Application of the instream flow incremental methodology to Southern African rivers: Protecting endemic fish of the Olifants River

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Abstract

The instream flow incremental methodology (IFIM) has become a recognised technique in the United States for assessing minimum flow requirements of rivers, but is less well known or used elsewhere. The authors have examined the applicability of its software, PHABSIM, in Southern Africa, during a preliminary study of the endemic fish fauna of the Olifants River, western Cape Province. Despite little change in water quality and flow patterns in the upper mainstream over the last 50 years, most of these fish are now confined to remote headwater tributaries, presumably through the introduction of an alien predator/competitor - the smallmouth bass, *Micropterus dolomieui*. It was investigated if, with removal or reduction in numbers of the alien fish species, the endemic fish would still have sufficient physical habitat to re-establish themselves in the mainstream. Additionally, as the river is to be dammed in its upper reaches soon, an attempt was made to provide a preliminary minimum flow assessment. This could be used by local water-resource managers in initial development plans as well as providing information on the utility of IFIM in this region of Africa. The simulations have predicted that there is considerable physical habitat available for the endemic fish species in the mainstream and, for some species, more habitat than for the introduced alien. This supports the claim that predation and/or competition by smallmouth bass has been primarily responsible for the eradication of the endemic species from the mainstream. A preliminary minimum flow recommendation for maintaining re-introduced endemic species during the summer low-flows was 0,8 cumecs (m^3/s), very close to the 0,9 cumecs measured during summer in the unimpounded upper reaches of the system, which are subject to heavy water extractions for irrigation.

Introduction

Much of the Southern African subcontinent lies in the rain shadow of the mountains of the south-eastern coast and so is primarily arid and semi-arid. Lentic ecosystems are scarce, rivers are usually short and often seasonal or variable in flow regime (O'Keeffe, 1986), and water is a scarce and critical commodity. The coastal rivers contain over 50% of the mean annual runoff of South Africa (Dept. of Water Affairs, 1986; Davies and Day, 1986), yet the needs for water for inland development continue. Demands for freshwater in the region will increase dramatically over the next two decades, as its population is expected to double by the year 2025 (Davies and Day, 1986).

As in most nations, water resources in South Africa have been valued for their use to humans, either as potable, irrigation, or industrial (including hydroelectric power, mining, and forestry usage) water. In order to increase the availability of this scarce resource, the great majority of the country's rivers has been impounded. The resulting alteration of the physico-chemical characteristics of the rivers has the potential to alter both the composition of downstream biotic communities and the functional stability of the ecosystems themselves (Petts, 1984). Davies (1979) estimated that 8 500 km of South African rivers have been impounded and may feel these impacts. Ward *et al.* (1984) summarised specific factors critical to southern hemisphere rivers and floodplains impacted by river regulation. These include thermal modifications of receiving waters, which often result in species elimination; and changes in flow patterns, which can result in degradation and aggradation of the channel, and decreased water levels which, in turn, can influence the success of many floodplain-spawning fish species. Ward *et al.* (1984) emphasised that changes in the kind and amount of organic loading, combined with reduced suspended sediment, usually result in alterations of the trophic dynamics of the tailwater communities. Thermal and chemical alterations influencing dramatic changes in downstream fauna have been reported recently for the impounded sections of two South African Rivers, the Buffalo and Palmiet (Byren and Davies, 1989; O'Keeffe *et al.*, 1990; Palmer and O'Keeffe, 1990a,b). These changes in pH, alkalinity, and temperature have probably resulted in a reduction of habitat diversity and food supply for the tailwater biota.

Only recently has the conservation status of South African river systems (i.e. the rating on their ability to maintain biological integrity) been classified as a major water resource issue. Although not listed as a priority research project for river ecosystems at initial meetings to determine the conservation status and research needs for South African rivers, development of methods to determine minimum quantities of water required to maintain conservation status was a suggested project (O'Keeffe, 1986). The concept of maintenance of discharges to meet instream flow requirements has since been given the status of a national priority research topic (Ferrar *et al.*, 1988).

Although in its infancy as a management concept in South Africa, a variety of instream flow techniques (for water reservations) has been applied to riverine resource problems elsewhere, primarily in the United States (Wesche and Rechard, 1980). Currently, the most commonly accepted method for minimum flow analysis is the instream flow incremental methodology (IFIM) (Bovee, 1982). Not without criticism (Mathur *et al.*, 1985; Shirvell, 1986), it must be remembered that IFIM is one of many tools available to help make effective decisions regarding water resource allocations under regulated flow conditions. Ultimately, instream flow analysis must also be combined with analyses of water quality, historical flow records, and socio-economic impacts before a final decision can be made (Gore and Nestler, 1988). The physical habitat simulation (PHABSIM), the software from which IFIM predictions are made, has been found to be a defensible technique for adjudicating flow reservations, especially in the western United States where the greatest number of applications has occurred (Gore, 1989; Stalnaker, 1982; Sweetman, 1980). It was decided,

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therefore, to examine the application of IFIM to a variety of water-resource related problems specific to Southern Africa.

IFIM is a technique which combines measurements of physical habitat conditions of biota (most often fish species) and field measurements of hydraulic and hydrological conditions of the river of management concern, to make predictions of habitat availability over a range of discharges. The PHABSIM predictions do not indicate a relationship between ecosystem function or productivity with the changes in available habitat, but merely state how much habitat (weighted by preference for velocity, depth, and substrate) is available to targeted species or communities at different discharges. In fact, IFIM is based on the assumption that lotic organisms are limited in their distribution (longitudinally and laterally) by hydraulic conditions. Although, intuitively, this concept may seem to be true, only recently have studies been made available which appear to demonstrate this phenomenon (Scarnecchia, 1988; Statzner *et al.,* 1988). Indeed, Gore and Nestler (1988) recommend that the best species for evaluation are those which have demonstrably narrow ranges of depth or velocity preference, as indicated by habitat suitability data. When determining habitat availability as an aid to minimum flow decisions, the range of flows of concern (and simulation) are from close to zero flow to conditions of mean annual flow. Minimum flow assessments for rivers which annually stop flowing during a natural dry season are aimed at maintaining habitat for biota which are adapted to this intermittency and have evolved life cycles which are completed during the periods of flow or have life stages (diapause stages, eggs, etc.) which survive the no-flow periods.

The hydraulic information is evaluated using field measurements of cross-sectional profiles of the stream at typical stream reaches. Calibration data sets of velocities and channel index (a combined rating of substrate and cover conditions) at discrete intervals (called cells) along the transect, with stage/discharge relationships for each set, provide the information to predict discharge and water surface elevation (stage) at each discharge to be simulated. In turn, cell-by-cell velocity, depth, and channel index values are also derived (via Manning's or Chezy's equations).

Bovee (1986) and Gore and Judy (1981) have described exact techniques for producing habitat suitability curves (regressions which relate velocities, depths and substrate and cover to habitat use by a targeted life stage) for fish and benthic macroinvertebrates, respectively. Briefly, the habitat simulation programmes combine habitat suitability information for the biota and simulated changes in cell-by-cell flow conditions to predict the weighted usable area (WUA) of habitat.

The final product of the PHABSIM activity is a plot of WUA against the range of discharges of concern. It provides a guideline to potential gains and losses in habitat under the flows examined. Thus, a certain amount of *a priori* problem and goal identification must be made before field work can commence. For example, if monthly flow allotments to protect biota are of primary concern, it will be necessary to obtain habitat criteria for all life stages of the species of concern, as some life stages (say, spawning or egg incubation) may require critical flows, but exist for only a short period (less than 6 weeks) during the water year. However, if flow concerns are limited, say, to recreational boating or adult fish survival, a less rigorous field programme need be instituted.

The authors chose to assess flows on the Olifants River, southwestern Cape Province, with the goals of providing a training experience for regional aquatic biologists and determining habitat availability for certain endemic fish species as well as for the introduced predator, smallmouth bass (*Micropterus dolomieui*). Gaigher *et al.* (1980) indicated that predation has reduced or eliminated almost all endemic fish species from the mainstream, and the remaining viable populations are now restricted to a few of its perennial tributaries. These fish species are of special conservation value and management concern, as all 8 endemic species that occur in this river are listed in the *South African Red Data Book for Fishes* (Skelton, 1987). The authors were interested in answers to 2 primary questions. If (by flow manipulation or some elimination program) exotic predatory fish could be removed or reduced in numbers in the Olifants River, would there still be sufficient suitable habitat for endemic fish populations to re-establish themselves in the mainstream? This is a rather non-traditional application of IFIM, but appropriate to the mechanisms of the technique. Secondly, assuming that construction of the Keerom and/or Rosendaal Dams on the upper Olifants River is eventually approved (Dept. of Water Affairs, 1986), would IFIM analysis of the habitat requirements of the endemic fish provide information that could aid decisions on water releases from these dams for environmental conservation goals?

A listing of the indigenous fish of the Olifants River and their conservation status is given in Table 1. It was decided to concentrate on 7 fish species, 6 of which are endemic to the Olifants River system. Very little is known of the biology or life histories of these organisms. Van Rensburg (1966) undertook a study on aspects of the biology of *Barbus capensis* and *B. serra.* He recorded that these species were omnivores and their main spawning season was from October through December. At that time, few individuals of the endemic species were found in the mainstream of the Olifants River and distributions were limited to tributaries where no introduced largemouth bass *(Micropterus salmoides)* or smallmouth bass (*M. dolomieui)* occurred.

TABLE 1
INDIGENOUS FISH SPECIES OF THE OLIFANTS RIVER SYSTEM AND THEIR CONSERVATION STATUS (AFTER SKELTON, 1987)

Species	Conservation status
Family Bagridae	
Austroglanis barnardi (Skelton)*+ (Barnard's rock-catlet)	Endangered
A. gilli (Barnard)*+ (Clanwilliam rock-catlet)	Rare
Family Cyprinidae	
Barbus anoplus (Weber) (Chubbyhead barb)	Widespread
B. calidus (Barnard)*+ (Clanwilliam redfin)	Rare
B. capensis (Smith)*+ (Clanwilliam yellowfish)	Rare
B. erubescens (Skelton)* (Twee River redfin)	Vulnerable
B. serra (Peters)*+ (Sawfin)	Vulnerable
Labeo seeberi (Gilchrist and Thompson)* (Clanwilliam sandfish)	Rare
Pseudobarbus phlegethon (Barnard)*+ (Fiery redfin)	Endangered
Family Galaxiidae	
Galaxias zebratus (Castelnau)+ (Cape galaxias)	Widespread

*endemic to the Olifants
+included in this study

Materials and methods

Study site

The Olifants River catchment is the second largest in South Africa, covering just over 46 000 km^2 (Morant; 1984). The river rises in the Cedarberg mountain range, 100 km north of Cape Town, and runs north for 260 km, mostly through mountainous terrain, to its estuary on the Atlantic Ocean seaboard (31° 42′S, 18° 12′ E). The main river and most of its minor tributaries drain sandstones and quartzites of the Table Mountain Group, and so carry clear, slightly-brown stained water with negligible silt loads except during spates. The Doring River, which is the main tributary of the system, enters downstream of the study site and drains the more arid inland areas of soft tillites and shales and thus has heavier silt loads. Mean annual precipitation over the catchment from 1924 to 1979 ranged between 111 mm and 655 mm with more than two-thirds of it receiving less than 300 mm (Pitman *et al.,* 1981). The simulated mean annual runoff for the entire catchment is 102 x 10^7 m^3. There is a marked seasonal pattern of high flows in the austral winter (mean, in the lower Olifants River, between 1934 and 1960: 27 to 39 cumecs and low summer flows (mean: 0,3 to 1,4 cumecs) (Morant, 1984). The catchment is almost entirely rural, with a vegetation consisting largely of indigenous, sclerophyllous bush (collectively called fynbos) on the mountain slopes, and irrigated agricultural land in the valley of the mainstream.

The study site for hydraulic and hydrological measurements was located on the main river, about 110 km from its source, and 23 km north of the town of Citrusdal, on the farm Arbeidsgenot. Characteristic riparian elements of fynbos lined the river, providing virtually no overhead cover, and beyond occurred mixed stands of exotic tree species backed by orange orchards. During summer, stream width ranged between 10 and 21 m with a maximum depth of 0,4 m in riffles and 2 m in pools. Overall gradient of the river was 0,1% to 0,5%, and streambed morphology ranged from boulders and cobbles in riffles to sand in pools. Instream vegetation was rare and consisted mainly of islands or bankside stands of palmiet (*Prionium serratum,* Juncaceae). Physicochemical data for the river system is limited to an unpublished report by Coetzer (1982). The waters of the main stream and its tributaries are generally of high quality, with very low levels of dissolved solids (conductivity ranging from 44,7 to 116 μS/cm; 32,7 to 38,0 μS/cm in Noordhoek River, a typical tributary), pH values ranging between 6,2 and 7,7 and water temperatures between 9,5° and 22,7°C (Coetzer, 1982).

Measurements of fish habitat requirements were taken at Noordhoek River (North Bend River) and Thee River (Tea River), two adjacent, upstream tributaries of the Olifants River located, respectively, 15 and 25 km south of Citrusdal. These tributaries continue to support good populations of 6 of the 8 fish species that are endemic to the Olifants River system, and are characteristic of mountain streams of the area, running largely through undisturbed mesic fynbos. Noordhoek River is 7 to 10 m wide, less than 60 cm deep except when in spate, and has a substrate of mostly boulders and cobbles and an open canopy. Thee River is 4 to 6 m wide, similar in depth but with more pools than Noordhoek River in its lower reaches, and has a similar streambed under a mostly closed canopy in the study area. Gradients of both streams range from 2% to 5% (both are ungauged).

Field methods

Cross-sectional profiles of 5 transects were surveyed according to the methods described by Bovee and Milhous (1978). A total length of 200 m of stream reach was evaluated for habitat availability. This representative section included a riffle and a run separated by a deep, sand-bottomed pool. Two sets of velocity calibration data were recorded: in March 1989, when flows were low at 0,9 cumecs, and in May 1989, when flows were moderately high at 7,5 cumecs.

Habitat suitability criteria were developed, from information on habitats collected in the two tributaries, according to methods recommended by Bovee (1986). Both juveniles and adults of target fish species were observed by snorkeling in riffles and pools of Noordhoek River and Thee River during sampling trips in early March and late May 1989. Since underwater observation was difficult in some instances, shallow riffles were also electro-fished for collection of riffle dwellers. This was particularly beneficial in collecting accurate information on the riffle dwelling *Austroglanis barnardi* and *A. gilli.*

Interviews with fisheries biologists of the Cape Chief Directorate of Nature and Environmental Conservation complemented the field data which allowed us to construct spawning and adult habitat suitability curves for *Barbus capensis.* Data on *Micropterus dolomieui* were not collected locally but taken from category one SI curves (generic curves from literature surveys) of Edwards *et al.* (1983).

Substrate and cover categories were recorded according to a modified listing suggested by Bovee (1982) (Table 2).

Results and discussion

The habitat suitability curves used in this evaluation are listed in **Appendix 1.** With the exception of the riffle-dwelling *Austroglanis* species, the endemic fish showed preferences for slow-moving, shallow to moderately deep pools. There appeared to be a preference for substrates of small, medium, and large cobble (**Appendix 2**). Although all species have been observed to take

TABLE 2
SUBSTRATE/COVER CODE USED IN THE OLIFANTS RIVER STUDY. THE CODE WAS ENTERED AS THREE DIGITS IN THE FORM "xx.x" AS FOLLOWS:

Tens digit (Cover) (Visually estimated)	
1	<25% Overhead cover
2	25% - 50% Overhead cover
3	51% - 75% Overhead cover
4	>75% Overhead cover
Ones digit (Refuge value)	
1	No cover
2	Object cover (hydraulic refuge) only
3	Overhead cover only
4	Overhead and object cover
Tenths digit (Substrate composition) (Visually estimated)	
1	Fines (sand and smaller)
2	Small gravel (4 - 25 mm diameter)
3	Medium gravel (25 - 50 mm)
4	Large gravel (50 - 75 mm)
5	Small cobble (75 - 150 mm)
6	Medium cobble (150 - 225 mm)
7	Large cobble (225 - 300 mm)
8	Small boulder (300 - 600 mm)
9	Large boulder (>600 mm)

some sort of cover during the colder high-flowing winter months, there was no apparent major preference for hydraulic cover during the lower-flow periods when habitat criteria were measured and only *Galaxias zebratus* and some of the juveniles of *Barbus* and *Pseudobarbus* species sought vegetative cover in shallow, non-moving water beside banks (edge effect). Although adults of *B. capensis* exhibited preference for relatively fast-moving water and a broad range of depth preferences, *Austroglanis gilli* and *A. barnardi* both exhibited preferences for shallow, faster moving water, with substrates of large cobbles and boulders as refugia. This was particularly evident for individuals of *A. barnardi*. In effect, then, there were three habitat guilds identified: riffle-dwellers *(A. gilli* and *A. barnardi),* edge-dwellers *(G. zebratus* and juveniles of *Pseudobarbus phlegethon* and *B. calidus),* and pool-dwellers (juvenile *B. capensis* and *B. serra,* and adults of *B. calidus* and *P. phlegethon).* Thus, habitat suitability curves could be employed for representative species/life stages from each of these guilds to predict the general availability of those habitat types (i.e. not a species specific analysis).

The habitat simulations predicted that there was sufficient physical habitat in the mainstream to support all species of endemic fish as well as the *M. dolomieui* populations (Figs. 1 to 4). Indeed, there should be more habitat available for juveniles of *B. capensis* and *B. serra* (Fig. 1b and 3a) than for *M. dolomieui* (Fig.

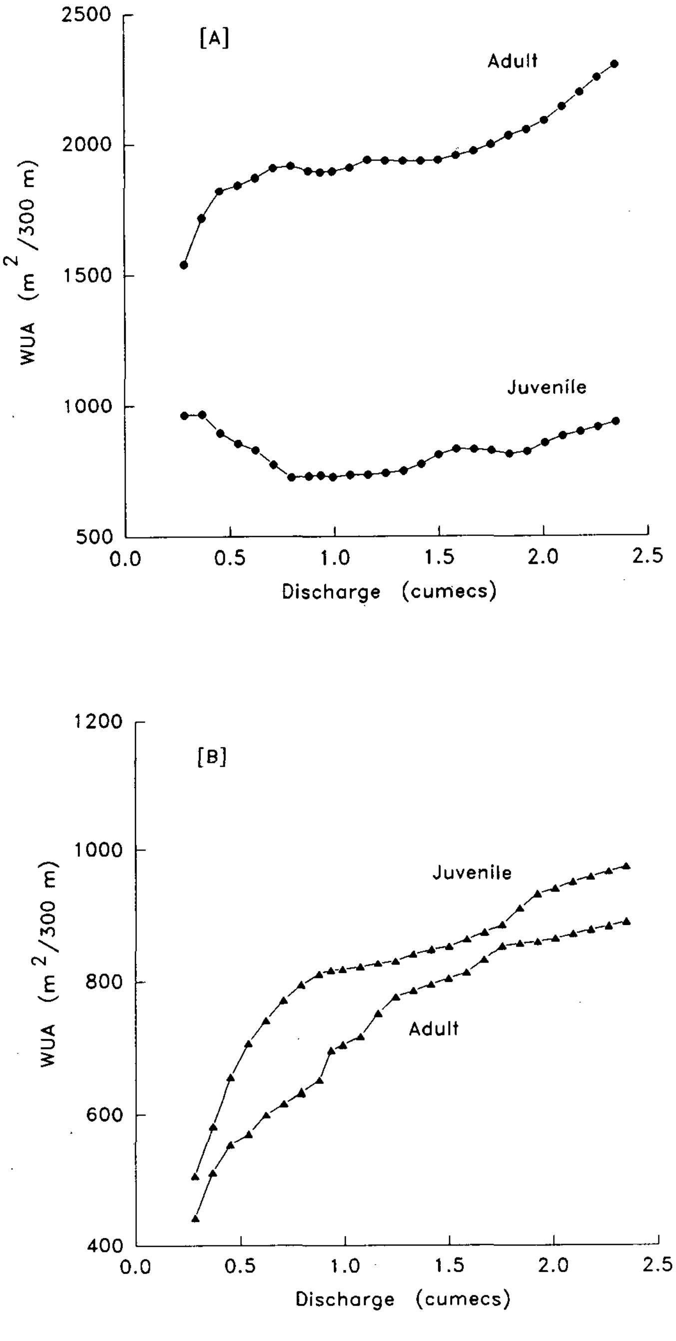

Figure 1
Habitat availability (surface area of stream for a given length of stream) for Barbus calidus *(A) and* Barbus capensis *(B) in the Olifants River*

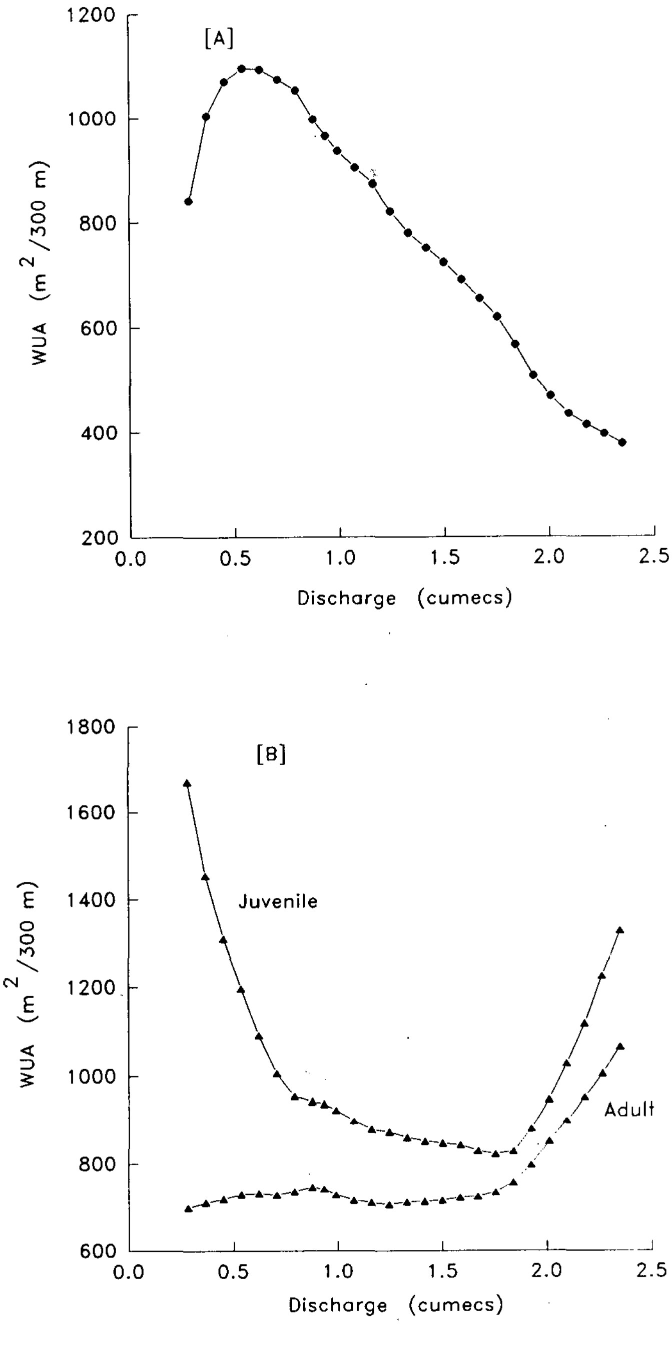

Figure 2
Habitat availability for Barbus serra *juveniles (A) and* Pseudobarbus phlegethon *(B) in the Olifants River*

4a). This supports the contention of Van Rensburg (1966) and Gaigher *et al.* (1980) that predation or competition, especially by *M. dolomieui*, must be one of the primary causes for losses of endemic fish from the mainstream of the Olifants River system. Although water quality and discharge pattern have changed somewhat over the past 50 years (due to increased irrigation demand and abstraction), the major ecological changes that have occurred during this time period seem to have been the introduction and subsequent spread of alien predatory fish species and invasive alien vegetation such as Port Jackson willow *(Acacia saligna)* and sesbania *(Sesbania punicea)*. A number of strategies could be used to eliminate or reduce the *Micropterus* populations and the results produced by PHABSIM suggest that flow manipulations could be one of these. That is, the WUA predictions for spawning of *M. dolomieui* (Fig. 4b) suggest that low flows (about 0,3 cumecs) during spawning, probably in October, would reduce the overall recruitment to the population. Temporary losses of habitat for adults and juveniles of *B. capensis* would also occur during that time period and stream managers must be able to weigh these losses and their affect on *B. capensis* populations against the potential for reducing the population of the introduced alien, *M. dolomieui*. Although not part of our minimum flow evaluations, WUA predictions for flushing flows (> 9 cumecs) also resulted in reduced spawning habitat for *M. dolomieui*. The low flows would

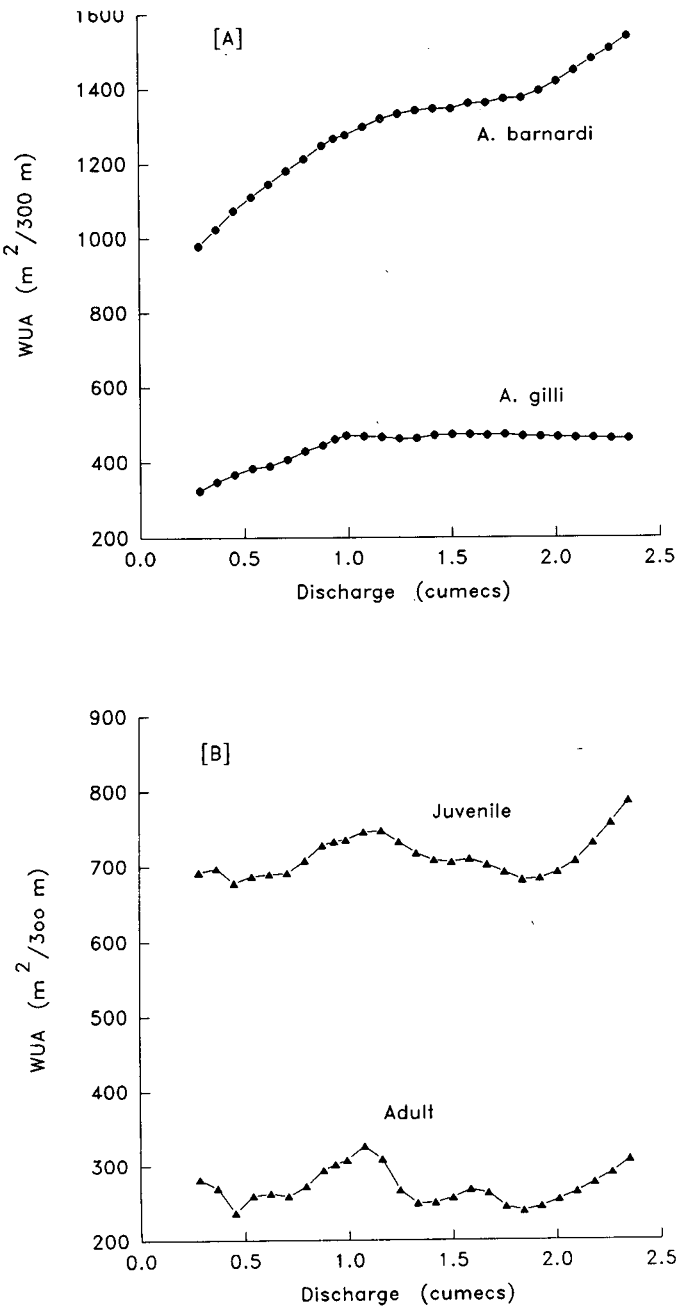

Figure 3
Habitat availability for Austroglanis *species adults (A) and* Galaxias zebratus *(B) in the Olifants River*

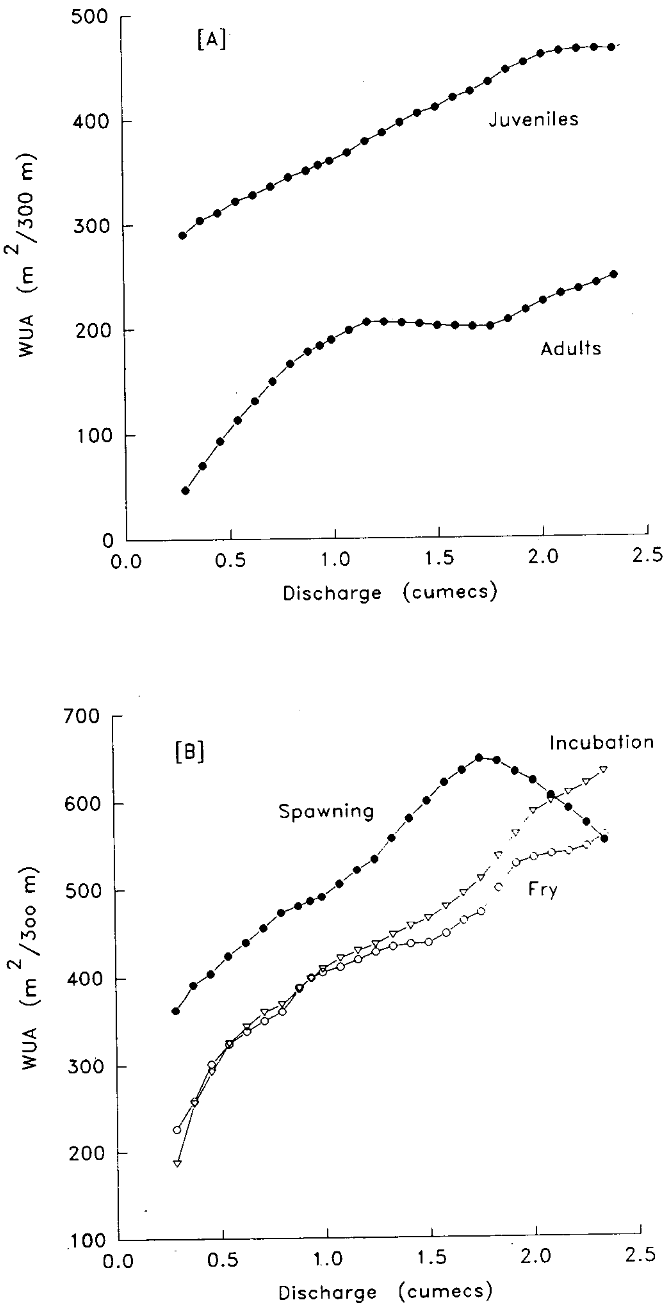

Figure 4
Habitat availability for various life stages of Micropterus dolomieui *in the Olifants River*

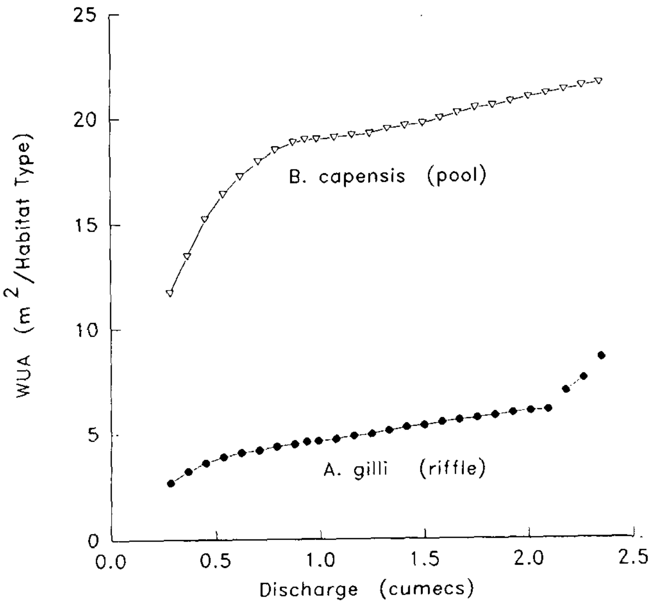

Figure 5
Comparison of habitat availability for pool-dwelling versus riffle-dwelling species in the Olifants River. WUA estimates are based on average values for all riffles or pools as simulated by the HABTAE program of PHABSIM v. 2.

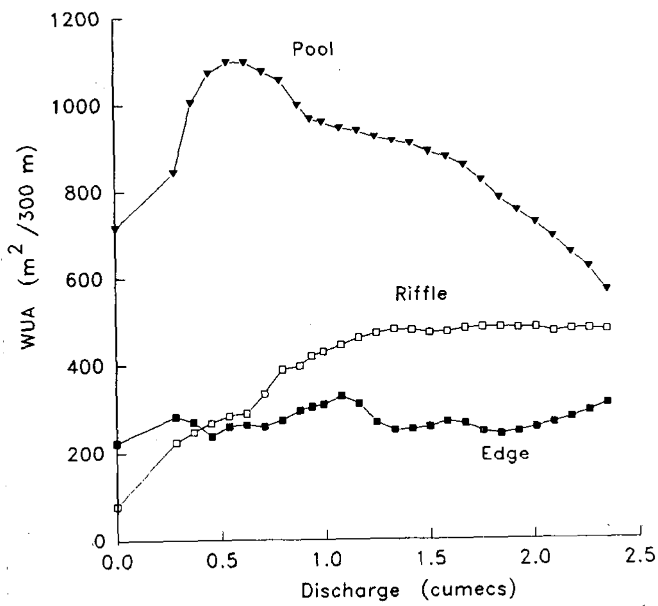

Figure 6
Comparisons of habitat availability for habitat types over the entire surveyed reach. WUA is a weighted composite of values for all species of that habitat type.

also reduce the available maintenance habitat for adults (Fig. 4a) which may lead to reduced physiological success. Although it would be possible to manipulate flows every month of the year to affect all life stages of the alien predator (<0,4 cumecs for juveniles [Fig. 4a], <0,5 cumecs for fry [Fig. 4b]), this strategy is probably unworkable, considering other water resource demands. Since spawning is the stage of shortest duration in the life history of *M. dolomieui*, this might be the easiest and most effective stage to attempt to control. Again, this manipulation should be in concert with other population-reduction techniques such as increased fishing pressure (bounties on reproductive adults, etc.). Our PHABSIM analysis indicates that a sufficient amount of physical habitat remains in the Olifants River to support the endemic fish populations presently restricted to the tributaries, and that with reduction of the alien predator/competitor species, they should be able to repopulate these habitats. Of course, this statement assumes that water quality in the mainstream will remain adequate to sustain the fish populations, as it was at the time of this study.

Leonard and Orth (1988) have suggested that minimum flow assessments in streams with a complex assemblage of target fish species should be aimed at functional guilds rather than individual target organisms. Thus, certain reproductive guilds, feeding guilds, or habitat guilds are the appropriate level of analysis. Further, Leonard and Orth suggest that individual species should be analysed to check the validity of the guild assessment and to ensure that all species needs have been met. When representatives of each of the habitat guilds were examined, some striking differences in predicted habitat availability at different discharges were noticed. Edge-dwellers, like *Galaxias zebratus*, neither gained nor lost habitat over the range of discharges examined (Fig. 3b). *G. zebratus* occurs in a wide range of habitat types and its success in many western and southern Cape rivers can be ascribed to its ability to adapt to a wide variety of environmental conditions (Gaigher *et al.*, 1980). Had this species, or other edge-dwellers, been examined as the sole kind of target species, minimum flow assessment could not have been made. Simulation of habitat availability for pool-dwellers, like *Pseudobarbus phlegethon*, also presented difficulties in analysis. In most cases, predicted gains or losses in habitat were associated with hydraulic changes that would occur when overbank conditions prevailed (approximately 1,8 cumecs) (Fig. 2b). This artifact in the model does, indeed, simulate prevailing hydraulic conditions but does not take into account the fact that the new substrate available would not be biologically "prepared" (available periphyton and bacterial production as a food base for consumers) for resident fauna. Thus, it was predicted that, with flooding, pool formation and resulting slow water periods outside the main channel would result in additional habitat availability. At the other extreme, as the depths of pools within the channel decreased with decreasing flows, a sharp decline in habitat availability was predicted for lower flows at the point where depths became too shallow for the different species. Traditionally, a minimum flow recommendation is based on examining the minimum discharge necessary to maintain habitat for each of the test species and selecting the highest of these values. This value, the highest minimum discharge, should provide protection for all other species of concern (Bovee *et al.*, 1978; Bovee, 1982). That is, as discharge is reduced, the lower limits of velocity and/or depth tolerances for *Austroglanis* species were exceeded before discharges were reached which exceeded the lower limit of depth tolerances of pool- or edge-dwelling species. Thus, reduction of flows to less than the highest minimum discharge would result in significant habitat losses for *Austroglanis* with no apparent loss of habitat for the other species (Fig. 5).

When comparing the habitat availability of all three habitat guilds (Fig. 6), it can be seen that the riffle-dwellers in the Olifants

River are likely to be the best indicators of low flow optima and minima. Even at no flow, it is predicted that a substantial amount of habitat remains for the edge-dwellers and the pool-dwellers, while only 25% of maximum available habitat remains for the riffle-dwellers. This result must be further evaluated since *Austroglanis*, despite the predictions of the model, has not been reported from non-perennial tributaries which consist of series of isolated pools during the dry months (Hamman; personal observation). Indeed, *Austroglanis* appears to be entirely dependent upon riffles for feeding and/or breeding (Hamman; personal observation). These are not surprising observations since it is well known that standing water is capable of dramatic change in physico-chemical condition. Thus, *inter alia*, decreases in dissolved oxygen and/or increases in temperature could preclude occupancy of the predicted hydraulic habitats at no flow conditions. Pool- and edge-dwelling species would be less likely to feel the impact of these changes since to some extent they will have occurred in such conditions at higher flows. Indeed, the pool- and edge-dwelling endemic species can still be found in the isolated pools which exist under no flow conditions during the dry months (Hamman; personal observation). When all of these changes have been taken into consideration, it would appear that minimum flows for maintaining the habitat of endemic fish of the Olifants River should be based on riffle dwellers like the *Austroglanis* species and should probably be in the vicinity of 0,8 cumecs of flow. Lower flows would likely result in significant loss of habitat for several of these endemic species, while flows of 0,8 cumecs will maintain habitat for all species of concern at a minimum of 80% of maximum levels of available habitat according to the PHABSIM predictions.

Through this initial examination, we conclude that IFIM does have useful application to the rivers of the western Cape Province, South Africa. Some understanding of the habitat requirements of the endemic fish of the Olifants River system has been gained, and a tentative identification has been made of a suitable minimum flow for the mainstream during the dry summer months. Because of limited time, no attempt could be made to recommend minimum flows for each month of the year, nor could those habitat requirements not related to flow be determined. These criteria must also be examined before an effective recommendation can be made (Gore, 1989).

Since this research was completed, the Department of Water Affairs (South Africa) has reiterated the proposals to increase regulation of the mainstream of the Olifants River, either through raising the wall of the Clanwilliam Dam, downstream of our study site, or through constructing the Keerom and/or Rosendaal Dams; in an upstream area of the river which could be considered the most important area for breeding and recruitment of the remaining endemic fish populations. In addition, due to expanding farming activities, the tributaries are themselves under renewed threat from water abstraction and crude alterations to bed morphology.

The endemic fish species of the Olifants River are a major conservation feature of the southwestern Cape, and much more data are required to conserve them and their habitat effectively. Further research (by King and Hamman) has been initiated in 1990 on a more integrated approach to minimum flow assessments for the river. It is envisaged that this will include research on the life history requirements of the endemic fish species, so that all life phases can be catered for in-flow recommendations. Verification of the habitat data on *M. dolomieui* residing in the Olifants River, and flow requirements of the benthic invertebrate communities, as the latter may be more specific than those for fish, will also be conducted. Since reservoir operations often have an effect on water quality conditions, habitat requirements other than those directly related to flow (especially temperature and dissolved oxygen) will be analysed. Recommendations can then be made with more precision for a year-round flow regime for the regulated river and, if necessary, for an acceptable level of abstraction from the tributaries. In the interim, concentrating limited research time on one of the months of lowest summer flows, has allowed the authors to provide water-resource managers with a working figure of the required minimum flows for that critical period, to include in their initial development plans.

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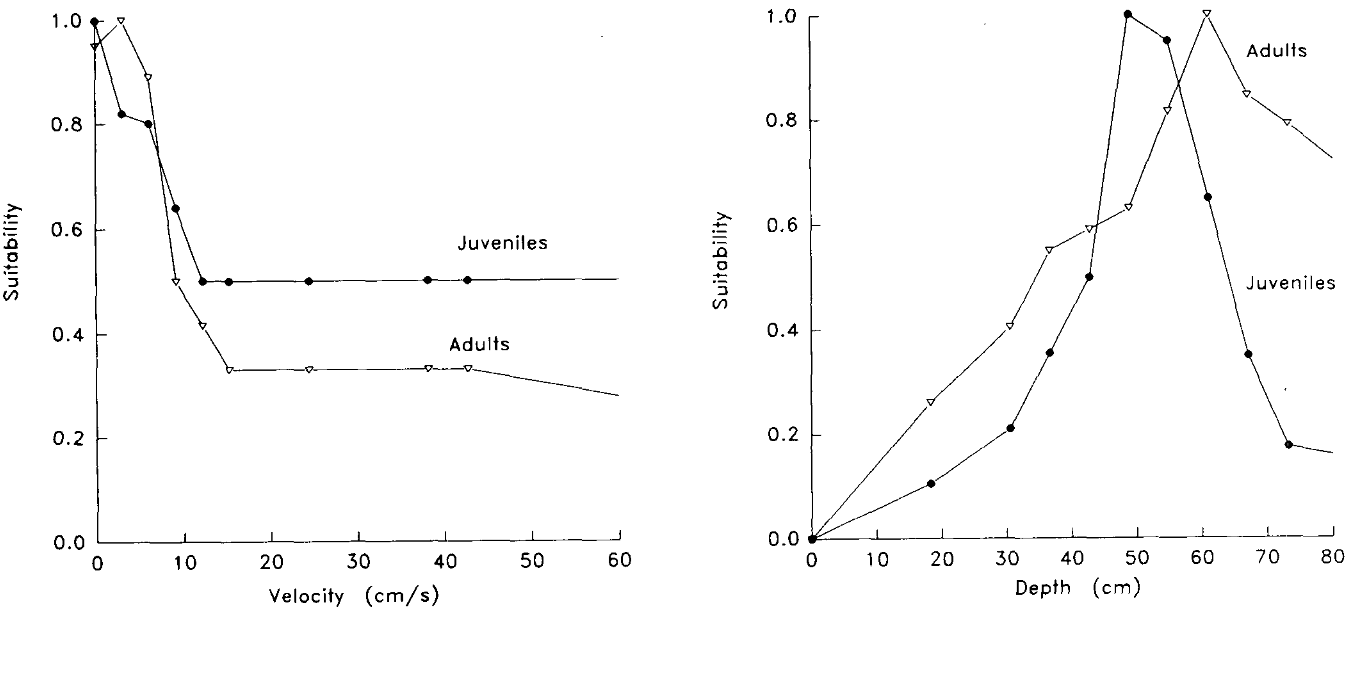
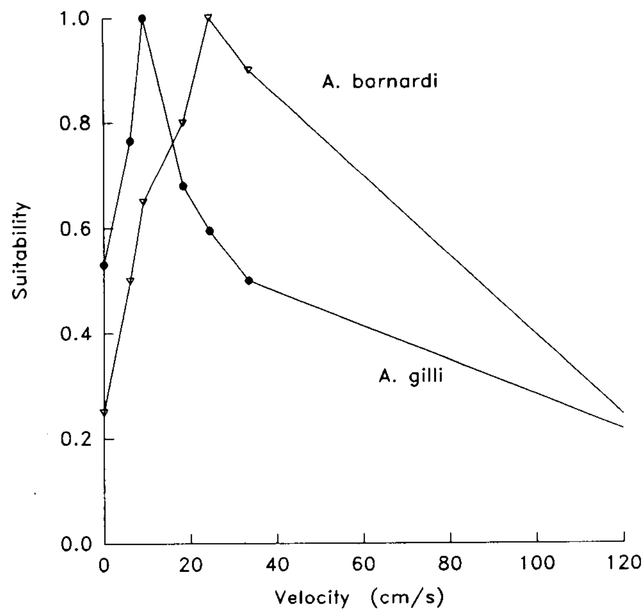
Appendix 1

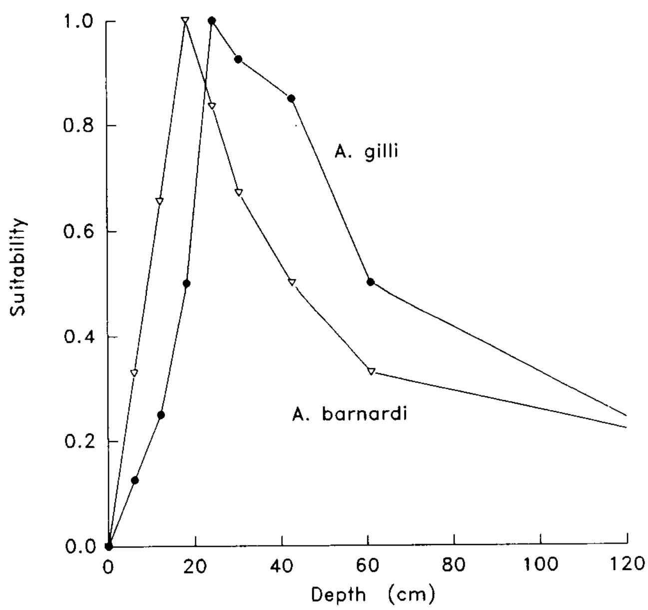
Habitat suitability criteria of depth and velocity for various life stages of the endemic fish species of the Olifants River. The suitability curves are extrapolated beyond field measured data points in order to accommodate PHABSIM requirements that a suitability value be assigned to a value of depth or velocity which could not be reasonably exceeded in a normal situation; in this case, a value of 3 000 cm of depth and 3 000 cm/s in velocity.

Barbus calidus

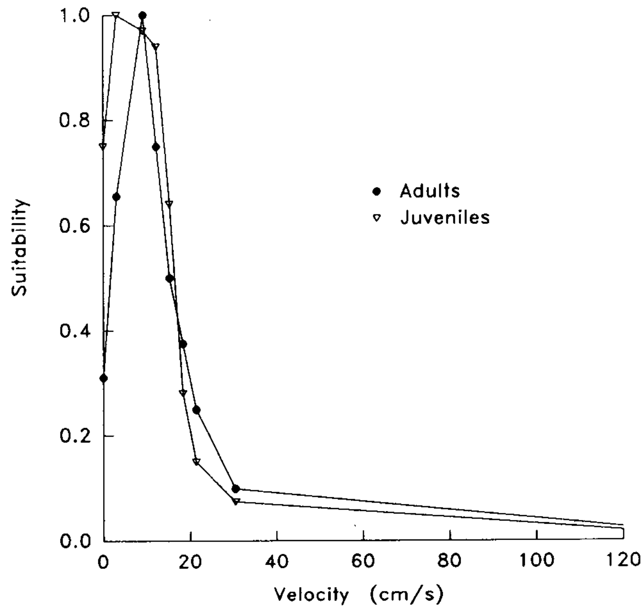


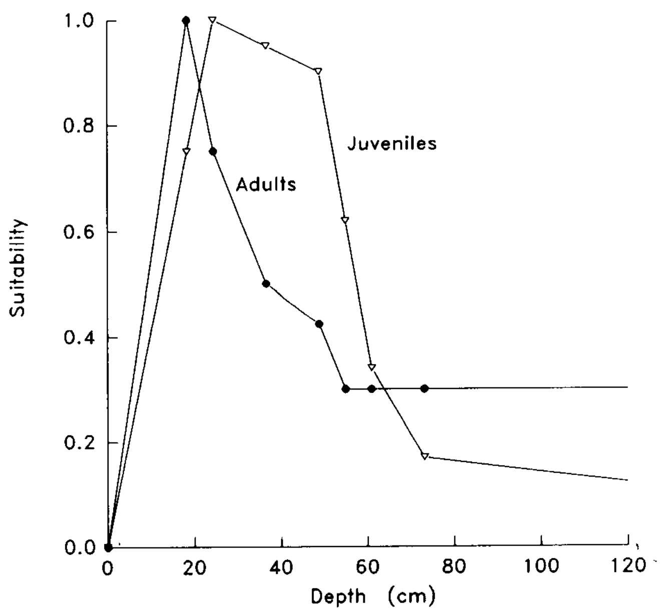
Austroglanis adults

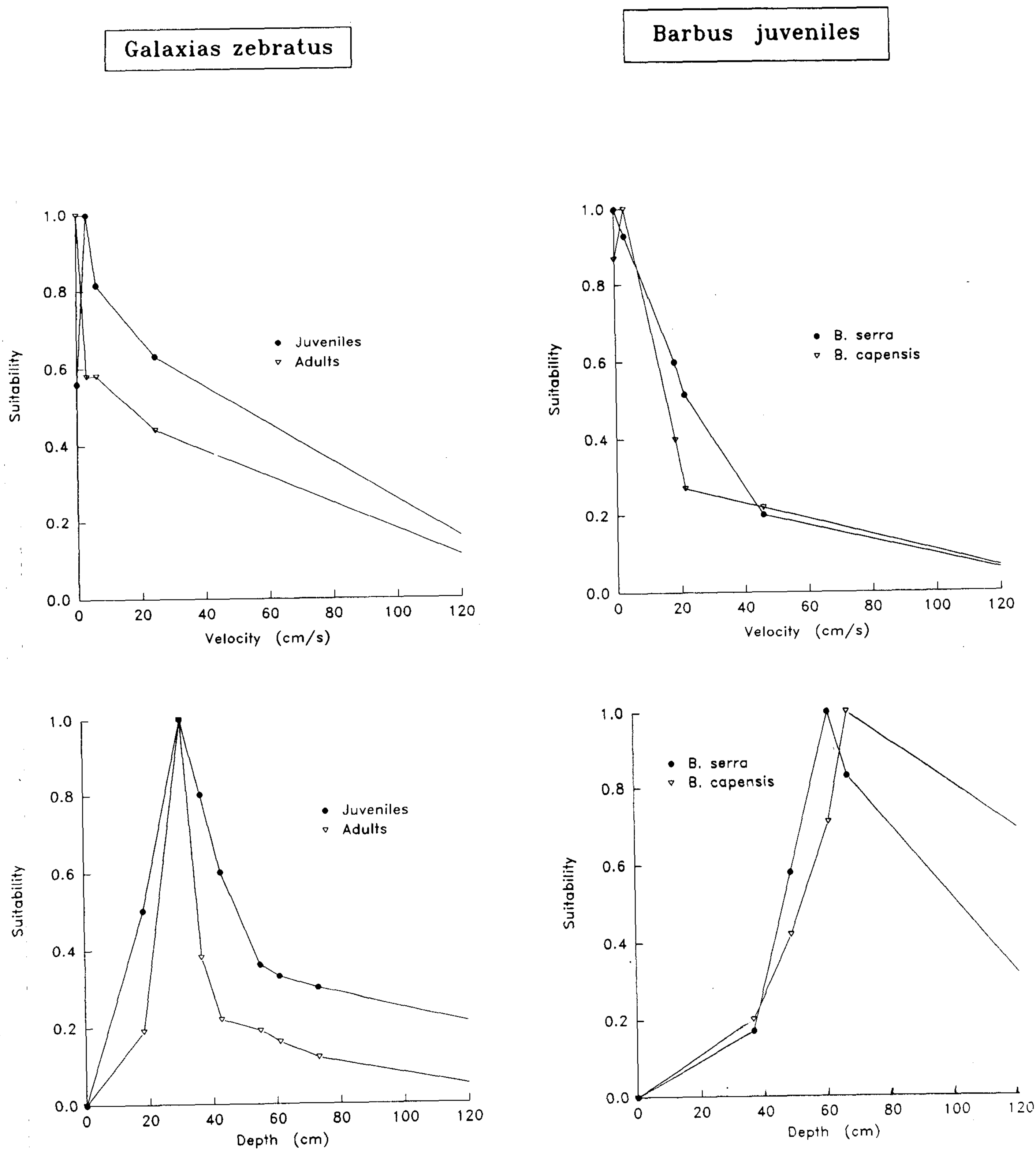




Pseudobarbus phlegethon





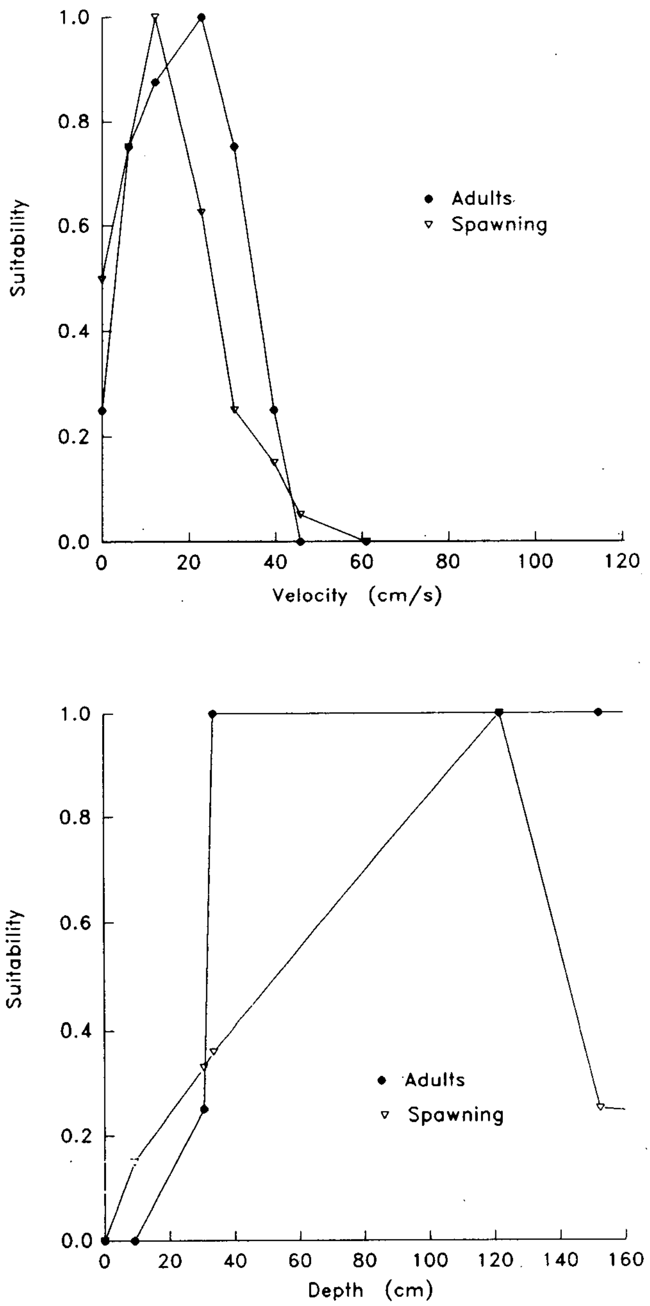


Galaxias zebratus
Barbus juveniles
Juveniles
Adults
Suitability
Velocity (cm/s)
Depth (cm)
B. serra
B. capensis
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
100
120

Appendix 2

Substrate/cover preferences of Olifants River fish. Code is as in Fig. 1 of text. Values are as entered into the simulation. Intermediate values are extrapolated by HABTAT.

Barbus capensis



SPECIES	SUBSTRATE/ COVER	SUITABILITY
Barbus calidus	0	0
(adults)	11,1	0,76
	14,6	1,0
	24,8	0,29
	44,8	0,22
(juveniles)	0	0
	11,1	1,0
	14,6	0,52
	44,6	0,21
Barbus capensis	0	0
(juveniles)	12,6	0,25
	14,8	0,30
	34,7	1,0
Barbus serra	0	0
(juveniles)	13,8	0,73
	34,6	1,0
	44,6	0,6
Pseudobarbus phlegethon	0	0
(adults)	11,1	1,0
	34,6	0,95
	44,8	0,95
(juveniles)	0	0
	11,1	1,0
	24,8	0,92
	44,4	0,81
	44,8	0,61
	44,9	0,52
Austroglanis gilli	0	0
(adults)	11,1	0
	12,2	0,04
	12,4	0,11
	12,6	0,31
	12,8	1,0
	22,1	0,33
	34,8	0,12
	44,8	0,06
Austroglanis barnardi	0	0
(adults)	11,1	0
	12,2	0,05
	12,4	0,20
	12,5	0,45
	12,7	1,0
	12,8	0,50
	34,8	0,50
	44,8	0,50

SPECIES	SUBSTRATE/ COVER	SUITABILITY
Galaxias zebratus	0	0
(adults)	14,8	0,48
	32,2	0,67
	34,6	1,0
	44,1	0,65
	44,9	0
(juveniles)	0	0
	11,1	0,3
	12,3	0,41
	14,6	0,6
	44,8	1,0