Conservation biology and management of the Twee River redfin, *Barbus erubescens* (Pisces: Cyprinidae)

Thesis

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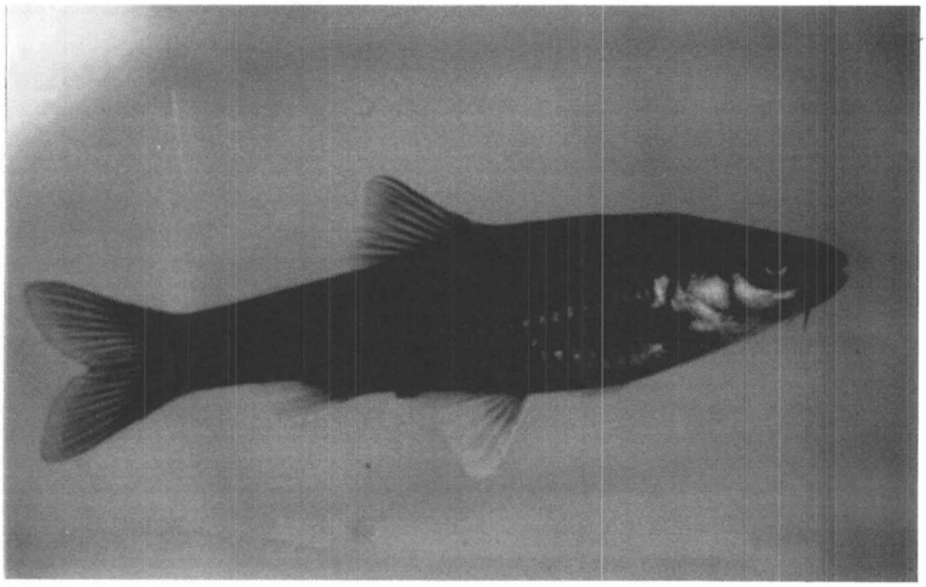

Adult Twee River redfin, *Barbus erubescens*

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ABSTRACT

Agricultural practices and increasing levels of pollution, water abstraction and numbers of predatory exotic fishes gave rise to mounting concern for the survival of the already endangered Twee River redfin, *Barbus erubescens*. Numbers were believed to be dwindling and an urgent re-assessment of the species' conservation status and major threats was called for. Distribution and estimated numbers of *B. erubescens* were determined from a census conducted in the Twee River catchment, and baseline knowledge of age and growth, reproduction, diet and habitat preferences was gained from biological work on collected specimens. Such understanding was necessary to formulate management ideas.

Although an estimated 40% reduction in area of occupancy has occurred in the middle reaches of the Twee River system, the known distribution of *B. erubescens* was extended into the upper Suurvlei River. Despite fragmentation, surviving redfin populations remained healthy and total population size was estimated at 8400 individuals, 4100 of which were considered mature. Adults preferred pools with water exceeding 1 m in depth and tended to be associated with sandy or boulder substrates. Due to low numbers no such study was conducted on juveniles, although observations indicated a preference for the upper 50 cm of the water column, in or around marginal vegetation. *Barbus erubescens* spawn in summer and follow an asynchronous, iteroparous pattern. Males and females reach a maximum age of six years, maturing after two years at calculated SL of 45 mm in males and 42 mm in females. The diet was dominated by simulid and ephemeropteran larvae.

Although the combined pressures of pesticide and fertiliser use, predation and competition from exotic species have undoubtedly had a negative impact on *B. erubescens*, the species has maintained viable

populations. With continued expansion of these threats the focus of conservation attention may change but, at present, it is most likely agricultural water use, amounting to 7.43 x 10^6 m^3y^{-1}, 15% of the entire catchment production, which poses the greatest immediate threat to the survival of the species. Based on a deteriorating habitat and restricted area of occupancy, *B. erubescens* was rated Critically Endangered, and it is recommended that a conservation management plan be implemented in the Twee River catchment. The focus of such action should be on genetic preservation, with immediate projects including gamete cryopreservation and captive breeding and rearing programmes. Catchment management, including education and rehabilitation programmes, must be the long-term aim of conservation, to ensure the survival of *B. erubescens*.

CHAPTER 1

GENERAL INTRODUCTION

One must agree with Allen et al. (1982), there can be no doubt the modern human habitat is vast, drawing from a wide range of resources and extending to incorporate the entire biosphere. Allen et al. (1982) advise that the influence of such a lifestyle on the environment is so great that man may ultimately be responsible for the fate of numerous organisms. Accordingly, in modern society, conservation has become a major concern, although ideas as to when conservation action is necessary do vary. Some take an ethical standpoint, wishing to conserve species for their own sake, whilst others argue that efforts should be concentrated on economically important taxa only. It should not be forgotten, though, that conservation is for and about people (Allen et al. 1982, O'Keeffe 1986) and should aim to resolve problems to satisfy all viewpoints. The IUCN (1980) defines conservation as: "The management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations, while maintaining its potential to meet the needs and aspirations of future generations." This is an holistic concept which embodies both the use and preservation of resources (O'Keeffe 1986) and which, according to Allen et al. (1982), has three overall aims, 1) to ensure that the biosphere can continue to renew itself and provide the means for all life, 2) to ensure human survival and well being, and 3) to keep options open to meet the potential needs of future generations. Since the requirements of future generations are unpredictable, we have to recognise that the long term conservation of life hinges on the preservation of genetic diversity (Allen et al. 1982, Pullin 1990).

Although many aquatic organisms are as seriously threatened as terrestrial biota, few have been awarded equivalent publicity, and their situation, especially with regards to freshwater ecosystems, is often not fully appreciated (Pullin 1990, Ryman et al. 1995). Aquatic ecosystems tend to be particularly vulnerable to human intervention and climatic change (Pullin 1990) and are subject to a number of impacts, including habitat degradation, direct over-exploitation and the introduction of exotic species (Gaigher et al. 1980, Pullin 1990, Skelton 1987). South Africa is a naturally dry country and water bodies are consequently heavily impacted. Moreover, as a result of the Cape Province's long history of European settlement the habitats of its freshwater fishes have been subjected to more changes than other areas in South Africa (Gaigher et al. 1980). Political entities in South Africa have recently been revised and mention of the Cape Province, in the context of this thesis, refers to the existing Eastern, Western and Northern Cape Provinces. Besides European settlement, the climate in this region is also highly erratic over most parts, and many rivers are acidic and oligotrophic, with a natural scarcity of fish species and abundance. Because these fishes have adapted to certain environmental conditions, after long periods of natural selection, any human impacts can be expected to influence their survival (Jubb 1964, Skelton et al. 1995). This is especially true in rivers, where upstream disturbances are often transmitted a considerable distance downstream. Aspects of habitat degradation and introduced species, have been identified in the Twee River and its two source tributaries, the Middeldeur and Suurvlei Rivers (Hamman et al. 1984, Hamman 1996, Skelton 1987). The Twee River catchment, a total of roughly 46 km of river course, forms part of the Olifants system in the Western Cape, and is the only known locality of the Twee River redfin, *Barbus erubescens* Skelton, 1974.

The Twee River redfin is a small cyprinid minnow. Fishes included in the redfin group comprise two phyletic lineages of barbine minnows, endemic and apparently restricted to the Cape Fold Mountain drainage system, with one isolated species occurring in the Drakensberg and Maluti ranges, in headwater tributaries of the Orange River (Barnard 1943, Gaigher et al. 1980, Jubb 1963, Skelton 1980, 1988). The 'redfins' were first recognised to comprise a distinct group of southern Cape freshwater fishes by Barnard (1943), who based his observation on the presence of bright red patches at the base of the fins. They were originally considered to constitute a monophyletic lineage in the genus *Barbus* (Barnard 1943, Jubb 1965), although Barnard (1943) did note that *Barbus calidus* differed from other redfins by having a serrated last dorsal unbranched ray and six branched anal fin rays. Notwithstanding the fact that the dorsal ray character has been used extensively in *Barbus* taxonomy, its phylogenetic significance was vague (Skelton 1974b). The first suggestion of phylogenetic differences within the redfin group came from Skelton (1976) who showed that *B. calidus* and *B. erubescens* were not phyletically true redfins, differing from the rest of the group in that they have strong supraneural bones and a greater number of anal branched rays. Later phylogenetic studies (Skelton 1980, 1988) revealed other differences and the redfin group was separated into those with smooth, flexible last dorsal rays and those with serrated, bony rays. Based on their many differences, Skelton (1988) reassigned all flexible-rayed species to the genus *Pseudobarbus*. Today nine redfin species are recognised, two belonging to the genus *Barbus* and seven to *Pseudobarbus* (Skelton 1987, 1988). The Twee River redfin belongs to the serrated-rayed group but differs from all other *Barbus* species in having seven branched rays in the anal fin (Skelton 1974b, 1988). It appears most closely related to *B. calidus* from which it differs slightly in a number of ways, primarily by having weaker serrations on the last unbranched dorsal ray and that the breeding males attain an overall reddish hue, not observed in *B. calidus* (Skelton, 1974b, 1988).

Barnard (1943) listed the presence and biogeographical uniqueness of the redfin group as one of the 'outstanding' features of the ichthyofauna of the south western Cape, yet recent papers (Cambray & Cambray 1988, Cambray & Stuart 1985, Cambray & Meyer 1987) conclude that man's activities, either directly or indirectly, affect these minnows, all of which hold conservation status in the South African Red Data Book - Fishes (Skelton 1987). *Barbus erubescens* was included in the Red Data

Book for the first time in 1977 (Skelton), farming and manganese mining being mentioned as its major threats. The possibility that alien predators would be introduced to the Twee River catchment was considered a further potential threat. In 1987, though mining activity had ceased, eutrophication through runoff from cultivated lands, insecticide spraying, water abstraction and the possible predation from the introduced *Sandelia capensis* were emphasised and the Twee River redfin was again listed as Vulnerable (Skelton 1987). Recommendations that the entire drainage of the Twee River be accorded sanctuary status, the biology, ecology and captive potential of *B. erubescens* be investigated and that the system be monitored on a regular basis were made. By 1996, in line with reviewed IUCN status requirements, Hamman (1996) recommended that the species should be considered Critically Endangered (IUCN 1996).

Recent conservation criteria (IUCN 1996) have been designed to incorporate all taxa, with the exception of micro organisms, and also to improve the objectivity in assessment of conservation status, thus improving consistency between users. Species are measured against such quantifiable variables as distribution, population structure and possible threats. However, Cambray & Hecht (1995) caution that species are not equally susceptible to perturbations. Management decisions should therefore be based not only on the conservation status and potential threats in the area, but should also consider the relative consequence of each of these threats to the organisms concerned. This requires some knowledge of species' biology, as aspects of the reproductive, feeding and growth biology may prove useful in the interpretation of a species' tolerance to impacts (Cambray & Hecht 1995).

Research presented in this thesis was initiated and supported by Western Cape Nature Conservation with a twofold interest, firstly, through a study of their biology and ecology, to accurately assess the status of the Twee River redfin and secondly, to present ideas for an action plan with the focus of ensuring the species long-term survival. The study was structured around three key questions:

1) Is *Barbus erubescens* really threatened, and if so, to what extent?

2) What factors threaten the survival of the species?

3) What viable management options are there?

These questions are tackled in the following chapters. Chapter 2, "Study Area" introduces the Twee River catchment as an isolated system of first and second order streams in the Western Cape. The distribution and population status of *B. erubescens* and other fish species within this system, important considerations when assigning a species to a conservation category, are investigated in chapter 3. *Barbus erubescens*' reproductive, feeding and growth biology are discussed in chapter 4. Chapter 5 outlines all possible threats to this fish species and investigates those which are relevant to the Twee River and its source tributaries. Results from the previous chapters are pooled into a summary of the conservation status of *B. erubescens*, constructed according to the 1994 IUCN guidelines. Having established where the source of the problem lies, various management options are discussed in chapter 6. Chapter 7 critically evaluates the feasibility of ideas and techniques presented in the thesis.

CHAPTER 2

STUDY AREA

Research presented in this study was conducted on the Twee River system, a total of roughly 46 km of clear water, first and second order streams in the Cedarberg Mountains, Western Cape (Figure 2.1). Mean annual runoff (MAR) of the catchment has been estimated at 49.4 x $10^6 m^3 a^{-1}$ (Impson, Unpublished report), and rainfall, measured near the Middeldeur source between January 1990 and

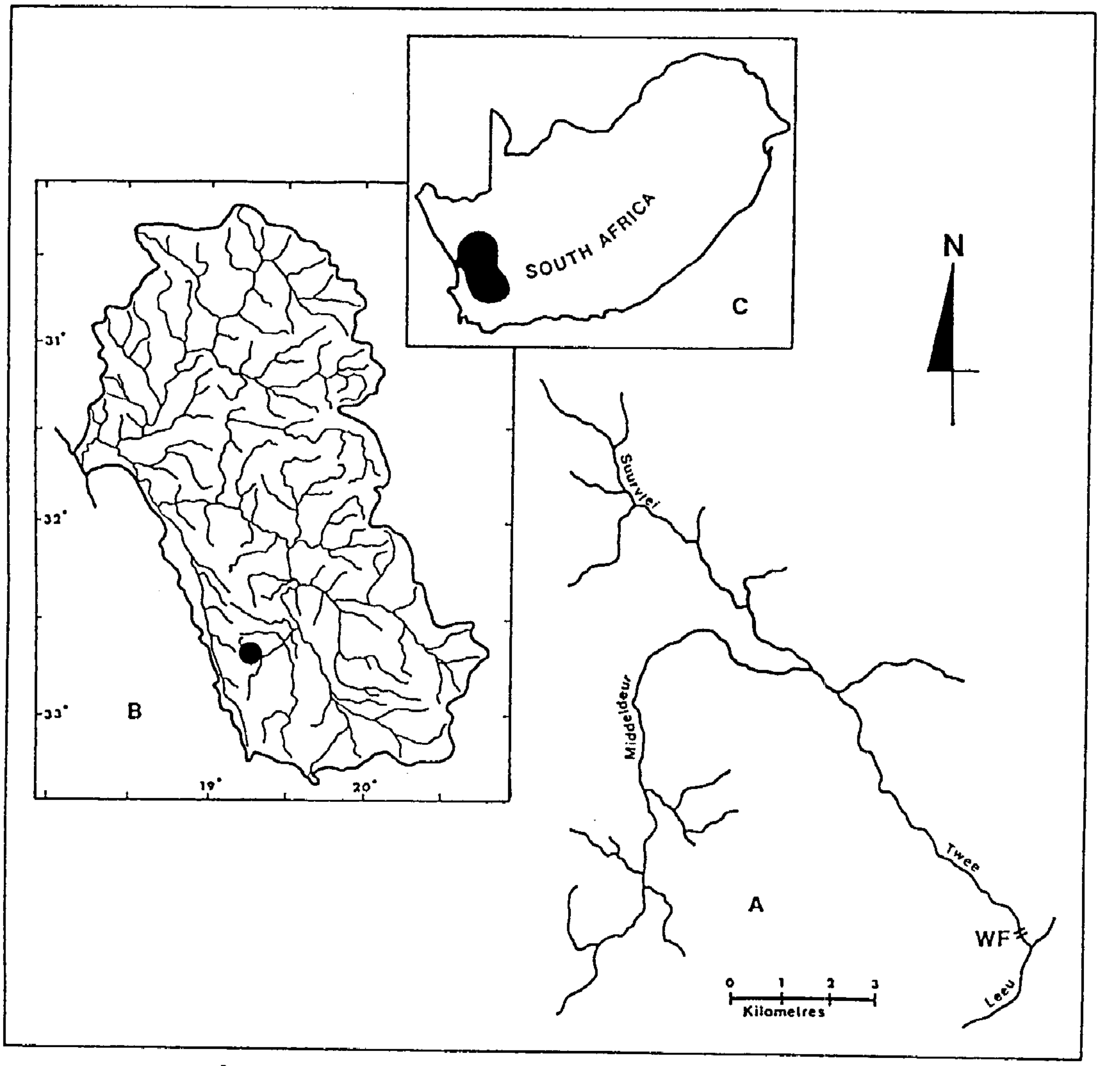


Figure 2.1. Map of the study area showing the Twee River catchment (A) situated in the Olifants River system (B), Western Cape. The shaded area on the inset map of southern Africa (C) represents the Olifants River system. The barrier waterfall which isolates the fish fauna of the Twee River is represented as WF.

December 1996 by Mr S. Du Toit, averaged 581.5 mm.y^{-1} (Figure 2.2). The area is characterised by predominantly winter rainfall, with seasonal floods transforming the streams into large, turbid rivers (Figure 2.4). Water temperatures may fluctuate between a low of less than 5°C and a high of greater than 27°C during the year (Skelton 1974b, pers. observ.), whilst diurnal temperature fluctuations of up to 6°C were measured in October/November 1996.

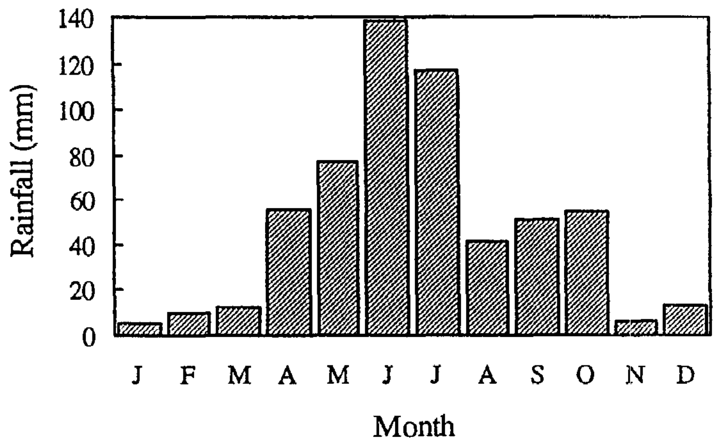


Figure 2.2. Mean monthly rainfall near the Middeldeur River source, measured by Mr S. Du Toit of the farm De Straadt, between January 1990 and February 1996.

Arising in the Cedarberg, at 1200 m.a.s.l., the Middeldeur River feeds a marshy intermontane plateau at approximately 850 m (Skelton 1974b). From here the river flows NNE for 12.5 km before curving round to follow an ESE direction for another 3.5 km, at which point it is joined by the Suurvlei to form the Twee River (Figures 2.1 & 2.3). The Suurvlei originates at around 1130 m and follows a SE course for 15 km. From the confluence of the Suurvlei and Middeldeur, the Twee River flows SE for a further 11 km before joining with the Leeu River. One smaller tributary, the Heks River, was also included in the study. This stream joins the Middeldeur from the west, with the uppermost site approximately 2.2 km up from this junction, at an altitude of 840 m. A variety of habitat types are represented within the river complex, including fast flowing, rocky riffles, shallow pools with sandy and rocky substrates, large pools, up to 12 m in depth, narrow channels and a number of substantial waterfalls (Figure 2.5).

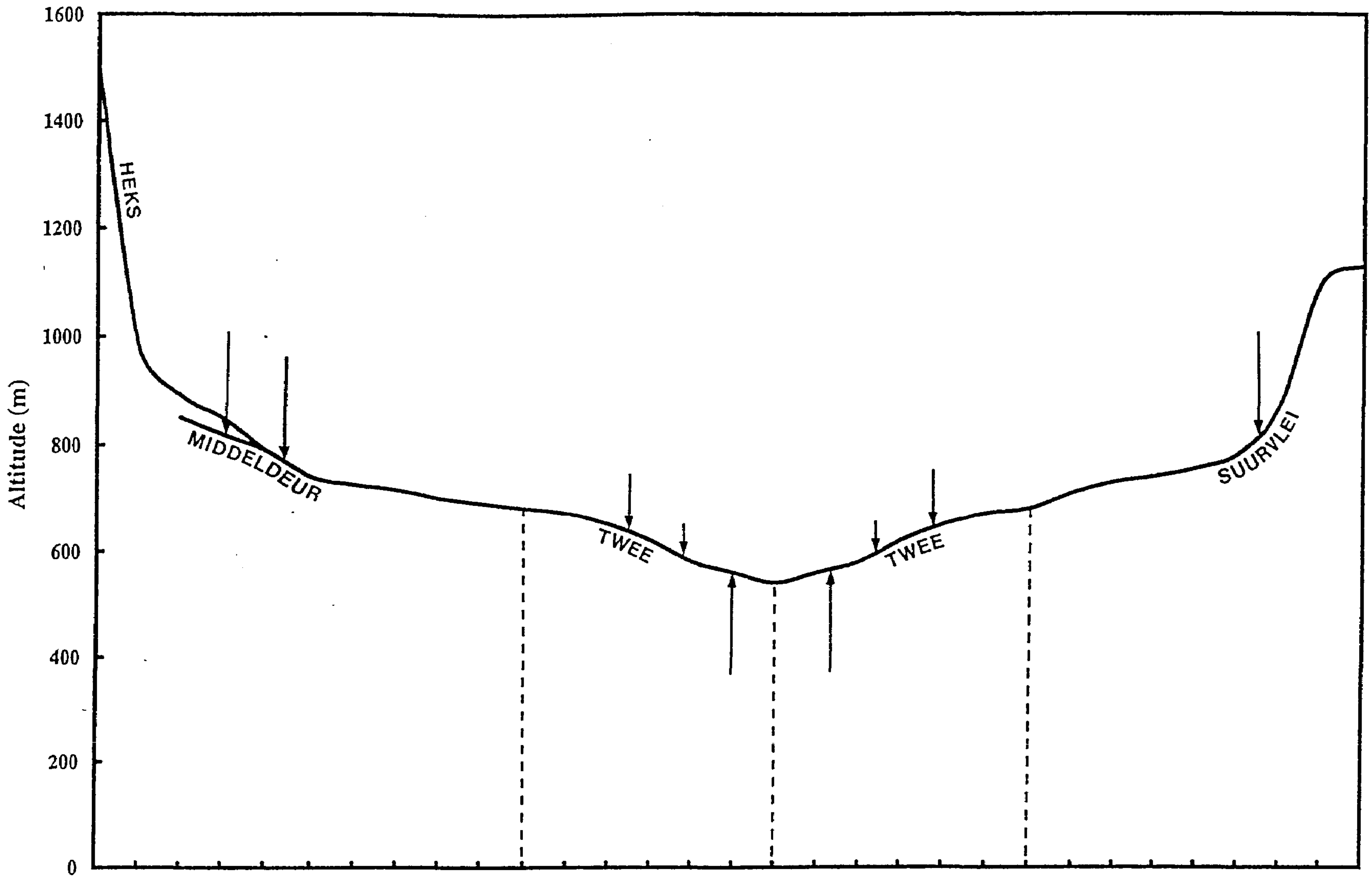


Figure 2.3. Gradient profile of rivers in the Twee River catchment, showing altitudinal distribution of river confluences and barrier waterfalls (indicated by arrows). The Twee River is depicted as a mirror image (separated by dotted lines) with its source tributaries, the Middeldeur and Suurvlei Rivers, entering from either side. X-axis tick marks represent 2 km intervals.

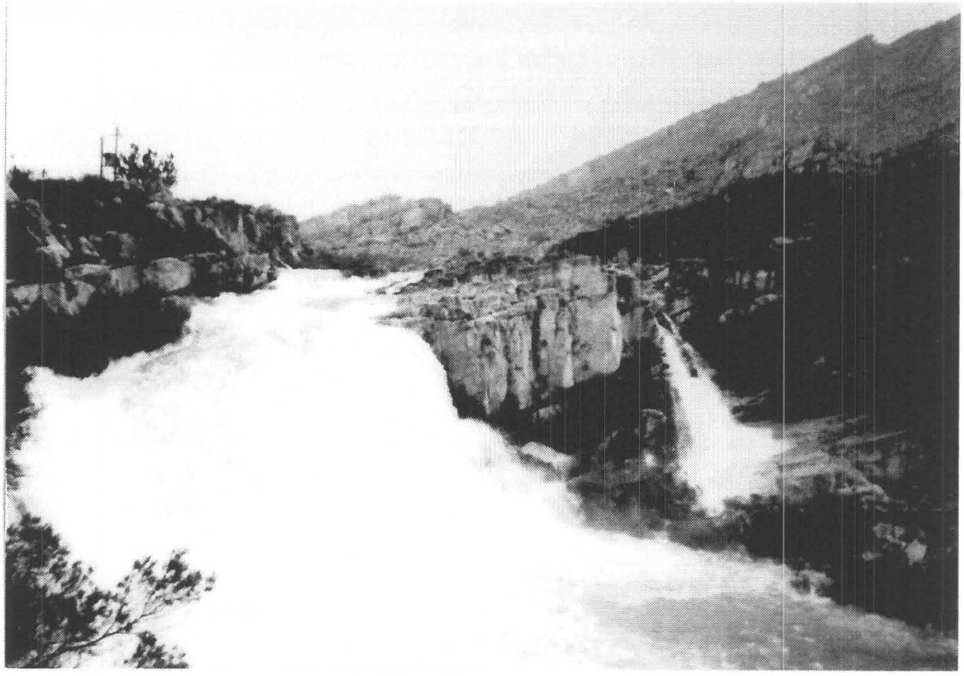


Figure 2.4. Winter rainfall transforms the usually clear streams of the Twee River catchment into torrents. This waterfall in the middle reaches of the Middeldeur River was photographed in August 1996.

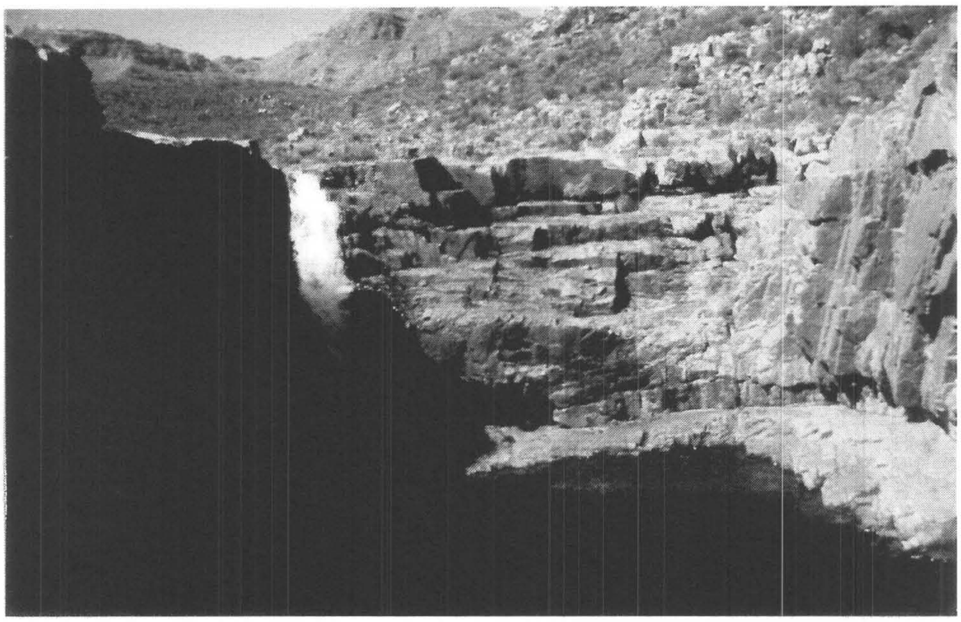


Figure 2.5. A 12 m waterfall on the Twee River, photographed in October 1996. This waterfall marks the lower boundary limit of the Twee River redfin, *Barbus erubescens*.

Although artificial impoundments do exist in the catchment (Figure 5.1), these are not on the main rivers, which remain largely free of constructed barriers. Cultivated lands occur along much of the Middeldeur and Suurvlei Rivers, but the Twee River flows almost exclusively through an unfarmed area, most of which constitutes reclaimed cultivated and grazing lands, and is presently maintained in its natural state. Elsewhere, farming is crop orientated, including citrus and deciduous orchards, as well as a variety of vegetables. The mountainous nature of the region restricts arable lands to the valley floors through which the rivers flow (Figure 2.6).

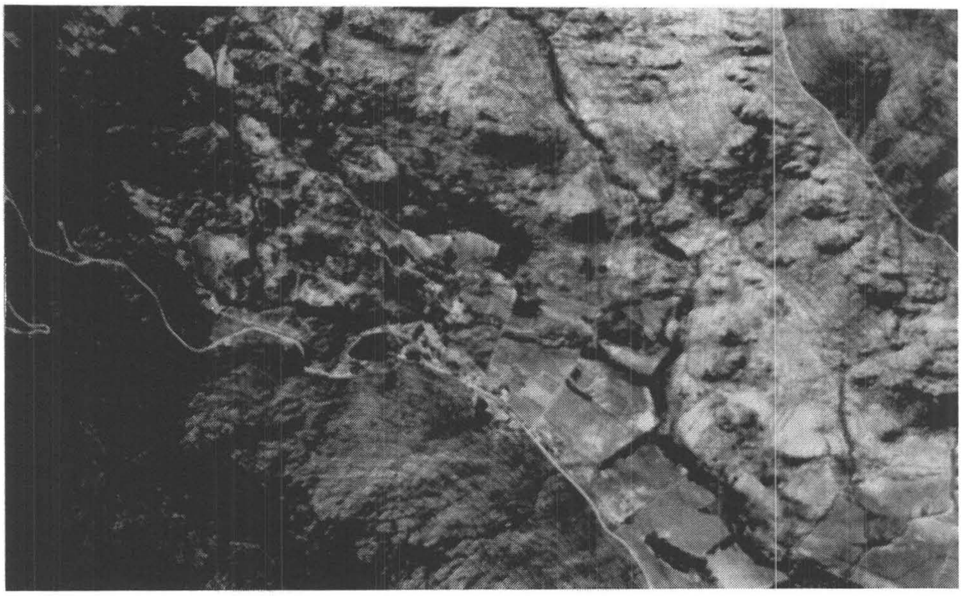


Figure 2.6. Aerial photograph of the upper Suurvlei River, showing how farming is restricted to the river valleys. The rocky, mountainous nature of the region prevents development of land higher in the catchment.

Vegetation in the Twee River catchment comprises of Mountain Fynbos (Barrie & Rebelo 1996). Not being rigorously defined in terms of floristics and structure, this is seen merely as Fynbos on the mountains of the Fynbos Biome (Barrie & Rebelo 1996). Fynbos is characterised by having restioid, ericoid and proteoid components, prevailing genera including *Erica*, *Restio*, *Ficinia*, *Senecio*, *Cliffortia* and *Aspalathus* (Teague et al. 1989, Barrie & Rebelo 1996). Dominant plants identified during this study included *Cliffortia ruscifolia*, *Metrosideres angustifolia*, *Prionum palmita* and *Restio spp*. Although these plants are largely associated with sandstone derived soils, in relatively high rainfall areas (greater than 300 - 400 $mm.a^{-1}$) they may also occur on leached soils derived from granites (Barrie & Rebelo 1996). In the Olifants River system most of the tributaries drain sandstone and quartzite of the Table Mountain Group, and so carry slightly stained, but clear, water with negligible silt loads except during spates (Gore et al. 1991). This water is generally high quality with a pH between 6.2 and 7.7 and very low levels of dissolved solids (conductivity ranging from 44.7 to 116 $\mu S.cm^{-1}$).

CHAPTER 3

CENSUS AND DISTRIBUTION

Introduction

The IUCN (1996) have outlined a range of quantitative criteria for listing taxa in a Red Data Book threatened category. Meeting the requirements of any one of these results in acceptance at that level of threat. A taxon is considered Critically Endangered when "it is facing an extremely high risk of extinction in the wild in the immediate future, as defined by any of the criteria (A to E)" (IUCN 1994):

A) declining population

B) small distribution

C) small population size and decline

D) very small population

E) quantitative analysis

Although a number of variables are considered for each of the categories, and the actual values set to describe population size or distribution vary considerably, all rely, to some extent, on accurate distribution data and estimates of population number.

Skelton (1974b, 1987, 1993) advises that *B. erubescens* is restricted to the Twee River complex, its downstream limit marked by a 12 m high waterfall on the Twee River, approximately 800 m upstream from the confluence with the Leeu. Extensive collections by Gaigher (1973) provide further evidence for this, indicating that *B. erubescens* is not found elsewhere where populations of indigenous fish, including *B. calidus*, are found in the Olifants system (cited in Skelton 1974b). Although the numbers of *B. erubescens* are believed to be declining (Hamman 1996), no known population estimates existed prior to this study. Furthermore, the exact extent of distribution of this species, within its known range, had not been fully documented. The present chapter investigates these two aspects of the study, also exploring the fish community structure and current status of alien and translocated species.

Materials and methods

Thirty three sites were used for census work and collections. They were selected at roughly 1 km intervals, between the upper boundary limits of the known fish distribution and the waterfall marking the lower known limit of *B. erubescens* (Figure 3.1). Upper distribution was accepted where fish were found up to, but not above, a barrier. In cases where barriers, such as waterfalls, apparently restricted upstream movement, the stretches of river above and below were considered separate. In this way exact upper limits could be clearly defined at a specific point on the river.

Hankin (1984) cautioned that errors in fish abundance estimates arise from two sources, 1) through extrapolation from a small number of sampled stream sections to an entire stream, and 2) from estimation of fish numbers within sampled sections. He recommended that sampled areas should correspond to natural habitat units and, as such, an attempt was made to include a number of habitat types at each site (e.g. pool, riffle, channel). The length of sites therefore varied and were not standardised. Rather, site lengths were estimated for later calculations. Also recorded were GPS (geographical positioning system) readings and brief site descriptions. A total of approximately 3990 m of river were censused.

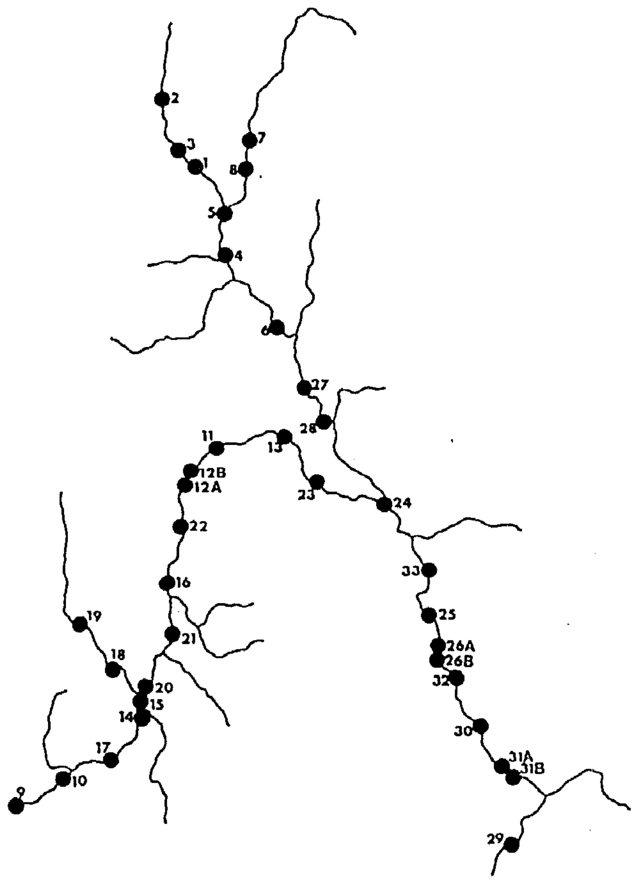


Figure 3.1. Distribution of study sites (dots) along streams in the Twee River catchment. Site numbers correspond with details given in Appendix A. In an effort to include a number of different habitat types at each site, lengths were not standardised. A total of roughly 3990 m of river was sampled.

Fish were identified and counted using snorkelling techniques. Since Red Data Book threatened categories rely on estimates of numbers of mature individuals only, *B. erubescens* were further classified either as mature or immature, based both on colouration and size. Juveniles, although counter-shaded, had an overall light grey colour, whereas mature individuals, even out of breeding season, were dark olive dorsally with a distinct dark stripe along each flank and red flashes at the base of the fins. Habitats were searched thoroughly, and all fish counted. In an effort to cover as much area as possible, given time constraints, different stretches of river within each site were censused by individual divers, and counts were combined to give a total for each site. The divers did not follow set transects and in this way the method differed from other snorkel studies (Northcote & Wilkie 1963, Griffith 1981, Slaney & Martin 1987, Hankin & Reeves 1988, Zubik & Fraley 1988, Hillman et al. 1992, Rodgers et al. 1992). There were several reasons for this, including the extreme variation in stream width and depth, and uneven local distribution of species, some displaying shoaling behaviour and occupying only small areas within each site. Counts were conducted in March 1996 and repeated in January/February 1997. Wilcoxon's test for matched pairs (Fowler & Cohen 1992) was used to determine whether these counts differed significantly. This test requires six or more comparisons and thus demanded that a species was identified from at least six sites. It was accepted that the ratio of fish species had remained the same if the counts did not differ significantly.

Snorkelling tends to underestimate fish numbers (Northcote & Wilkie 1963, Griffith 1981, Slaney & Martin 1987, Zubik & Fraley 1988, Rodgers et al. 1992). This negative bias is species dependent (Northcote & Wilkie 1963) but, in a study by Rodgers et al. (1992), it was found that snorkelling never leads to overestimation. Furthermore, Northcote & Wilkie (1963) observed that although average counts by divers underestimated fish numbers, maximum counts were close to numbers recovered after poisoning. For this reason, only the highest observed number, from either March or Jan/Feb counts, was used in calculations. Fish numbers were assumed to be directly proportional to the length of river included in study sites, and absolute numbers were therefore determined by extrapolation to the total length of river occupied by each species.

Collection of distribution data also made use of electrofishing, in shallower, accessible areas, and gillnetting and rod and line fishing for larger species in some of the deeper pools (Table 3.1) (Hayes 1983, Reynolds 1983). In these cases only the presence or absence of a species was recorded.

Table 3.1. Alternative sampling methods used for collection of fish distribution data in the Twee River catchment, Western Cape. Snorkelling was used at all sites, except where indicated.

Site number	Sampling Methods
1	electrofishing (no snorkelling)
2	electrofishing (no snorkelling)
3	electrofishing (no snorkelling)
5	electrofishing (no snorkelling)
6	electrofishing
12	rod & line angling
26	rod & line angling, gill nets
29	rod & line angling
30	rod & line angling
31	rod & line angling

Results

Population census

Six fish species were identified in the Twee River system, *B. erubescens* (Twee River redfin), *Galaxias zebratus* (Cape galaxias), *Sandelia capensis* (Cape kurper), *Lepomis macrochirus* (bluegill sunfish), *Oncorhynchus mykiss* (rainbow trout) and *Barbus capensis* (Clanwilliam yellowfish). *Micropterus dolomieu* (smallmouth bass) was found up to, but not above, the waterfall forming the lower boundary limit of *B. erubescens*. Details of numbers of fish counted at sites are given in Appendix A. Total numbers counted are given in Table 3.2.

The results from Wilcoxon's test for matched pairs (Fowler & Cohen 1992) indicate that numbers of *B. erubescens* ($T = 145$, $p > 0.1$), *S. capensis* ($T = 100$, $p > 0.1$) and *G. zebratus* ($T = 20$, $p > 0.1$), the three most abundant species, did not differ significantly between counts. *Lepomis macrochirus* ($T = 2$,

$p < 0.05$) and *B. capensis* ($T = 0$, $p = 0.05$) did show significant differences but were found in very low numbers. *Oncorhynchus mykiss* was found at only four sites and could therefore not be tested, however numbers were again very low (Table 3.2). Even though water clarity had deteriorated in Jan/Feb and some sites could not be censused, only the results for species already found in low numbers were affected significantly. For the purposes of this study, therefore, the ratio of fish species was considered to have remained relatively constant and in line with observations made in clearer water during March 1996. Table 3.3 summarises total estimates of fish numbers and area of occurrence.

Table 3.2. Total number of fish counted at study sites in the Twee River complex, Western Cape, during March 1996 and January/February 1997.

Species	March 1996	Jan/Feb 1997
Barbus erubescens	1147 (564 mature)	1426 (316 mature)
Galaxias zebratus	757	186
Sandelia capensis	1008	1276
Lepomis macrochirus	58	4
Oncorhynchus mykiss	11	4
Barbus capensis	196	51

Table 3.3. Total numbers of fish in the Twee River catchment, Western Cape. Figures are based on estimates from maximum counts made during March 1996 or January/February 1997 (Table 3.2). Counts were extrapolated from sampled river length, within the inhabited area of individual species, to total river length within this inhabited area. Hence smaller counts for some species resulted in larger ultimate totals, where higher densities were observed along a shorter sampling length.

Species	Total estimated fish #	%River length inhabited
Barbus erubescens	8400 (4100 mature)	60
Galaxias zebratus	14100	46
Sandelia capensis	17600	74
Lepomis macrochirus	600	21
Oncorhynchus mykiss	70	9
Barbus capensis	2400	34

Distribution

Historical distribution data, based on collections made between 1964 and 1988, are presented in Figure 3.2. Comparative distributions of fish species, from the March 1996 and Jan/Feb 1997 censuses, are given in Figures 3.3 and 3.4. The downstream limit of *B. erubescens* and *S. capensis* (site 31A) agreed with observations by Skelton (1974b), being marked by a 12 m waterfall. Below this fall only large species, *B. capensis*, *O. mykiss*, *M. dolomieu* and one large *L. macrochirus*, were found. In both surveys, juveniles of these species were absent. Altitudinal limits of all species, along a gradient profile, are presented in Figure 3.5.

Barbus erubescens was found uppermost in all tributaries, at ± 770, 800 and 840 m.a.s.l, on the Middeldeur (site 9), Suurvlei (site 7) and Heks Rivers (site 19) respectively. Upper distribution was limited by small waterfalls and cascades. On the Middeldeur this coincided with the base of the fall line from the source plateau, and on the Suurvlei included an extension on previous records. Redfins were absent from the middle reaches of the system. Although previous distribution data is sparse, and based on collections from relatively accessible sites only, it nevertheless does show a more continuous distribution than is observed today (Figure 3.2). A 40% decline in area of occupancy is estimated.

Galaxias zebratus, the only other fish species indigenous to the Twee River catchment, was restricted almost exclusively to the Middeldeur River, with one site on the Twee River. Skelton previously collected this species from small tributaries of the Suurvlei River (pers. comm. 1998) and it seems that their absence may coincide with the absence of *B. erubescens* from this area. Upper and lower limits were not clearly defined by barriers.

The introduction of *S. capensis* is purported to have taken place accidentally in the early 1950's (Hamman et al. 1984), although there are no official records of this event and the species apparently remained hidden, despite extensive monitoring, until the early 1980's. The natural distribution of the Cape kurper extends from Verlorevlei in the south-western Cape to the Coega in the Eastern Cape (Gaigher et al. 1980), but the species was found to have become even more widespread in the Twee River catchment than native species. On the Middeldeur River, further upstream dispersal is prevented by a waterfall (32°43'27"S, 19°13'40"E - site 20), but on the Suurvlei, only minor riffle areas and cascades prevent upstream movement into the remaining refuge of *B. erubescens*.

Lepomis macrochirus appeared to be restricted entirely to the Middeldeur River in March 1996, but in 1997, was found 13 km downstream (Figure 3.3 & 3.4). The 1996 sightings of this species were the first record of bluegill in the Twee River catchment. It is conceivable that, with winter flooding, dispersal over this distance did occur in the short period between the two surveys. Alternatively, the species may have remained unseen during previous surveys due to low numbers. There appeared to be no knowledge, amongst locals, of the introduction of this species and the site and year of introduction are therefore not known. Although an apparently recent introduction, bluegill have already become established downstream and further upstream dispersal is possible.

In 1989 200 *B. capensis* (10-20 of TL = 20 cm, 180 of TL = 10 cm), a threatened species indigenous to the Olifants system, were introduced to the Twee River catchment between sites 20 and 26 (Figure 3.1), by Mike Dolhoff, a nature conservator with Cape Nature Conservation (Impson, D. pers. comm. 1998). Yellowfish were also stocked into dams at the head of the catchment. Although no official stocking records were kept there is a likelihood that another stocking, by R. Kourie, took place in 1984

(Impson, D. pers. comm. 1998). The distribution does not appear to have expanded since then, but the presence of juveniles at some sites provides evidence that yellowfish are established and breeding.

Oncorhynchus mykiss was observed in very low numbers during 1996 and 1997, but the presence of a few small individuals and the species' presence during yellowfish stocking in 1989, suggest that trout are reproductively active in the Twee River. An 8 m high waterfall on the Twee River (32°41'09"S, 19°16'39"E - site 26) restricts upstream movement. The date of introduction is unknown.

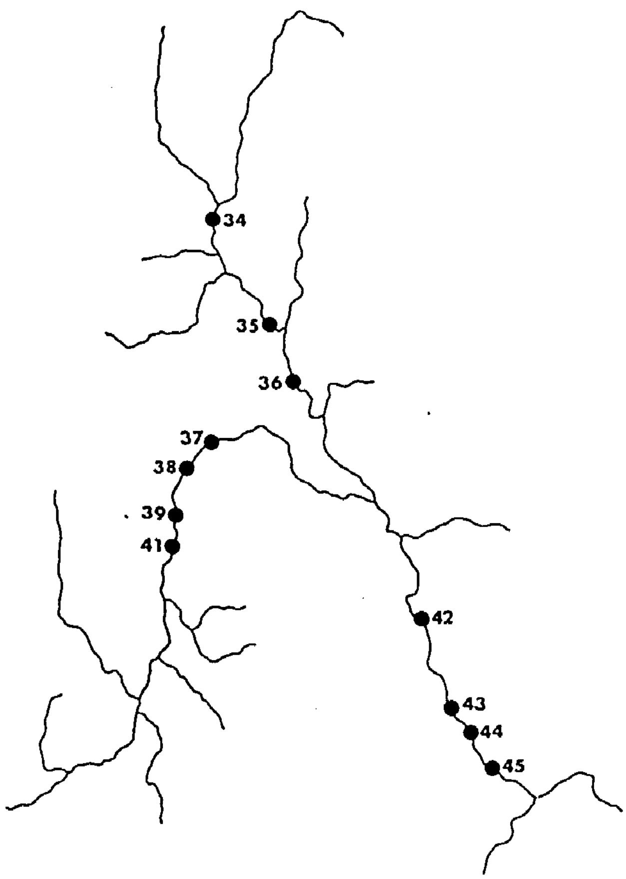
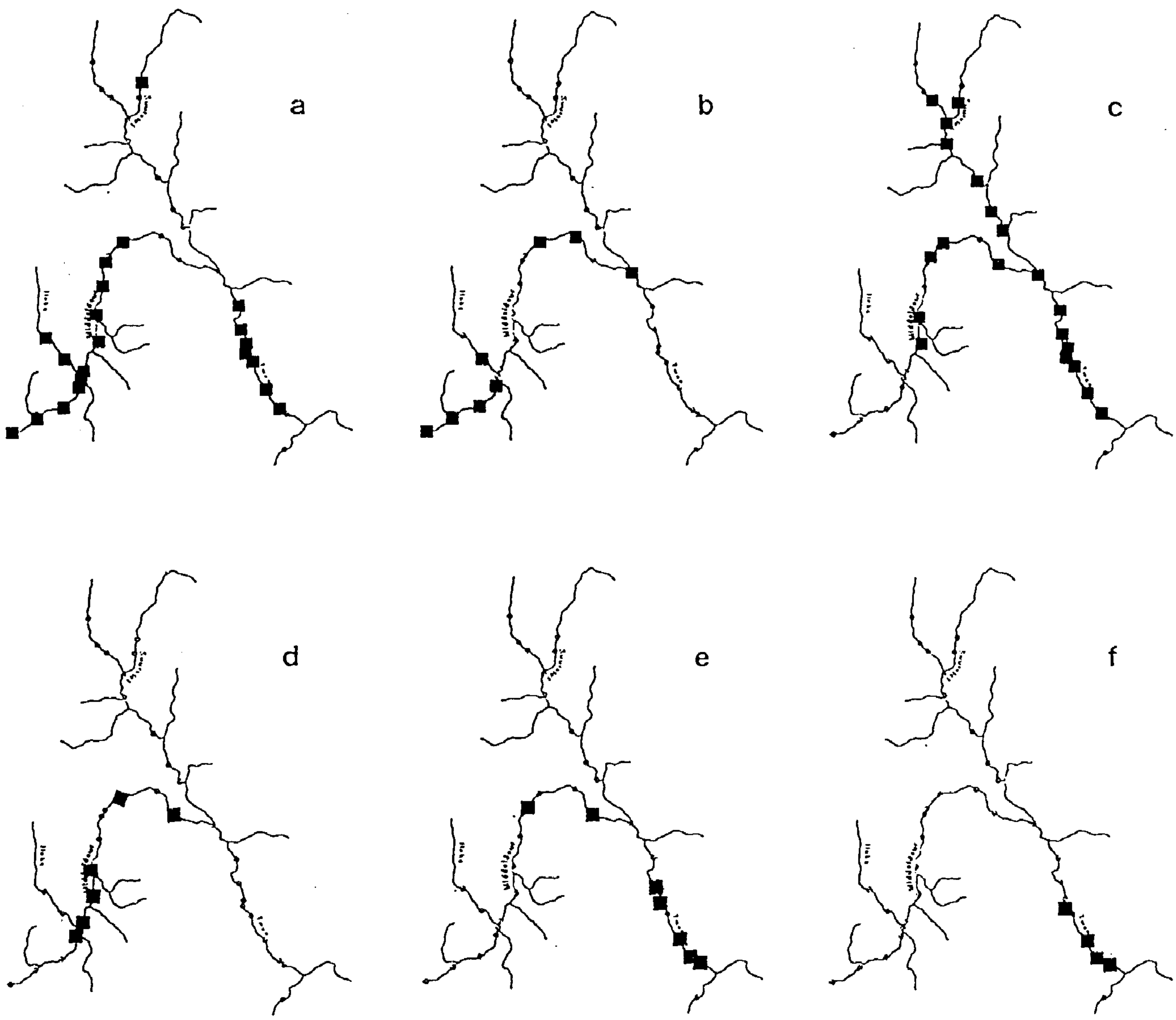


Figure 3.2. Historical distribution of *Barbus erubescens* within the Twee River catchment, Western Cape, based on Albany Museum collections made between 1964 and 1988.



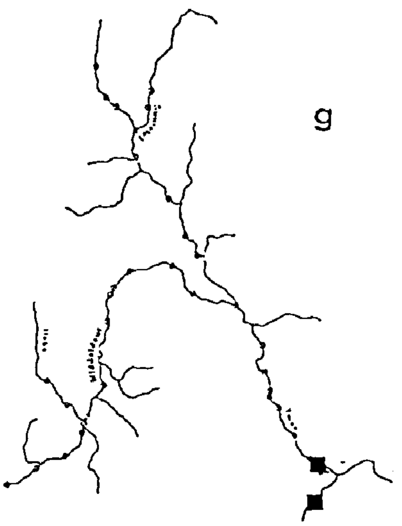


Figure 3.3. Distribution of fishes in the Twee River catchment, Western Cape, during March 1996. Sites were chosen at approximately 1 km intervals and fishes were observed by snorkelling. Black dots represent sites where the species was observed and clear dots where they were absent. a = *Barbus erubescens*, b = *Galaxias zebratus*, c = *Sandelia capensis*, d = *Lepomis macrochirus*, e = *Barbus capensis*, f = *Oncorhynchus mykiss*, g = *Micropterus dolomieu*.

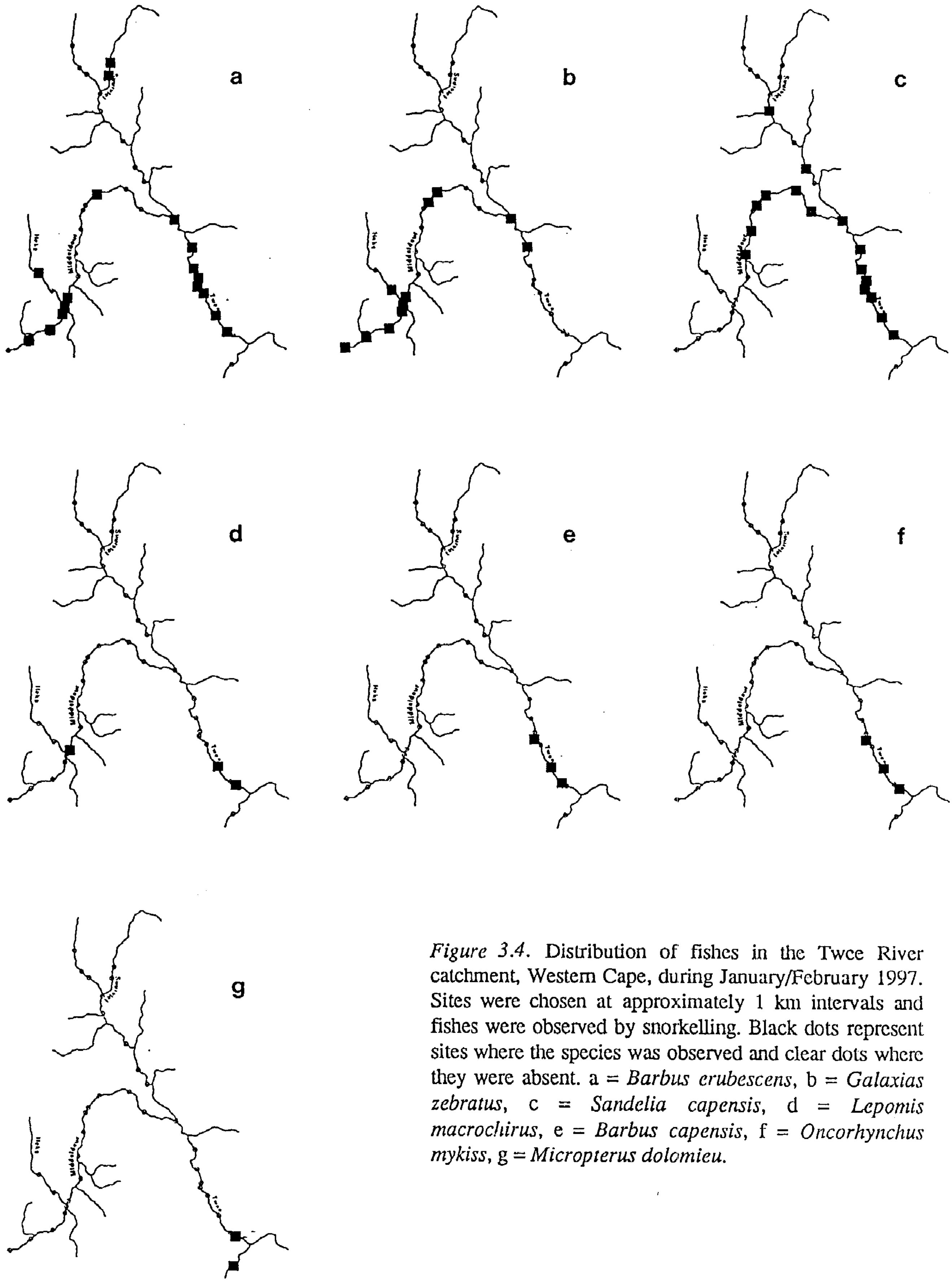


Figure 3.4. Distribution of fishes in the Twee River catchment, Western Cape, during January/February 1997. Sites were chosen at approximately 1 km intervals and fishes were observed by snorkelling. Black dots represent sites where the species was observed and clear dots where they were absent. a = *Barbus erubescens*, b = *Galaxias zebratus*, c = *Sandelia capensis*, d = *Lepomis macrochirus*, e = *Barbus capensis*, f = *Oncorhynchus mykiss*, g = *Micropterus dolomieu.*

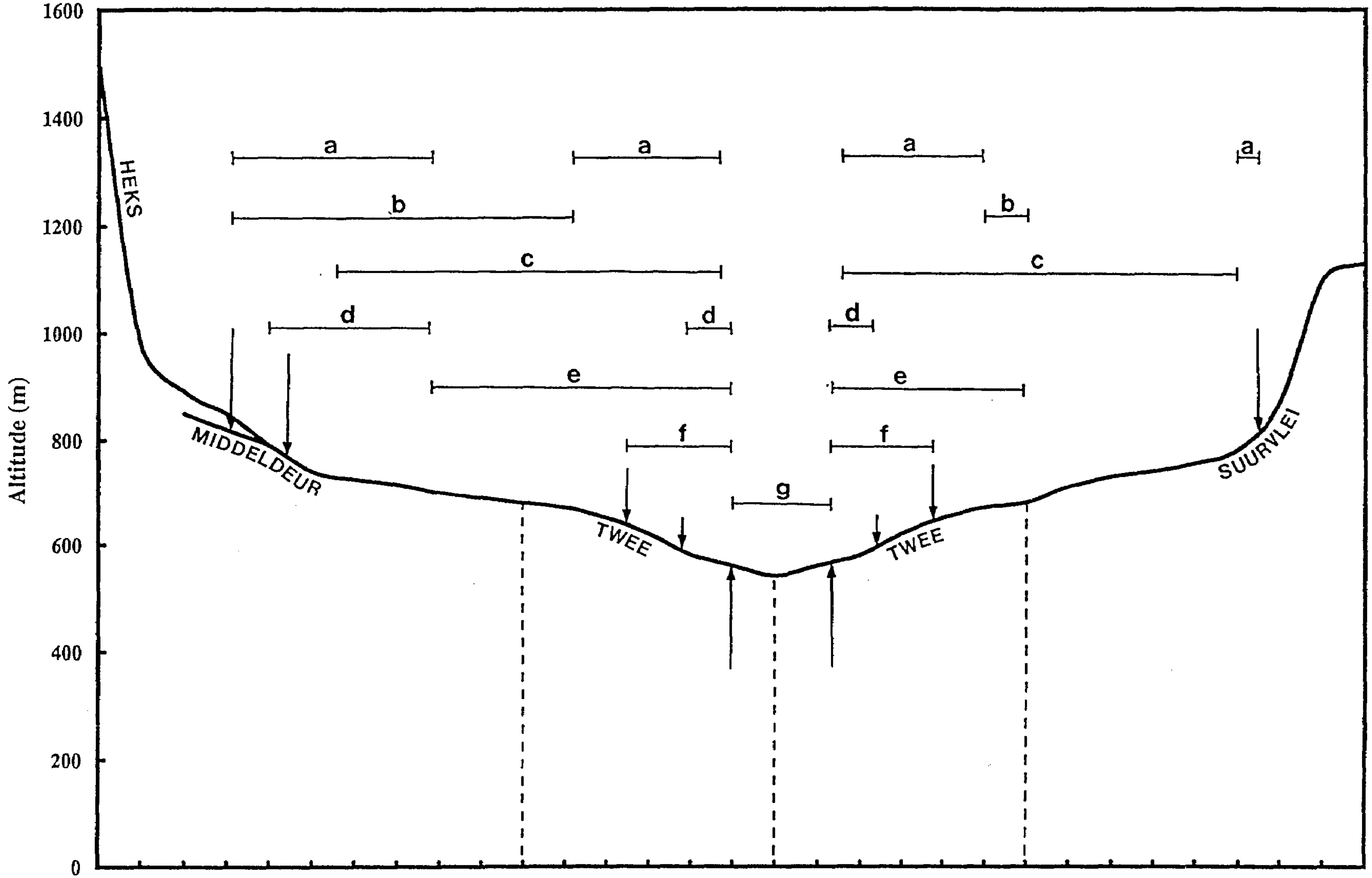


Figure 3.5. River gradients in the Twee River catchment, showing longitudinal distribution of fishes, based on March 1996 and January/February 1997 snorkel surveys. The Twee River is depicted as a mirror image (separated by dotted lines) with its source tributaries, the Middeldeur and Suurvlei Rivers, entering from either side. X-axis tick marks represent 2 km intervals. a = *Barbus erubescens*, b = *Galaxias zebratus*, c = *Sandelia capensis*, d = *Lepomis macrochirus*, e = *Barbus capensis*, f = *Oncorhynchus mykiss*, g = *Micropterus dolomieu*. Positions of barrier waterfalls are indicated by arrows.

Discussion

Reliable enumeration of fishes in large streams has long challenged researchers (Northcote & Wilkie 1963, Vincent 1971, Griffith 1981, Mann & Penczak 1984, Slaney & Martin 1987, Hankin & Reeves 1988, Zubik & Fraley 1988, Hillman et al. 1992, Rodgers et al. 1992). Whilst results may be obtained by several means, most are suitable only under a narrow range of conditions. In ecologically sensitive studies the use of destructive techniques, such as piscicides, cannot be justified, and other popular techniques, including mark-recapture (Zubik & Fraley 1988), angling (Slaney & Martin 1987, Zubik & Fraley 1988), electrofishing (Vincent 1971, Reynolds 1983, Mann & Penczak 1984) and seine netting (Hayes 1983), are often time consuming, costly and labour intensive. In clearwater streams, underwater observation provides a quick, cost effective alternative, which is not inhibited by cumbersome equipment, low conductivity, deep water or boulder substrates (Slaney & Martin 1987), and which can be used to sample large areas (Griffith 1981, Hillman et al. 1992). In spite of its advantages, though, a number of factors undoubtedly influence the efficiency of this technique. Snorkelling is reliant on suitably clear water, with 3-4.5 m visibility recommended as a minimum (Northcote and Wilkie 1963, Griffith 1981, Gardiner 1984, Zubik & Fraley 1988). Furthermore, warm water may be necessary for an accurate result as low temperatures cause fishes to seek cover (Zubik & Fraley 1988, Hillman et al. 1992). Hillman et al. (1992) discovered that below 14°C, juvenile salmonids were undercounted by 50%. Finally, Northcote & Wilkie (1963) documented the problems associated with hiding, dispersion and counting of large, rapidly moving groups. They suggested that reactions may be species dependent, divers possibly causing fishes to seek cover, or alternatively attracting them to disturbed sediments.

The six species investigated in this study differed greatly. Adult *B. erubescens* showed an affinity for sheltered areas, including overhangs and caves formed by boulders, where they sometimes accumulated in large shoals. In most cases they were not frightened off by divers but the size of shoals and the continuous movement of individuals in and out of inaccessible recesses, made them particularly difficult to count. Juveniles were usually encountered in large groups in the water column, in or around marginal vegetation. Under certain light conditions and levels of suspended sediment, they too were sometimes difficult to see. *Galaxias zebratus* and *S. capensis* displayed a tendency to hide, often in dense aquatic vegetation, necessitating close approach. Trout and bluegill were more active and usually seen only briefly, although in some instances bluegill were noted to take refuge under rocks. On the other hand, large yellowfish were inclined to follow divers, thereby increasing the probability of repeated counts.

"Even under the most favourable conditions, diver counts by themselves are nothing more than rough indicators of true abundance" (Hankin & Reeves 1988), and studies have consistently shown that snorkelling underestimates fish numbers (Northcote & Wilkie 1963, Griffith 1981, Slaney & Martin 1987, Zubik & Fraley 1988, Rodgers et al. 1992). It is likely that small size and the presence of cover contribute most to the risk of negative bias (Slaney & Martin 1987, Zubik & Fraley 1988). Nevertheless, snorkelling may suffice in cases where less accuracy is required for management needs (Rodgers et al. 1992). In accordance with Red Data Book threatened categories (IUCN 1996), for a species to be considered Critically Endangered, based in any way on the number of individuals, fewer than 250 adults must be known to exist, 2500 to classify as Endangered and 10000 for Vulnerable (IUCN 1994). The need for accuracy, with broad categories such as these, is therefore limited. Without earlier counts for comparative purposes though, absolute numbers alone, unless remarkably small, provide little indication of threat status. According to the census results from this study, *B. erubescens* should be considered no more than Vulnerable. This status changes when the species distribution is considered, and attention needs to be drawn to such criteria.

The smallest area of occupancy recognised by the IUCN (1994) is 10 km^2. Over a 40 km stretch of river, average width, to exceed this, would have to be 25 m. The Suurvlei River varies between 3 and 7 m, the Middeldeur 10-15 m and the Twee River has some pools of up to 30 m in width. At the time of its description *B. erubescens* had a relatively continuous distribution within this complex (Skelton 1974b). The 1996-1997 survey showed this area of occupancy to have declined by approximately 40%, manifested by the complete absence of the species from the middle reaches of the river system, the original population having been fragmented. A corresponding decline in numbers might also be expected. Fragmented populations are more susceptible to threats and more fragile than the original whole, and faced with a previously restricted, and presently deteriorating distribution, *B. erubescens* is therefore likely to become increasingly susceptible to perturbations.

Already, alien species are widespread in the Twee River system and there is little to prevent further expansion. Even so, in many cases *B. erubescens* appear to co-exist with these species. The effect of exotic fishes on an indigenous species, or the combined effect with other threats, is impossible to determine from distribution information alone. Dispersal of fishes may be dependent on a number of factors, including intra- and interspecific interactions, food and habitat availability, habitat structure, and abiotic factors such as light and temperature (Freeman & Grossman 1993, Podolszky et al. 1995). An understanding of the ecological and biological requirements of *B. erubescens*, and the corresponding needs of exotic species, as well as an informed knowledge of other threats, is necessary before conclusions can be drawn and management plans developed.

CHAPTER 4

GENERAL BIOLOGY

Introduction

Cambray & Hecht (1995), in a study of two closely related redfin minnows, discussed the relevance of species biology to conservation management schemes. They proposed that fish species in clear water, oligotrophic systems are adapted to stable conditions and are therefore less able to withstand environmental fluctuations. The rivers in which *B. erubescens* occur are typically cool and clear, although slightly peat stained (Skelton 1974b, 1987). Under continued threat from alien fishes and the effects of land use practices (Hamman 1996), *B. erubescens* has become the focus of some conservation attention, yet, despite its Critically Endangered status, no work on its biology has been published. Until now, this information was restricted to observations (Skelton 1974b, 1988) and chapter 4 presents the first quantitative study on aspects of the species' biology. Spawning seasonality, gametogenesis, feeding, age and growth and habitat preference analysis will provide an insight into the population dynamics of the species, thereby contributing to management decisions.

Materials and methods

Barbus erubescens were collected with a minnow seine net from sites on the Twee, Middeldeur, Suurvlei and Heks Rivers, between March 1996 and March 1997 (Table 4.1). Sampling during winter months, from May to September, was excluded due to the generally unfavourable conditions of elevated water levels. A total of 81 fish were collected for the study. Collections were limited in size due to the fragile conservation status of the species and 33 specimens from the Albany Museum, Grahamstown, sampled between March 1964 and March 1980 (Table 4.3), were used to supplement the small sample size.

Specimens were fixed in 10% formalin before being transferred to 70% propyl-alcohol for storage. Excess liquid was blotted off and individual fish weighed, to the nearest 0.01 g, and measured [total (TL), standard (SL) and fork lengths (FL)], to the nearest 0.1 mm. After removal of the viscera, mass was again recorded (0.01 g) and the dissected gonads blotted and weighed (0.0001 g). Gonads and foregut contents were retained for histological examination and dietary analysis respectively. Due to the advanced stage of prey digestion, the contents of the hindgut (*i.e.* that section after the first U-bend) were not examined (Froglia 1977, Buxton 1984).

Table 4.1. Collection and accession details of *Barbus erubescens* sampled during this study, from the Twee River catchment, Western Cape. Specimens are housed in the JLB Smith institute, RUSI collection, Grahamstown. Site numbers correspond with Figure 3.1.

Date	Site number	# Males	# Females	# Juveniles	RUSI #
16/03/1996	7	-	-	10	-
16/03/1996	10	1	5	1	-
01/11/1996	25	-	1	-	053463
03/11/1996	8	4	3	4	053466
06/11/1996	10	-	-	5	053458
05/12/1996	25	2	-	-	054127
06/12/1996	25	5	3	-	054129
23/01/1997	25	-	-	3	054262
24/01/1997	31	2	2	-	054259
25/01/1997	19	3	3	-	054257
07/02/1997	15	5	7	-	054258
07/02/1997	10	1	-	-	054266
21/03/1997	15	4	6	1	054649

Table 4.2. Accession details of *Barbus erubescens* used in this study, from the Albany Museum, AMG collection, Grahamstown. Specimens were collected from the Twee River catchment, Western Cape. Site numbers correspond with Figure 3.2.

Date	Site number	# Males	# Females	# Juveniles	AMG #
11/03/1964	42	1	-	-	1882
06/04/1967	Twee River	3	1	-	1388
08/10/1973	41	2	1	-	2047
10/10/1973	41	-	4	1	2046
11/10/1973	43	-	-	1	2045
14/10/1973	43	1	-	1	2043
08/12/1973	36	5	-	-	2074
08/12/1973	42	1	3	-	2075
28/11/1977	37	-	7	-	7348
20/03/1980	42	-	-	1	7682

Reproduction

Gonad samples from 41 fish were embedded in paraffin wax and sectioned to 6-10 µm, before staining with Gill's Haematoxylin and Papanicoloau's Eosin A, in a procedure similar to that described by Yamamoto & Yamazaki (1961). Maturity was determined for male and female fish sampled during the breeding season according to the following criteria: females if they contained eggs from the primary yolk vesicle stage, and males if they had fully developed sperm in the testes (West 1990, Palmer et al. 1995). Size at sexual maturity was calculated by fitting a logistic ogive to the proportion of mature fish in 5 mm SL size classes. The 2 parameter logistic ogive used can be described by the equation:

$$P(l) = \frac{1}{1 + \exp^{-(l - l_{50})/\delta}}$$

where $P(l)$ is the percentage of mature fish at length l; l_{50} is the length at 50% sexual maturity; exp is the exponential and δ the width of the ogive. Gonado-somatic indices (GSI) for mature males and females were calculated as gonad mass as a percentage of eviscerated body mass. Spawning seasonality was deduced by plotting mean GSI against time (months). Length frequencies for male and female fish were determined as the total number of individuals of each sex in 4 mm size classes, and represented as percentage values. Median lengths for gender maturity were compared using the Mann-Whitney *U*-test.

Feeding

Gut contents from all specimens were sorted and identified to the lowest possible taxon. Visual estimates of percentage volume (%V), the number of individuals of each prey item (N) and the frequency of occurrence (F) were determined. An index of relative importance (IRI) was calculated for each prey item according to Hyslop (1980) where:

$$IRI = (\%N + \%V) \times \%F$$

To investigate changes in seasonal dietary preference, expected and observed monthly F values for the principle dietary items [(insects, other invertebrates, algae/plant and grit/amorphous) and primary insect groups (Ephemeroptera, Diptera, Trichoptera and other insects)] were compared in contingency tables, using chi-square analysis.

Age and growth

Three scales were removed from the left side of each of 91 fish, above the lateral line and immediately below the dorsal fin (Secor & Trice 1995). After soaking in water with a small amount of detergent, for a period of at least one day, to aid removal of mucus and excess skin, scales were rubbed clean and dried between microscope slides to prevent curling. Growth rings (Figure 4.1) were counted under transmitted light using a Micrographix MGX 1100 Microfiche reader, at high magnification. A practice reading of all scales was conducted and this data set was, for the most part, ignored. A second set of readings was taken and where all three scale readings agreed the value was accepted. In cases where one scale had been resorbed, these were discarded. If the readings from the other two scales agreed, they were compared to the readings from the first data set. If all four values corresponded, they were accepted. When two or three scales were readable but disagreed by one year, a third set of readings was taken. If, when compared to the second set, at least three out of four, or four out of six readings agreed, this value was accepted. In the few cases where more than one scale had been resorbed, additional scales were prepared.

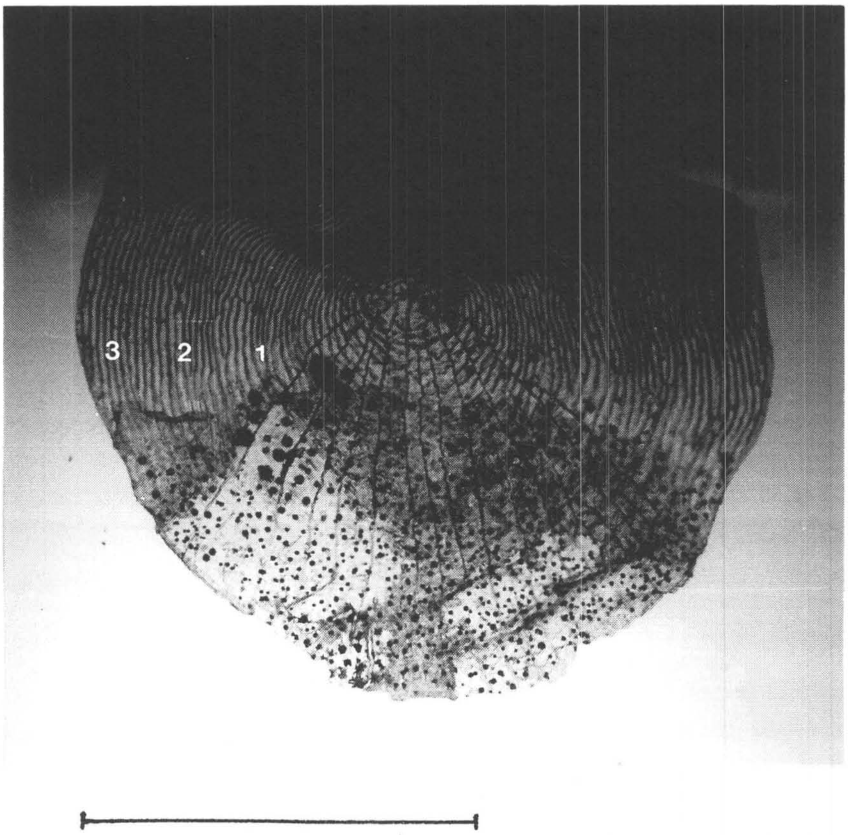


Figure 4.1. A sample scale of *Barbus erubescens*, estimated to have an age of 3 years. Annual rings are continuous across the anterior field and were counted at points of crossing over (1, 2, 3). Marginal zone analysis was used to validate the periodicity of ring formation. Scale = 2 mm.

Marginal zones of scales were examined in order to validate the periodicity of ring formation. Rings on the scales were formed by an interruption of the regular arrangement of circuli in the lateral field (Figure 4.1). Only rings which were continuous across the anterior field, from one lateral field to the other, were considered to be valid. Width of the outer margin was expressed as a percentage of the monthly sample. Length-at-age was modelled using non-linear minimisation of the difference between absolute and expected values, to fit a best-fit von Bertallanfy growth equation of the form:

$$L_t = L_\infty(1-e^{-K(t-t0)})$$

where L_t is the length-at-age, L_∞ the predicted asymptotic length, K the Brody growth co-efficient and t_0 the age at zero length (Ricker 1975).

Habitat preference

Fish were observed at four selected 50 m sites, using snorkelling techniques. Two unimpacted sites (7 & 19 - a, b), on the Suurvlei and Heks Rivers, an impacted site (10 - d), on the Middeldeur River and a recovery site (25 - d), on the Twee River were chosen (Figure 3.1). The same sites were also used for water quality assessment (chapter 5). Divers worked alone, moving slowly upstream and attempting not to disturb fish. At each observation, numbers of *B. erubescens* were noted, a weighted float being dropped at the spot to mark fish presence. Later, habitat type and depth were recorded at the markers. Inasmuch as adult *B. erubescens* tended to be associated with the substrate (pers. observ.) and only one small group of juveniles was seen and were therefore not included in the study, the specific depth, in the water column, at which fish were observed, was not recorded. Following the mapping of habitats at each site (Appendix E), habitat types were combined from all four sites and expressed as a total percentage of wetted area. Relative heights and water depths, across bankfill cross-sections, at 1 m intervals were established using a theodelite and measuring pole. Five cross-sections, distributed evenly along the length of the site, were measured at each location and represented graphically (Appendix F). The number of measurements in each of 1 m depth categories was calculated and assumed to be representative of the whole site. Percentage area-at-depth was established from these calculations.

It was hypothesised that, in the absence of habitat preferences, fish would be evenly distributed across all habitat types and depths. Observed and expected numbers of fish-at-habitat and fish-at-depth, were compared using the chi-square statistic.

Results

Morphometrics and population structure

Morphometric relationships between length and mass of preserved fish are summarised in Table 4.3 and presented graphically in Appendix G. Male and female length frequency distributions are described in Figure 4.2. After normal approximation, the median lengths of the sexes were found to be significantly different ($Z = 2.56 > t_{0.05(2),\infty}$, $p < 0.05$), females attaining a larger size than males.

Table 4.3. Morphometric relationships between length and mass of *Barbus erubescens*, sampled from the Twee River complex, Western Cape, South Africa. Measurements are based on samples stored in 70% propyl-alcohol.

Equation		r^2	n
Total mass (g)	$= 1E\text{-}05$ standard length$^{3.0932}$ (mm)	0.9941	114
Eviscerated Mass (g)	$= 9E\text{-}06$ standard length$^{3.1381}$ (mm)	0.9933	114
Standard length (mm)	= 0.8817 fork length (mm) - 0.2689	0.9967	114
Standard length (mm)	= 0.8213 total length (mm) - 1.3951	0.9964	114

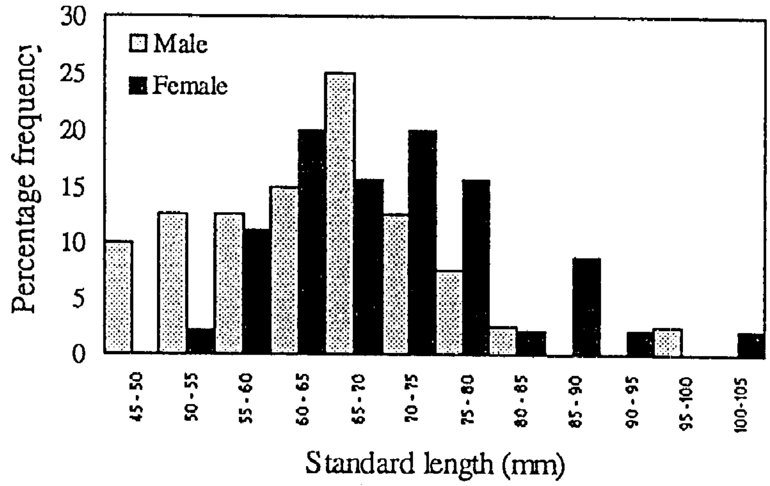


Figure 4.2. Length frequency distributions of male and female *Barbus erubescens*, sampled from the Twee River complex, Western Cape, South Africa.

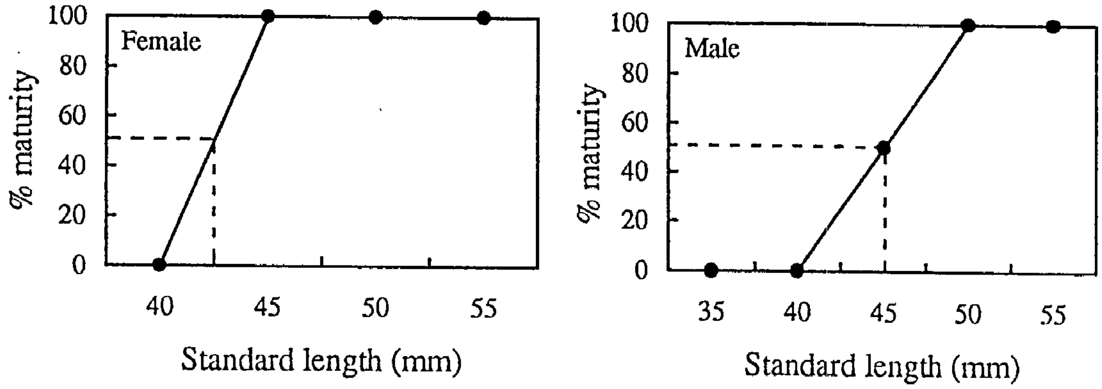


Figure 4.3. Percentage frequency of mature male and female *Barbus erubescens* in different size classes. A 2-parameter logistic ogive was used to fit the curve to the data points.

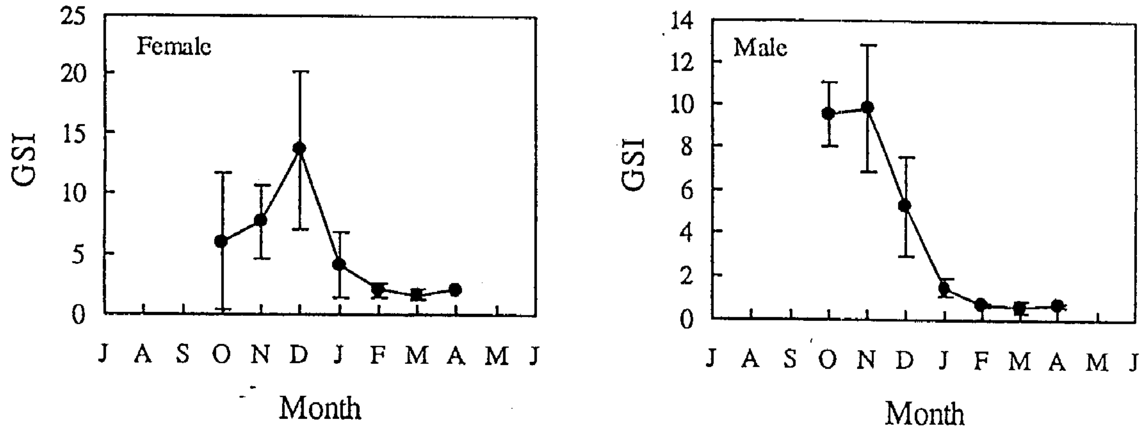


Figure 4.4. Variation in mean (± standard deviation) gonado-somatic indices of sexually mature male and female *Barbus erubescens*, collected from the Twee River complex, Western Cape, South Africa. Specimens were stored in 70% propyl-alcohol. Note, Y-axis scales differ and variation in male GSI values is not as distinct as that of females.

Median length-at-maturity for males and females was estimated at 45 mm SL and 42 mm SL respectively (Figure 4.3). Both sexes had achieved total maturity by 50 mm SL (Figure 4.3). Although females appear to mature at a slightly smaller size, this may be explained by the small number of individuals in the l_{50} size categories. Seasonal variations in male and female GSI peaked during spring and summer, corresponding with an increase in gametogenesis, exhibited by greater proportions of mature eggs in the ovaries and mature spermatozoa filling the testis lumen (figure 4.6). Maximum GSI values occurred approximately one month earlier in males than in females (Figure 4.4). During the spawning season, reproductively active adults, particularly males, developed an overall reddish hue, and small nuptial tubercles became visible on the head (Figure 4.5).

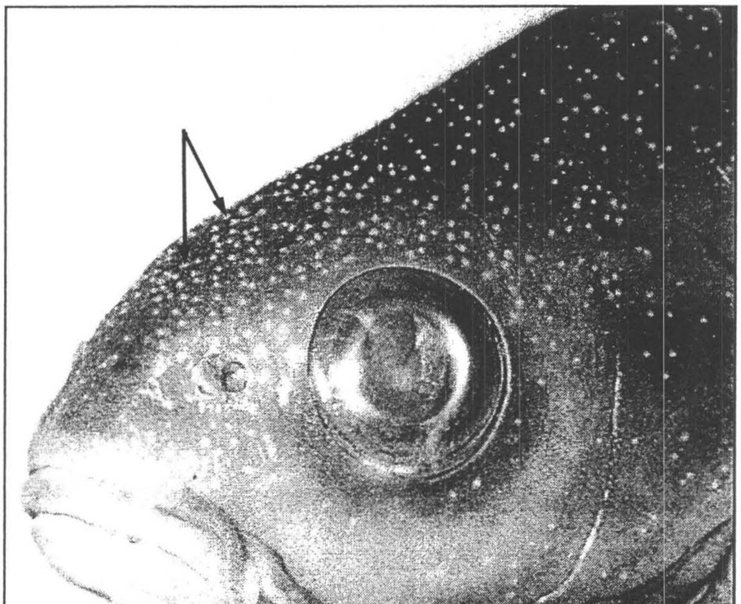


Figure 4.5. Nuptial tubercles, indicated by arrows, are visible as small white spots scattered irregularly over the dorsal and latero-dorsal surfaces of the heads of mature male and female *Barbus erubescens*. Skelton (1974a, 1988) listed the possible functions of these tubercles as: maintenance of body contact between the sexes and stimulation of females during breeding.

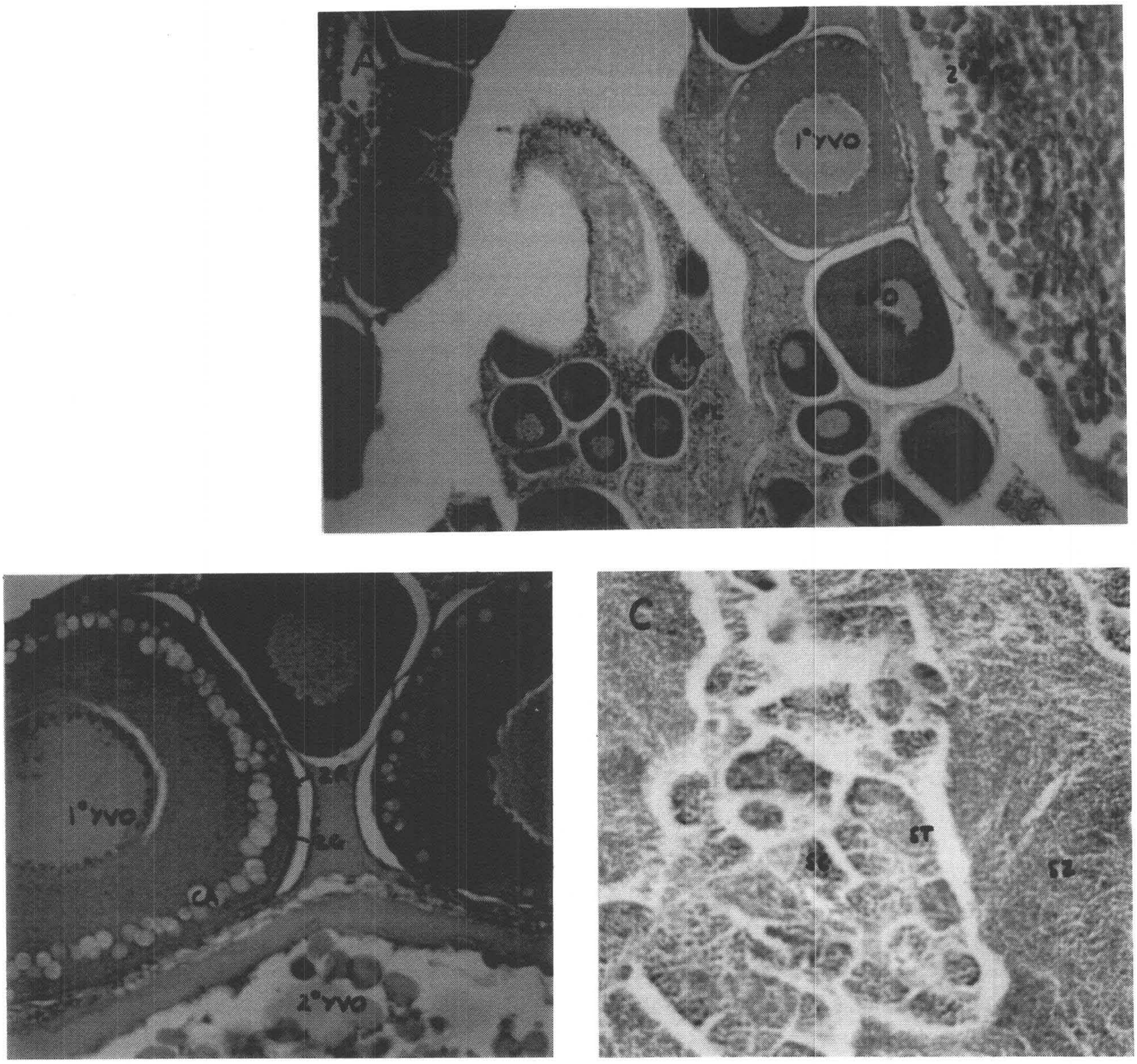


Figure 4.6. Transverse sections through gonads of male and female *Barbus erubescens*, illustrating gametogenesis: a - Mature ovary containing all stages of egg development: follicle cells (FC), pre- (PPO), early (EPO) and late (LPO) perinuclear oocytes. b - The onset of maturation begins with the appearance of primary yolk vesicle oocytes (1°YVO) (the formation of a Zona Radiata (ZR) and Zona Granulosa with cortical alveoli (CA) are characteristic of this stage). Secondary yolk vesicle oocytes (2°YVO) appear with the sequestration of true vitellogenic yolk. c - During the breeding season, spermatids (ST) move into the testis lumen where they mature as spermatozoa (SZ)(SC = spermatocytes).

Oogenesis

Mature ovaries contained up to 400 eggs in various stages of development, from the pre-perinuclear stage through to mature eggs measuring 1.17 mm in diameter (± 0.12 standard deviation, n = 30).

Oogenesis commenced with the multiplication of oogonia on the ovarian lamellae (Hibiya 1982), forming pre-perinuclear oocytes (Figure 4.6a). Size and number of nucleoli increased with cytoplasmic growth. At the same time, nucleoli moved to the periphery of the nucleus, becoming basophilic and less angular. In the late perinuclear stage, oocytes were greatly enlarged, rounded and had formed a distinct zona radiata and zona granulosa (Figure 4.6b). The onset of the primary yolk vesicle stage was heralded by the formation of cortical alveoli on the inside of the cell periphery (Figure 4.6b). These increased in size and number as they moved within the cytoplasm. The final phase of egg maturation, the formation of secondary yolk vesicle oocytes, involved the sequestration of true vitellogenic yolk, shortly before spawning, and the cell cytoplasm became strongly acidophilic (Figure 4.6b).

Spermatogenesis

Spermatogenesis was initiated with the proliferation and growth of spermatogonia in the interstitial tissue (Hibiya 1982), forming primary spermatocytes (Figure 4.6c). Following a meiotic division, secondary spermatocytes were formed. Further meiotic divisions resulted in the development of spermatids which were similar in size to spermatozoa, but remained associated with the interstitial tissue. Spermatids were released into the lobule lumen where they matured as spermatozoa .

Feeding

The presence, in the gut contents of *B. erubescens*, of at least 22 identifiable invertebrate taxa and a substantial allochthonous component (Appendix B, Table B1) suggests that *B. erubescens* is an opportunistic feeder. Figure 4.7 illustrates the relative importance of the most abundant dietary groups.

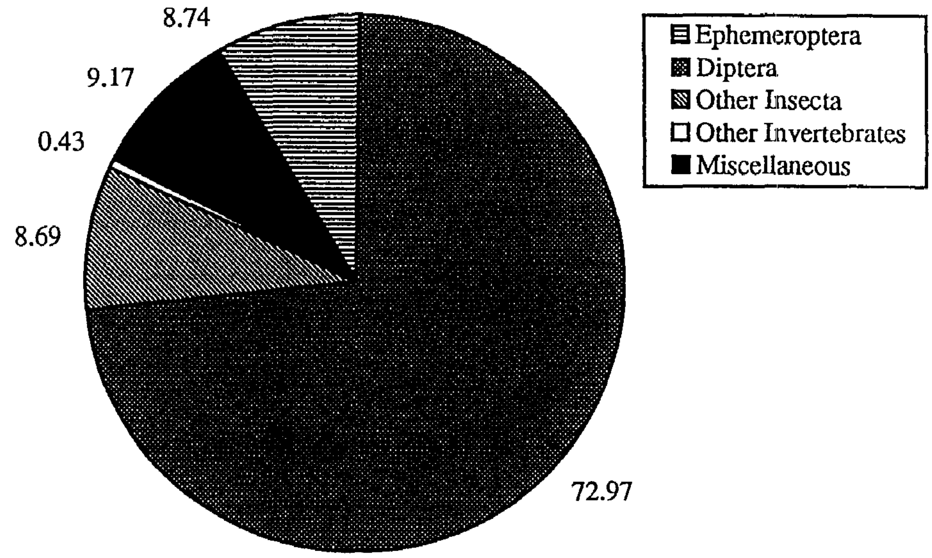


Figure 4.7. Principle dietary items from gut content analysis of *Barbus erubescens* sampled from the Twee River complex, Western Cape, South Africa. Figures are expressed as percentage IRI.

In all months, except February, insects dominated the diet, albeit that grit and algae were found in many of the guts. Algal material exceeded animal matter in relative importance during February but, following microscopic examination of algal cells from the fore- and hind-guts which revealed no signs of digestion, was considered incidental. It is suggested that algae is acquired as a by-product of substrate foraging. Larvae of the dipteran species *Simulium nigritarse* were the most abundant prey items. Other simulid spp. and Ephemeropteran larvae comprised the largest proportion of the remaining diet. Although this dominance of characteristically benthic prey species (Scholtz & Holm 1989) is an indication of substrate feeding, *B. erubescens* were frequently seen picking at drift material and taking insects from the water surface (pers. observ.). These observations are supported by the presence of an allochthonous dietary component.

Details of monthly IRI values for all prey items are presented in Appendix C, Tables C1-6. Significant differences between the broader dietary groups (insects, other invertebrates, algae/plant and grit/amorphous) were described for monthly diets ($\chi^2_{[0.05,15]} = 39.51$, $p < 0.05$), but the insect composition remained similar ($\chi^2_{[0.05,15]} = 21.93$, $p > 0.05$). It is likely that the high incidence of algae during February accounted for the above-mentioned anomaly.

Age and growth

Figure 4.8 shows the variation in width of *B. erubescens* scale margins in relation to time of year. Interpretation of ring periodicity was restricted by the lack of winter samples, but results did tend towards a single trough during winter. It was concluded that one ring was laid down annually and therefore could be used to estimate age. Of the 91 fishes used in the age and growth study, the scale readings from 18 were rejected as unreadable.

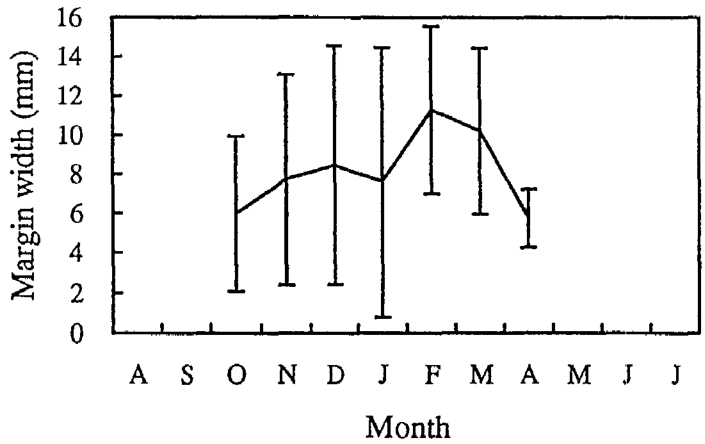


Figure 4.8. Monthly variation in the mean width (± standard deviation) of scale margins of *Barbus erubescens* sampled from the Twee River complex, Western Cape, South Africa. Specimens were stored in 70% propyl-alcohol.

The relationship between standard length and age of *Barbus erubescens* is reflected in Figure 4.9. Growth is described by the von Bertallanfy model, where: $L_t = 8.31(1-e^{-0.489(t+0.398)})$. In older fish, scales became difficult to read and a maximum age of six years was estimated. Due to the small sample size (n = 73), males and females were not analysed independently.

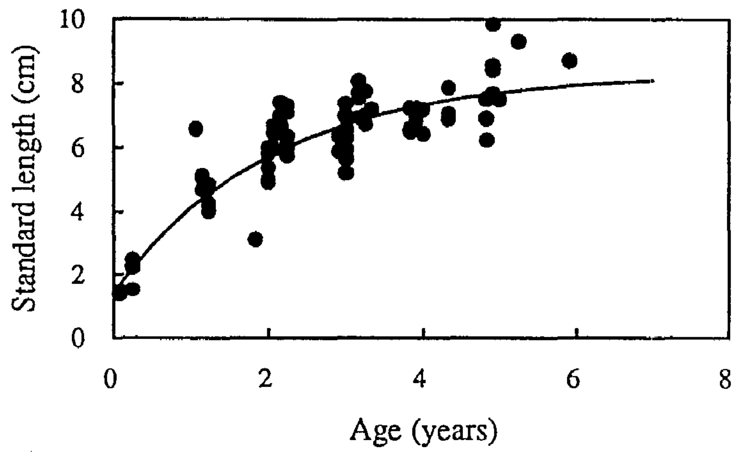


Figure 4.9. Observed length-at age, using scales, of *Barbus erubescens* sampled from the Twee River complex, Western Cape, South Africa. Specimens were stored in 70% propyl-alcohol. The curve was fitted using the von Bertallanfy growth model (n = 73).

Habitat preference

Observed numbers of adult *B. erubescens*, in defined habitats ($\chi^2_{[0.05,6]} = 35.20$, $p < 0.05$) and at given depths ($\chi^2_{[0.05,4]} = 44.73$, $p < 0.05$) were significantly different from expected values. For habitat types, greatest χ^2 values were calculated for fish associated with sand and boulder substrates (Table 4.4),

Table 4.4. Expected and observed numbers of adult *Barbus erubescens* in defined habitats. Observations were made during October/November 1996, at four selected sites on the Twee, Middeldeur, Heks and Suurvlei Rivers, Western Cape (n = 50).

Habitat type	Total % covering	Expected # of fish	Observed # of fish	χ^2
Sand	4.12	2.06	7	11.85
Mud	14.54	7.27	1	5.41
Boulders	44.85	22.43	36	8.21
Bare rock	10.89	0.44	1	3.62
Rocky overhang	5.68	2.84	1	1.19
Submerged vegetation	6.40	3.20	3	0.013
Emergent vegetation	13.52	1.76	1	4.91

observed numbers significantly exceeding expected in both cases. χ^2 values for depth categories were greatest for depths of 0 - 1 m and 1 - 2 m, observed numbers of fish significantly lower than expected at depths of 0 - 1 m, and higher at 1 - 2 m. It was concluded that adult *B. erubescens* showed a preference for sandy or boulder substrates at depths of greater than 1 m. Juvenile *B. erubescens* occurred in the upper 50 cm of the water column, associated with the weedy river margin, but, due to small numbers, habitat preference was not tested statistically.

Table 4.5. Expected and observed numbers of adult *Barbus erubescens* at given depths. Observations were made during October/November 1996, at four selected sites on the Twee, Middeldeur, Heks and Suurvlei Rivers, Western Cape (n = 50).

Depth (m)	Total % area	Expected # of fish	Observed # of fish	χ^2
0 - 1	50.2	25.1	7	13.05
1 - 2	26.8	13.4	31	23.12
2 - 3	7.2	3.6	4	0.04
3 - 4	8.1	4.05	0	4.05
4 - 5	7.7	3.85	8	4.47

Discussion

Prior to this study, breeding behaviour in *B. erubescens* had been observed on at least two occasions (Skelton 1974b, 1988). Adult males were noted to congregate in nuptial schools, over loose pebble substrates, where they immediately attended large females which joined the group. Observations made during this study suggest that attended females then leave the group accompanied by a small number of males. This movement away from the nuptial group seems to be in keeping with the pattern shown by some *Pseudobarbus* species (Cambray & Meyer 1987, Cambray & Cambray 1988), breeding adults undergoing short migrations to suitable spawning sites, where eggs are released under boulders or into rock crevices in the mid-channel of streams. Further investigations concerning redfins from the genus *Pseudobarbus, P. quathlambae* (Cambray & Meyer 1987) and *P. afer* (Cambray & Cambray 1988), showed that, following fin and swimbladder development, these species undergo a swim-up stage during which juveniles are carried to quieter backwaters. All indications are to differences between the redfin lineages but it is unknown if *B. erubescens* undergo a similar stage.

Reproductive activity in *B. erubescens* is reflected in the seasonal variation in male and female GSI, peaking in late spring and continuing through to January. Similar studies on other redfin minnows agree with these findings. Nthimo (1997) described a breeding season, in *B. calidus*, extending from November to January. Boullè (1989) observed peak GSI for male *P. afer* in October, females attaining maximum gonad development one month later, in November, while *P. burchelli* has a breeding season from September to February (Cambray & Stuart 1985). Spawning season is well correlated with both an increase in temperature and photoperiod but, although all these species occur in a typically winter rainfall area, Cambray & Cambray (1988) suggest that the possibility of unseasonal heavy rainfall does exist and may trigger spawning in some redfin species. Skelton (pers. comm. 1998) supports this suggestion, based on observations of nuptial schooling in *B. erubescens*, during a wet December period. A slight rise in the average rainfall, in the Twee River catchment, during October (Figure 2.2) may also be responsible for initiating the onset of gametogenesis. Maximum male GSI in *B. erubescens* preceded the female peak by one month. In clear water streams, male colouration, the presence of nuptial tubercles and schooling behaviour may play a role in stimulating the onset of female gametogenesis and reproductive activity (Skelton 1974a, Cambray & Hecht 1995). The comparatively small size of reproductively active males is borne out by an apparent lack of territoriality and aggression, fitness not necessarily being a function of body size (Choat & Robertson 1975). In nonaggressive males, energy would rather be directed into gonadal development, resulting in earlier maturity and extended reproductive activity (Gross 1984).

Oocyte growth in fish is an interactive process that is able to adjust to the prevailing conditions (Tyler & Sumpter 1996). The pattern of gametogenesis in *B. erubescens* is typical of most freshwater teleosts (Gupta 1975, Wallace & Selman 1981, Makeyeva & Yemel'yanova 1989, Palmer et al. 1995) and the presence of various oocyte developmental stages indicates that *B. erubescens* is an asynchronous, iteroparous spawner with unknown spawning periodicity. The largest group of eggs constitutes the next clutch. The extended breeding season of *B. erubescens* is typical of many fish species. Cambray & Stuart (1985) propose that an extended breeding season allows for multiple spawning, a possible adaptation to unstable environments, but also allows females to carry more eggs. Protracted spawning also allows for reproduction to coincide with favourable environmental conditions including food availability and suitable nursery areas (Bruton 1979, Rinne & Wanjala 1983).

Gut length and orientation of the mouth are commonly related to diet and feeding habits (Cambray & Stuart 1985). Skelton (1988) further relates body shape to the degree of predation, a slimmer body indicating a more carnivorous diet. *Barbus erubescens* has been described as a relatively slender, fusiform minnow with a slightly sub-terminal, U-shaped mouth (Skelton 1974b). The gut length varies between 0.5-1.5 SL (Skelton 1980, 1988). Morphologically, *B. erubescens* is suited to a carnivorous diet, concentrating feeding on the substrate and in the water column. This is supported by observation and gut content analysis, which shows a dominance of benthic prey species (Scholtz & Holm 1989). This diet contrasts with some other redfins (Cambray & Stuart 1985, Boullè 1989), but is similar to findings by Nthimo (1997), concerning the closely related Clanwilliam redfin minnow, *B. calidus*. Nthimo (1997) proposes that apparently clear preferences may merely be a reflection of prey availability. Although allochthonous material is often included in freshwater fish diets (Garman 1991, Daniels & Wiesniewski 1994, Marriott et al. 1997), sometimes forming an important dietary component, in *B. erubescens* aquatic organisms constituted the major portion of the diet, indicating that energy is utilised and retained within the aquatic system.

A number of environmental variables may be responsible for slowing growth in fishes, resulting in the formation of scale growth rings (Booth et al. 1995). The periodicity of these variables accounts for the number of rings formed per year. In *B. erubescens*, a single ring was formed during the winter months, possibly associated with flooding, reduced temperature or reduction in food availability. Booth et al. (1995) observed that annulus formation in *Oreochromis andersonii*, *O. machrochir* and *Tilapia rendalli* occurred during peak flood conditions and summer breeding, yet in captivity was asynchronous with the hydrological cycle. Similarly, without further study under controlled conditions, it is not possible to accurately determine which of the possible variables affects *B. erubescens*.

Cambray & Hecht (1995) propose that the maximum lifespan of an African minnow is six years and that in *Barbus* minnow species the females usually live longer and ultimately achieve a greater maximum size. Cambray (1983) further observes that 82% of all *Barbus* species, including all redfins, have a fork length of less than 150 mm. Fecundity in teleosts is usually a positive allometric function of body size, larger females being able to carry more eggs (Blaxter 1969). In a study of *P. afer* and *P. asper*, Cambray & Hecht (1995) found that although males did achieve comparable size to females, more females lived to these large sizes. They also suggested that species from clear, oligotrophic streams are slower growing, mature later and have greater longevity. Their study showed that *P. afer*, from clear streams reached a maximum age of six years, maturing after two, as opposed to *P. asper*, from turbid streams, which matured after only one year and attained a maximum age of three. *Barbus* *erubescens* displayed a similar growth and maturity pattern to *P. afer*. Cambray & Hecht (1995) advise that species with a shorter lifecycle and early maturity are adapted to living under conditions of high and variable mortality, whereas those such as *B. erubescens*, with a delayed maturity and individuals in relatively more age groups, have slower population replacement and are therefore adapted to conditions of stable food supply and negligible fluctuations in mortality.

A further consideration, which may be applied in terms of tolerance to perturbations, is that of habitat preference. Cambray (1989) proposed that species which are morphologically adapted to specific habitat types, such as riffles, are more prone to flow changes than those in pools, making only occasional forays into the current. In terms of water abstraction, *Barbus erubescens* may therefore be seen as relatively tolerant. However, their preference for depths of greater than 1 m restricts the use of headwater streams as potential sanctuary areas. Instead, prime habitat is limited to the impacted and recovery zones, below farming activity. Furthermore, dietary and substrate preferences are liable to be affected greatly by algal sedimentation resulting from excessive fertilisation. Such threats are investigated in chapter 5.

CHAPTER 5

CONSERVATION STATUS

Introduction

Skelton (1983) listed six factors threatening vertebrates: 1) habitat degradation, 2) the effects of introduced species, 3) over-exploitation, 4) loss or contamination of food supply, 5) killing to protect crops and 6) incidental take. Fishes may be faced with most of these, but in southern Africa the major threats have been narrowed to factors associated with habitat degradation and introduced species (Gaigher et al. 1980, Skelton 1987, 1990, Coward 1988, Pullin 1990). A number of variables may be incorporated into the sweeping term 'habitat degradation', the first being that of catchment perturbations. Day et al. (1986) defined a catchment as "all the land drained by a river ....", and commented that, since the water in a river comes either from groundwater that has percolated through from the surface, or directly as surface runoff from rainfall, the geology, soils, vegetation and land use of the entire catchment will have an effect on the quality of water in a system. Organisms in a system are adapted to certain flow regimes, water chemistry and food availability, and any alteration to the river or its catchment has the potential to disrupt this balance (Day et al. 1986). In Skelton's (1974b) description of the Twee River and its associated tributaries, typically clear, rocky bottomed first and second order streams were noted. Since then farming has largely turned to fruit orchards (Hanekom, L. pers. comm. 1996), both modifying the environment, and increasing the level of water abstraction and pesticide and fertiliser applications. Furthermore, whereas in 1974 the sole alien fish species known to occur in the Twee River catchment was *M. dolomieu*, which occurred only below the lower boundary waterfall of *B. erubescens*, today four exotic species are also recognised to exist above this point.

A species' conservation status is widely dependent on the criteria outlined in the IUCN Red List conservation categories (IUCN 1996), the result of years of research and consultation. The classification system now covers a broad range of criteria, taking into account species distribution, numbers and threats. Chapter 5 investigates all possible impacts to the Twee River catchment and combines these findings with the census results discussed in chapter 3, to advise the conservation standing of *B. erubescens*.

Materials and methods

Owners of land in the Twee River catchment were interviewed on factors associated with type of farming and allocation of land, history of land use, physical destruction through constructions or channelization, pesticide and fertiliser applications, water abstraction, drainage, and the utilisation of fish, for recreational or subsistence purposes.

Water quality comparisons were conducted at the four study sites discussed in chapter 4, again representing two apparently undisturbed sites (a, b), an impacted site (c) and a recovery site (d). Financial constraints precluded the use of direct water quality testing. Rather, SASS (South African Scoring System) was used as an indirect method, interpreting the macroinvertebrate fauna as a reflection of long term impacts. Grabow (1986) declared that the use of living organisms in water quality surveillance has important advantages in that all compounds and conditions which affect biological systems are detected. Invertebrates were collected at each site in accordance with SASS3 guidelines (Chutter 1994), in October/November 1996 and again in March 1997. An additional site (15 - e) on the Middeldeur River was included in March sampling. Invertebrates were preserved in 60% propyl-alcohol and identified in the laboratory. Interpretation of results was based on SASS3 (Table

5.1), where taxa which are intolerant of poor water quality are assigned high scores. These values were used in conjunction with habitat scores (HABS1) (Chutter 1994) and the results were used only as an indication of water quality deterioration.

Table 5.1. Suggested ranges of SASS3 and ASPT (Average Score Per Taxon) associated with differing water quality (Chutter 1994).

Water quality	SASS3 Score	ASPT
Poor	< 35	< 4
Intermediate	40 - 85	3.5 - 4.5
Good	> 95	> 5.5

Table 5.2. Collection details for alien fishes sampled from the Twee River catchment, Western Cape, during this study. *S. cap* = *Sandelia capensis*, *L. mac* = *Lepomis macrochirus*, *B. cap* = *Barbus capensis*, *O. myk* = *Oncorhynchus mykiss*, *M. dol* = *Micropterus dolomieu*. Site numbers correlate to Figure 3.1.

Date	Site number	*S. cap.*	*L. mac.*	*B. cap.*	*O. myk.*	*M. dol.*	Method
14/03/1996	1	6	-	-	-	-	electrofish
14/03/1996	5	1	-	-	-	-	electrofish
14/03/1996	4	10	-	-	-	-	seine
17/03/1996	11	20	-	-	-	-	seine
18/03/1996	Kunje farm dam	-	30	-	-	-	seine
20/03/1996	20	-	9	-	-	-	seine
21/03/1996	23	16	-	-	-	-	seine
22/03/1996	27	4	-	-	-	-	electrofish
23/03/1996	29	-	-	-	-	10	angling
23/03/1996	30	-	-	-	1	-	angling
23/03/1996	26	-	-	3	-	-	gillnet
02/11/1996	12	33	11	-	-	-	seine
05/12/1996	25	5	-	-	-	-	seine
25/12/1996	31	7	-	-	-	-	seine
21/01/1997	30	-	-	1	-	-	angling
23/01/1997	25	10	-	-	-	-	seine
24/01/1997	31	8	-	-	-	-	seine
04/02/1997	31	-	-	-	-	2	angling

Distribution data and estimated numbers of introduced and translocated fishes are discussed in chapter 3. Specimens of *S. capensis*, *L. macrochirus*, *B. capensis*, *O. mykiss* and *M. dolomieu* were collected using a combination of electrofishing gear, a minnow seine net, gill nets and angling (Table 5.2). Samples were fixed in 10% formalin before transferring to 70% propyl-alcohol for storage. Gut contents were analysed according to the methods described in chapter 4, the presence of fish remains indicating piscivory. Competition for the same food source utilised by *B. erubescens*, was determined by comparisons of the diets, using chi-square analysis of contingency tables. Absence of significant differences was accepted as evidence for competition. All fish, particularly *B. erubescens*, were examined for evidence of disease and parasite infestations.

Results from chapters 3, 4 & 5 were critically evaluated in terms of IUCN (1996) conservation category guidelines, to assess the conservation status of *B. erubescens*.

Results

Possible threats

Over-exploitation, incidental take and killing to protect crops were obviated as possible threats. Apart from a small degree of recreational angling which targets only the larger, alien species, the fish resource in the Twee River catchment was not harvested. Moreover, *B. erubescens* was not targeted as a pest. The probability of disease or parasite infestations was also nullified as a threat, as macroscopic examination of all collected specimens revealed fishes to be in good health. Further still, although some manganese mining historically took place in the Twee River valley, there was no evidence of physical alteration or destruction to the river channel. Lastly, since the aquatic macroinvertebrate food resource was not directly utilised by humans, any loss or contamination of the food source of *B. erubescens* could be related to other impacts. Potential threats were therefore reduced to components of habitat degradation (land use, pesticides, fertilisers, water abstraction) and introduced species (predation, competition).

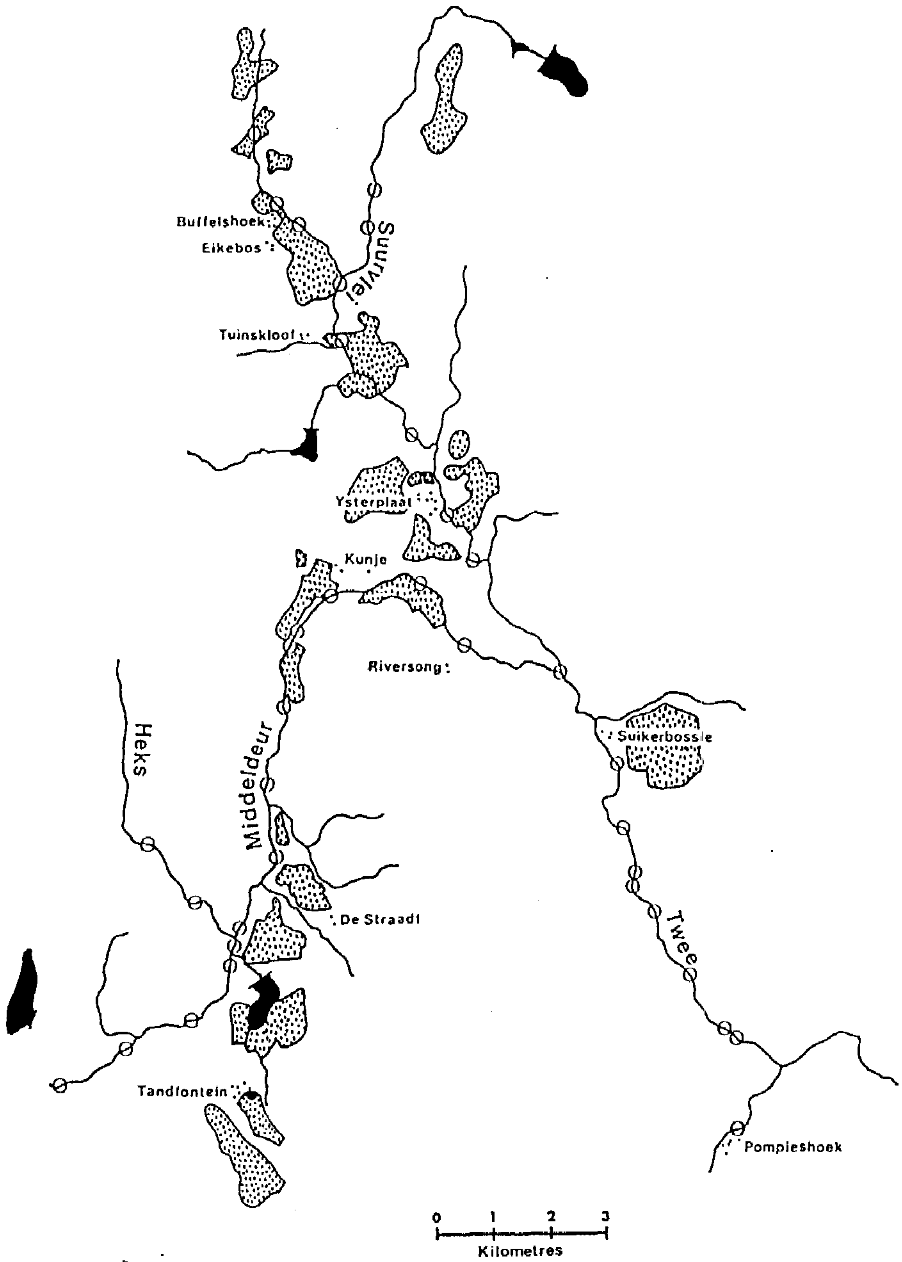


Figure 5.1. The Twee River catchment, Western Cape, showing the distribution of cultivated lands (stippled) and water impoundments (black). Circled areas represent study sites used during this study. Small dots represent farm buildings.

Approximate layout of impoundments and cultivated lands in the Twee River catchment are shown in Figure 5.1, heaviest agriculture occurring along the Middeldeur and Suurvlei Rivers. In March 1996, at the time of interviewing, 570 ha of cultivated lands existed along approximately 30 km of river. This included 170 ha of mixed deciduous orchards (apples, pears, peaches, nectarines), 75 ha of citrus and 325 ha of vegetables (onions, tomatoes, pumpkins). The farms Tuinskloof and Eikebos have since come under new management and a further 200 ha of orchards are currently being developed (Treptow, R. pers. comm. 1997). With the exception of the farm Suikerbossie, most of the land along the Twee River belongs to a holiday syndicate (Riversong) and is maintained in its natural state. Pompieshoek, too, is largely unfarmed, used only for collection of wild flowers. The planting of orchards is recent, over the last two decades, following a switch from stock and vegetable farming (Hanekom, L. pers. comm 1996).

Farms in the Twee River catchment, with the exception of Suikerbossie, are situated on low drainage soils (Hanekom, J. pers. comm. 1996) and rely on subsurface drainage pipes (Figure 5.2). Surface water drains into these perforated pipes, and is transported directly back to the river.

The variable nature of fertilising and pest control programmes complicated the calculation of absolute amounts of chemicals being introduced into the Twee River catchment. Standard pesticide spray programmes target only coddling moth, red spider mite and fusae, whilst other pests are dealt with when and if they occur (Landman, A. pers. comm. 1996, Anon. 1997a). Furthermore, numerous chemical options are available for each stage of fruit and pest development, and the possibility of pest resistance necessitates alternation of these chemicals. Fertilizer (N, P, K) and trace element applications were equally difficult to quantify, depending on such variables as age, type and average size of fruit trees as well as localized deficiencies in these elements. Nevertheless, the diversity of crops in the Twee River catchment does demand an extensive schedule of chemical applications. The spray calendar centers around the fruiting seasons, April to September in citrus and September to March in deciduous fruits (Landman, A. pers. comm 1996). Although some applications are usually omitted, up to 19 sprays per annum may be performed. Fertilizing is restricted to three periods, blossom, bud fall and after harvest, in deciduous fruits, whereas citrus requires numerous smaller applications.

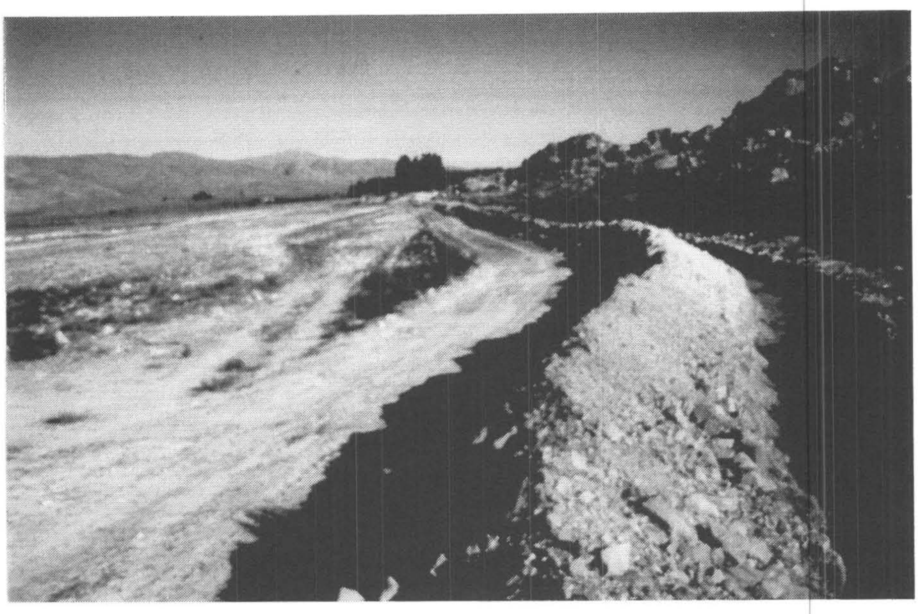


Figure 5.2. Poor soil drainage requires the use of subsurface drainage pipes, placed into trenches such as this. Surface water which filters into these pipes is carried directly back to the rivers, partially eliminating the natural filtering effect of the soil.

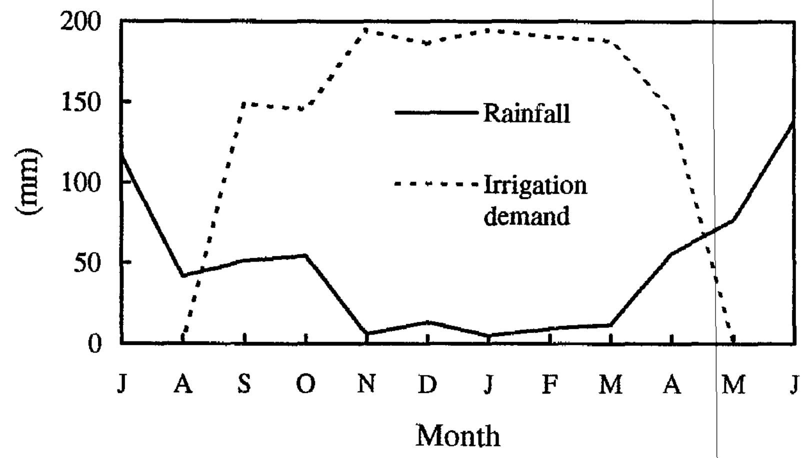


Figure 5.3. Mean monthly rainfall and irrigation demand per hectare in the Twee River Catchment, Western Cape. Irrigation was calculated assuming a requirement of 200 $mm.ha^{-1}.month^{-1}$, from September to April.

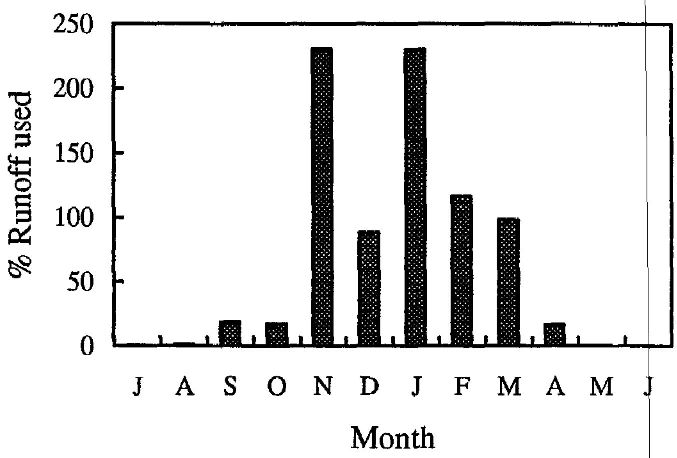


Figure 5.4. Percentage runoff used for agriculture in the Twee River catchment. Although in some months, abstraction appears to exceed river flow, monthly flow was calculated directly from monthly rainfall and did not take into account the holding capacity of the catchment. This is particularly evident in November and January where rainfall was negligible (Figure 2.2).

Besides the threat of direct poisoning, pesticides also require the addition of water. A single application in a deciduous orchard requires 2000 $\lambda.ha^{-1}$, whereas fruit-bearing citrus trees use up to 6000 $\lambda.ha^{-1}$. Irrigation programs further try to simulate two 25 mm rain showers per week, from September to April (Landman, A. pers. comm. 1996), amounting to $7.41 \times 10^6\ m^3y^{-1}$. Total water use for agricultural purposes therefore amounts to $7.43 \times 10^6\ m^3y^{-1}$, roughly 15% of the entire water production of Twee River catchment. Of this, 7.42 x 10^6 m^3y^{-1} is used during the summer months (Figure 5.3), with water abstraction exceeding runoff, estimated from monthly rainfall, in some months (Figure 5.4).

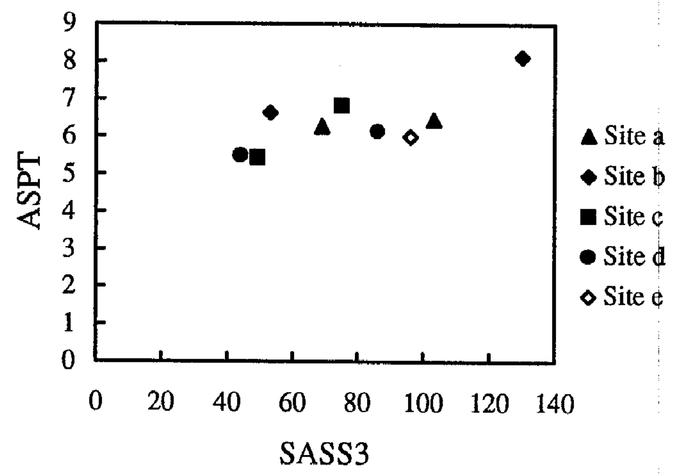


Figure 5.5. SASS3 (South African Scoring System) and ASPT (Average Score Per Taxon) values for macroinvertebrates collected at sites in the Twee River complex, Western Cape, during October/November 1996 and March 1997.

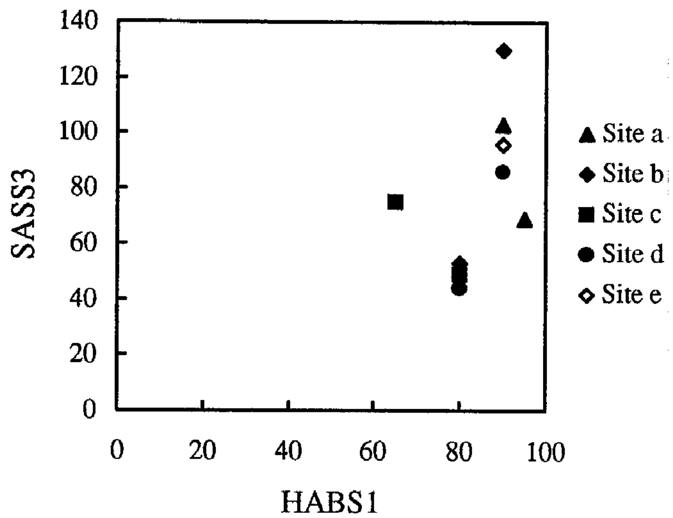


Figure 5.6. SASS3 (South African Scoring System) and HABS1 (Habitat scores) during October/November 1996 and March 1997, for sites in the Twee River complex, Western Cape.

In accordance with values outlined in Table 5.1, all sites chosen for water quality comparison, except site 'c' in Oct/Nov 1996, had ASPT values associated with good water quality (Figure 5.5). Site 'c' was marginally lower, falling into the category of intermediate water quality. SASS scores at three sites agreed with ASPT findings, whilst other sites had intermediate scores. In all cases, highest SASS and ASPT scores were calculated for samples collected during March 1997. Habitat scores (HABS1) were calculated from the number and types of habitat sampled at each site, and indicated habitat diversity. Low SASS scores, where ASPT scores were high, were related to low HABS1 scores, where habitat diversity was inferior (Figure 5.6).

Appendix D lists IRI values for prey items of alien fish species. Due to the low numbers collected, *Oncorhynchus mykiss* (n = 1) and *Barbus capensis* (n = 4) were not included in statistical analysis, but were both insectivorous with no evidence for piscivory. The diets of *B. erubescens* and *L. macrochirus* were found to differ significantly in both the broader dietary groups (insects, other invertebrates, algae/plant and grit/amorphous) ($\chi^2_{[0.05,3]} = 9.96$, $p < 0.05$) and insect composition ($\chi^2_{[0.05,3]} = 40.21$, $p < 0.05$). *Sandelia capensis* and *B. erubescens* were both primarily insectivorous with a similar insect composition ($\chi^2_{[0.05,3]} = 4.25$, $p > 0.05$), although the diets differed in the broader categories ($\chi^2_{[0.05,3]} = 15.14$, $p < 0.05$), *S. capensis* making more use of small crustacea. Scales of *S. capensis* and *O. mykiss* were found in three *S. capensis* stomachs. Although they apparently do not compete spatially with *B. erubescens*, *M. dolomieu* were tested for potential dietary competition. They too had a largely insectivorous, and similar overall, diet ($\chi^2_{[0.05,3]} = 5.78$, $p > 0.05$), but concentrated feeding on large insects including Odonata. The insect composition of bass diets differed from that of *B. erubescens* ($\chi^2_{[0.05,3]} = 11.76$, $p < 0.05$). All species tested had broad diets and were seemingly opportunistic. The differences in diet may therefore be attributed to different collection sites.

Barbus erubescens was classified as Critically Endangered according to Criterion B of the 1996 IUCN conservation categories. The evaluation of *B. erubescens* on all criteria is as follows:

A. Population reduction. A decline in area of occupancy of 40% over the past 20 years is suspected. Assuming that the decline rate increased with increasing environmental pressure (subcriteria **A1e**), there has been greater than a 20% decline over the past 10 years (subcriteria **A1c**). This qualifies *B. erubescens* as **Vulnerable: A1c,e.**

B. Small distribution. Confined to a single tributary complex of the Olifants River system in the western Cape, South Africa, the area of occupancy is less than 10km^2. Considering that the species is restricted to this complex, with a non-continuous distribution (subcriteria **B1**), and that the catchment, and hence habitat, quality is in a state of decline (subcriteria **B2c**), the species qualifies as **Critically Endangered: B1+2c.**

C. Small population size and decline. Based on snorkel counts in 1997, the number of mature individuals was estimated at 4100. Taking into account the spread of exotic species and the threat of increasing land use, combined with an already fragmented population (subcriteria **C2a**), *B. erubescens* qualifies as **Vulnerable: C2a.**

D. Very small population. Restricted to a single tributary complex, with an area of occupancy less than 100 km^2 (subcriteria **D2**), the species qualifies as **Vulnerable: D2.**

E. Quantitative analysis. No quantitative analysis has been conducted for this species.

Discussion

Gaigher et al. (1980) propose that farming practices over the past 300 years have contributed most to the decline in numbers of Cape freshwater fishes. As a result of these practices, South Africa has amongst the highest rates of soil erosion in the world (Edwards 1969). Heavy siltation in rivers, resulting from high levels of erosion, affects the majority of stream dwelling invertebrates by smothering the substrate (Chutter 1969). This in turn modifies the food source of many fishes. A similar effect is experienced when fertilisers are released into waterbodies, resulting in excessive nutrient loading or eutrophication, from phosphates, nitrates, ammonia and potassium (Cullen et al. 1984). Nitrogen containing nutrients, unless in large quantities, are relatively harmless as they are converted into atmospheric nitrogen by micro-organisms. Phosphates, however, accumulate in the water and aquatic vegetation (Day et al. 1986). In low flow areas with little washout this can result in algal blooms, with a corresponding decline in the effective grazing by zooplankton. Much of the algal material dies and sinks where it remains to be broken down by bacteria (Cullen et al. 1984, Day et al. 1986). Subsequent microbial decay may cause deeper waters to become deficient in oxygen, where anaerobic conditions promote the release of noxious substances including phosphorus, hydrogen sulphide, ammonia, iron and manganese (Cullen et al. 1984, Day et al. 1986). As a consequence, the available habitat of most organisms is reduced, although some hardy species such as bluegill may be favoured to the detriment of indigenous, oligotrophic species (Day et al. 1986, Gaigher et al. 1980). A range of authors (Boullè 1989, Bruton & Merron 1985, Gaigher et al. 1980, Hamman et al. 1984, Skelton 1983) have implicated eutrophication as a major reason for declining fish populations.

Toxins such as heavy metals, organic solvents and biocides can be directly damaging to aquatic organisms (Day et al. 1986, Hamman et al. 1984), but usually have only a very localised effect

(Gaigher et al. 1980). Species which are confined to small areas are therefore more susceptible to such threats (Gaigher et al. 1980). Pollutants may enter a river as seepage from spraying (MacDonald et al. 1984), and Cambray & Stuart (1985) propose that, when used during the breeding season, probably account for large-scale embryo mortality. van Vuren et al. (1994) found that metals were taken up via the gut and gills of fishes, accumulating in body tissues and resulting in prolonged stress. Sublethal doses of these pollutants may decrease an organisms' tolerance to other perturbations (Maitland 1995).

Man, through his own population growth, has an ever increasing need for water (Cambray & Meyer 1987). In winter rainfall areas, where a large proportion of South Africa's threatened endemics occur, water abstraction is a major problem. In these regions the greatest irrigation demand coincides with the summer breeding habits of many fish species (Cambray & Stuart 1985, Gaigher et al. 1980). Besides compounding the effects of other toxins, through concentration, irrigation in arid regions also increases the risk of salinization, a process whereby the concentration of total dissolved solids in inland waters is increased (Williams et al. 1984). This increased salinity may result where water that is sprayed onto the land partially evaporates and the proportionally more saline residue seeps into the ground, where it accumulates more salts and eventually returns to the river (Day et al. 1986). Adequate drainage under such conditions prevents excessive evaporation and partly prevents this problem.

Eighteen species of alien or exotic fish have become established in South African freshwaters (Skelton et al. 1995). These have been known to introduce parasites and diseases, and several alien fish parasites have been associated with disease outbreaks in aquaculture systems and aquaria in southern Africa (Bruton & Merron 1985). Invasive species may also alter the trophic structure through forage supplementation, competition or predation, which may lead to local extinction of indigenous populations (Bruton & Merron 1985, Coblentz 1990). The smallmouth bass, *Micropterus dolomieu* has been the most destructive predator introduced into South African freshwaters (O'Keeffe 1985). The presence of a large predator inhibits forage fish movement and habitat occupancy and, in a study by Cambray & Stuart (1985), *Pseudobarbus burchelli* were found only once in the mainstream where bass (*Micropterus* sp.) occurred. A similar investigation (Cambray & Cambray 1988) showed that very few, if any, *Pseudobarbus afer* have survived where bass have been introduced into the Gourits River system. Redfins may be particularly vulnerable to predatory interactions as they do not reach a size where they can escape predation (Cambray & Meyer 1987), and it is also possible that the red colouration of the fins serves to attract bass (Cambray & Cambray 1988). According to Gaigher et al. (1980), the effect of predation is increased by pollution and water abstraction, which force fish out of their preferred habitats into areas where they become more vulnerable. Whilst such effects may be controlled by refined land practices, exotic species, in ecological terms, are permanent (Coblentz 1990).

Environmental impacts in the Twee River catchment have undoubtedly had a negative influence on populations of *B. erubescens*, now absent from the middle reaches of this river system. Their absence, though, coincides both with highest numbers of introduced species and heaviest land use, making it difficult to determine which has had the greatest effect. Although dietary comparisons presented some evidence for piscivory and competition from alien species, *B. erubescens* of all age classes were found to co-exist with these fishes. Nevertheless, de Moor (1991) did observe that benthic macroinvertebrate communities in rivers decrease with increased fish predation. Amongst some contradiction, the general consensus is that fish in standing waters can cause a reduction in the abundance, density and mean size of aquatic invertebrates and change the evenness and diversity of invertebrate species (de Moor 1989). In running waters, recent indications are that fish eliminate conspicuous taxa and reduce the abundance of dominant groups of stream invertebrates. Also, despite the lack of evidence for predation on *B. erubescens*, it is likely that all exotic species will opportunistically prey on juveniles and eggs. Possibly the greatest predatory threat is from *S. capensis*, already well established throughout the Twee River system (Figure 3.3). Hamman et al. (1984) suggest that the aggressive, predatory nature of this species threatens juvenile *B. erubescens*, which may not be picked up in gut contents analysis. *Lepomis macrochirus* and *O. mykiss*, too, are noted predators (Skelton 1993). Whilst presently restricted in their distribution, *O. mykiss* pose a serious threat in that they are winter spawners (Skelton 1993), trout fingerlings reaching a size large enough to target *B. erubescens* fry during the summer breeding season. The absence of *B. erubescens* below the lower boundary waterfall may, in itself, be further evidence for predation. Although the species has not been reported from below this fall, Cambray & Meyer (1987) testify that fish are well known to survive such obstacles, and it is probable that, before the introduction of bass, redfins did occupy this stretch (Skelton 1974b).

Cambray (1989) recognised the sensitivity of *S. capensis* to perturbations and the presence of this species throughout the Twee river complex, even where *B. erubescens* is absent, is an indication that water quality alone is not the major threat in the Twee River catchment. This observation is supported by the SASS results which found that water, even at sites with point source pollution, was of intermediate to good quality. Even so, there was some visual evidence for eutrophication and algal sedimentation, and the fact that the lowest scoring site, in all cases, was that chosen as impacted, is some indication that water quality has been negatively influenced. Nevertheless, all fishes caught were in apparently good health and it is probable that the flushing action of winter flooding plays a vital role in preventing the build-up of toxins and anoxic algal sediments.

Whilst all threats should be considered in management planning, the most important must be those associated with alien fishes, particularly *S. capensis*, and water abstraction. These threats are compounded by land use practices and pollution.

CHAPTER 6

MANAGEMENT ACTION

Listing a taxon at a specific level of threat is not sufficient to determine priorities for its conservation, but simply provides an assessment of the likelihood of extinction under prevailing environmental conditions (IUCN 1994). A system for assessing priorities should take into account other factors, such as costs, logistics, chances of success and even perhaps the taxonomic distinctiveness of the subject.

Increasing awareness and research have highlighted the growing dangers to South Africa's freshwater fishes (Coward 1988). Their dependence on the aquatic environment restricts these species to single river systems or at most connected basins, and the characteristic biotic community is therefore a reflection not just of conditions in the river channel, but of events in the catchment as a whole (Maitland 1995, O'Keeffe 1985, 1986). Conservation is therefore largely dependent on the management of entire systems (Botkin 1984). Conservation of fishes has tended to emphasise habitat preservation and single-species management (Sheldon 1988), echoed in the Cape by practices which are directed primarily towards conserving species in their natural habitats, allowing maximum opportunity for genetic variation (Gaigher et al. 1980). Even though 87% of South Africa's freshwater fishes are represented in formally protected reserves, few of these areas encompass whole catchments of significant size (Skelton et al. 1995) and recent ideas submit that aquatic freshwater conservation should focus on: 1) **education**, adopting and propagating the ecosystem conservation approach at all levels (Cambray 1989, Gaigher et al. 1980), 2) more **stringent control** of negative factors such as constructions, chemical releases and further spread of exotic species (Cambray 1989, Gaigher et al. 1980, Skelton 1993), 3) development of **sanctuary areas** protecting whole catchments (Cambray &

Meyer 1987, Cambray & Stuart 1985, Gaigher et al. 1980), 4) establishing **breeding populations** of threatened species at provincial hatcheries, for restocking purposes (Cambray & Stuart 1985) and 5) **conserving genetic diversity** (Gaigher et al. 1980).

At present levels of threat, combined effects have been insufficient to eradicate the Twee River redfin from its natural range. Although fragmented, genetic viability has been maintained in all populations, this being suggested as greater than 50 mature adults of each sex (Maitland & Lyle 1990). Nevertheless, Brussard (1991) states that no population size is large enough to guarantee avoidance of extinction if an environmental catastrophe is sufficiently severe and widespread, and populations which are restricted to just a small number of localities are extremely vulnerable to a number of catastrophes capable of eliminating the entire community (Ginsberg 1987, Maitland & Lyle 1990). In the Twee River catchment, the major threats are greatest during summer, the spawning season of *B. erubescens*, when irrigation and pest control programmes are most intense. Perhaps the most likely calamity, and that which would serve to concentrate all other effects, is therefore drought, where maintaining present levels of water abstraction could lead to extinction. With water use already exceeding summer production, this threat will increase with expansion of cultivated lands.

In an ecological study on the Maluti minnow, *P. quathlambae*, Rall (1993) proposed a conservation strategy divided into three components, 1) catchment management, 2) species conservation and 3) monitoring. In terms of catchment management, however, rivers tend to flow through numerous ownership boundaries, and Skelton (1993) warns that human ignorance and attitude are one of the major setbacks to conservation management. Although it should be emphasised that habitat protection and restoration are the principal long-term means through which successful fish conservation will be achieved (Maitland 1995), except in cases where legislation is contravened, or suitable alternatives are made available to landowners, it may be difficult to implement management strategies which require that land use practices are modified. At present, biological control of fruit pests is largely unsatisfactory due to the intensive spray programme required for coddling moth (Anon 1997a), and other alternatives are wanting. A scoring system based on the environmental toxicity of pesticides is the only incentive to farmers to minimise chemical pollution (Anon 1997a). Furthermore, the Water Act, 1956 (Act 54 of 1956, S.10 as amended), states that "every riparian landowner can use as much surplus water from a public stream as he can beneficially use". Complications arise with the term 'surplus water', when trying to calculate realistic instream flow requirements without before-and-after comparisons of species composition, population dynamics, growth rates, recruitment, biomass and movement of fishes (Cambray 1989). The new water policy (Anon 1997b) has addressed this problem, with the proposed Water Act of 1998 scheduled to reflect a number of changes. The riparian system of water allocation, in which the right to use water is tied to ownership of land alongside rivers, will effectively be abolished, and water use allocations will no longer be permanent but rather given for a reasonable period of time. All water use will also be subject to a catchment management charge and a resource conservation charge, in cases of competing beneficial uses. The agricultural sector will have to re-evaluate their use of and impact on water resources, and will be required to pay a price for water, that reflects the real economic cost, including the indirect costs to society and the environment. The emphasis of the new water policy is first and foremost on the basic needs of citizens, with the only other water to be provided as a right, being that used to protect the ecosystems that underpin South Africa's water resources. A system to calculate the needs of these ecosystems is required, to ensure that enough water, of an appropriate quality, is set aside (Anon. 1997b). Such a study should be implemented in the Twee River catchment, where agricultural practices and water use currently threaten the aquatic fauna.

Lacking suitable alternatives to farming practices or the legal backing to impose bans on further development, current threats will undoubtedly be aggravated. As such it is recommended that a conservation programme for *B. erubescens* be initiated. This programme should centre around continued monitoring and conservation of genetic variability, with the focus of catchment management on maintaining the status quo. These objectives can be achieved through education, establishment of sanctuary areas and refuge gene pools, and captive breeding. The first consideration, though, must be to alleviate the risk of chance extinction, after which longer term projects can focus on improving the species' capacity to cope with disaster or natural environmental fluctuations.

Because many fish populations are confined to a single aquatic system, within which there is usually substantial water movement, the entire population is vulnerable to the effects of perturbations. Thus, for river species, the number of separate populations is usually of far greater importance than the number of individuals (Maitland 1995). The ideal solution for conservation is to give total protection to several ecosystems (Maitland 1995), but Maitland & Lyle (1990) propose that, as well as trying to protect habitats, an often difficult or virtually impossible task, an effective way to avoid extinction is to increase the number of populations. This may be accomplished by introductions to areas beyond the species' natural range or through the protection of sanctuaries, or by establishing discrete gene pools in captive populations.

Inbreeding in *Mus musculus* and *Drosophila melanogaster* was observed to increase extinction rates in study animals (Frankham 1995). Of primary concern, therefore, should be the prevention of genetic deterioration in *B. erubescens*, the first task involving the removal from the wild of genetically viable breeding stocks. Ideally two populations, with 50 mature individuals from each sex, should be held at separate institutions. These populations may be used as the foundation for captive breeding research.

Philippart (1995) observes that captive breeding and restocking have produced positive results with fishes of all sizes, from a large variety of habitats and from all regions of the world, but advises that, despite its considerable potential and the role that it has played, artificial propagation of fish must never be considered as an effective means for the long-term safeguard of most species. Rather, captive breeding should be viewed as a temporary measure while waiting for the restoration of suitable habitats, as genetic and other difficulties are likely to arise if small numbers are kept in captivity over a number of generations (Maitland 1995). Nevertheless, regular stocking of captive-reared fishes into their native streams, on an annual basis, will ensure continued genetic diversity in wild populations (Maitland & Lyle 1990) and may be an important last resort for endemics which may otherwise become extinct (Reid 1990). In the event that captive breeding programmes are unsuccessful, Maitland & Lyle (1990) propose stripping wild fish and incubating eggs under controlled conditions. This technique could prove invaluable as the vulnerable egg and larval stages would be protected from threats during the breeding season. Rana (1995) also discussed the possibilities of gamete cryopreservation as a means of ensuring genetic variability in case of wild gene deterioration. Although still unsuitable for storing eggs, rapid freezing, to very low temperatures, has been used successfully with sperm from a variety of animals, including fish (Steyn & Van Vuren 1987, 1991, Maitland 1995, Rana 1995). Milt is extracted from reproductively active males, with little adverse effect on the parent fish, which can safely be returned to the water. After freezing for many years and then thawing, the material is still viable (Maitland 1995). Most cryopreservation work, however, has been conducted on salmonids and other aquaculture species (Steyn & Van Vuren 1991) and there is a paucity of literature relating to cyprinids. The success of both cryopreservation and captive breeding or egg incubation programmes have yet to be tested on *B. erubescens* and crucial preventative measures cannot rely only on these approaches alone. Extending the species' distribution, though, need not rely on captive populations.

Sanctuaries have been used successfully for numerous threatened species (Ingram et al. 1990, Maitland & Lyle 1990). Ingram et al. (1990) discuss cases involving threatened fishes of Australia, where restocking, following captive breeding, has been implemented and is used to establish secure refuge populations. In such cases, post-release surveys are used to monitor stocking success. Unfortunately, limited pristine environment within the known natural confines of *B. erubescens* inhibits the potential of this conservation technique. Although translocations and introduction into unstocked catchment dams are possibilities, the success of such ventures cannot, without further study, be guaranteed. In South Africa successful translocation programmes include those of *Nothobranchius orthonotus*, *N. rachovii* and *Protopterus annectens brieni*, all temporary pool or pan-dwelling species (Skelton 1987). Similar practices are not always possible in rivers, where introductions might be incompatible with the conservation of the receiving system. Intra-basin translocations may, however, provide an effective supplement for genetic loss within fragmented populations. An alternative which may warrant further investigation is the active removal of alien species from below the lower boundary waterfall of *B. erubescens*. Although part of a large catchment, this area is remote and little used, with no indigenous fishes. If cleared as far as a downstream barrier, natural or artificial, re-invasion of bass would be prevented. This method may meet with some controversy, but the advantages of extending *B. erubescens*' distribution range into an already impacted area must be weighed against the disadvantages of translocation outside the species' natural area of occurrence.

On-going projects are those which should continue until such time as developments in the Twee River catchment, and numbers of *B. erubescens* have stabilised. Suggested projects include education and monitoring programmes. In particular, bluegill, an apparently recent introduction which poses a serious potential threat, must be continuously monitored. Other monitoring agendas may include levels of genetic heterozygosity and the National Biomonitoring Programme (NBP) for aquatic ecosystems.

Testing present levels of heterozygosity will provide a baseline in terms of future trends, and could be a valuable conservation indicator for both the natural and captive stocks. The National Biomonitoring Programme, implemented in September 1996 (Anon. 1996), is a nation-wide programme aimed at using biological indicators, in conjunction with the traditional physical and chemical techniques, to assess the health of South Africa's ecosystems. It is envisaged that all South Africa's major river systems will ultimately be included in this programme. Used together with continued snorkel counts at selected sites on the Twee, Middeldeur, Suurvlei and Heks Rivers, this method will provide a convenient and relatively inexpensive means of monitoring both river health and post-stocking or colonisation success.

Education is simplified by the small number of people associated with the Twee River catchment, and can be considered in terms of both short and long-term projects. An awareness of the possible implications of land use practices and translocating or introducing alien fishes should be the emphasis of initial attention, future projects concentrating on keeping landowners informed of technological, 'environmentally friendly' developments. The goal of such projects should be water conservation; encouraging the use of techniques such as drip irrigation and offstream water storage. Furthermore, although drainage pipes alleviate the problems associated with salinization, they also serve to bypass the natural filtering effect of the soil. A possible solution to this is the addition of simple settling ponds before water enters the mainstream. Conservation authorities should make known such techniques, through the use of simple information leaflets and agricultural extension officers, who should be drawn into the education programme.

Despite the difficulties, in developing countries, of mustering support for conservation of small, effectively 'invisible' species, there is a need, where possible, to maintain genetic diversity and aesthetics in nature. Often a compromise between optimal and minimal requirements must be reached (Cambray 1989) and for this reason the options discussed in this chapter have been kept simple and relatively inexpensive. It is recommended that the strategy outlined in the summary below be implemented in the Twee River catchment, Western Cape, for the conservation of *Barbus erubescens*. The proposed management action plan may be considered in terms of immediate, long-term and on-going projects:

IMMEDIATE

1) Visit landowners and explain the value of *Barbus erubescens* in terms of biogeographical and phylogenetic uniqueness. Emphasis should be placed on the fragility of the environment.

2) Distribute information leaflets to landowners in the Twee River catchment. The focus should be on discouraging introductions and translocations. Impacts of land use practices should be included.

3) Collect genetically viable (50 of each sex) breeding stocks from the wild. These fishes should be held in captivity, under controlled conditions. Ideally at least two populations should be maintained at separate institutions.

4) Investigate the possibility of milt cryopreservation in cyprinid species. Acquisition of milt requires only one outing, at the start of the breeding season.

5) Establish a Twee River conservation forum and apply to have the river system included on the National Biomonitoring Programme. The catchment may also be proclaimed as a Natural Heritage site.

6) Implement an investigation into the instream flow requirements of the Twee River system. Although the river does not stop flowing, agricultural water use in summer already exceeds summer rainfall and catchment water production.

LONG-TERM

1) A project in egg incubation and larval rearing should be started immediately. This project will require that wild fish are stripped and will prove valuable if more detailed captive breeding programmes are unsuccessful. Such a project should be afforded high priority status.

2) Initiate research into the captive breeding potential of *B. erubescens*. Captive stocks should be used as the basis for this research.

3) Remove alien fishes from stretches of river below the lower boundary waterfall of *B. erubescens*, as far as a downstream barrier. *Barbus erubescens* should be allowed to recolonise this area naturally, or be stocked manually from captive populations.

4) Catchment dams (Figure 5.1) may be stocked with captive reared redfins. Redfin populations in the pristine upper reaches of the Suurvlei and Heks Rivers (sites 7 & 19) should also be secured, by periodical supplementation with genetic stock from the Twee River.

ON-GOING

1) Information leaflets promoting advanced pest control techniques should be distributed amongst farmers, at all opportunities. landowners should be encouraged to make use of drip irrigation, offstream water storage and drainage settling ponds.

2) Monitor river conditions using NBP. Snorkel counts at selected sites should be conducted at the same time as these surveys. These should be used to monitor re-stocking and colonisation success.

CHAPTER 7

GENERAL DISCUSSION

Various methods have been developed for more unbiased assessment of the conservation status of plant and animal species, but the major classification system used internationally for determining the threat status of fishes, is that developed and adopted by the IUCN (Maitland 1995). Following recommendations that species should be categorised according to their probability of extinction over time, the system was developed to provide a clear, quantitative framework for the categories of threat. Criteria could thus be applied to all taxa, and so increase the objectivity of the listing process (IUCN 1996). Today such factors as extent of occurrence and area of occupancy, population size, rate of decline and environmental threats are considered (IUCN 1996), allowing comparisons to be made across taxonomic groups. However, conservation action cannot be implemented based only on a species' status. A variety of factors must be taken into account when developing a conservation action plan. Vulnerability of a population is far more important as a conservation measure than is distribution or population numbers, and Maitland (1995) proposes that a basic requirement, and one which is often sorely underestimated, is the need for a thorough knowledge of the taxonomy, distribution and conservation status of the species concerned. Only when this is available is it possible to consider all feasible management options.

Investigations presented in the previous chapters were initiated with the ultimate aim of outlining a practical management strategy for *B. erubescens*. This species, confined to a single tributary complex of the Olifants River system, Western Cape, was found to have disappeared from as much as 40% of its former range, over the past 20 years. The reasons for this decline were circumspect and a number of possible threats were implicated. Since species differ in their tolerance to perturbations, it was necessary to study both the biology of the species and the individual effects of each threat.

Fishes with a short life cycle and a population which consists of only a few age groups are adapted to living under conditions of very high and variable mortality, their population dynamics including early maturity and multiple annual spawning, to ensure rapid replacement of the stock (Cambray & Hecht 1995). These fishes can usually sustain years where their numbers will be greatly reduced, as they will recover quickly in favourable years. Conversely, those species associated with stable environments may mature later, have relatively more age groups and tend to be adapted to conditions of stable food supply and negligible annual fluctuations. Such species are less tolerant of environmental impacts. Bruton (1989) discusses these alternative life-history styles in terms of generalists (r-selected) and specialists (K-selected). The typically clear, oligotrophic streams in which the Twee River redfin occurs have, in the past, provided the species with a relatively stable environment. In relation to other minnows, the comparatively slow growth and late maturation exhibited by *B. erubescens* reflects this stability, and in this regard, although African minnows are short lived in comparison to larger fishes (Cambray & Hecht 1995), one may still consider the Twee River redfin to be a specialist, K-selected species. With the few breeding guilds, narrow niche overlaps, and high extinction rates characteristic of such a life-history style (Bruton 1989), *B. erubescens* must be considered intolerant of perturbations and should be a prime target for conservation action. In the light of this, and bearing in mind that viable genetic populations have been maintained, and all fishes appeared to be in good health under current environmental pressures, it seems that threats are presently at a sustainable level.

A number of factors have altered the natural ecological state of the Twee River system, however, and *B. erubescens*, through its weaknesses, is vulnerable to these. Being a summer spawner in a winter rainfall zone, the most sensitive stages in the life cycle, i.e. eggs and fry, are subjected to the heaviest levels of toxins, irrigation and concentration of alien species. In rivers, where perturbations are easily transferred considerable distances, the number of populations and their distribution through unconnected river basins is therefore usually of far greater significance than absolute numbers of mature individuals (Maitland 1995). In the case of *B. erubescens*, the entire population may be subjected to a single catastrophic event, capable of eliminating the species. Based on this vulnerability, the Twee River redfin was given the status of Critically Endangered. Emphasis in this category is on the risk of extinction in the immediate future. In the past two decades farming practices in the Twee River catchment have changed and we have seen the introduction of at least three alien species. However, whilst human ignorance and attitude may be the most serious long-term threats, possibly the biggest concern should be that of drought, where all other threats, though presently sustainable, would be aggravated by current levels of water abstraction. The likelihood of such an event has not been investigated, but should be considered in management schemes.

Minnows exist largely in environments where they are seldom seen, this possibly being the main reason for the lack of public interest, and making it difficult to muster support for their conservation (Maitland 1995, Sheldon 1988). The Olifants system although unique both in its high level of endemicity, is also unique in its high degree of threatened species (Skelton et al. 1995), and is consequently the focus of much conservation attention. Nevertheless, given that the Twee River redfin is presently distinct only by its interest value and phylogenetic significance, and that management is likely to impact in some way on planned farming developments, it is unlikely that cost or labour intensive management practices could be initiated. Optimistically, some degree of riparian control and prevention of agricultural pollution and water abstraction may be sufficient to maintain ecological stability (Sheldon 1988), but *B. erubescens* is also faced with other threats. Short of actively removing these threats, by eradication of exotic species, or disallowing further developments, an almost impossible task, the only alternatives are 1) to prevent further introductions or spread, 2) to educate farmers and encourage new practices and 3) to establish refuge populations. Philippart (1995) maintains that, while translocations and captive breeding may play a significant role in conservation, priority field activities should involve reducing the negative effects to the environment. Enormous damage has been done to many fish habitats, however, and the situation is often not easy to reverse, especially in the short term where fishes are severely threatened (Maitland 1995). MacDowall (1984) emphasises the importance of 'naturalness' when designing reserves, and faced with such difficulties, even where restoration is considered, stock transfers could thus be important interim measures.

After considering all the options, recommended management actions outlined in this thesis have kept in mind the biology of *B. erubescens*, its conservation status and the likely support that this project will receive. It is hoped that the most serious immediate threat, that of water abstraction, will be handled with the new water legislation, but this is not enough. A conservation action plan focusing on education and rehabilitation must be a priority. "A land owner who is sympathetic to the cause of conserving a threatened species, no matter how spectacular or commercially viable the species may be, is essential for effective conservation. The landowner who is indifferent or unsympathetic to the conservation cause is himself a threat to the species" (Skelton 1987).

REFERENCES

Allen, R., Bowmaker, A.P., Brain. C.K., Edwards, D., Newman, G., Owen-Smith, R.N., Ribbink, A.J. & R.L. Specht. 1982. Goals of ecosystem conservation. *In:* Siegfried, W.R. & B.R. Davies (eds) Conservation of ecosystems: theory and practice. S. Afr. Nat. Sci. Prog. Rep. (61): 4-9.

Anon. 1996. What is the National Biomonitoring Programme for aquatic ecosystems? River Health - Newsletter of the National Aquatic Ecosystem Biomonitoring Programme. Department of Water Affairs and Forestry, Pretoria.

Anon. 1997a. Manual for spray programmes. Sanachem, Paarl.

Anon. 1997b. White Paper on a National Water Policy for South Africa. Department of Water Affairs and Forestry.

Barnard, K.H. 1943. Revision of the indigenous freshwater fishes of the S. W. Cape region. Ann. S. Afr. Mus. 36: 101-262.

Barrie, L.A. & A.G. Rebelo. 1996. Vegetation of South Africa, Lesotho and Swaziland. Dept. Env. Affairs.

Booth, A.J., Merron, G.S. & C.D. Buxton. 1995. The growth of *Oreochromis andersonii* (Pisces: Cichlidae) from the Okavango Delta, Botswana, and a comparison of the scale and otolith methods of ageing. Env. Biol. Fish. 43: 171-178.

Botkin, D.B. 1984. The garden of the unicorn - the ecosystem context of the management of endangered species. *In:* Hall, A.V. (ed.). Conservation of threatened natural habitats. S. Afr. Nat. Sci. Prog. Rep. (92): 66-81.

Boullè, D.P. 1989. Aspects of the biology and ecology of a small stream fish community . Unpublished Honours Project. Rhodes University, Grahamstown.

Brussard, P.F. 1991. The role of ecology in biological conservation. Ecological Applications 1 (1): 6-12.

Bruton, M.N. 1979. The breeding biology and early development of *Clarias gariepinus* (Pisces: lariidae) in Lake Sibaya, South Africa, with a review of breeding in species of the subgenus *Clarias (Clarias)*. Trans. Zool. Soc. Lond. 35: 1-45.

Bruton, M.N. & S.V. Merron. 1985. Alien and translocated aquatic animals in southern Africa: a general introduction, checklist and bibliography. S. Afr. Nat. Sci. Prog. Rep. (113): 71pp.

Bruton, M.N. 1989. The ecological significance of alternative life-history styles. *In:* Bruton, M.N. (ed). Alternative Life-History Styles of Animals. Kluwer Academic Publishers, Dordrecht, pp. 503-553.

Buxton, C.D. 1984. Feeding biology of the Roman *Chrysoblephus laticeps* (Pisces: Sparidae). S. Afr. J. Mar. Sci. 2: 33-42.

Cambray, J.A. 1983. Early development and larval behaviour of a minnow, *Barbus anoplus* (Pisces: Cyprinidae). S. Afr. J. Zool. 18 (4): 331-336.

Cambray, J.A. 1989. The management of the Eastern Cape redfin (*Pseudobarbus afer*) and the Cape kurper (*Sandelia capensis*) in the Baviaanskloof-Kouga Complex. *In:* Kerley, G.I.H. & L.M. Els (eds). The Kouga-Baviaanskloof Complex: Conservation Status and Management Problems. President Printers, Port Elizabeth, 67pp.

Cambray, J.A., Alletson, D.J., Kleynhans, C.J., Petitjean, M.O.G. & P.H. Skelton. 1989. Flow requirements of fish. *In:* Ferrar, A.A. Ecological flow requirements for South African rivers. S. Afr. Nat. Sci. Prog. Rep. (162): 71-93.

Cambray, J.A. & E. Cambray. 1988. The Eastern Cape redfin (*Barbus afer*) and the Loerie Dam Nature Reserve. The Naturalist 32 (1): 4-7.

Cambray, J.A. & T. Hecht. 1995. Comparison of the growth of two closely related redfin minnows, *Pseudobarbus afer* (Peters, 1864) and *P. asper* (Boulenger, 1911) (Pisces, Cyprinidae), in the Gamtoos River System, South Africa. J. Afr. Zool. 109: 349-376.

Cambray, J.A. & K. Meyer. 1987. The endangered spirit of the Drakensberg and Maloti Mountains. Quagga 18: 18-20.

Cambray, J.A. & C.T. Stuart. 1985. Aspects of the biology of a rare redfin minnow, *Barbus burchelli* (Pisces, Cyprinidae), from South Africa. S. Afr. J. Zool. 20 (3): 155-165.

Choat, J.H. & D.R. Robertson. 1975. Protogynous hermaphroditism in fishes of the family Scaridae. pp. 263-283. *In:* R. Reinboth (ed). Intersexuality in the Animal Kingdom, Springer-Verlag, Berlin.

Chutter, F.M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia. 34: 29-37.

Chutter, F.M. 1994. The rapid biological assessment of stream and river water quality by means of the macroinvertebrate community in South Africa. *In:* Uys, M.C. (ed). Classification of Rivers, and Environmental Health Indicators. Proceedings of a Joint South African/Australian Workshop. Feb 7-14 1994, Cape Town, South Africa. Water Research Commission Report No. TT 63/94.

Coblentz, B.E. 1990. Exotic organisms: a dilemma for conservation biology. Conservation Biology 4: 261-265.

Coward, F. 1988. The number of endangered fish species has increased. The Naturalist 32 (1): 8-9.

Cullen, P., Walmsley, R.D., Ashton, P.J., Claasens, G.C.D., Esteves, F. de A., Grobler, D.C., Heynike, J., Jarvis, A.C., Seaman, M.T., Silberbauer, M.J., Thornton, J.A. & H.N.S. Wiechers. 1984. Eutrophication. *In:* Hart, R.C. & B.R. Allanson (eds). Limnological criteria for management of water quality in the southern hemisphere. S. Afr. Nat. Sci. Prog. Rep. (93): 134-152.

Daniels, R.A. & S.J. Wiesniewski 1994. Feeding ecology of redside dace, *Clinostomus elongatus*. Ecol. Freshw. Fish 3: 176-183.

Day, J.A., Davies, B.R. & J.M. King. 1986. Riverine ecosystems. *In:* O'Keeffe, J.H. (ed) The conservation of South African rivers. S. Afr. Nat. Sci. Prog. Rep. (131): 1-18.

de Moor, F.C. 1989. Fish and aquatic invertebrate interactions in the Wit River and their management implications. *In:* Kerley, G.I.H. & L.M. Els (eds). The Kouga-Baviaanskloof Complex: Conservation Status and Management Problems. President Printers, Port Elizabeth, 67pp.

de Moor, F.C. 1991. The influence of fish on the structure and behaviour of macroinvertebrates in a second order headwater stream. Verh. Internat. Verein. Limnol. 24: 2050-2055.

Edwards, D. 1969. Some effects of siltation upon aquatic macrophyte vegetation in rivers. Hydrobiologia 34: 29-37.

Fowler, J. & L. Cohen. 1992. Practical statistics for field biology. John Wiley & Sons Ltd, Chichester. 227pp.

Frankham, R. 1995. Inbreeding and extinction: a threshold effect. Cons. Biol. 9 (4): 792-799.

Freeman, M.C. & G.D. Grossman. 1993. Effects of habitat availability on dispersion of a stream cyprinid. Env. Biol. Fish. 37: 121-130.

Froglia, C. 1977. Feeding of *Lithognathous mormyrus* in Central Adriatic sea (Pisces, Sparidae). Rapp. Commn. Int. Mer. Med. 24: 95-97.

Gaigher, C.M. 1973. Die status van die inheemse vis in die Olifants Rivier. Voorlopige Verslag, (Department van Natuurbewaring, Kaapse Provinsiale Administrasie). 1-19.

Gaigher, I.G., Hamman, K.C.D. & S.C. Thorne. 1980. The distribution, conservation status and factors affecting the survival of indigenous freshwater fishes in the Cape Province. Koedoe 23: 57-88.

Gardiner, W.R. 1984. Estimating population densities of salmonids in deep water in streams. J. Fish. Biol. 24: 41-49.

Garman, G.C 1991. Use of terrestrial arthropod prey by a stream dwelling cyprinid fish. Env. Biol. Fish. 30: 325-331.

Ginsberg, J.R. 1987. What is conservation biology? Trends Ecol. Evol. 2: 262-264.

Gore, J.A., King, J.M & K.C.D. Hamman. 1991. Application of the instream flow incremental methodology to southern African rivers: protecting endemic fish of the Olifants River. Water SA 17: 225-236.

Grabow, W.O.K. 1986. Water quality assessment and control in South Africa. S. Afr. J. Sci. 82: 342-346.

Griffith, J.S. 1981. Estimation of the age-frequency distribution of stream-dwelling trout by underwater observation. Prog. Fish-Cult. 43 (1): 51-53.

Gross, M.R. 1984. Sunfish, salmon, and the evolution of alternative reproductive strategies and tactics in fishes. pp. 57-76. *In:* G.W. Potts & R.J. Wootton (eds) Fish Reproduction: Strategies and Tactics, Academic Press, London.

Gupta, S. 1975. The development of carp gonads in warm water aquaria. J. Fish Biol. 7: 775-782.

Hamman, K.C.D., Thorne, S.C. & P.H. Skelton. 1984. The discovery of the Cape Kurper, *Sandelia capensis* (Cuvier in C. & V., 1831) in the Olifants River System (Western Cape Province). The Naturalist. 28 (1): 24-26.

Hamman, K.C.D. 1996. Newsletter ANO 2/17 CNC.

Hankin, D.G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Can. J. Fish. Aquat. Sci. 41: 1575-1591.

Hankin, D.G & G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish. Aquat. Sci. 45: 834-844.

Hayes, M.L. 1983. Active fish capture methods. *In:* Nielsen, L.A. and D.L. Johnson, Fisheries Techniques. Southern Printing Company, Inc., Blacksburg, Virginia. 468pp.

Hibiya, T. 1982. An atlas of fish histology, normal and pathological features. Gustav Fischer Verlag. Stuttgart. 147pp.

Hillman, T.W., Mullan, J.W. & J.S. Griffith. 1992. Accuracy of underwater counts juvenile chinook salmon, coho salmon, and steelhead. N. Am. J. Fish. Man. 12: 598-693.

Hyslop, E.J. 1980. Stomach contents analysis - a review of methods and their application. J. Fish Biol. 17: 411-429.

Ingram, B.A., Barlow, C.G., Burchmore, J.J., Gooley, G.J., Rowland, S.J. & A.C. Sanger. 1990. Threatened native freshwater fishes in Australia - some case histories. J. Fish Biol. 37(Suppl A): 175-182.

IUCN 1980. World Conservation Strategy. IUCN, Gland, Switzerland. Cited in O'Keeffe, J. H. 1986. Conservation aims, criteria and goals for rivers. In: O'Keeffe, J. H. (ed) The conservation of South African rivers. S. Afr. Nat. Sci Prog. Rep. (131): 19-23.

IUCN 1994. IUCN Red List Categories. Gland, Switzerland.

IUCN 1996. 1996 IUCN Red List of Threatened Animals. IUCN, Gland, Switzerland.

Jubb, R.A. 1963. A revised list of the freshwater fishes of southern Africa. Ann. Cape Prov. Mus. (nat. Hist.) 3: 5-39.

Jubb, R.A. 1964. Freshwater fishes and drainage basins in southern Africa 1. The Orange and South Coastal drainage basins. S. Afr. J. Sci. 60 (1): 17-21.

Maitland, P.S. & A.A Lyle. 1990. Practical conservation of British fishes: current action on six declining species. J. Fish Biol. 37(Suppl A): 255-256.

Maitland, P.S. 1995. The conservation of freshwater fish: past and present experience. Biol. Cons. 72 (2): 259-270.

Mann, R.H.K. & T. Penczak. 1984. The efficiency of a new electrofishing technique in determining fish numbers in a large river in central Poland. J. Fish Biol. 24: 173-185.

Makeyeva, A.P. & N.G. Yemel'yanova. 1989. Periodization of oogenesis in cyprinids. J. Ichthyol. 29: 55-67.

Marriott, M.S., Booth, A.J. & P.H. Skelton. 1997. Reproductive and feeding biology of the Natal mountain catfish, *Amphilius natalensis* (Siluriformes: Amphiliidae). Env. Biol. Fish. 49 (4): 461-470.

McDowall, R.M. 1984. Designing reserves for freshwater fish in New Zealand. Proceedings of a workshop on biological reserve design in New Zealand. J. Royal Soc. New Zealand 14 (1): 17-27.

Northcote, T.G. & D.W. Wilkie. 1963. Underwater census of stream fish populations. Trans. Am. Fish. Soc. 92 (2): 146-151.

Nthimo, M. 1997. The reproductive and feeding biology of Clanwilliam redfin minnow, *Barbus calidus* (Pisces: Cyprinidae). Unpublished Honours Project. Rhodes University, Grahamstown.

O'Keeffe, J.H. 1985. River conservation in South Africa. The Naturalist 29 (2): 9-13.

O'Keeffe, J.H. 1986. Conservation aims, criteria and goals for rivers. In: O'Keeffe, J. H. (ed) The conservation of South African rivers. S. Afr. Nat. Sci Prog. Rep. (131): 19-23.

Palmer, E.E., Sorensen, P.W. & I.R. Adelman. 1995. A histological study of seasonal ovarian development in freshwater drum in the Red Lakes, Minnesota. J. Fish Biol. 47: 199-210.

Philippart, J.C. 1995. Is captive breeding an effective solution for the preservation of endemic species? Cons. Biol. 72 (2): 281-295.

Podolszky, D., Uiblein, F. & H. Winkler. 1995. Visual habitat choice in cyprinid fishes: an experimental approach. Ecol. Freshwater Fish 4: 160-167.

Pullin, R.S.V. 1990. Down-to-earth thoughts on conserving aquatic genetic diversity. NAGA The Iclarm Quarterly. 13 (1): 5-8.

Rall, J.L. 1993. An ecological study on the Maluti minnow (*Pseudobarbus quathlambae*) in the catchment area of phase 1B of the Lesotho Highland Water Scheme. Unpublished Masters thesis, Rand Afrikaans University, Johannesburg.

Rana, K. 1995. Cryopreservation of aquatic gametes and embryos: recent advances and applications. *In:* Goetz, F.W. & P. Thomas (eds). Fish Symposium 95: Austin, TX (USA), pp 85-89. Proceedings of the Fifth International Symposium on the Reproductive Physiology of Fish, University of Texas, Austin, 2-8 Jul 1995.

Reid, G.M. 1990. Captive breeding for the conservation of cichlid fishes. J. Fish Biol. 37A (Suppl.): 157-166

Reynolds, J.B. 1983. Electrofishing. *In:* Nielsen, L.A. and D.L. Johnson, Fisheries Techniques. Southern Printing Company, Inc., Blacksburg, Virginia. 468pp.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191: 1-382.

Rinne, J.N. & B. Wanjala. 1983. Maturity, fecundity and breeding seasons of the major catfishes suborder: Siluroidea) in Lake Victoria, East Africa. J. Fish Biol. 23: 357-363.

Rodgers, J.D., Solazzi, M.F., Johnson, S.L. & Mary A. Buckman. 1992. Comparison of three techniques to estimate juvenile coho salmon populations in small streams. N. Am. J. Fish. Man. 12: 79-86.

Ryman, N., Utter, F. & Linda Laikre. 1995. Protection of intraspecific biodiversity of exploited fishes. Rev. Fish Biol. Fish. 5: 417-446.

Scholtz, C.H. & E. Holm. 1989. Insects of Southern Africa. Butterworths, Durban. 502 pp.

Secor, D.H. & T.M. Trice. 1995. Validation of otolith-based ageing and a comparison of otolith and scale-based ageing in mark-recaptured Chesapeake Bay striped bass, *Morone saxatilis*. Fish. Bull. 93: 186-190.

Sheldon, A.L. 1988. Conservation of stream fishes: patterns of diversity, rarity, and risk. Cons. Biol. 2 (2): 149-156.

Skelton, P.H. 1974a. On the life colours and nuptial tubercles of *Oreodaimon quathlambae* (Barnard, 1938) (Pisces, Cyprinidae). Ann. Cape Prov. Mus. (nat. Hist.) 9 (12): 215-222.

Skelton, P.H. 1974b. A new *Barbus* species (Pisces, Cyprinidae) from the Olifants River System, Western Cape Province, South Africa. Spec. Publs. R. U. dept. Ichthyol. (13): 1-12.

Skelton, P.H. 1976. Preliminary observations on the relationships of *Barbus* species from Cape coastal rivers, South Africa (Cypriniformes, Cyprinidae). Zool. Afr. 11 (2): 399-411.

Skelton, P.H. 1977. South African Red Data Book - Fishes. S. Afr. Nat. Sci. Prog. Rep. (14): 1- 39.

Skelton, P.H. 1980. Systematics and biogeography of the redfin *Barbus* species (Pisces: Cyprinidae) from southern Africa. Unpublished Ph.D. thesis, Rhodes University, Grahamstown.

Skelton, P.H. 1983. Perspectives on the conservation of threatened fishes in southern Africa. The Naturalist 27(1): 3-12.

Skelton, P.H. 1987. South African Red Data Book - Fishes. S. Afr. Nat. Sci. Prog. Rep. (137): 1-199.

Skelton, P.H. 1988. A taxonomic revision of the redfin minnows (Pisces, Cyprinidae) from southern Africa. Ann. Cape Prov. Mus. (nat. Hist) 16 (10): 1-307.

Skelton, P.H. 1990. The conservation and status of threatened fishes in southern Africa. J. Fish Biol. 37 (Suppl. A): 87-95.

Skelton, P.H. 1993. A Complete Guide to the Freshwater Fishes of Southern Africa. Southern Book Publishers, Halfway House. 388pp.

Skelton, P.H., Cambray, J.A., Lombard, A. & G.A. Benn. 1995. Patterns of distribution and conservation status of freshwater fishes in South Africa. S. Afr. J. Zool. 30 (3): 71-81.

Slaney, P.A. & A.D. Martin. 1987. Accuracy of underwater census of trout populations in a large stream in British Columbia. N. Am. J. Fish. Man. 7: 117-122.

Steyn, G.J. & J.H.J. Van Vuren. 1987. The fertilising capacity of cryopreserved sharptooth catfish (*Clarias gariepinus*) sperm. Aquaculture 63: 187-193.

Steyn, G.J. & J.H.J. Van Vuren. 1991. Cryopreservation of the spermatozoa of two African freshwater fishes (Characidae). S. Afr. J. Wildl. Res. 21 (3): 76-81.

Teague, W.R., Scheltema, J.C. & F.J. Weitz. 1989. Recommended agricultural practices in the mountain fynbos vegetation of the Baviaanskloof, Kouga and Elands River Mountains in the Eastern Cape Region. *In:* Kerley, G.I.H. & L.M. Els (eds). The Kouga-Baviaanskloof Complex: Conservation Status and Management Problems. President Printers, Port Elizabeth, 67pp.

Tyler, C.R. & J.P. Sumpter. 1996. Oocyte growth and development in teleosts. Rev. Fish Biol. Fish. 6: 287-318.

van Vuren, J.H.J., du Preez, H.H. & A.R. Deacon. 1994. Effect of pollutants on the physiology of fish in the Olifants River (Eastern Transvaal). Department of Zoology, Rand Afrikaans University. 214pp.

Vincent, R. 1971. River electrofishing and fish population estimates. Prog. Fish-Cult. 33 (3): 163-167.

Wallace, R.A. & K. Selman. 1981. Cellular and dynamic aspects of oocyte growth in Teleosts. Amer. Zool. 21: 325-343.

West, G. 1990. Methods of assessing ovarian development in fishes: a review. Aust. J. Mar. Freshw. Res. 41: 199-222.

Williams, W.D., Noble, R.G., Best, H.J., Forster, S., Herold, C.E., Moolman, H. & C.H.G. Schlettwein. 1984. Salinization. *In:* Hart, R.C. & B.R. Allanson (eds). Limnological criteria for management of water quality in the southern hemisphere. S. Afr. Nat. Sci. Prog. Rep. (93): 87-107.

Yamamoto, K. & F. Yamazaki. 1961. Rhythm of development in the oocyte of the gold-fish, *Carassius auratus*. Bull. Fac. Fish 12: 93-110.

Zubik, R.J. & J.J. Fraley. 1988. Comparison of snorkel and mark-recapture estimates for trout populations in large streams. N. Am J. Fish. Man. 8: 58-62.

Personal communications

Hanekom, J. 1996. P.O. Box 662, Citrusdal, 7340.

Hanekom, L. 1996. P.O. Box 66, Koue Bokkeveld, 6836.

Impson, D. 1998. Western Cape Nature Conservation, Private Bag X5014, Stellenbosch, 7599.

Landman, A. 1996. P.O. Box 117, Koue Bokkeveld, 6836.

Skelton, P.H. 1998. J.L.B. Smith Institute of Ichthyology, Private Bag 1015, Grahamstown, 6139.

Treptow, B. 1997. P.O. Box 645, Grabouw, 7160.

APPENDIX A

Table A.1. Numbers of fish collected in the Twee, Middeldeur, Suurvlei and Heks Rivers during March 1996. *B. eru* = *Barbus erubescens*, *L. mac* = *Lepomis macrochirus*, *B. cap* = *Barbus capensis*, *S. cap* = *Sandelia capensis*, *O. myk* = *Oncorhynchus mykiss*, *M. dol* = *Micropterus dolomieu*, *G. zeb* = *Galaxias zebratus*.

Site number & GPS	#*B. eru*	#*L. mac*	#*B. cap*	#*S. cap*	#*O. myk*	#*M. dol*	#*G. zeb*
1 - 32°37'56"S 19°10'16"E				3			
2 - 32°37'49"S 19°09'37"E							
3 - 32°37'54"S 19°09'52"E							
4 - 32°38'39"S 19°11'08"E							
5 - 32°38'14"S 19°10'51"E				1			
6 - 32°38'54"S 19°12'15"E				1			
7 - 32°37'42"S 19°10'53"E	150						
8 - 32°37'53"S 19°11'00"E	100						
9 - 32°45'20"S 19°13'04"E	6						300
10 - 32°44'49"S 19°13'19"E	90						200
11 - 32°40'30"S 19°12'38"E	6	1		15			2
12 - 32°41'05"S 19°12'33"E	1		2	192			
13 - 32°39'59"S 19°13'13"E							1
14 - 32°43'53"S 19°13'46"E	27						153
15 - 32°43'34"S 19°13'38"E	169	3					
16 - 32°42'14"S 19°13'02"E	4	6		6			
17 - 32°44'07"S 19°13'49"E	7						92
18 - 32°43'22"S 19°13'11"E	4						11
19 - 32°43'12"S 19°12'27"E	36						
20 - 32°43'27"S 19°13'40"E	28	24					
21 - 32°42'58"S 19°13'30"E	11	23					
22 - 32°41'42"S 19°12'53"E	3			7			
23 - 32°40'17"S 19°14'05"E	1	1	2	260			
24 - 32°40'04"S 19°15'04"E				17			4
25 - 32°40'35"S 19°10'16"E	150		2	38			
26 - 32°41'09"S 19°16'39"E	140		3	241	3 (below fall)		
27 - 32°39'12"S 19°12'49"E				11			
28 - 32°39'12"S 19°12'49"E				1			
29 - 32°42'37"S 19°18'58"E						20	
30 - 32°41'38"S 19°17'40"E	37		117	113	6		
31 - 32°42'07"S 19°18'28"E	13 (above fall)		70		2	6 (below fall)	
32 - 32°41'18"S 19°16'52"E	39			75			
33 - 32°41'18"S 19°16'52"E	125			27			

APPENDIX A (continued)

Table A.2. Numbers of fish collected in the Twee, Middeldeur, Suurvlei and Heks Rivers during January/February 1997. *B. eru = Barbus erubescens, L. mac = Lepomis macrochirus, B. cap = Barbus capensis, S. cap = Sandelia capensis, O. myk = Oncorhynchus mykiss, M. dol = Micropterus dolomieu, G. zeb = Galaxias zebratus.*

Site number & GPS	#*B. eru*	#*L. mac*	#*B. cap*	#*S. cap*	#*O. myk*	#*M. dol*	#*G. zeb*
1 - 32°37'56"S 19°10'16"E							
2 - 32°37'49"S 19°09'37"E							
3 - 32°37'54"S 19°09'52"E							
4 - 32°38'39"S 19°11'08"E				200			
5 - 32°38'14"S 19°10'51"E							
6 - 32°38'54"S 19°12'15"E							
7 - 32°37'42"S 19°10'53"E	45						
8 - 32°37'53"S 19°11'00"E	5						
9 - 32°45'20"S 19°13'04"E							7
10 - 32°44'49"S 19°13'19"E	1						100
11 - 32°40'30"S 19°12'38"E	106			250			4
12 - 32°41'05"S 19°12'33"E				190			1
13 - 32°39'59"S 19°13'13"E				2			
14 - 32°43'53"S 19°13'46"E	90						42
15 - 32°43'34"S 19°13'38"E	220						17
16 - 32°42'14"S 19°13'02"E				7			
17 - 32°44'07"S 19°13'49"E	203						18
18 - 32°43'22"S 19°13'11"E							1
19 - 32°43'12"S 19°12'27"E	33						
20 - 32°43'27"S 19°13'40"E	70	2					1
21 - 32°42'58"S 19°13'30"E							
22 - 32°41'42"S 19°12'53"E				1			
23 - 32°40'17"S 19°14'05"E				48			
24 - 32°40'04"S 19°15'04"E	3			71			5
25 - 32°40'35"S 19°16'05"E	230			180			
26 - 32°41'09"S 19°16'39"E	92		1	26	1		
27 - 32°39'12"S 19°12'49"E				46			
28 - 32°39'12"S 19°12'49"E							
29 - 32°42'37"S 19°18'58"E						25	
30 - 32°41'38"S 19°17'40"E	175	1	1	5	1		
31 - 32°42'07"S 19°18'28"E	11	1	49	200	2	15	
32 - 32°41'18"S 19°16'52"E	2			11			
33 - 32°41'18"S 19°16'52"E	140			39		40	

APPENDIX B

Table B.1. Stomach content analysis of *Barbus erubescens* sampled from the Twee River complex, Western Cape, South Africa (RUSI $n = 83$, AMG $n = 31$).

	%N	%V	%F	IRI
INSECTA	**77.49**	**70.70**	**59.65**	**8839.16**
EPHEMEROPTERA	11.44	12.23	17.54	415.28
Baetidae	10.70	9.90	15.79	325.32
Cloeon sp.	0.37	0.49	0.88	0.75
baetid sp.	10.33	9.41	14.91	294.47
Leptophlebiidae	0.74	2.33	1.75	5.38
Adenophlebia sp.	0.74	2.33	1.75	5.38
DIPTERA	46.86	33.80	42.98	3467.32
Chironomidae	10.33	11.79	14.91	329.93
Tanypodinae	6.64	6.52	8.77	115.50
Orthocladiinae	2.95	3.88	5.26	35.95
Chironiminae	0.37	0.41	0.88	0.69
chironomid sp.	0.37	0.98	0.88	1.18
Simuliidae	35.79	20.30	30.70	1722.31
Simulium nigritarse	35.06	19.45	29.82	1625.64
Simulium medusaeforme	0.37	0.12	0.88	0.43
simulid sp.	0.37	0.73	0.88	0.97
dipteran Sp.	0.74	1.71	1.75	4.29
HYMENOPTERA	1.11	2.00	1.75	5.45
Formicidae	0.74	1.22	0.88	1.72
Mymaridae	0.37	0.78	0.88	1.01
ODONATA	0.74	0.61	0.88	1.18
Libellulidae	0.74	0.61	0.88	1.18
ISOPTERA	0.74	1.22	0.88	1.72
LEPIDOPTERA	0.74	0.45	1.75	2.09
HEMIPTERA	0.37	0.60	0.88	0.85
Heteroptera	0.37	0.60	0.88	0.85
TRICHOPTERA	7.38	1.51	6.14	54.60
Ecnomidae	2.21	0.51	1.75	4.78
Ecnomus sp.	2.21	0.51	1.75	4.78
Leptoceridae	0.74	0.34	1.75	1.89
Athripsodes sp.	0.74	0.34	1.75	1.89
trichopteran sp.	4.43	0.66	2.63	13.39
ORTHOPTERA	0.37	1.22	0.88	1.39
Gryllotalpidae	0.37	1.22	0.88	1.39
COLEOPTERA	1.11	2.39	2.63	9.20
Dryopidae	0.37	0.82	0.88	1.04
Elmidae	0.37	1.22	0.88	1.39
coleopteran sp.	0.37	0.35	0.88	0.63

APPENDIX B (continued)

INSECT REMAINS	6.54	14.66	15.79	336.33
CRUSTACEA	**6.27**	**0.91**	**2.63**	**18.91**
CLADOCERA	6.27	0.91	2.63	18.91
Daphnidae	6.27	0.91	2.63	18.91
Daphnia	6.27	0.91	2.63	18.91
ARACHNIDA	**0.74**	**0.01**	**0.88**	**0.66**
HYDRACARINA	0.74	0.01	0.88	0.66
Orobatidae	0.74	0.01	0.88	0.66
NEMATODA	**0.74**	**0.16**	**0.88**	**0.79**
PLANT MATERIAL	**2.21**	**0.77**	**2.63**	**7.85**
FILAMENTOUS ALGAE	**4.06**	**10.28**	**9.65**	**138.36**
AMORPHOUS MATERIAL	**5.17**	**14.64**	**12.28**	**243.31**
GRIT	**3.32**	**2.52**	**7.89**	**46.15**

APPENDIX C

Table C.1. Stomach content analysis of *Barbus erubescens.* January samples from collections made between 1964 and 1997, from the Twee River catchment, Western Cape, South Africa ($n = 14$).

	%N	%V	%F	IRI
INSECTA	**94.23**	**96.45**	**78.57**	**14982.42**
EPHEMEROPTERA	23.08	26.00	35.71	752.75
Baetidae	23.08	26.00	35.71	1752.75
DIPTERA	57.69	29.00	50.00	4334.62
Chironimidae	3.85	5.18	14.29	128.97
Tanypodinae	1.92	4.91	7.14	48.80
Orthocladiinae	1.92	0.27	7.14	15.68
Simuliidae	53.85	23.82	42.86	3328.47
Simulium nigritarse	53.85	23.82	42.86	3328.47
LEPIDOPTERA	1.92	3.00	7.14	35.16
TRICHOPTERA	1.92	2.00	7.14	28.02
Leptoceridae	1.92	2.00	7.14	28.02
Athripsodes sp.	1.92	2.00	7.14	28.02
INSECT REMAINS	9.62	36.45	35.71	1645.36
ARACHNIDA	**3.85**	**0.09**	**7.14**	**28.12**
HYDRACARINA	3.85	0.09	7.14	28.12
Orobatidae	3.85	0.09	7.14	28.12
PLANT MATERIAL	**1.92**	**3.45**	**7.14**	**38.41**

Table C.2. Stomach content analysis of *Barbus erubescens.* February samples from collections made between 1964 and 1997, from the Twee River catchment, Western Cape, South Africa ($n = 12$).

	%N	%V	%F	IRI
INSECTA	**59.57**	**9.09**	**58.33**	**4005.48**
EPHEMEROPTERA	12.77	2.27	33.33	501.29
Baetidae	12.77	2.27	33.33	501.29
DIPTERA	14.89	0.64	33.33	517.67
Simuliidae	14.89	0.64	33.33	517.67
Simulium nigritarse	14.89	0.64	33.33	517.67
TRICHOPTERA	25.53	4.91	25.00	761.03
INSECT REMAINS	6.38	1.27	25.00	191.39
FILAMENTOUS ALGAE	**23.40**	**76.64**	**91.67**	**9170.39**
GRIT	**17.02**	**14.27**	**66.67**	**2086.27**

APPENDIX C (continued)

Table C.3. Stomach content analysis of *Barbus erubescens*. March samples from collections made between 1964 and 1997, from the Twee River catchment, Western Cape, South Africa (n = 30).

	%N	%V	%F	IRI
INSECTA	**80.26**	**77.27**	**73.33**	**11552.38**
EPHEMEROPTERA	6.58	14.58	16.67	352.60
Baetidae	3.95	7.23	10.00	111.78
Cloeon sp.	1.32	1.54	3.33	9.51
baetid sp.	2.63	5.69	6.67	55.49
Leptophlebiidae	2.63	7.35	6.67	66.52
Adenophlebia sp.	2.63	7.35	6.67	66.52
DIPTERA	61.84	45.69	63.33	6810.51
Chironimidae	15.79	21.31	26.67	989.26
Tanypodinae	10.53	13.27	16.67	396.59
Orthocladiinae	5.26	8.04	10.00	133.02
Simuliidae	46.05	24.38	40.00	2817.49
Simulium nigritarse	44.74	24.00	40.00	2479.47
Simulium medusaeforme	1.32	0.38	3.33	5.67
HYMENOPTERA	2.63	3.85	3.33	21.59
Formicidae	2.63	3.85	3.33	21.59
ODONATA	2.63	1.92	3.33	15.18
Libellulidae	2.63	1.92	3.33	15.18
INSECT REMAINS	6.58	11.23	16.67	296.83
CRUSTACEA	**11.84**	**2.08**	**6.67**	**92.79**
CLADOCERA	11.84	2.08	6.67	92.79
Daphnidae	11.84	2.08	6.67	92.79
Daphnia	11.84	2.08	6.67	92.79
AMORPHOUS MATERIAL	**7.89**	**20.65**	**20.00**	**570.97**

Table C.4. Stomach content analysis of *Barbus erubescens*. October samples from collections made between 1964 and 1997, from the Twee River catchment, Western Cape, South Africa (n = 11).

	%N	%V	%F	IRI
INSECTA	**70.59**	**75.44**	**63.64**	**9292.99**
DIPTERA	29.41	25.67	27.27	1502.14
Chironimidae	5.88	8.89	9.09	134.28
Simuliidae	23.53	16.78	18.18	732.86
Simulium nigritarse	23.53	16.78	18.18	732.86
ISOPTERA	11.76	11.11	9.09	207.96
LEPIDOPTERA	5.88	0.44	9.09	57.52

APPENDIX C (continued)

HEMIPTERA	5.88	5.44	9.09	102.97
Heteroptera	5.88	5.44	9.09	102.97
INSECT REMAINS	17.65	32.78	27.27	1375.22
PLANT MATERIAL	**11.76**	**1.78**	**9.09**	**123.11**
AMORPHOUS MATERIAL	**17.65**	**22.78**	**27.27**	**1102.50**

Table C.5. Stomach content analysis of *Barbus erubescens*. November samples from collections made between 1964 and 1997, from the Twee River catchment, Western Cape, South Africa ($n = 24$).

	%N	%V	%F	IRI
INSECTA	**74.63**	**81.47**	**70.83**	**11057.12**
EPHEMEROPTERA	11.94	16.47	25.00	710.35
Baetidae	11.94	16.47	25.00	710.35
DIPTERA	43.28	38.26	54.17	4417.12
Chironimidae	19.40	14.53	25.00	848.23
Tanypodinae	13.43	7.16	16.67	343.18
Orthocladiinae	4.48	5.58	8.33	83.80
Chironiminae	1.49	1.79	4.17	13.68
Simuliidae	22.39	20.58	33.33	1432.23
Simulium nigritarse	20.90	17.42	29.17	1117.57
simulid sp.	1.49	3.16	4.17	19.38
dipteran sp.	1.49	3.16	4.17	19.38
HYMENOPTERA	1.49	3.37	4.17	20.25
Mymaridae	1.49	3.37	4.17	20.25
TRICHOPTERA	10.45	2.53	12.50	162.18
Ecnomidae	8.96	2.21	8.33	93.05
Ecnomus sp.	8.96	2.21	4.17	93.05
Leptoceridae	1.49	0.32	4.17	7.53
Athripsodes sp.	1.49	0.32	4.17	7.53
ORTHOPTERA	1.49	5.26	4.17	28.15
Gryllotalpidae	1.49	5.26	4.17	28.15
COLEOPTERA	4.48	10.32	12.50	184.92
Dryopidae	1.49	3.53	4.17	20.91
Elmidae	1.49	5.26	4.17	28.15
coleopteran sp.	1.49	1.53	4.17	12.58
INSECT REMAINS	1.49	5.26	4.17	28.15
CRUSTACEA	**11.94**	**1.11**	**4.17**	**54.36**
CLADOCERA	11.94	1.11	4.17	54.36
Daphnidae	11.94	1.11	4.17	54.36
Daphnia	11.94	1.11	4.17	54.36
NEMATODA	**2.99**	**0.68**	**4.17**	**15.29**
PLANT MATERIAL	**4.48**	**0.47**	**4.17**	**20.63**

AMORPHOUS MATERIAL	**4.48**	**13.63**	**12.50**	**226.36**
GRIT	**1.49**	**2.63**	**4.17**	**17.18**

Table C.6. Stomach content analysis of *Barbus erubescens*. December samples from collections made between 1964 and 1997, from the Twee River catchment, Western Cape, South Africa (n = 19).

	%N	%V	%F	IRI
INSECTA	**83.33**	**66.67**	**21.05**	**3157.90**
DIPTERA	75.00	30.00	15.79	1973.68
Simuliidae	66.67	36.67	15.79	1631.58
Simulium nigritarse	66.67	36.67	15.79	1631.58
dipteran sp.	8.33	13.33	5.26	114.04
INSECT REMAINS	8.33	16.67	5.26	131.58
AMORPHOUS MATERIAL	**16.67**	**33.33**	**10.53**	**526.32**

APPENDIX D

Table D.1. Stomach content analysis of *Lepomis macrochirus* sampled from the Twee River complex, Western Cape, South Africa ($n = 50$).

	%N	%V	%F	IRI
INSECTA	**96.09**	**83.58**	**90.00**	**16170.42**
DIPTERA	8.07	3.83	26.00	309.45
Chironomidae	4.16	0.54	10.00	46.98
Tanypodinae	2.44	0.40	8.00	22.73
Chironomid sp.	1.71	0.15	2.00	3.71
Ceratopogonidae	2.20	0.67	10.00	28.67
Empididae	1.22	2.40	4.00	14.47
Muscidae	0.49	0.23	2.00	1.44
EPHEMEROPTERA	4.65	3.83	16.00	135.66
Baetidae	4.40	3.42	14.00	109.45
Cloeon sp.	4.40	3.42	14.00	109.45
Leptophlebiidae	0.24	0.42	2.00	1.32
Castanophlebia calida	0.24	0.42	2.00	1.32
COLEOPTERA	4.40	13.65	32.00	577.50
Carabidae	0.24	0.13	2.00	0.74
Scarabaeidae	0.24	1.02	2.00	2.53
Elmidae	0.49	3.13	4.00	14.46
Dytiscidae	0.73	0.27	4.00	4.02
Chrysomelidae	0.49	3.65	4.00	16.54
Dryopidae	2.20	5.46	16.00	122.54
Strina sp.	2.20	5.46	16.00	122.54
HEMIPTERA	2.20	0.54	10.00	27.42
Veliidae	1.22	0.29	4.00	6.06
Microvelia sp.	0.98	0.21	4.00	4.75
veliid sp.	0.24	0.08	2.00	0.66
Corixidae	0.24	0.08	2.00	0.66
Micronecta sp.	0.24	0.08	2.00	0.66
Aphididae	0.24	0.06	2.20	0.61
hemipteran sp.	0.49	0.10	4.00	2.37
BLATTODEA	1.71	1.13	2.00	5.67
Blaberidae	1.71	1.13	2.00	5.67
HYMENOPTERA	12.22	8.46	12.00	248.20
Formicidae	12.22	8.46	12.00	248.20
TRICHOPTERA	50.86	10.00	54.00	3286.21
Hydroptilidae	0.24	0.23	2.00	0.95
Oxyethira sp.	0.24	0.23	2.00	0.95
Leptoceridae	50.61	9.77	54.00	3260.63
Athripsodes sp.	50.61	9.77	54.00	3260.63
DERMAPTERA	0.24	0.23	2.00	0.95

APPENDIX D (continued)

ODONATA	2.69	5.19	12.00	94.52
Coenagrionidae	2.20	2.73	8.00	39.44
Pseudagrion sp.	2.20	2.73	8.00	39.44
Libellulidae	0.49	2.46	4.00	11.79
Tetrathemis sp.	0.49	2.46	4.00	11.79
ORTHOPTERA	0.49	0.33	4.00	3.29
Gryllidae	0.24	0.31	2.00	1.11
orthopteran sp.	0.24	0.02	2.00	0.53
MANTODEA	3.42	5.50	12.00	107.08
Mantidae	3.42	5.50	12.00	107.08
INSECT REMAINS	5.13	30.90	42.00	1513.27
ARACHNIDA	1.22	0.19	8.00	11.28
HYDRACARINA	1.22	0.19	8.00	11.28
Oxidae	0.24	0.02	2.00	0.53
Frontipoda sp.	0.24	0.02	2.00	0.53
hydracarinid sp.	0.98	0.17	6.00	6.87
CRUSTACEA	0.24	0.04	2.00	0.57
CLADOCERA	0.24	0.04	2.00	0.57
Chydoridae	0.24	0.04	2.00	0.57
AMORPHOUS MATERIAL	**2.44**	**16.19**	**20.00**	**1372.65**

Table D.2. Stomach content analysis of *Sandelia capensis* sampled from the Twee River complex, Western Cape, South Africa (n = 120).

	%N	%V	%F	IRI
INSECTA	**66.17**	**69.84**	**60.83**	**8274.39**
EPHEMEROPTERA	23.99	17.13	15.83	651.07
Baetidae	23.86	16.01	15.00	598.10
Afroptilum excisum	23.37	15.26	14.17	547.24
baetid sp.	0.49	0.75	1.67	2.07
Caenidae	0.12	1.12	0.83	1.04
DIPTERA	32.35	17.01	40.00	1974.42
Chironomidae	29.52	14.97	36.67	1631.18
Chironominae	25.09	11.27	30.00	1090.86
Chironomini	23.49	8.31	26.67	848.21
Tanytarsini	1.60	2.96	5.00	22.77
Tanypodinae	3.32	2.03	11.67	62.47
Orthocladiinae	0.86	1.33	4.17	9.11
chironomid sp.	0.25	0.34	0.83	0.49
Simuliidae	1.35	0.51	5.00	9.29
Simulium sp.	1.35	0.51	5.00	9.29
Ceratopogonidae	1.23	0.70	4.17	8.03

APPENDIX D (continued)

Bezzia sp.	1.11	0.42	3.33	5.08
ceratopogonid sp.	0.12	0.28	0.83	0.34
Culicidae	0.12	0.22	0.83	0.29
Toxorhynchitinae	0.12	0.22	0.83	0.29
dipteran sp.	0.12	0.62	0.83	0.62
COLEOPTERA	3.57	10.80	14.17	203.50
Dytiscidae	0.37	3.02	2.50	8.48
Elmidae	0.37	1.57	1.67	3.24
Helodidae	2.46	4.45	7.50	51.82
Gyrinidae	0.25	0.85	1.67	1.83
coleopteran sp.	0.12	0.90	0.83	0.85
HEMIPTERA	0.49	0.55	3.33	3.48
Corixidae	0.49	0.55	3.33	3.48
Micronecta sp.	0.49	0.55	3.33	3.48
HYMENOPTERA	0.37	1.63	2.50	5.00
Formicidae	0.37	1.63	2.50	5.00
TRICHOPTERA	2.09	2.58	10.00	46.75
Leptoceridae	0.37	0.24	1.67	1.01
Athripsodes harrisoni	0.37	0.24	1.67	1.01
Ecnomidae	0.74	1.29	2.50	5.08
Ecnomus sp.	0.74	1.29	2.50	5.08
Hydroptilidae	0.98	1.06	5.83	11.90
Oxyethira sp.	0.98	1.06	5.83	11.90
ODONATA	1.35	8.45	7.50	73.52
Aeshnidae	0.25	1.12	0.83	1.14
Anax sp.	0.25	1.12	0.83	1.14
Libellulidae	0.86	5.53	5.00	31.95
Trithemis sp.	0.86	5.53	5.00	31.95
odonatan sp.	0.25	1.80	1.67	3.41
ORTHOPTERA	0.12	1.12	0.83	1.04
INSECT REMAINS	1.85	10.56	12.50	155.09
CRUSTACEA	**28.78**	**4.63**	**11.67**	**389.80**
CLADOCERA	23.12	1.81	4.17	103.89
Chydoridae	23.12	1.81	4.17	103.89
AMPHIPODA	0.37	1.12	0.83	1.24
Paramelitidae	0.37	1.12	0.83	1.24
Paramelita nigroculus	0.37	1.12	0.83	1.24
COPEPODA	5.29	1.70	7.50	52.39
CYCLOPOIDA	5.29	1.70	7.50	52.39
ARACHNIDA	**0.37**	**0.08**	**2.50**	**1.12**
HYDRACARINA	0.37	0.08	2.50	1.12
PISCES	**1.11**	**5.04**	**7.50**	**46.14**
Salmonidae	0.49	1.61	3.33	7.00
Oncorhynchus mykiss	0.49	1.61	3.33	7.00
Anabantidae	0.49	3.36	3.33	12.84

Sandelia capensis	0.49	3.36	3.33	12.84
piscean sp.	0.12	0.08	0.83	0.17
PLANT MATERIAL	**0.62**	**2.99**	**4.17**	**15.02**
AMORPHOUS MATERIAL	**2.83**	**16.52**	**19.17**	**370.80**
GRIT	**0.12**	**0.90**	**0.83**	**0.85**

Table D.3. Stomach content analysis of *Micropterus dolomieu* sampled from the Twee River complex, Western Cape, South Africa, below lower boundary waterfall (*n* = 10).
A. peringueyella = *Adenophlebia peringueyella*
A. sudafricanum = *Afroptilum sudafricanum*

	%N	%V	%F	IRI
INSECTA	**88.40**	**96.74**	**100.00**	**18514.00**
EPHEMEROPTERA	58.60	91.85	80.00	12036.00
Leptophlebiidae	2.50	0.54	10.00	30.40
A. peringueyella	2.50	0.54	10.00	30.40
Baetidae	56.10	91.31	80.00	11792.80
A. sudafricanum	3.00	0.54	10.00	35.40
baetid sp.	53.10	90.77	80.00	11509.60
DIPTERA	0.20	0.54	10.00	7.40
Chironomidae	0.20	0.54	10.00	7.40
Tanypodinae	0.20	0.54	10.00	7.40
ODONATA	11.60	2.17	30.00	413.10
Aeshnidae	9.00	0.54	10.00	95.40
Libellulidae	1.40	1.09	10.00	24.90
Tetrathemis sp.	1.40	1.09	10.00	24.90
Coenagrionidae	1.20	0.54	10.00	17.40
Pseudagrion sp.	1.20	0.54	10.00	17.40
HEMIPTERA	12.90	1.09	20.00	279.80
Nepidae	10.00	0.54	10.00	105.40
Ranatra sp.	10.00	0.54	10.00	105.40
hemipteran sp.	2.90	0.55	10.00	34.50
TRICHOPTERA	5.10	1.09	20.00	123.80
Ecnomidae	5.10	1.09	20.00	123.80
Ecnomus thomasetti	5.10	1.09	20.00	123.80
ARACHNIDA	**0.20**	**0.54**	**10.00**	**7.40**
Tetragnathidae	0.20	0.54	10.00	7.40
CRUSTACEA	**10.70**	**2.17**	**20.00**	**257.40**
Potomonautidae	10.70	2.17	20.00	257.40
Potomonautes perlatus	10.70	2.17	20.00	257.40
PLANT MATERIAL	**0.70**	**0.55**	**10.00**	**12.50**

APPENDIX D (continued)

Table D.4. Stomach content analysis of *Barbus capensis* sampled from the Twee River complex, Western Cape, South Africa ($n = 4$).

	%N	%V	%F	IRI
INSECTA	54.55	1.25	100.00	5580.00
EPHEMEROPTERA	18.18	0.18	25.00	459.00
Baetidae	18.18	0.18	25.00	459.00
Cloeon sp.	18.18	0.18	25.00	459.00
TRICHOPTERA	31.82	0.82	75.00	2448.00
Ecnomidae	22.73	0.33	50.00	1153.00
Ecnomus sp.	22.73	0.33	50.00	1153.00
trichopteran sp.	9.09	0.49	25.00	239.50
INSECT REMAINS	4.55	0.25	25.00	120.00
FILAMENTOUS ALGAE	**18.18**	**53.50**	**100.00**	**7169.00**
AMORPHOUS MATERIAL	**18.18**	**44.00**	**100.00**	**6218.00**
GRIT	**9.09**	**1.25**	**50.00**	**517.00**

Table D.5. Stomach content analysis of *Oncorhynchus mykiss* sampled from the Twee River complex, Western Cape, South Africa ($n = 1$).

	%N	%V	%F	IRI
INSECTA	100.00	100.00	100.00	20000.00
EPHEMEROPTERA	33.33	65.00	100.00	9833.33
Baetidae	33.33	65.00	100.00	9833.33
Cloeon sp.	33.33	65.00	100.00	9833.33
DIPTERA	66.67	35.00	100.00	10166.67
Simuliidae	66.67	35.00	100.00	10166.67
Simulium nigritarse	66.67	35.00	100.00	10166.67

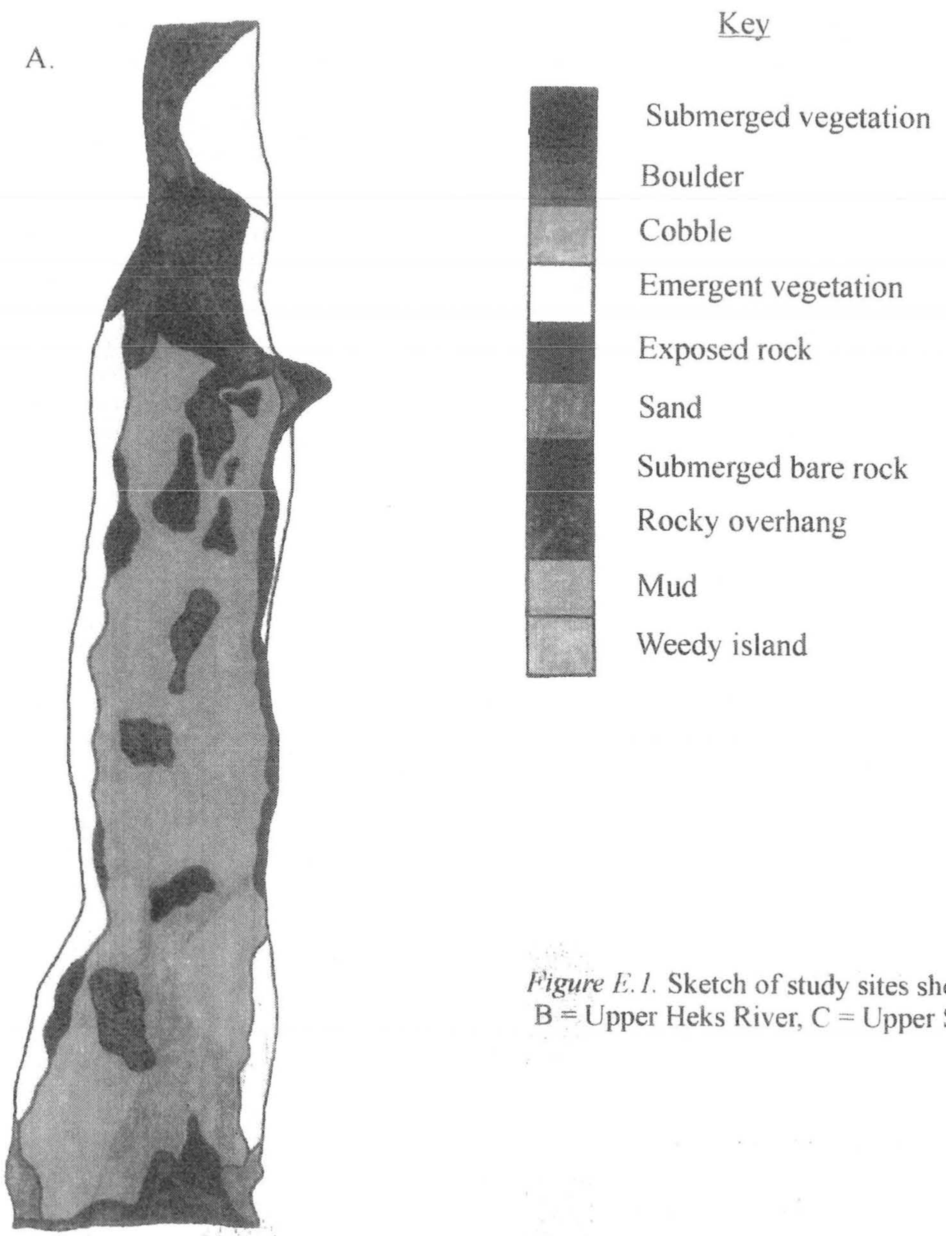
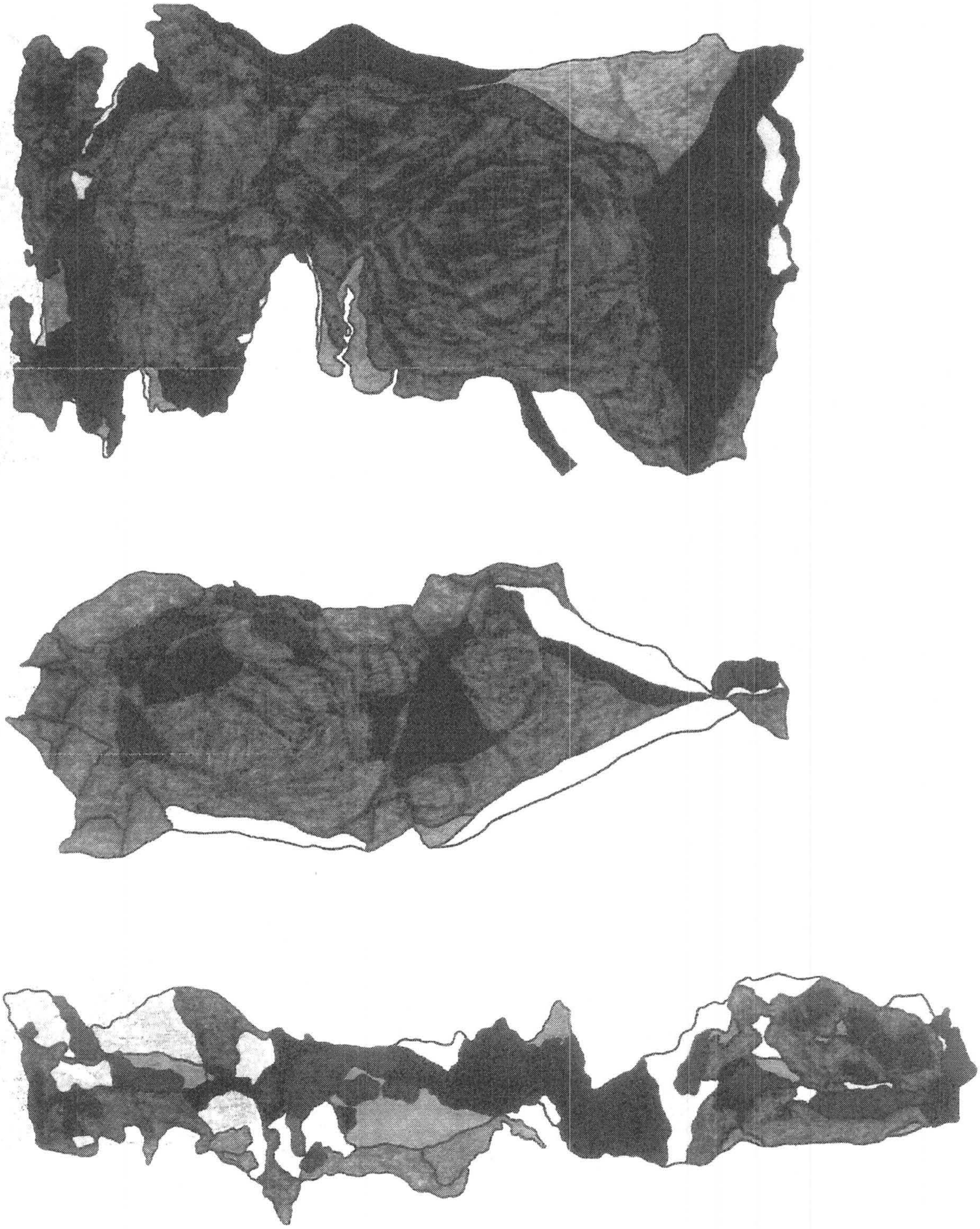


Figure E.1. Sketch of study sites showing habitat types. A = Upper Middeldeur River, B = Upper Heks River, C = Upper Suurvlei River, D = Middle Twee River.

APPENDIX E (continued)



D.

C.

B.

APPENDIX F

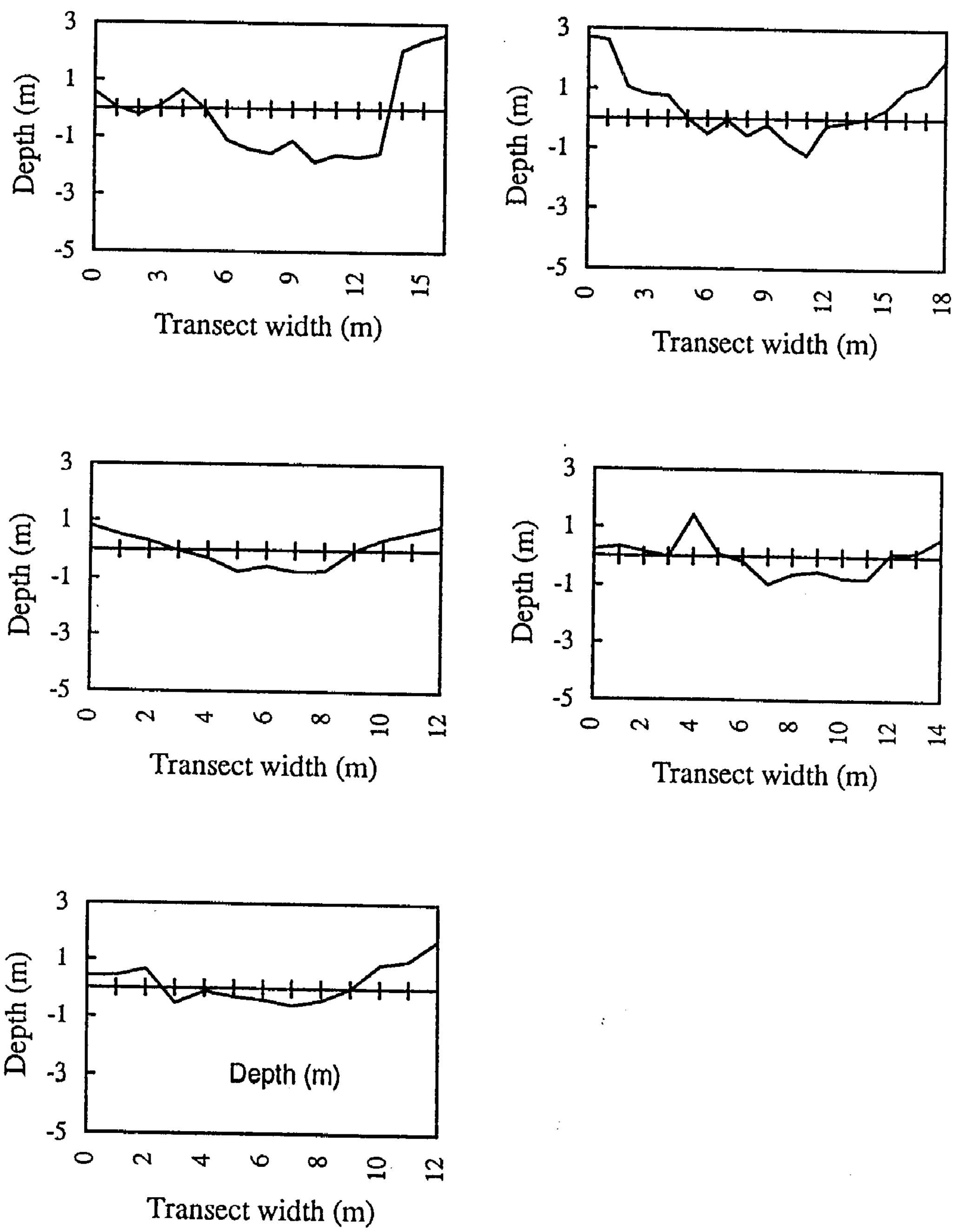


Figure F.1. Bankfill cross-sections at 10 m intervals on the Heks River (32°43'12'S, 19°12'27"E), Twee River catchment, Western Cape, during October/ November 1996. Measurements were calculated from theodelite readings.

APPENDIX F (continued)

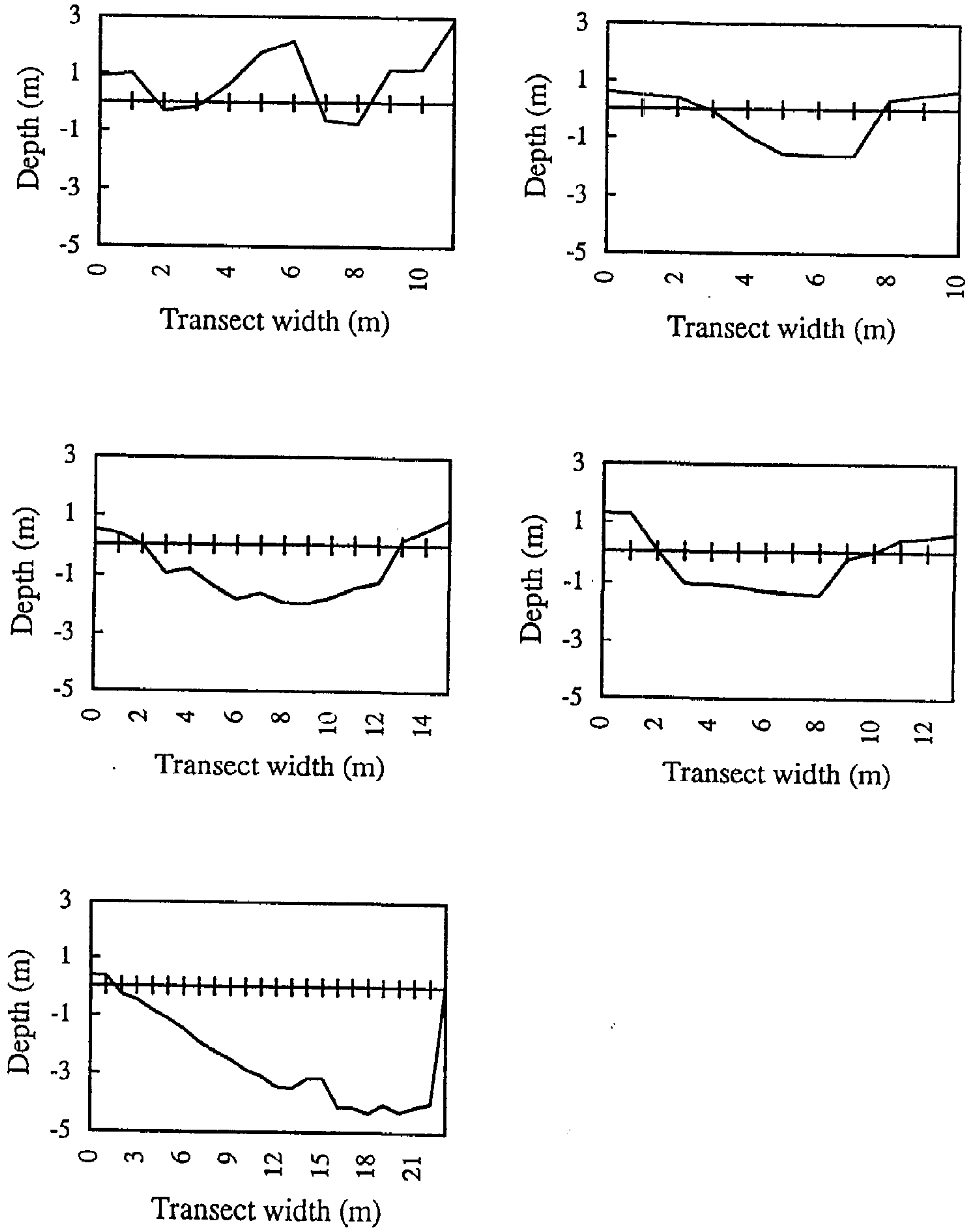


Figure F.2. Bankfill cross-sections at 10 m intervals on the upper Middeldeur River (32°44'49'S, 19°13'19"E), Twee River catchment, Western Cape, during October/ November 1996. Measurements were calculated from theodelite readings.

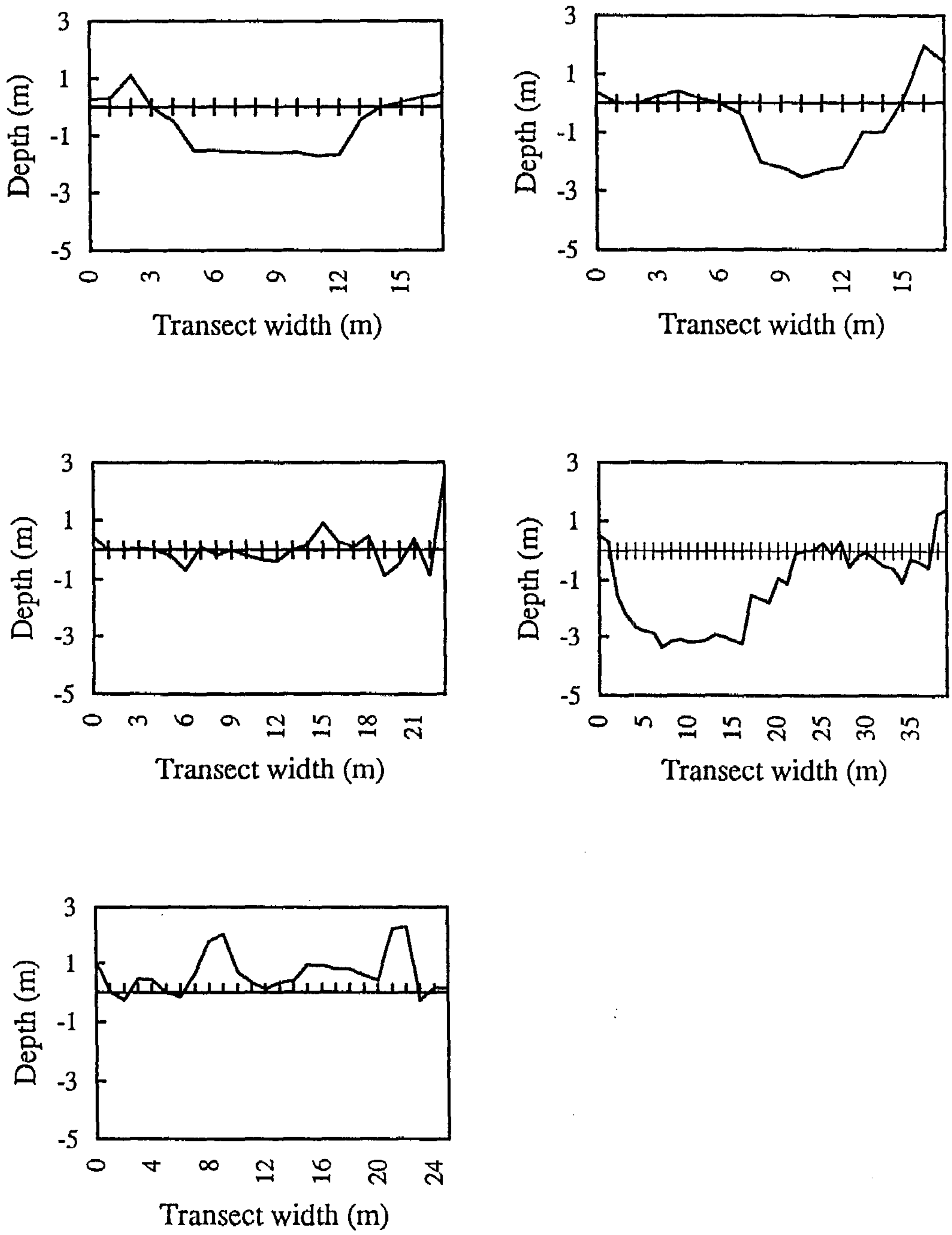


Figure F.3. Bankfill cross-sections at 10 m intervals on the upper Suurvlei River (32°37'42'S, 19°10'53"E), Twee River catchment, Western Cape, during October/ November 1996. Measurements were calculated from theodelite readings.

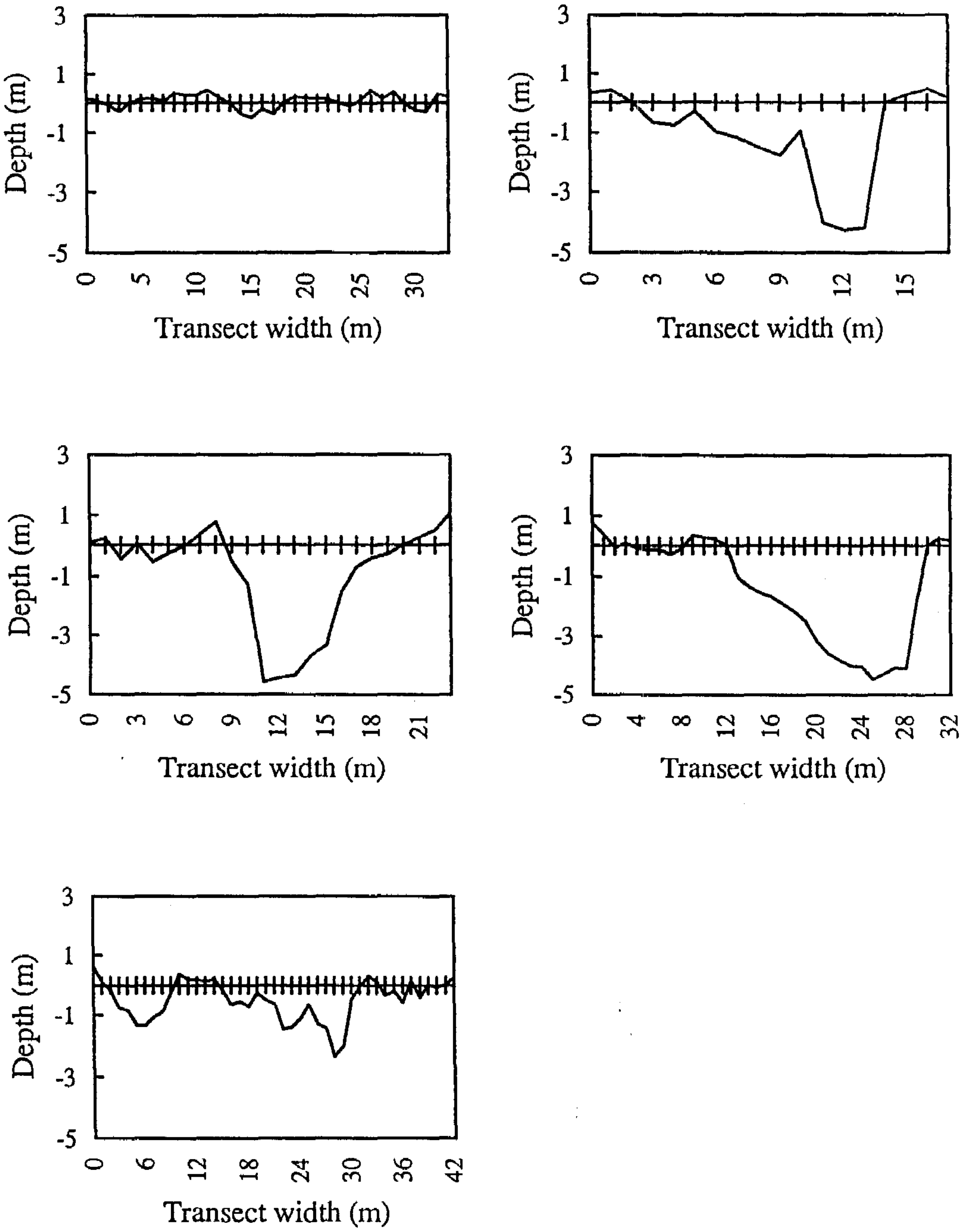


Figure F.4. Bankfill cross-sections at 10 m intervals on the Heks River (32°40'35'S, 19°16'05"E), Twee River catchment, Western Cape, during October/ November 1996. Measurements were calculated from theodelite readings.

APPENDIX G

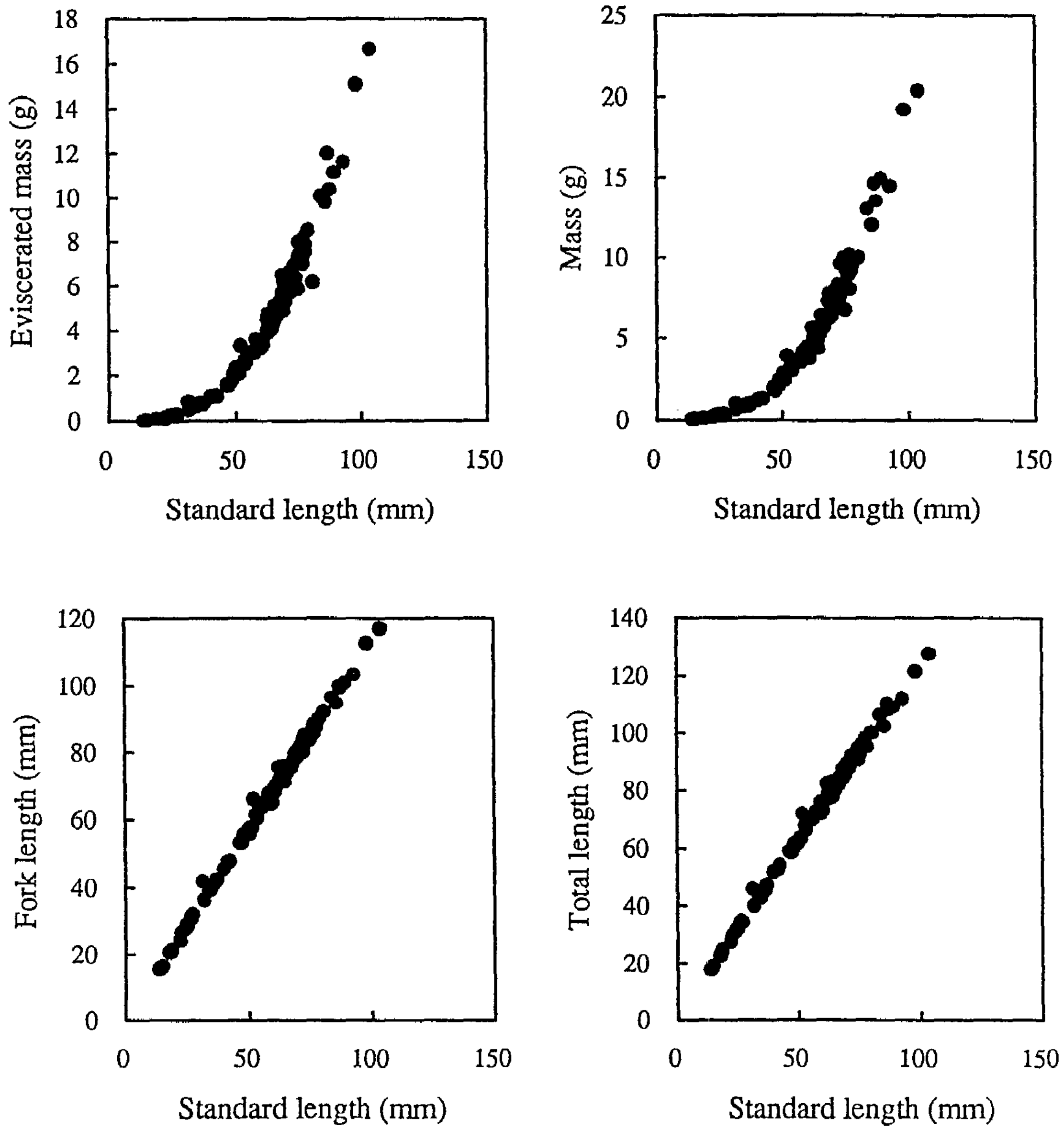


Figure G.1. Morphometric relationships between length and mass measurements of *Barbus erubescens* collected from the Twee River catchment, Western Cape.