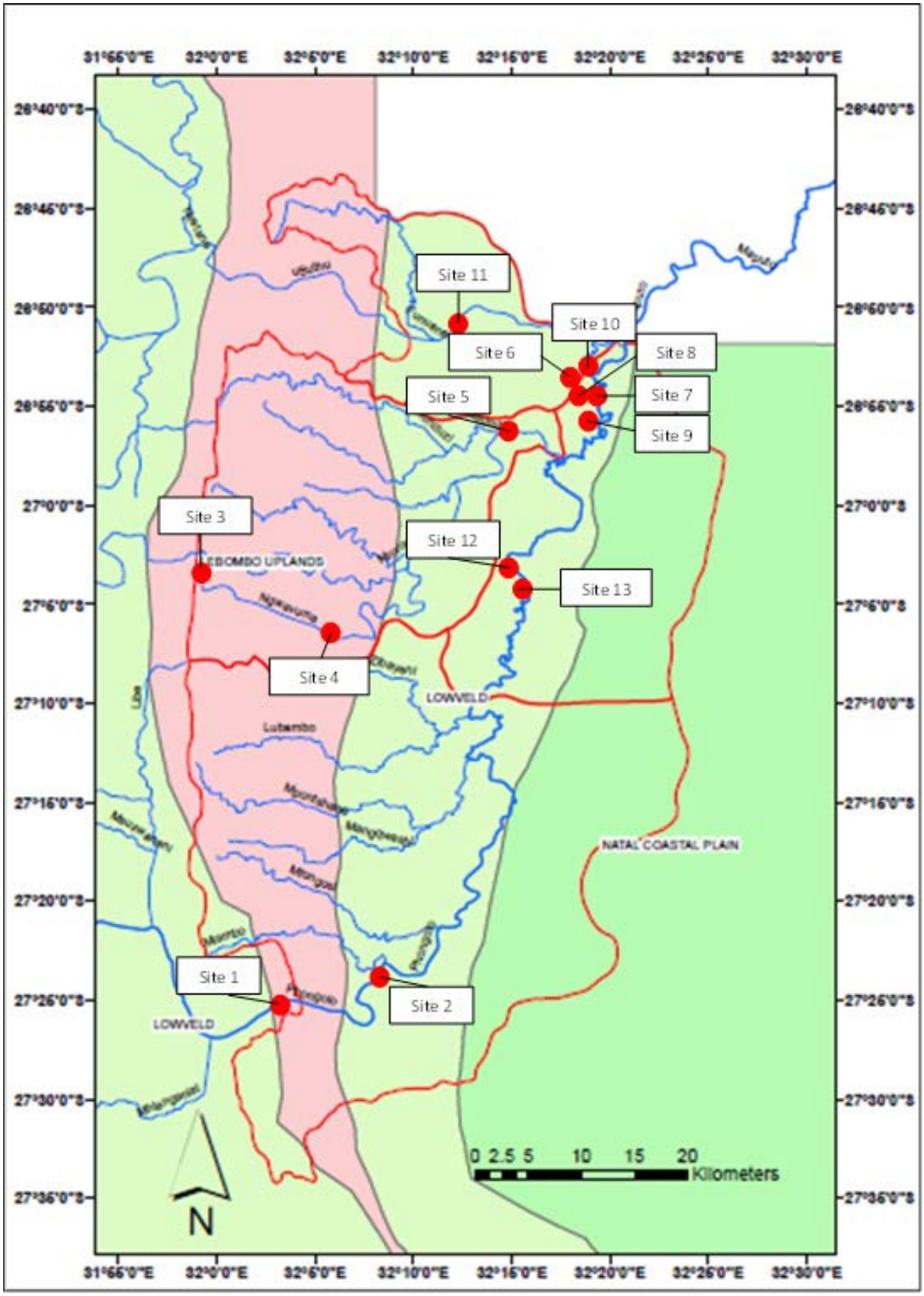


Figure 2.3: Location of the study sites within the two regions.

The river's upstream sites (Sites 1, 2 and 3) were selected to determine the water quality and diversity before any major impacts and stressors like urbanization and agriculture had an effect. The downstream sites (Sites 4, 5, 7 and 8) were selected to determine

anthropogenic impacts on fish community structures. Site 11 in the Usutu was selected as a reference site. This can then be used to compare with sites further downstream that may be impacted by the above-mentioned stressors in order to determine changes along the ecoregion. Site 1, in the Phongolo River, represents the highest and least impacted site in the Lebombo Uplands ecoregion and Site 2, also in the Phongolo River, and represents the highest and least impacted site in the Lowveld ecoregion.

2.1.1 Sites in the Lebombo Uplands ecoregion

A total of three sites located on two rivers were selected in this ecoregion. Site 1 is located in the Phongolo River immediately below the dam wall (Figure 2.1). Two sites were selected in the Ngwavuma River. The first (Site 3) is 5 km downstream from the South Africa-Swaziland border and the second site (Site 4) approximately 13 km downstream.

2.1.2 Sites in the Lowveld ecoregion

A total of ten sites were selected on this ecoregion and this consists of five pans, four river sites and one site at the outflow of a pan. Three of the pans are located in the Ndumo Game Reserve and two outside the reserve. Of the four river sites one is located in the Phongolo River, two in the Ngwavuma River and one in the Usutu River.

Site 2 is in the Phongolo River and Site 5 is in the Ngwavuma River. Site 6 is the Nyamiti Pan in Ndumo Game Reserve and it was selected to determine the health status of selected species. Site 7 in the Phongolo River is also located in Ndumo Game Reserve and is at the pump station which provides the camp with water. This site was selected to compare fish of the Phongolo River from inside and outside the Game Reserve as well as fish from the river to fish from the pans. Sites 8 and 9 are both pans close to Site 7. During high flow these pans are connected to the Phongolo River. Site 10 is the outflow of Nyamiti Pan and was selected to determine the water quality changes associated with outflows into the river as well as possible migrations of fish into the pan and vice versa. Site 11 was the only site in the Usutu River and was regarded as a reference to previous work done on the Phongolo River. This site is a River Health Programme site, thus there is a lot of historical data available. The data from this site can be used to better understand the contribution of the Usutu River with regards to fish diversity and possible alien introduction into the Phongolo River.

Site 12, Nomaneni Pan, and Site 13, Bumbe Pan, are located outside the Game Reserve and were selected to determine the impact of human exploitation on the fish communities within these pans. Data obtained from these sites can be used to compare with data from

the Ndumo Game Reserve to determine the effect of human impacts on the fish communities within these water bodies.

All available habitats at each site were sampled. These habitats were classified based on parameters and variables set out by Kleynhans (2007)Within each of these parameters the extent of the potential cover for the fish, such as substrate, overhanging vegetation, undercut banks, rapids, riffles and back water pools were estimated and scored. Fish in these habitats at all the sites were sampled according to the protocol set out by Kleynhans (2007).

2.2 Site description

2.2.1 Site 1 (Phongolo River)

Site 1 is situated immediately downstream of the Pongolapoort Dam wall approximately 200 m from the dam wall. Changes to this site can be attributed to the flood releases from the impoundment. During the low flow season a regulated flow of 8 $m.s^{-1}$ is maintained but during the high flow season volumes of 600–800 $m.s^{-1}$ can be released. Therefore this section of the river is greatly impacted by the strong flows that are released from the dam. The habitat of this site has been altered by the flow from the dam and the alluvial material is thus predominantly rocks and cobbles. A series of vegetated islands are present at this site, but very little sedimentation of fine alluvials are observed.

Table 2.1: Summary of the ecologically important features of Site 1 and the sampling method applied.

Site 1	
River:	Phongolo
Method:	Electrofishing/7 m seine net/angling
GPS Coordinates:	S27 25 12.3; E32 04 35.6
Depth:	250–500 mm
Substrate:	Boulders/cobbles/riffles
Habitat:	Riffle rapids, backwater pools, marginal vegetation
Vegetation:	Western Maputaland Clay Bushveld (Mucina & Rutherford, 2006)

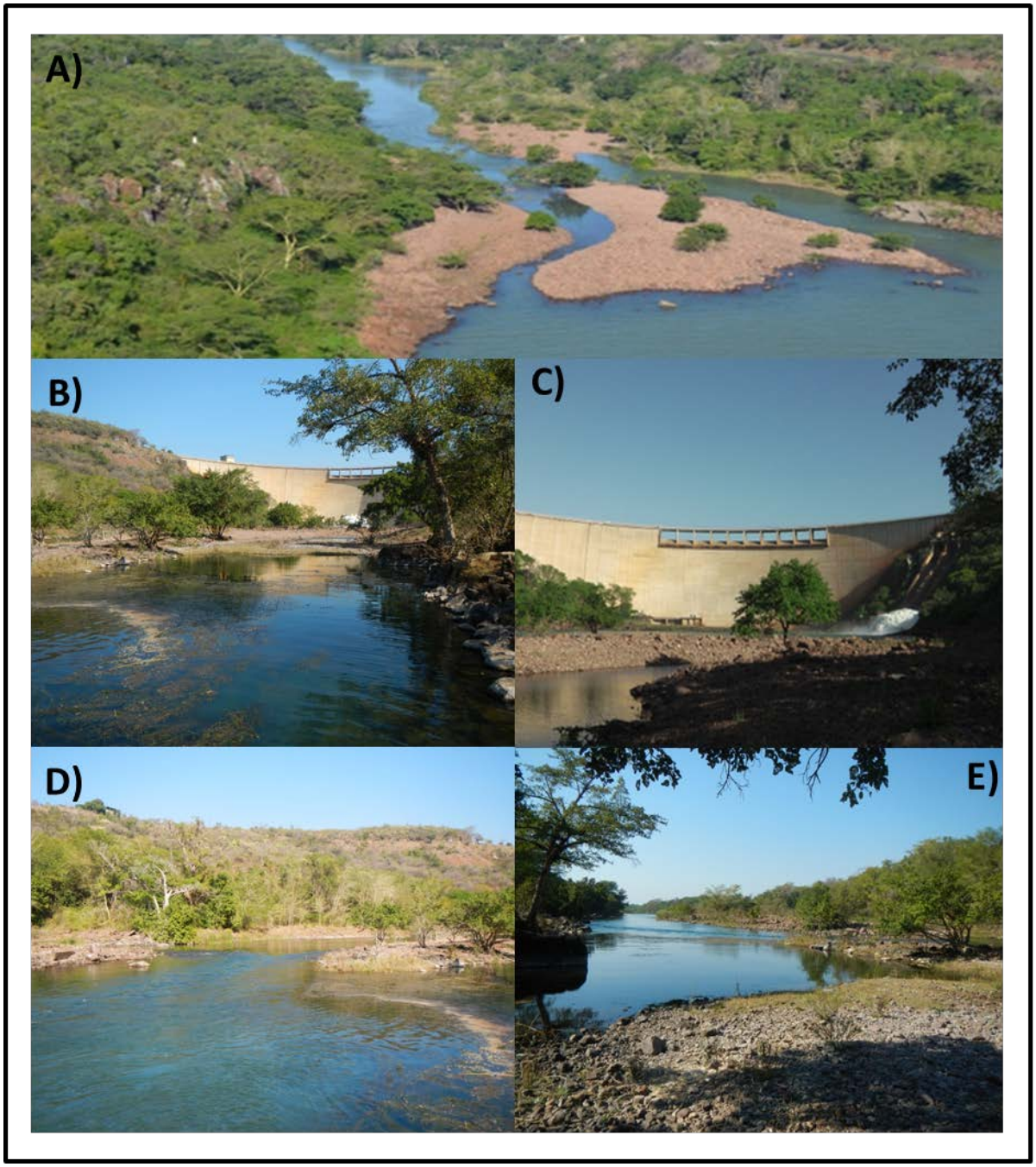


Figure 2.4: Site 1.

A) an aerial photo taken from the dam wall, B–C) upstream view of the site illustrating the various backwater pools, D–E) downstream view of the site illustrating the riffle section of the river.

2.2.2 Site 2 (Phongolo River)

The second site is approximately 12 km downstream from the dam wall just as the river enters the Lowveld ecoregion. There are a riffle section, a backwater pool and a rapid at the downstream end of the site. The flow at this site is slower than at Site 1 because of the decrease in slope. The backwater pool has aquatic vegetation and there are vegetated side bars. A large area of the river bank's 2 ha is used for sand mining and the surrounding area has agricultural activities, e.g. sugarcane farming.

Table 2.2: Summary of the ecologically important features of Site 2 and the sampling method applied.

Site 2	
River:	Phongolo
Method:	Electrofishing/angling/7 m seine net
GPS Coordinates:	S27 24 50.8; E32 07 49.0
Depth:	700 mm
Substrate:	Sand/pebbles/cobbles/boulders
Habitat:	Riffles, backwater pools, rapids, marginal vegetation
Vegetation:	Western Maputaland Clay Bushveld (Mucina & Rutherford, 2006)

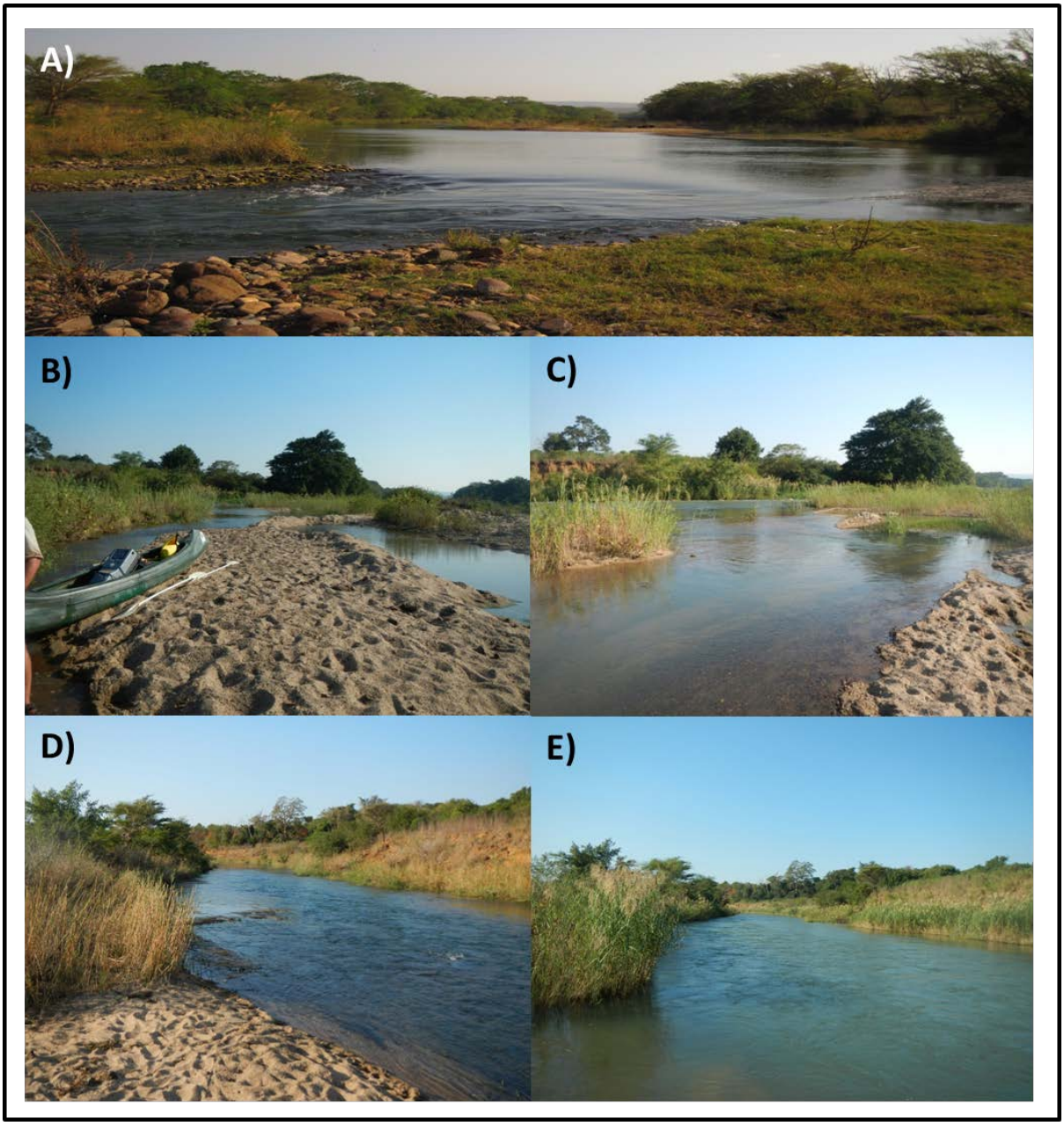


Figure 2.5: Site 2.

A) Upstream view of Site 2, illustrating riffles on the left and a pool area on the right, B–C) backwater pools with slow flowing water, D–E) downstream view of the site.

2.2.3 Site 3 (Upper Ngwavuma River)

This site is located on the Upper Ngwavuma River about 1.4 km east of the Swaziland and South African border. The site consists predominantly of bedrock and boulders with pools and riffles. Further downstream the river has a flat sand bed. There are limited impacts at this site, as it is very difficult to get to it. The only impact on this site was the burning of the vegetation on the steep slope adjacent to the site which can lead to siltation due to possible erosion.

Table 2.3: Summary of the ecologically important features of Site 3 and the sampling method applied.

Site 3	
River:	Ngwavuma
Method:	Electrofishing
GPS Coordinates:	S27 4 15.93; E31 59 14.48
Depth:	250–500 mm
Substrate:	Bedrock/boulders/cobbles/sand
Habitat:	Riffles, backwater pools, rapids, marginal vegetation
Vegetation:	Western Maputaland Clay Bushveld (Mucina & Rutherford, 2006)

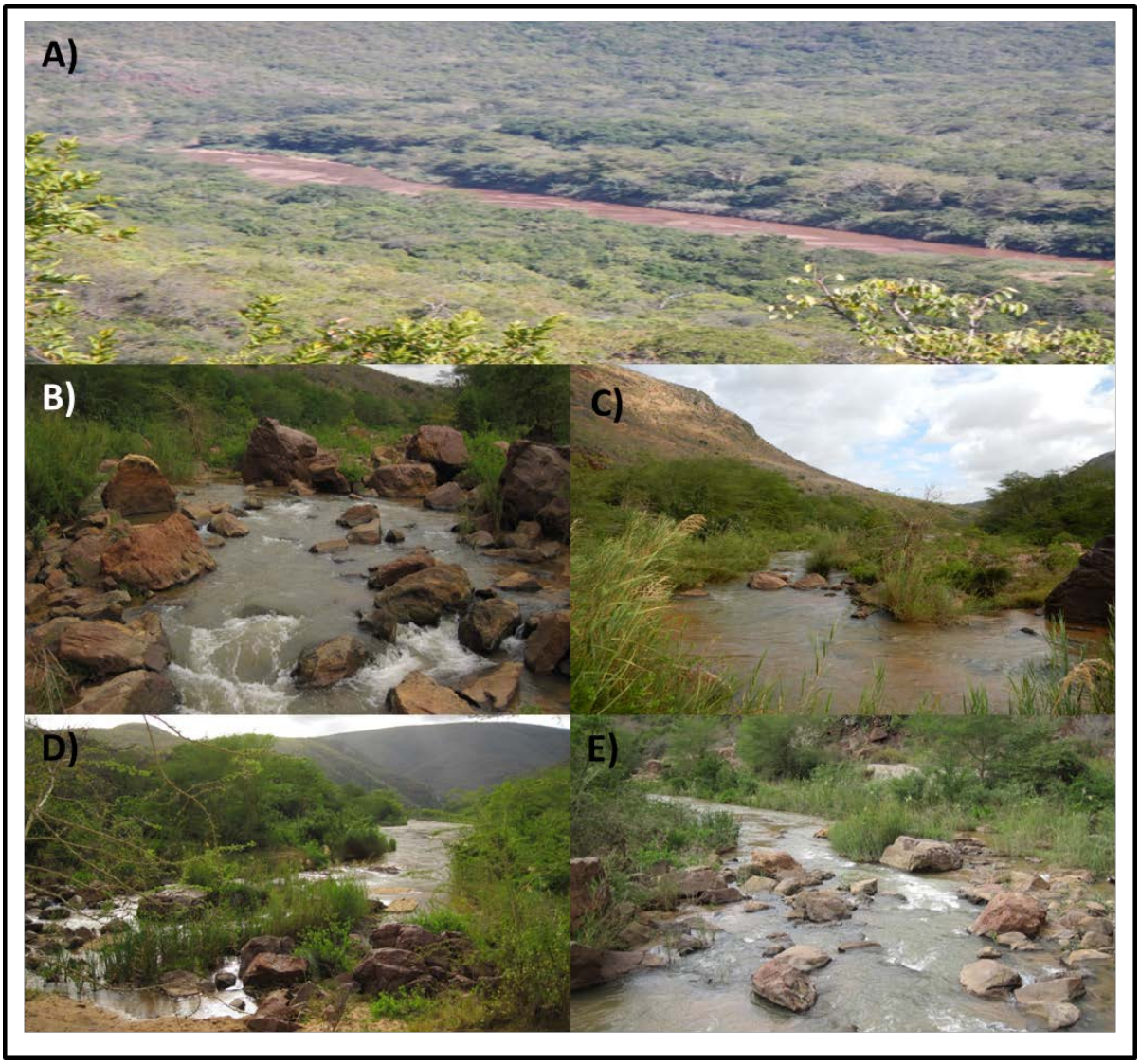


Figure 2.6: Site 3.

A) An aerial view of the Upper Ngwavuma River as it enters South Africa from Swaziland, B–C) upstream view of Site 3, illustrating the large boulders that dominate this site, D–E) downstream view of the site illustrating the boulders and sand substrate at this site.

2.2.4 Site 4 (Middle Ngwavuma River)

This site is situated in the Middle Ngwavuma River and is about 12.5 km downstream from Site 3. The site has limited marginal vegetation along the banks and the river bed consists mainly of a sand and mud. There are also man-made objects such as building rubble and concrete blocks in the river. There is a bridge crossing the river and extensive sand mining activities along the banks of this stretch of the river. People use this site for water abstraction and as a washing area. Other impacts include: trampling, grazing, cultivation and infrastructure development and these can be associated with the erosion on site.

Table 2.4: Summary of the ecologically important features of Site 4 and the sampling method applied.

Site 4	
River:	Ngwavuma
Method:	Electrofishing
GPS Coordinates:	S27 05 36.93; E32 03 28.67
Depth:	250–500 mm
Substrate:	Cobbles/sand and silt
Habitat:	Riffles, backwater pools, rapids, marginal vegetation
Vegetation:	Western Maputaland Clay Bushveld (Mucina & Rutherford, 2006)

Figure 2.7: Site 4.

A) 180 ° view of the site with a view of the new bridge crossing and the collapsed old low-water bridge, B) upstream view illustrating vegetated islands and bars, C) downstream view of the river with vegetated islands and bars. This photo also illustrates the use of the river for washing of clothes, D) water abstraction and the local population using the river to wash their cars, E) the collapsed low-water bridge that impacts the flow of the river, F) brick factory and large scale sand mining activities on site.

2.2.5 Site 5 (Lower Ngwavuma River)

Site 5 is in the Lower Ngwavuma River just before it flows into the Phongolo River. It is located approximately 2 km from the Ndumo Village, downstream of a culvert that crosses the river. The river flows through three pipes, which increases the velocity of the water. The site mainly consists of rocks and occasional mud and sand. The river banks along this stretch of river are eroded. Impacts on this site can be attributed to the wood collection in the riparian zone and trampling in the area due to agriculture activities along the river banks. These impacts along with the summer floods may be responsible for the extensive erosion at this site (see Figure 2.8 E–F).

Table 2.5: Summary of the ecologically important features of Site 5 and the sampling method applied.

Site 5	
River:	Ngwavuma
Method:	Electrofishing
GPS Coordinates:	S26 56 27.65; E32 14 33.00
Depth:	500 mm
Substrate:	Rocks
Habitat:	Riffles, backwater pools, undercut banks, root wads
Vegetation:	Lowveld Riverine Forest (Mucina & Rutherford, 2006)

Figure 2.8: Site 5.

A–B) Upstream views of the Lower Ngwavuma River illustrating the three pipes used to channel the water underneath the bridge and the dominant rocks and cobbles substrate, C) downstream view from the bridge, D) approximately 60 m downstream from the bridge an open channel with a sandy substrate, E–F) examples of the severe erosion at this site due to increased velocity of the water caused by the pipes.

2.2.6 Site 6 (Nyamiti Pan)

Nyamiti Pan is situated approximately 4 km north-east from the main entrance to Ndumo Game Reserve and is the second largest pan within the borders of the reserve. It is a perennial pan with a sandy substrate and occasional mud. The average depth is about 1 m and 1.5 m at the deepest point. The north-western side of the pan is flat and covered with grass and a lot of fever trees (*Vachellia xanthophloea*). The south-eastern side of the pan has steeper banks predominantly vegetated by Lowveld Riverine forest.

Table 2.6: Summary of the ecologically important features of Site 6 and the sampling method applied.

Site 6	
River:	Phongolo
Method:	35 m seine net
GPS Coordinates:	S26 53 29.7; E32 17 30.9
Depth:	1000–1500 mm
Substrate:	Sand/silt
Habitat:	Open water, secluded bays
Vegetation:	Lowveld Riverine Forest (Mucina & Rutherford, 2006)

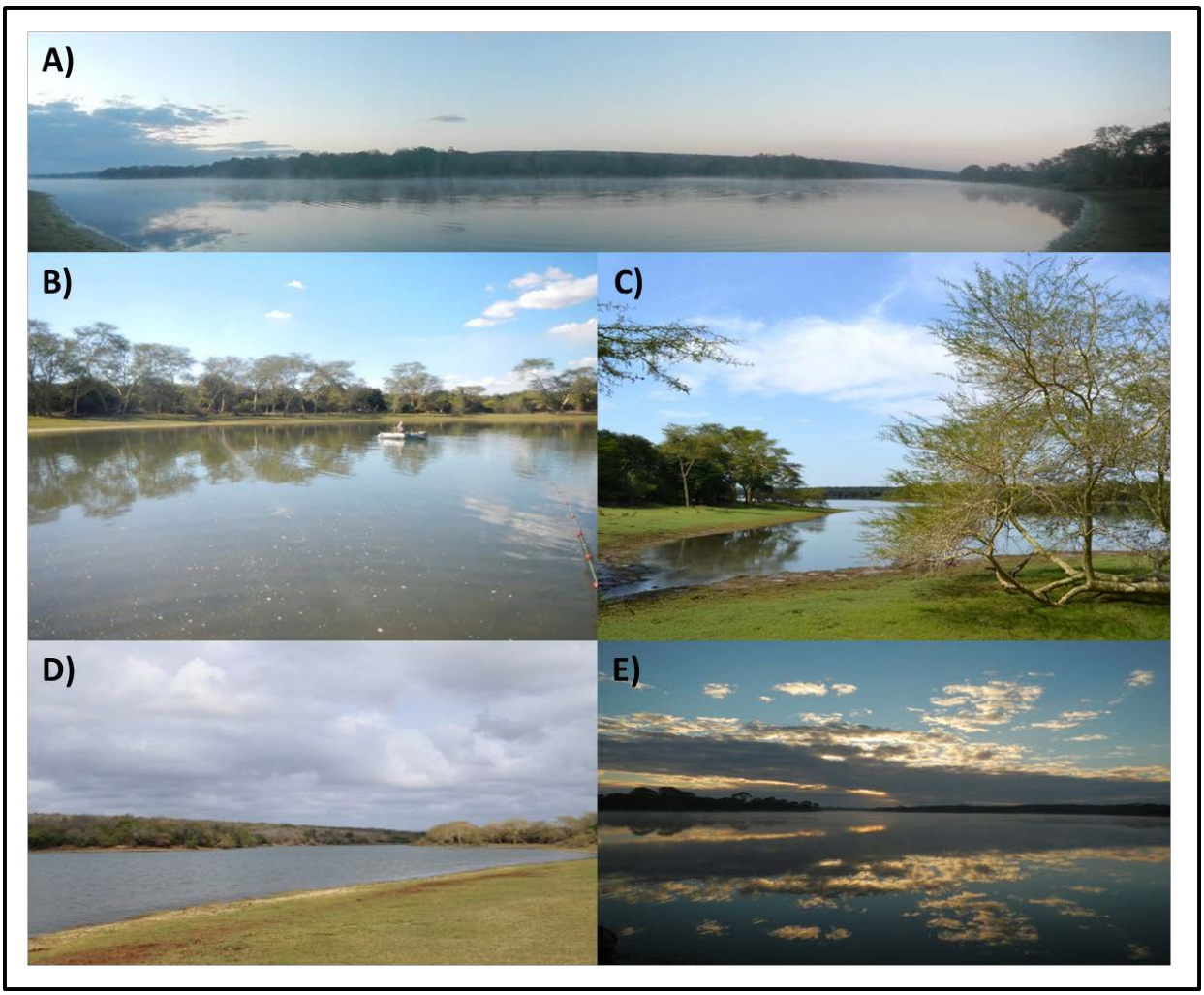


Figure 2.9: Site 6.

A) 180° view of Nyamiti Pan, B) a view of the north western side of the pan with flat banks dominated by grass and fever trees, C) one of the many bays formed on the north-eastern site of the pan, D) illustration of the contrast between the north western bank (grass) and the south western bank (far side) that is vegetated by Lowveld Riverine Forest, E) view of the large open body of water.

2.2.7 Site 7 (Phongolo River – Pump station)

This site is located approximately 1.5 km northeast from the Ndumo Game Reserve camp site. It is situated at the pump station that provides water to the camp site from the Phongolo River. The overall condition of this site is in a generally healthy state. Erosion along the banks does occur and can be attributed to the flood releases during summer months, although water abstraction by farmers in the surrounding area lowers the velocity of the water. The substrate of this site is predominantly mud and silt with no cobbles or rocks. There are a lot of backwater pools present as well as vegetated bars and islands.

Table 2.7: Summary of the ecologically important features of Site 7 and the sampling method applied.

Site 7	
River:	Phongolo
Method:	Electrofishing/Fyke nets
GPS Coordinates:	S26 88 27.7; E32 31 13.9
Depth:	700 mm
Substrate:	Sand/silt
Habitat:	Pools, backwater, woody debris, undercut banks, root wads
Vegetation:	Lowveld Riverine Forest (Mucina & Rutherford, 2006)

Figure 2.10: Site 7.

A–B) Photos taken upstream from the pump house at Site 8 illustrating large backwater pools, C) pool used for water abstraction for water supply to the campsite, D) downstream view illustrating the muddy substrate and erosion along the left bank, E) back water pool with steep banks on the left bank due to erosion.

2.2.8 Site 8 (Ndumo floodplain pan)

This site is a pan in close proximity to Site 7 and is located approximately 250 m north and downstream. This pan is a temporary one and fills up with water during the high flow season when water is released and it is connected to the Phongolo River. The edges of the pan are vegetated by tall reeds and grass.

Table 2.8: Summary of the ecologically important features of Site 8 and the sampling method applied.

Site 8	
River:	Phongolo
Method:	35 m and 7 m seine net
GPS Coordinates:	S26 88 27.7; E32 31 13.9
Depth:	700–1000 mm
Substrate:	Silt
Habitat:	Water column and marginal vegetation
Vegetation:	Lowveld Riverine Forest (Mucina & Rutherford, 2006)

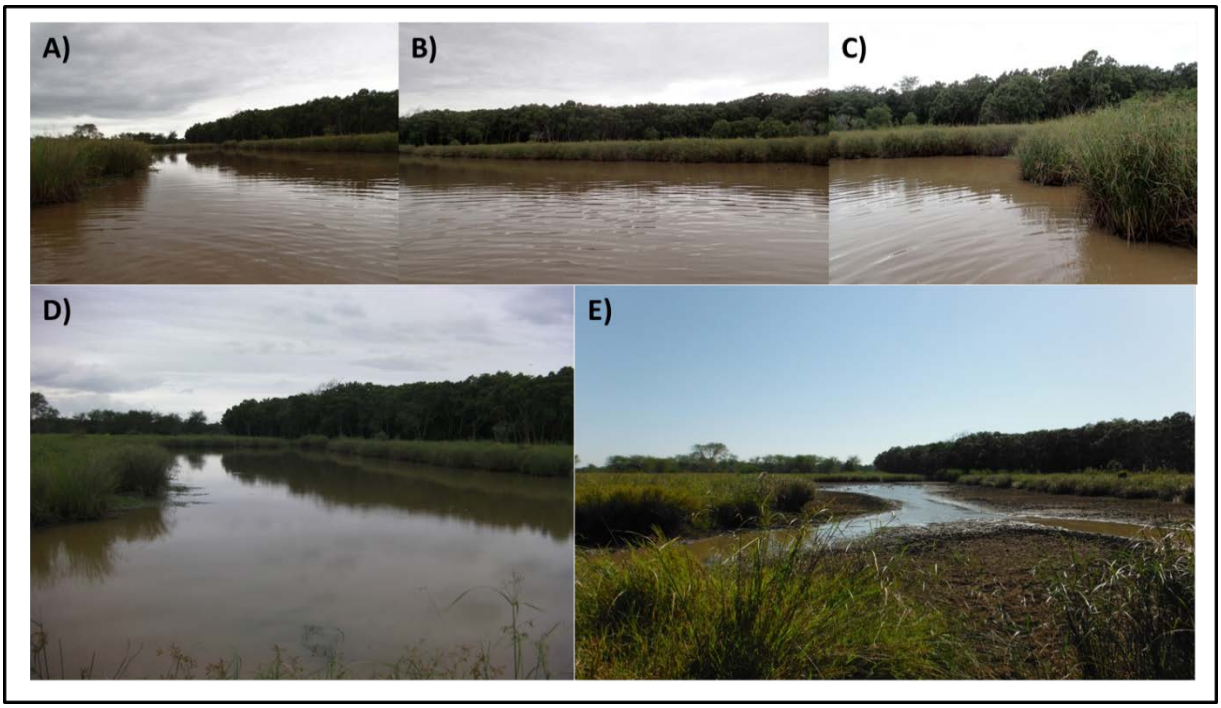


Figure 2.11: Site 8.

A–C) views of the right side of the pan illustrating that the dominant vegetation along the banks is tall reeds, D) complete view of the entire pan during high flow season, E) view of the pan during low flow season.

2.2.9 Site 9 (Ndumo floodplain pan)

This site is a pan in close proximity to Site 7 and is located approximately 600 m south-east and upstream. This pan is a temporary one and fills up with water during the high flow season when it is connected to the Phongolo River and water is released. The edges of the pan are also vegetated by tall reeds and grass.

Table 2.9: Summary of the ecologically important features of Site 9 and the sampling method applied.

Site 9	
River:	Phongolo
Method:	35 m and 7 m seine net
GPS Coordinates:	S26 54 27.90; E32 19 35.04
Depth:	500 mm
Substrate:	Silt
Habitat:	Water column and marginal vegetation
Vegetation:	Lowveld Riverine Forest (Mucina & Rutherford, 2006)

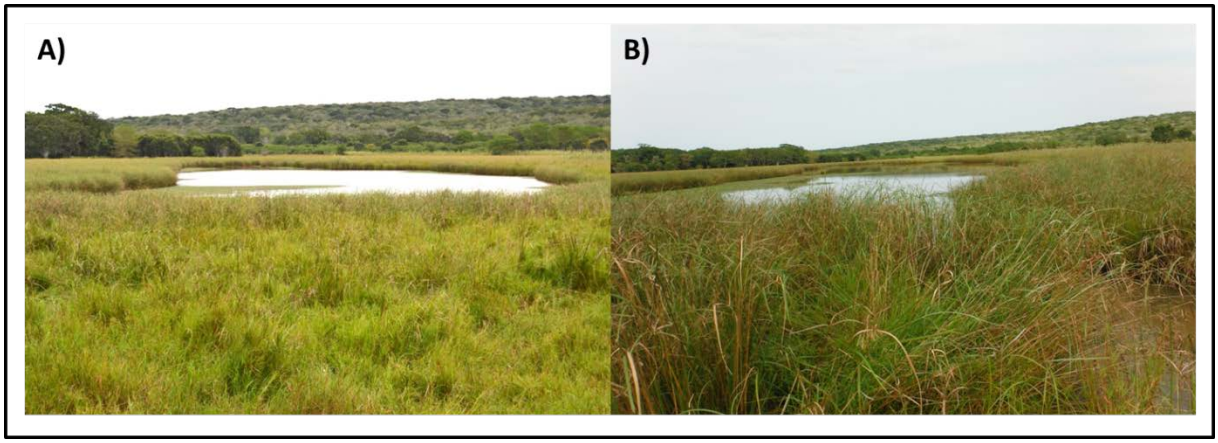


Figure 2.12: Site 9.

A) view of the entire pan, B) closer view of the pan illustrating the dominant vegetation (tall reeds).

2.2.10 Site 10 (Outflow of Nyamiti Pan)

This site is located at the outflow of Nyamiti Pan into the Phongolo River. There is a causeway that regulates flow from the pan into the river. The upstream area, Nyamiti Pan is a large pool and is approximately 1–1.5 m higher than the downstream area. During flooding in the Phongolo River the causeway is drowned out and back flow occurs into the pan. This allows upstream migration of fish into the pan. Erosion on the banks on both sides of the causeway can be attributed to flooding and has resulted in steep vertical banks on both sides. During the low flows the water that flows from the pan flows across a boulder/cobble bed which can be regarded as a riffle area.

Table 2.10: Summary of the ecologically important features of Site 10 and the sampling method applied.

Site 10	
River:	Phongolo
Method:	35 m seine net /fyke nets/electrofishing
GPS Coordinates:	S26 88 05.5; E32 31 17.8
Depth:	1000–1500 mm
Substrate:	Cobbles/silt
Habitat:	Riffles, pools, undercut banks
Vegetation:	Lowveld Riverine Forest (Mucina & Rutherford, 2006)

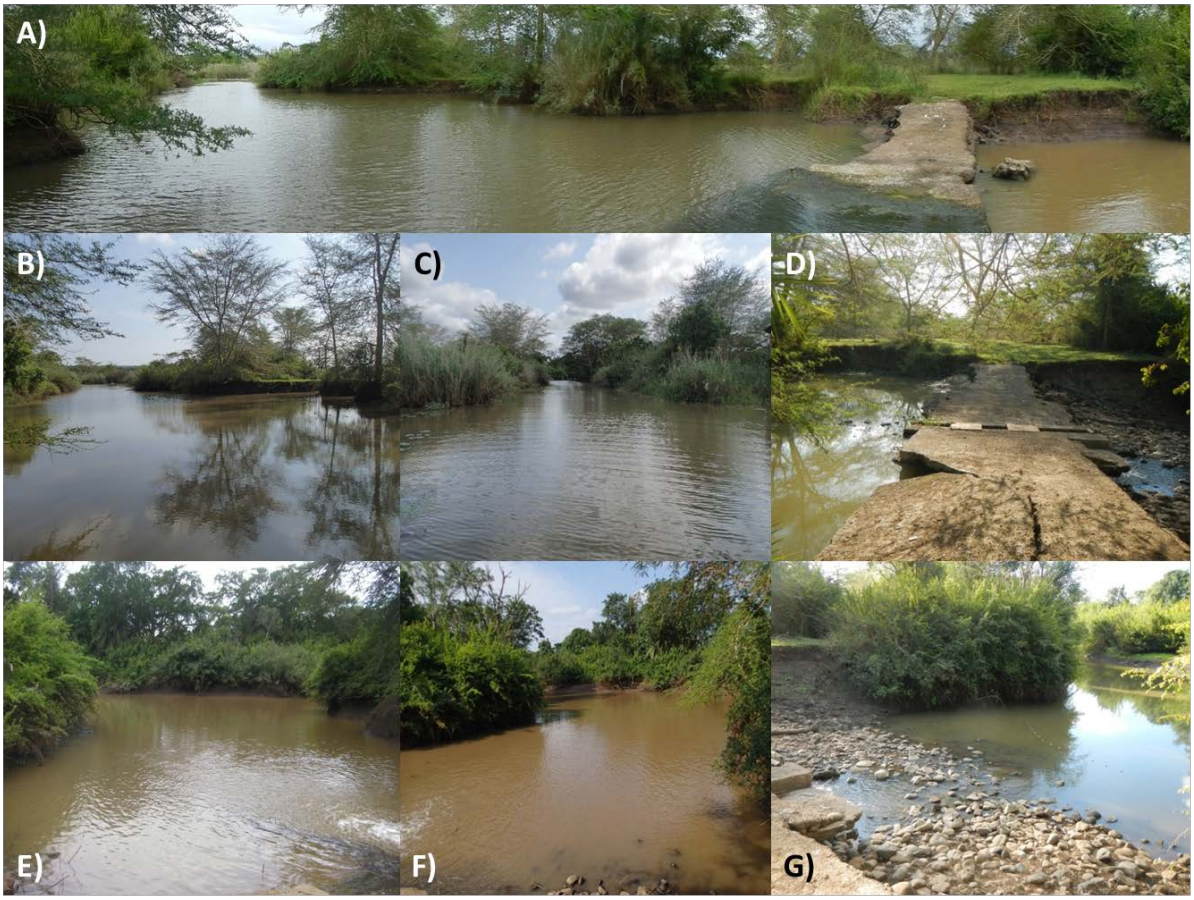


Figure 2.13: Site 10.

A) 180° view of the outflow of Nyamiti Pan illustrating the pan on the left of the causeway and the Phongolo River on the right, B) upstream view of the pan from the causeway illustrating the deep pool area, C) a downstream view towards the causeway, D) a photo of the collapsed causeway illustrating the steep eroded banks on both sides of the bridge, E–F) downstream view from the bridge illustrating the pool area created by the Phongolo River during high flow season, G) exposed rocks and cobbles on the right side (Phongolo River) of the causeway, during low flow.

2.2.11 Site 11 (Usutu River)

Site 11 is located in the Usutu River approximately 20 km from the camp site in the Ndumo Reserve just downstream of the Red Cliffs picnic site. The site is dominated by a single wide channel with a sandy substrate. There are sand bars in the middle of the channel which divide the channel during low flows but no vegetated islands are present. This river forms the border between South Africa and Mozambique. The right bank (South African side) is dominated by tall indigenous reeds during high flow.

Table 2.11: Summary of the ecologically important features of Site 11 and the sampling method applied.

Site 11	
River:	Usutu
Method:	Electrofishing
GPS Coordinates:	S26 52 58.04; E32 18 41.03
Depth:	250–500 mm
Substrate:	Sand, silt
Habitat:	Undercut banks
Vegetation:	Western Maputaland Clay Bushveld (Mucina & Rutherford, 2006)

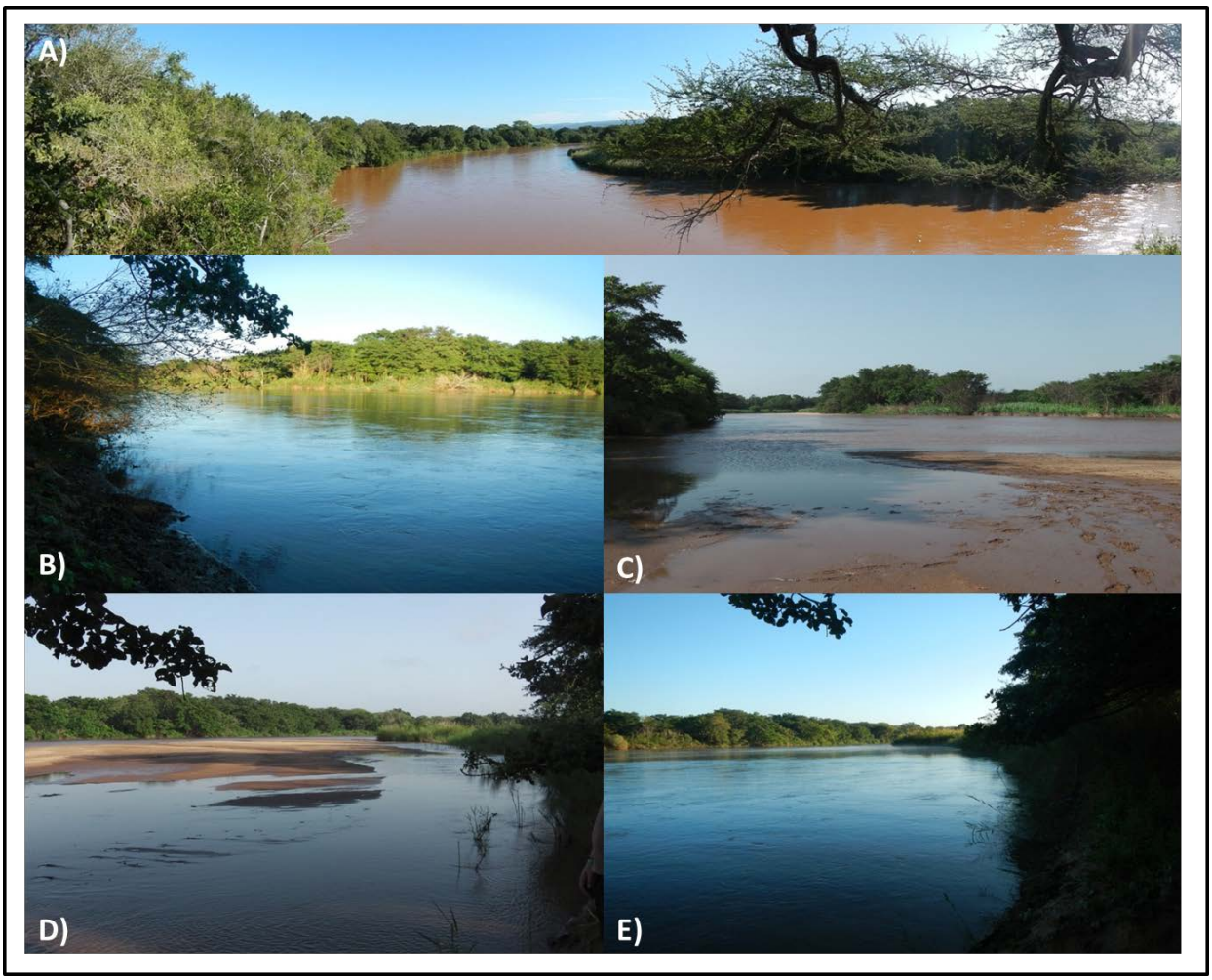


Figure 2.14: Site 11.

A) 180° view of the Usutu River, B–C) upstream views of the river illustrating the wide channel with the sandy substrate, D–E) downstream view of the wide channel with the tall reeds on the right-hand side banks.

2.2.12 Site 12 (Nomaneni pan)

This site is located outside the Ndumo Game Reserve and is in the middle of an informal settlement. It is a shallow muddy pan with aquatic vegetation. This is also a temporal pan that is connected to the Phongolo River during flood, but is disconnected from the river during the low flows. People from the community use this pan for washing, subsistence fishing, water abstraction and agriculture. Animals graze the grassland around the pan and all the riparian vegetation has been harvested.

Table 2.12: Summary of the ecologically important features of Site 12 and the sampling method applied.

Site 12	
River:	Phongolo
Method:	35 m seine net
GPS Coordinates:	S26 59 13.19; E32 16 21.38
Depth:	250–500 mm
Substrate:	Silt
Habitat:	Water column, aquatic vegetation
Vegetation:	Lowveld Riverine Forest (Mucina & Rutherford, 2006)

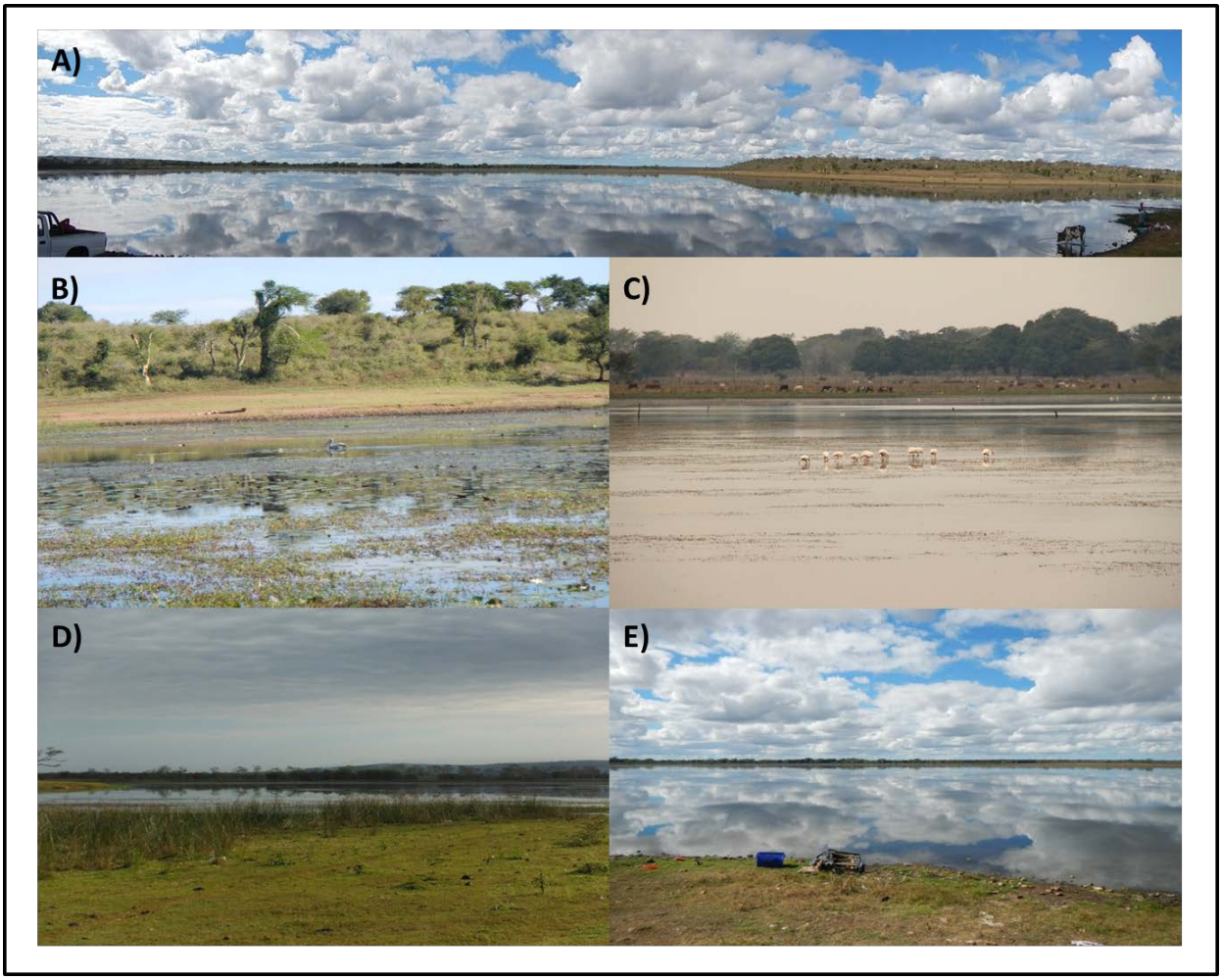


Figure 2.15: Site 12.

A) 180° view of Nomaneni Pan, B–C) illustrating the extent of the aquatic vegetation, D-E) illustrates that most of the riparian vegetation is removed.

2.2.13 Site 13 (Bumbe pan)

Bumbe Pan is situated 2 km south east from Nomaneni Pan and they are interconnected via Ngodo Pan. Bumbe Pan is also a perennial pan and gets its water from the Phongolo River during the high flow season. The impacts are similar to those observed at Site 12. Bumbe Pan is a shallow muddy pan with extensive aquatic vegetation. The riparian vegetation is less impacted at this site, but wood harvesting and animals trampling and grazing around the banks of this site cause erosion.

Table 2.13: Summary of the ecologically important features of Site 13 and the sampling method applied.

Site 13	
River:	Phongolo
Method:	7 m seine net
GPS Coordinates:	S26 59 13.19; E32 16 21.38
Depth:	250–500 mm
Substrate:	Silt
Habitat:	Water column, aquatic vegetation
Vegetation:	Lowveld Riverine Forest (Mucina & Rutherford, 2006)

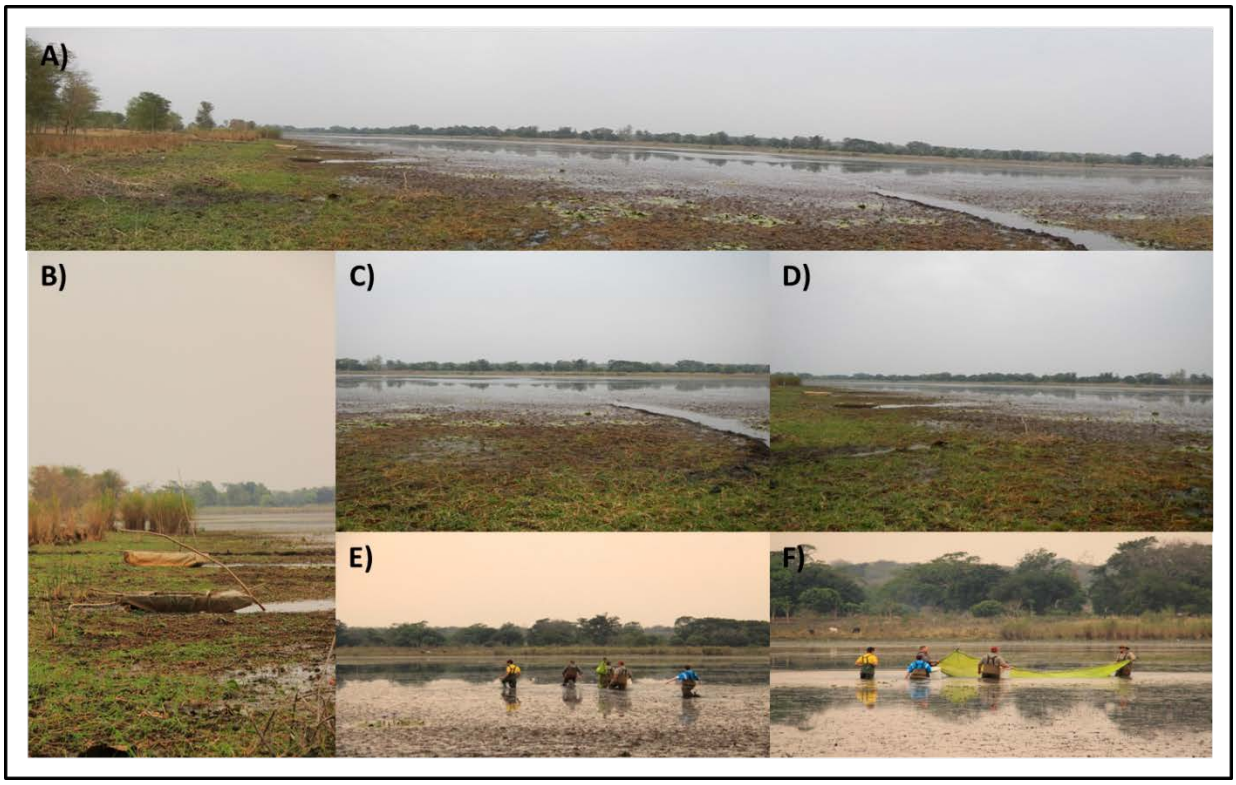


Figure 2.16: Site 13.

A) 180° view of Bumbe Pan, B) boats used by the local people for subsistence fishing and agriculture, C–D) illustrate that all the riparian vegetation has been removed and the channel used for water abstraction, E–F) an indication of how shallow this pan is.

2.3 Surveys

A total of five surveys were carried out in the period from 2012 to 2014 to ensure that all the different seasons as well as high flow and low flow periods were sufficiently sampled.

Table 2.14: Summary of surveys conducted from 2012 to 2014.

Survey no.	Date	Purpose
1	13th to 20th November 2012	Reconnaissance survey
2	15th to 24th April 2013	High flow
3	27th July to 4th August 2013	Low flow
4	9th to 15th September 2013	Low flow
5	6th to 14th April 2014	High flow

2.4 Materials and methods

2.4.1 Fish collection

A wide variety of sampling techniques was used for the different habitats that ranged from still standing water to fast flowing rivers. Angling techniques were used target specific species such as *Hydrocynus vittatus* and *Clarias gariepinus*. Two sizes of fyke nets were used in the river to sample the fast flowing water as well as the backwater pools and backwater slides (800 mm and 1500 mm hoops) (Figure 2.17 A–B). These nets were serviced at 12 hour intervals and were left in the water during the entire survey. A 35 m seine net with a 10 mm mesh size was mostly used in large pans (Figure 2.17 G–I) and a 7 m seine with a 1 mm mesh size was mostly used in the backwater pools of rivers (Figure 2.17 D–F). Electro-fishing with a Smith and Root© electro-shocker was used at all of the sites to target smaller species that often aren't caught using the above-mentioned methods (Figure 2.17 J–L).

Fish at all the sites were sampled according to the habitat-specific protocol described by Kleynhans (2007). Habitats include: slow deep, slow shallow, fast deep, fast shallow. Fish from the different habitats were kept separate for analysis, because if a certain habitat could not be sampled it is important to make conclusions within this limitation. This means that if one habitat was not sampled the species that would predominantly occur in this habitat must be excluded from the assessment in terms of the species that would occur in that region according to the reference condition.

All the individuals caught were identified using the key provided in Skelton (2001) and the total length (TL) and standard length (SL) was measured on a measuring board. Fish

diversity and abundance data were used to calculate the Fish Response Assessment Index (FRAI) scores as well as the community structure at all the sites. The fish community data was compared to historical data. Specimens of a number of selected species were retained for histological analysis. All other specimens were returned alive to the environment.

Figure 2.17: Methods of collecting fish for the study

A) Photograph of a standard fyke net (80 cm hoop), B) an example of what a fyke net looks like in a backwater pool, C) a group of scientists identifying fish in the field, D) photograph of the 7 m minnow seine net used during these surveys, E) an example of how this net is used, F) example of a successful pull using the 7 m seine net, G–H) setting out the 35 m seine net, I) example of a successful pull using the 35 m seine net, J–L) examples of electrofishing in different habitats.

2.4.2 Fish health

Selected specimens of *Oreochromis mossambicus, Coptodon rendalli* and *H. vittatus* were transported to the field laboratory. The standard and total lengths of each individual were measured to the nearest centimetre and the mass was recorded in order to calculate the condition factor (Carlander, 1969) and then photographed to from part of a reference list. Blood was drawn using 4 ml heparinised vacutainers and centrifuged at 3 000 r/min for 10 minutes (McHugh *et al.*, 2011). The blood plasma was transferred to 2 ml cryo-tubes and stored in liquid nitrogen for the calculation of the total blood protein levels (Figure 2.18 E–G). The fish were then sacrificed by severing the spinal cord. An external examination was done to identify parasites and if present they were carefully removed and preserved in 70% ethanol. The fish were then dissected and the gonads, spleen and liver removed and weighed to determine the Gonadal-Somatic Index (GSI), Spleno-Somatic Index (SSI) and Hepato-Somatic Index (HSI) (Adams *et al.,* 1993) (Figure 2.18 A–D). Samples of the gonads were preserved in buffered formalin for histological assessment. A complete fish necropsy was done according to Fish Health Assessment Index (FHAI) of Adams *et al*. (1993).

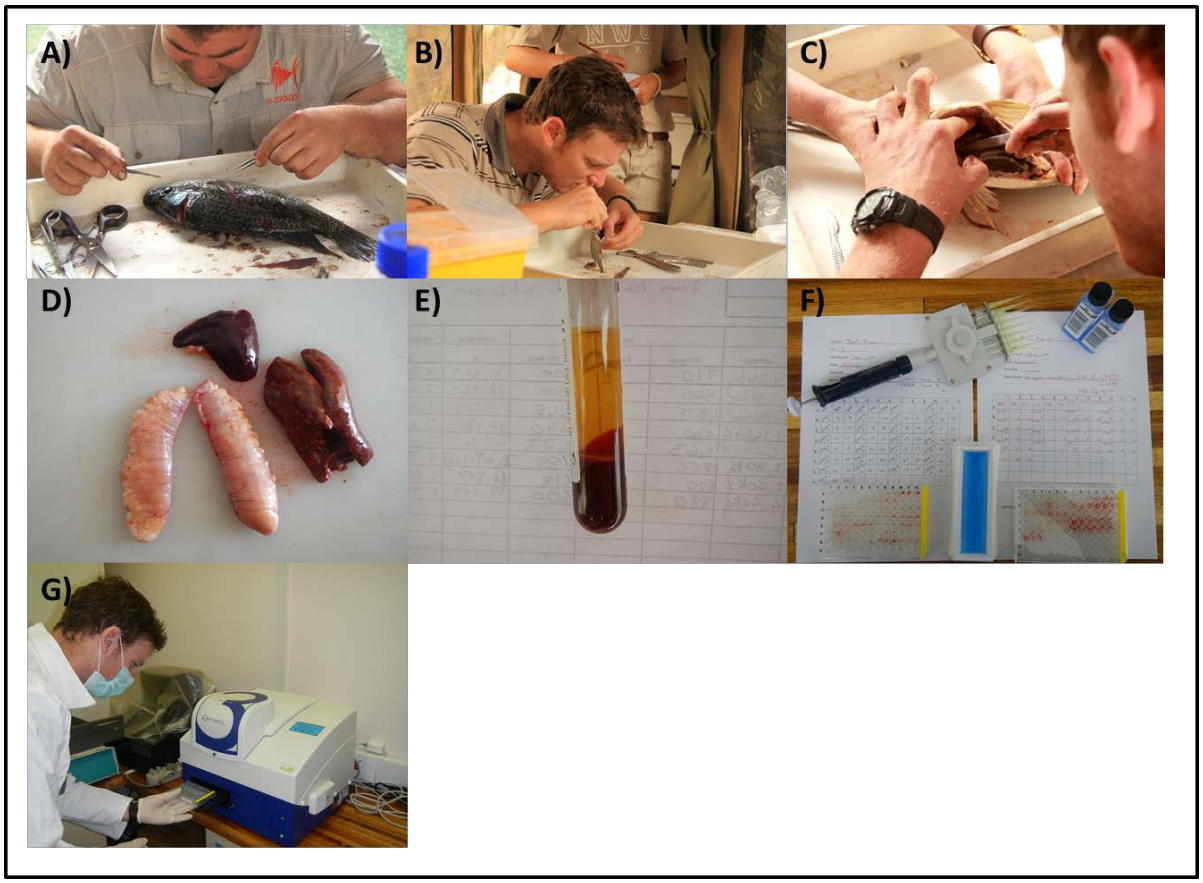


Figure 2.18: Assessing fish health in the field lab

A–C) Dissections at the field laboratory, D) removed spleen, gonads and liver, E) centrifuged blood, F–G) calculating blood protein levels.

2.4.3 Water quality

In situ physio-chemical water quality parameters were measured at each sampling site using a YSI 9260 water quality meter. The parameters used were:

- Temperature (ºC)
- Electrical conductivity (mSm^{-1})
- TDS (mg/l)
- pH
- Dissolved oxygen saturation (%)
- Dissolved oxygen concentration (mg/l)
- Turbidity (NTU).

2.4.4 Fish Response Assessment Index (FRAI)

The FRAI is one of many interdisciplinary indices used to determine the ecological classification of a certain area. Each of these indices is weighted in terms of their importance, but this study focuses only on fish and thus only the FRAI will be used and discussed.

The FRAI model is based on the environmental intolerances and preferences of the reference fish assemblage and the responses of these species to environmental determinants or drivers. These intolerances and preferences are categorised into metric groups with fundamental metrics that relate to the environmental requirements of each particular species. The response of any species to any change in environmental conditions can occur through direct measurements, such as surveys, or are inferred by environmental change, such as habitat. The responses to habitat changes are based on the ecological requirements of these species. The FRAI is based on a combination of fish sampling data and fish habitat data (Kleynhans, 2007).

Table 2.15: Steps and procedures to calculate the Fish Response Assessment Index (FRAI) (Adapted from Kleynhans, 2007).

Step	Procedure
River section earmarked for assessment	As for study requirements and design
Determine reference fish assemblage: species and frequency of occurrence	• Use information • Use expert fish reference frequency of occurrence database if available
Determine present state for drivers	• Hydrology • Physico-chemical • Geomorphology or • Index of habitat integrity
Select representative sampling sites	Field survey in combination with other survey activities
Determine fish habitat condition at site	• Assess fish habitat potential • Assess fish habitat condition
Representative fish sampling at site or in river section	• Sample all velocity depth classes per site if feasible • Sample at least three stream sections per site
Collate and analyse fish sampling data per site	• Transform fish sampling data to frequency of occurrence ratings
Execute FRAI model	• Rate the FRAI metrics in each metric group • Enter species reference frequency of occurrence data • Enter species observed frequency of occurrence data • Determine weights for the metric groups • Obtain FRAI value and category • Present both modelled FRAI & adjusted FRAI.