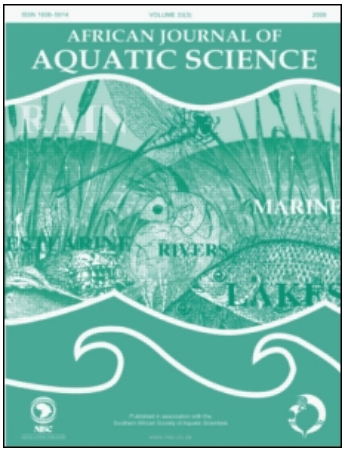

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Conservation biology and management of a critically endangered cyprinid, the Twee River redfin, *Barbus erubescens* (Teleostei: Cyprinidae), of the Cape Floristic Region, South Africa

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The Twee River redfin *Barbus erubescens* is a critically endangered small cyprinid endemic to the Twee River System, a sub-catchment of the Olifants-Doring River System of South Africa. It is currently the most threatened freshwater fish in both the Cape Floristic Region and South Africa. It inhabits deep pools in perennial rivers that have an abundance of instream and marginal vegetation and rock cover. Key threats include four introduced invasive fish species and habitat degradation due to increasing intensive agriculture in the Twee River catchment. Unless appropriate management action is taken, it may become the first freshwater fish species in South Africa to become extinct. The purchase of key riparian properties, the eradication of invasive species from part of the river system, the promotion of land-owner awareness, and the establishment of a conservancy as part of a long-term recovery programme are recommended to conserve *B. erubescens* effectively.

Keywords: *Barbus erubescens*, Cape Floristic Region, conservation, invasive alien fish, threatened endemic fishes

Introduction

The Cape Floristic Region (CFR) is recognised as a centre for a distinct 'Cape' component of Africa's ichthyofauna (Skelton *et al.* 1995). The freshwater ichthyofauna of the CFR comprises 19 species, which is relatively depauperate for a moderate-rainfall area of 90 000km^2 (WWF-SA 2000), but is exceptionally rich in terms of endemicity (16 species) (Impson *et al*. 1999). Cyprinids of the genera *Barbus*, *Labeo*, *Labeobarbus* and *Pseudobarbus* (15 species, 79% of the fauna) dominate the CFR's ichthyofauna (Impson *et al*. 2002). Two austroglanids, an anabantid and a galaxiid also occur here.

The freshwater fishes of this mainly Mediterranean-type climatic region are characterised by isolated and geographically-restricted distribution ranges, inflexible life history styles, and a low resilience to disturbance (Skelton 1987). Due to the impacts of habitat degradation and invasive alien fishes, 15 species (all endemics) are internationally listed as threatened.

The most notable freshwater fish 'hotspot' in the CFR, and indeed in South Africa, is the Olifants-Doring River System, where eight of its 10 species are endemic and threatened (Skelton *et al.* 1995). The most threatened fish here, and arguably South Africa's most threatened freshwater fish species, is the Twee River redfin *Barbus erubescens*, which was described as recently as 1974 (Skelton 1974) and is now critically endangered (Baillie and Groombridge 1996). This small species (maximum 95mm SL, Skelton 1993) is confined to the Twee River catchment (Figure 1), where itoccurs in the Heks, Middledeur, Suurvlei and Twee rivers. Expanding agriculture and increasing levels of pollution, water abstraction and numbers of predatory introduced fishes threaten this highly restricted cyprinid (Hamman *et al.* 1984, Skelton 1987). Skelton (1987) highlighted the need for a study on the ecology and biology of the species, to develop an effective conservation strategy.

Marriott (1998) conducted a study funded by Cape Nature Conservation on the conservation biology of *B. erubescens*, the key objectives of which were to determine the species' distribution range and population density and to identify key factors threatening its survival. This information was used to re-evaluate its conservation status. Other objectives included gaining a better understanding of its diet, breeding biology, age and growth. This paper presents the major findings of Marriott's study and highlights management options that could contribute to the recovery of *B. erubescens*.

Study area

The small perennial Twee River System, situated in the Cederberg Mountains of the Western Cape Province, is part of the Doring River System, the major sub-catchment of the Olifants-Doring River System (Figure 1). The major tributaries of the Twee River are the Heks, Middeldeur and Suurvlei rivers. Land use in the catchment varies from citrus and deciduous fruit farming to resort development and nature conservation. The uppermost and lower sections of the catchment are largely natural, whereas the

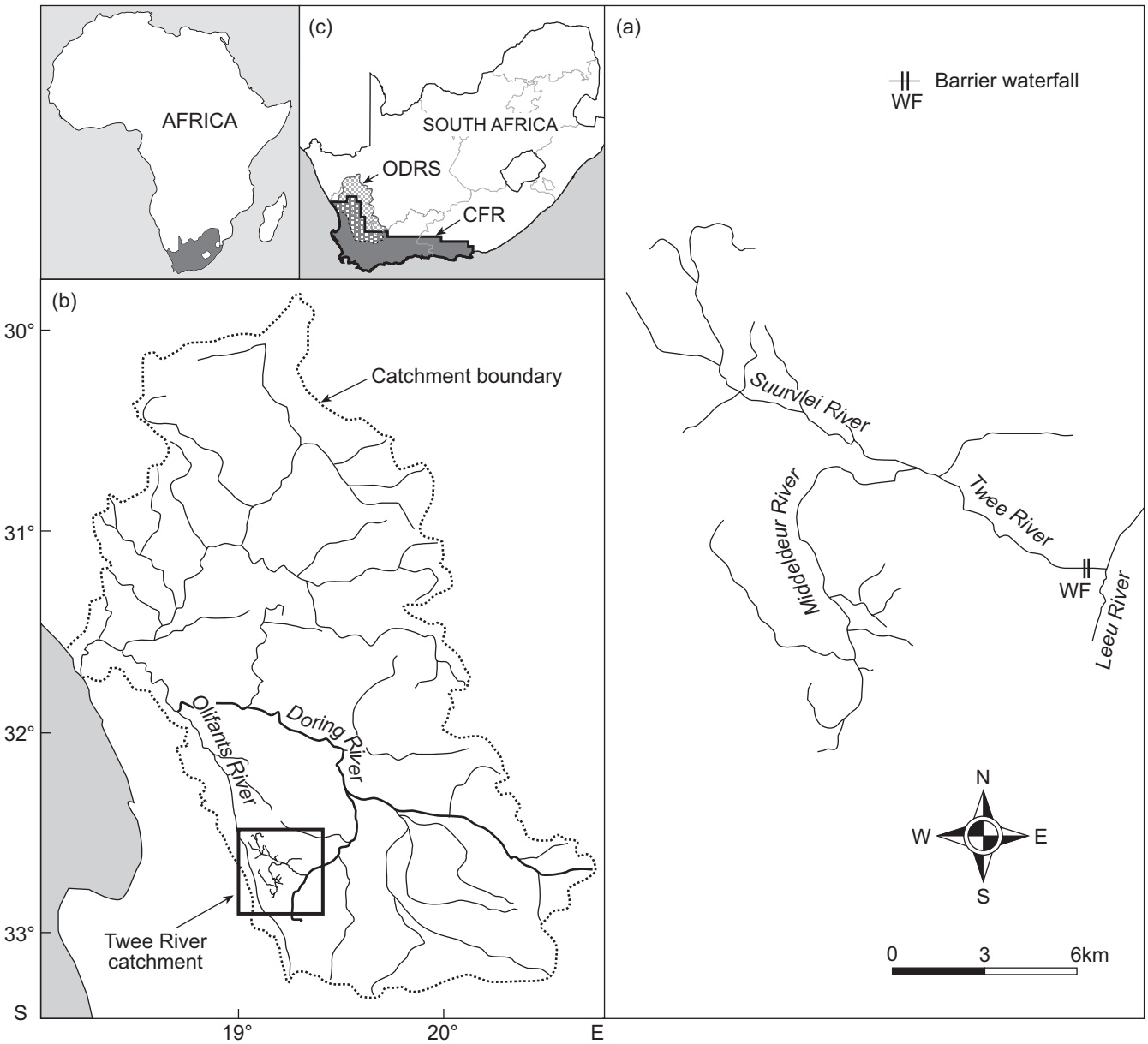

Figure 1: The Twee River catchment (a), situated in the Olifants-Doring River System (ODRS) (b) of South Africa's Cape Floristic Region (CFR) (c). WF = barrier waterfall below which *Barbus erubescens* was not found (after Marriott 1998)

middle section is subject to increasing irrigation-dependant orchard development, especially on the banks of the Suurvlei River. No instream dams or weirs are present on the larger rivers, but several dams have been constructed on the smaller tributaries.

The geology of the catchment comprises primarily sandstones and quartzites of the Table Mountain Group. Rain falls mostly in winter and averages 581.5mm y^{-1} but is highest at the source of the major tributaries. The mean annual run-off of the catchment has been estimated at 49.4 x $10^6 m^3$ a^{-1} (DWAF unpubl. data). Natural vegetation is mainly mountain fynbos. River water is clear, with a pH of 6.2–7.7 and a low level of dissolved solids (conductivity ranging from 44.7–116mS cm^{-1}). Water temperatures ranged between 27°C in summer and 5°C in winter (MSM, pers. obs.).

Riverine habitat is dominated by large deep pools interspersed with shallow riffles and rapids. There are four substantial waterfalls; the one furthest downstream on the Twee River (referred to as the 'fourth waterfall'), situated just upstream of its confluence with the Leeu River, marks the lower limit of the present distribution range of *B. erubescens*. Riparian vegetation includes *Brabejum stellatifolium*, *Erica caffra*, *Metrosideros angustifolia* and *Salix hirsute*, with palmiet *Prionium serratum* being abundant within the river channel.

Prior to Marriott's study, fish surveys of the Twee River above the fourth waterfall yielded two indigenous species, Twee River redfin and Cape Galaxias *Galaxias zebratus*, and three introduced species, the Cape kurper *Sandelia capensis*, Clanwilliam yellowfish *Labeobarbus capensis* and rainbow trout *Oncorhynchus mykiss*. Genetic studies indi-

cate that *G. zebratus* from the Twee River are genetically unique (E Swartz, South African Institute for Aquatic Biodiversity, pers. comm.). Cape kurper are indigenous to most CFR rivers, but not to the Olifants River System. In the 1970s they were illegally introduced into a farm dam in the Suurvlei catchment by a local farmer, in a misguided attempt to use an 'indigenous' fish species for mosquito control, but they escaped and invaded much of the Twee River catchment (Hamman *et al.* 1984). Cape kurper have not been recorded elsewhere in the Olifants River System, since the presence of smallmouth bass *Micropterus dolomieu* below the fourth waterfall is a biological barrier to their further invasion. Clanwilliam yellowfish, an Olifants System endemic, occur naturally below the Twee River fourth waterfall, but were unwisely introduced into the upper catchment of the Twee in the 1980s by Cape Nature Conservation. They are now common in the Twee catchment, with specimens of over 5kg frequently being seen when snorkelling in the larger pools. Rainbow trout, native to North America, were probably introduced into the river in the late 1980s by a local landowner, following the closure of an illegal trout farm in the lower catchment. They appear to be uncommon in this system, probably due to its elevated summer water temperatures.

Materials and methods

After a preliminary survey in March 1996 to determine the upper and lower distribution limits *of B. erubescens*, Marriott (1998) selected 15 sampling sites at regular intervals, about 1km apart, throughout the Twee River System. These sites were surveyed by snorkelling in March 1996 and January/February 1997, to determine the distribution and population size of *B. erubescens* and other fishes. Snorkelling is regarded as a quick cost-effective survey method in clear-water streams, as it is not limited by cumbersome equipment, low conductivity, deep water, or boulder substrates (Slaney and Martin 1987) and can be used to sample large areas (Griffith 1981). A major additional advantage is that it doesn't affect fishes physically, a critical consideration when sampling highly endangered species. Fish densities recorded in specific river stretches were assumed to be directly proportional to the length of river included in the study sites, and total population numbers were therefore determined by extrapolation to the full length of river occupied by each species. Immature fish were identified by their light grey colour compared to adults, which are dark olive dorsally with a dark mid stripe across each flank and red colour at the bases of fins.

For studies on age and growth, diet, and reproduction, Marriott collected 81 *B. erubescens* by electrofishing and supplemented these with 33 specimens loaned from the Albany Museum in Grahamstown. Gonadosomatic indices (GSI) for mature males and females were calculated from gonad mass as a percentage of eviscerated body mass, and spawning seasonality was deduced by plotting mean monthly GSI. Gut contents from all specimens were sorted and identified to the lowest possible taxon. An index of relative importance (IRI) for each prey item was calculated according to Hyslop (1980) as: IRI = (%N + %V) X %F, where N is the number of prey individuals, V is the prey volume and F is the frequency of occurrence of the prey item. Age and growth were determined by taking three scales from the left side of each fish (n = 91) above the lateral line and immediately below the dorsal fin (after Secor and Trice 1995). Growth rings were counted under transmitted light using a Micrographix MGX 1100 Microfiche reader, at high magnification, and age at length was modelled to fit the von Bertallanfy growth equation (after Ricker 1975).

Possible threats to *B. erubescens* were identified by analysing results from the fish surveys and from interviews with landowners in the catchment. Landowners were questioned on factors such as type of farming, history of land use, physical destruction to rivers, use of pesticides and fertilisers, water abstraction, river drainage, and the utilisation of fish.

Based on the findings of this study, the conservation status of *B. erubescens* was reviewed, based on the most recent IUCN 2001 conservation criteria.

Results

Distribution and population size of B. erubescens

The historical and 1997 distributions of the Twee River redfin are shown in Figures 2 and 3, respectively. During Marriott's study, the species was recorded from the upper reaches of the Middeleur, Suurvlei and Heks rivers, at about 770, 800 and 840m asl, respectively. It was widespread in the Heks, Middeldeurs and Twee rivers, but only occurred at the uppermost sampling site in the Suurvlei River, whereas historically it had been more widespread here. The upper distribution limits of *B. erubescens* were restricted by low waterfalls and cascades, whilst it was not recorded below the fourth waterfall on the Twee River.

The population size of *B. erubescens* was estimated at 8 400 individuals, of which 4 100 were adults. The total numbers of fish recorded at the study sites were 1 147 individuals (564 adults) in March 1996 and 1 426 individuals (316 mature) in January/February 1997 (Table 1).

Distribution of other fishes

Five other fish species, of which four are introduced species, were recorded in the Twee River catchment. The introduced *S. capensis* was the most widespread (Figure 3) and numerous (Table 1). The indigenous *G. zebratus* was widespread in the Heks and Middeldeur rivers (Figure 3) and was abundant at sampling sites in these rivers in March 1996. The introduced *L. capensis* was widespread in the Twee River (Figure 3), where it was also relatively numerous. Rainbow trout *O. mykiss*, another introduced species, appear to be confined to the lower Twee River (Figure 3), where only 15 individuals were recorded in both surveys. Alien bluegill sunfish *Lepomis macrochirus* were recorded for the first time in the upper reaches of the Middeldeur River (Figure 3). Their numbers declined substantially in the second survey (Table 1). Smallmouth bass were recorded in the Twee River below the fourth waterfall, outside the known distribution range of *B. erubescens*. The only river in the Twee River catchment without alien fishes was the Heks River, where both *B. erubescens* and *G. zebratus* were recorded.

Conservation status of B. erubescens

The study confirmed that the conservation status of *B. erubescens* was Critically Endangered, according to

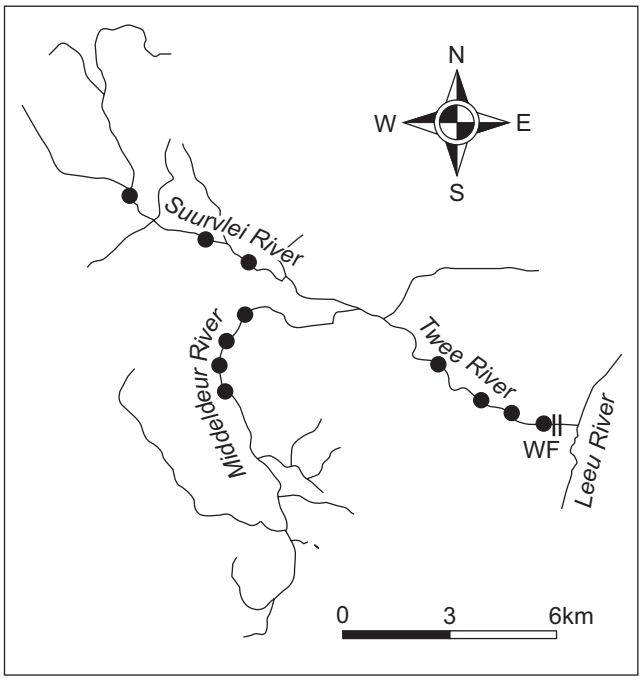

Figure 2: Historical (pre-1990) distribution of *Barbus erubescens* in the Twee River System (after Marriot 1998)

Criterion B2 'a' and 'b' (i, iii, v) of the 2001 IUCN conservation categories. Criterion B evaluates the restricted geographic range of a species in relation to the pressures of fragmentation, continuing decline, and extreme fluctuations in population size and distribution (IUCN 2001). The Twee River redfin qualifies because it is endemic to a single tributary complex with an area of occupancy of less than 10km^2, with a continuing decline in its extent of occurrence in terms of area, extent and quality of habitat, and number of mature individuals.

***Habitat preferences of* B. erubescens**

Adult Twee River redfin showed an affinity for sheltered areas in pools, particularly near overhanging vegetation and caves under boulders. The continuous movement of fishes in and out of inaccessible boulder- or vegetation-recesses, often in water deeper than 1.5m, made the assessment of their density difficult at times. Schools of juveniles were usually seen in pools in the upper water column near palmiet, *P. serratum*, or overhanging vegetation.

***Age and growth, reproduction and diet of* B. erubescens**

Growth of *B. erubescens* was described by the von Bertallanfy model: $L_t = 8.31\ (1–e^{-0.489\ (t + 0.398)})$. Males and females reached a maximum age of six years, maturing

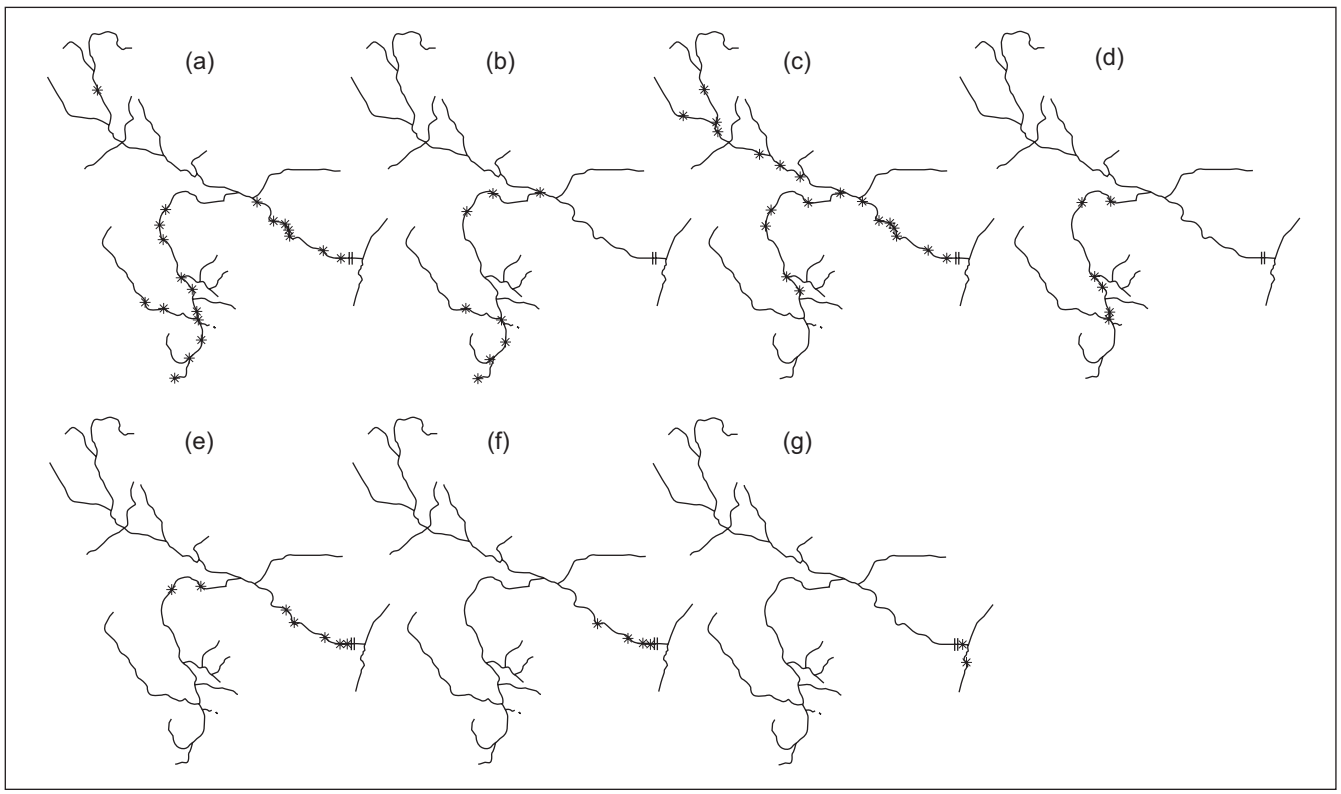

Figure 3: Distributions of freshwater fishes in the Twee River System in 1996 (after Marriott 1998). ✱ = Sites where the species was observed by snorkelling: a = *Barbus erubescens*, b = *Galaxias zebratus*, c = *Sandelia capensis*, d = *Lepomis macrochirus*, e = *Labeobarbus capensis*, f = *Oncorhynchus mykiss*, g = *Micropterus dolomieu*

Table 1: Densities of fishes and estimated percentages of river length of river inhabited by fishes in the Twee River catchment, based on counts made during March 1996 and January/February 1997 (*denotes introduced species) (from Marriott 1998)

Species	Numbers of fish counted in March 1996	Numbers counted in January/February 1997	Estimated % of river length inhabited
Barbus erubescens	1 147 (564 mature)	1 426 (316 mature)	60
Galaxias zebratus	757	186	46
*Sandelia capensis**	1 008	1 276	74
*Lepomis macrochirus**	58	4	21
*Oncorhynchus mykiss**	11	4	9
*Labeobarbus capensis**	196	51	34

after two years at a calculated standard length of 45mm in males and 42mm in females.

Twee River redfins spawned from late spring (October) to early summer (December) and followed an asynchronous iteroparous pattern of egg development. Females contained up to 400 ova in various stages of development, with mature eggs measuring 1.17mm in diameter (~0,12 SD, n = 30). Maximum GSI values occurred about one month earlier in males than in females. During the spawning period, the body and fin bases of both sexes developed an overall reddish hue, with males also being characterised by having small nuptial tubercles on the head.

The diet of *B. erubescens* was dominated by benthic invertebrates such as black fly (especially *Simulium nigritarse*) and ephemeropteran larvae (Figure 4). Individuals were also frequently seen eating drift material and taking terrestrial insects from the water surface. Algal material was common in their gut contents, but microscopic examination of algal cells from the fore- and hind-guts revealed no signs of digestion.

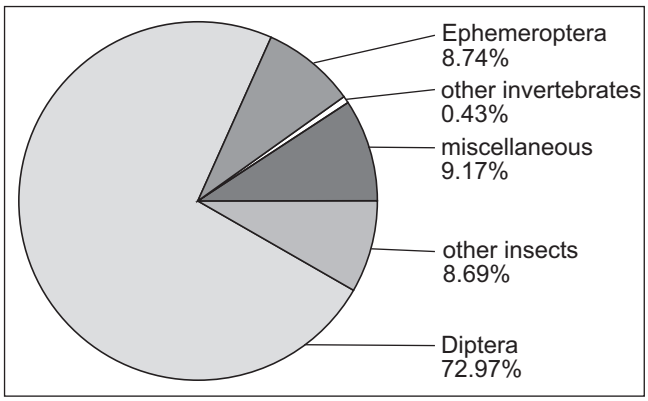

Figure 4: Diet of *Barbus erubescens*. Figures are expressed as percentage IRI. The category 'miscellaneous' represents grit, algae and amorphous material (after Marriott 1998)

Threats

The major threats identified were habitat degradation due to clearing of natural riparian vegetation, the use of pesticides and fertilisers, water abstraction and the impacts of introduced invasive fish species.

In terms of riverine habitat degradation, the Middeldeur and Suurvlei catchments were characterised by substantial agricultural development, particularly for citrus, deciduous fruit and vegetable production. Marriott's interviews with farmers revealed that 570ha of cultivated land existed along about 30km of river in 1996, comprising 170ha of mixed deciduous orchards (apples, pears and peaches), 75ha of citrus, and 325ha of vegetables (onions, tomatoes and pumpkins). A further 200ha of orchards were being developed on the farms Tuinskloof and Eikebos. Orchards and vegetables grown in winter-rainfall areas require substantial irrigation during summer, as well as fertiliser and pesticide application. These requirements make a large impact on river functioning, as in 1996 water abstraction for agriculture in the catchment was estimated at 7.43×10^6 m^3 y^{-1}, roughly 15% of the catchment's total annual yield, whilst abstraction exceeded runoff from November–March. Irrigation return-flows may contribute to the reduced water quality in summer, as most of the farms in the Twee River catchment are situated on low-drainage soils and rely on subsurface drainage pipes to take excess water back to the river.

The diversity of crops raised in the catchment requires an extensive schedule of pesticide application, with spraying being concentrated during the citrus (April–September) and deciduous fruiting (September–March) seasons. The impact of spraying is likely to be exacerbated by the close proximity of intensive agriculture to the rivers (often less than 10m). However, pesticide levels in the river were not measured.

The impact of introduced invasive species was the other major threat facing *B. erubescens.* The most significant impacts are likely to be predation by and competition from introduced fish species. Habitat damage caused by invading *Eucalyptus* tree species in the riparian zone of the Suurvlei River is also of concern. Too few stomachs of *L. capensis* (n = 4) and *O. mykiss* (n = 1) were examined to confirm whether or not these species were significant predators on *B. erubescens*. The analysis showed that *S. capensis* may be an important competitor for food, since both species have a similar diet of aquatic invertebrates $2 (0.05,3) = 11.76$, $p < 0.05$). Scales of *S. capensis* and *O. mykiss* were found in three *S. capensis* stomachs, and this species may also prey on juvenile *B. erubescens*.

Discussion

Snorkelling was useful in providing accurate information on the distribution of fishes in the Twee River System. It was of lesser value for estimating species density, as studies have shown that snorkelling can underestimate fish numbers

(e.g. Slaney and Martin 1987, Zubik and Fraley 1988). In addition, Marriott used daytime snorkelling, which may have underestimated densities of Cape galaxias and Twee River redfin. Preliminary work by two of us (IRB and NDI) involving snorkelling with torches at night, has yielded higher densities of these two species than daytime counts. Nevertheless, Marriott showed that *B. erubescens* was the most widely-distributed and common fish species in the Twee River catchment.

However, the survey indicated that from 1980 to 1997, the range of the Twee River redfin had declined by as much as 40%. The impact of introduced fishes compounds the effects of habitat degradation and pollution and forms a potentially lethal combination that many aquatic species cannot withstand (Bruton 1995). According to Skelton (2002), redfin minnows (*Pseudobarbus* spp.) are notoriously naïve in the presence of introduced predatory species and can rapidly be eliminated by them. The high numbers of *S. capensis* throughout the Twee River System are of particular concern, as this species is not only a predator but also competes with *B. erubescens* for food. The recent illegal introduction of bluegill sunfish is of special concern, as this species could have a major predatory effect on the redfins of the Olifants-Doring System (Swartz 2000). Once established, introduced fishes are notoriously difficult to eradicate, although international studies with the piscicide rotenone show that their eradication can be achieved.

The continued expansion of agricultural development in the catchment is of major concern, due to its impact on riparian habitat, water availability and water quality. Most agricultural developments in the study area are centred in the Suurvlei catchment where the absence of *B. erubescens* and low numbers of *S. capensis* indicate that pesticides may be a major problem. Bills (1999) highlighted the need for a study on the effect of copper-based agrochemicals in the Olifants-Doring System, as they are extensively used here.

The instream and riparian zones of most rivers in the Twee River catchment (except the middle Suurvlei River) are in good ecological condition and this perhaps explains why *B. erubescens* has managed to remain the dominant fish species here, despite the introduction of four alien species. It is essential that landowners, the Department of Agriculture, CapeNature and the Department of Water Affairs and Forestry work together to ensure the following objectives: that riparian zones in the Twee River catchment have adequate buffer areas that are kept clear of alien plants; that the river has an ecologically acceptable flow and quality; and that no further alien fish are introduced into the dams or rivers of this highly sensitive catchment.

Conclusions and recommendations

The Twee River catchment has several attributes that make it a viable area for a focused conservation management strategy. The catchment is part of the Greater Cederberg Biodiversity Corridor, a flagship Cape Action for People and the Environment (CAPE) initiative to conserve the CFR more effectively. The Water Research Commission is currently funding a project, under the leadership of the South African Institute for Aquatic Biodiversity, to develop a conservation plan for several priority rivers in the Cederberg region, including the Twee River System. Management recommendations include the following:

- promoting CAPE's dedicated project targetting the eradication of alien fishes from priority CFR rivers, including the Suurvlei River;
- consideration of land purchase as an option: the middle and lower reaches of the Heks River, currently within one farm, could be purchased and joined with the adjacent Cederberg Wilderness Area;
- further raising the awareness of riparian landowners regarding the conservation importance of the rivers in the catchment. Several ecotourism developments have been established in the catchment and considerable effort was made in this direction during Marriott's study. This initiative should be pursued;
- paying urgent attention to an updated fish survey of Marriott's study sites; the status of introduced fishes needs to be regularly monitored; night snorkelling should be included as a sampling method;
- establishing a conservancy (see Swartz 2000) in the Twee River catchment. Marriott's study contributed to the Twee River catchment's being identified as one of 41 priority areas for indigenous fish conservation in the CFR (Impson *et al.* 1999). Stakeholder cooperation could help in the development of a shared vision for the sustainable use of the catchment;
- effective implementation, in the catchment, of the Water Act by the Department of Water Affairs and Forestry, including the determination of the Environmental Reserve and the identification of additional Resource Protection Measures
- stocking of dams in the Twee River catchment with *B. erubescens* and *G. zebratus*, to create additional refuges for these species, as part of a documented recovery strategy. Landowners should not be allowed to stock other species into these dams;
- determining the effect of pesticide use on *B. erubescens*, *G zebratus* and aquatic macroinvertebrates in the Suurvlei and Middeldeur Rivers.

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