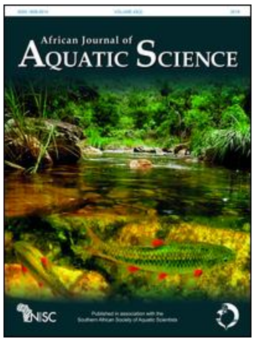

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Rapid biological assessment of the fishery potential of Xonxa Dam, near Queenstown, South Africa

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Rapid biological assessments have been proposed as the most cost-effective approach to identify suitable target species and to set initial catch and fishing effort levels for new fisheries. Xonxa Dam, a turbid irrigation dam situated in the White Kei catchment, rural Eastern Cape, is shown to provide fisheries potential for two alien species — smallmouth yellowfish *Labeobarbus aeneus* and sharptooth catfish *Clarias gariepinus* — that had been previously introduced into the catchment. Rapid appraisal of the biology, relative abundance, and population dynamics of the fish was effected during three sampling events in 2007. Using a combination of empirical yield and dynamic pool models, it was shown that two discrete fisheries can be developed. For *L. aeneus* a 60 mm stretched mesh gill net fishery could harvest 23 t y^{-1} and for *C. gariepinus* a longline fishery could yield 4 t y^{-1}. The combined fisheries could be valued at c. R135 000 (USD 18 000) per annum. Periodic monitoring would be necessary; firstly, to ensure that spawner biomass per recruit is not reduced below 40% of current levels and, secondly, to refine the potential harvest available from the resource once harvesting is initiated.

Keywords: *Clarias gariepinus*, *Labeobarbus aeneus*, rapid biological assessment, reservoir fisheries, spawner biomass per recruit, target reference points, yield per recruit

Introduction

In Africa, the harvesting of fish from small reservoirs has been identified as an important food resource for small rural communities, particularly those living close to waterbodies (Kapetsky and Petr 1984, Marshall and Maes 1994, van der Knaap 1994). Development of fisheries to utilize these resources has recently been identified by the African Union as a priority investment area for poverty alleviation and regional economic development (NEPAD 2005). Within a South African context, it is suspected that there will be increased interest in developing these fisheries to address major national policy objectives, which include food security, economic empowerment, optimal economic benefit from water, and poverty eradication (RSA 1998a, 1998b).

South Africa, however, presents a somewhat anomalous situation. The lack of a fishing history in communities, the lack of species with a high fisheries potential, inadequate inland fisheries policy and a lack of directed fisheries development have resulted in low utilisation levels of fish resources in South African reservoirs (Weyl et al. 2007).

However, there are also positive aspects. For example, the large number of reservoirs, particularly those constructed for irrigation, now support large populations of alien fishes that could be commercially or recreationally harvested. Inland fisheries in rural areas are being touted as a 'golden goose' and a possible solution to poverty alleviation. It is, however, prudent that, prior to the initiation of any form of fishery, viability analyses and resource assessment should be undertaken.

Weyl et al. (2007) suggest a rapid assessment based on a fishery productivity analysis, species composition, stakeholder consultation, market access and availability, and personal observations to recommend whether a fishery could be developed. This rapid assessment would also provide information on the suitability of the fishery's being a community-managed subsistence fishery, a commercial fishery, a recreational fishery, or simply for the fishery to remain at its open-access equilibrium. Each fishery type then requires exploitation rules, such as quotas, minimum size limits, closed seasons, gear limitations and access or effort limits.

To ensure that long-term resource and socio-economic sustainability is achieved, it is necessary to set initial exploitation rules. This is, unfortunately, only possible in the presence of a fishery. In a fished situation, if catches and catch-rates are monitored, then the population dynamics of the harvested resources can be modelled using the most appropriate stock-assessment methods. In new fisheries the choice of assessment method is constrained by the inherent data-limited nature of the fishery. In such situations, fisheries managers in developing countries have focused on the application of per-recruit models (Beverton and Holt 1957) as a cost-effective stock assessment technique (Thompson and Allison 1997, Booth and Weyl 2004, Kanyerere et al. 2005,

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Weyl et al. 2005a, 2005b). The application of per recruit models allows for the assessment of biological reference points (BRPs) to achieve management targets.

This paper presents a rapid biological assessment of the fish resources of Xonxa Dam that proposes initial exploitation regimes for harvesting two alien, although South African, fish species: smallmouth yellowfish *Labeobarbus aeneus* and sharptooth catfish *Clarias gariepinus*, that have invaded the White Kei catchment (Scott et al. 2006). It is hoped that this research can serve as a case study on the use of this methodology in providing rapid assessments of the biological potential of reservoirs for fisheries development.

Material and methods

Study site

Xonxa Dam (31°49′30.40″ S; 27°10′56.22″ E; 937 m asl), situated 27 km from Queenstown (Figure 1), at full capacity is a 1 450 ha impoundment on the White Kei River in the Eastern Cape Province of South Africa. Construction was completed in 1971 and, at full capacity, the reservoir has a mean depth of 10.87 m (DWAF 1997) and a maximum depth of 36.9 m (Schramm 1993). The western and northern arms of the dam are dominated by gently sloping, rocky or muddy banks, while the southern arm is dominated by steeper rocky banks. Mean annual water temperature is 16.5 °C (Table 1) and annual changes in water volume did not exceed 3% during the study period.

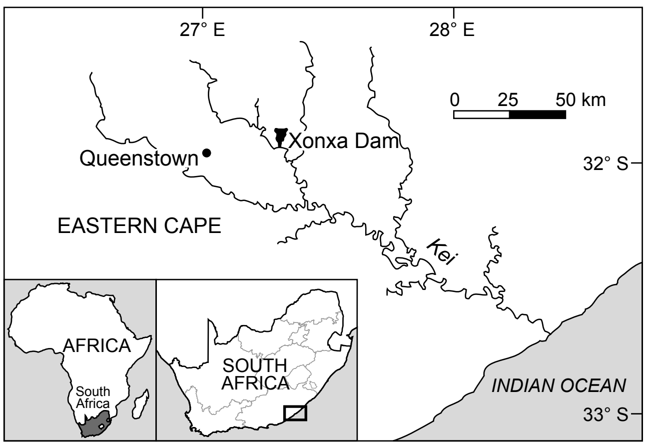

Figure 1: Map showing the location of Xonxa Dam on the Kei River system in the Eastern Cape

Previous research catches by Schramm (1993) were dominated by *Cyprinus carpio* and *L. aeneus* at 7.4% and 92.6%, respectively. Small quantities of banded tilapia *Tilapia sparmanii* and bluegill sunfish *Lepomis macrochirus* were also caught. Current fishing activity is low, with children and adults using handlines with small hooks baited with earthworms to target *L. aeneus* and *C. gariepinus*.

The reservoir is situated on communal land with an estimated c. 15 000 people living in the surrounding rural settlements (Rouhani 2002). Fishery development on the reservoir has previously been suggested (Duncan-Brown 1980, Schramm 1993, Rouhani 2002) but without a prior assessment to estimate initial sustainable harvest levels. Although attempts to develop a gillnet fishery have failed (Duncan-Brown 1980) there is renewed interest in fishery development by the local municipality to provide additional employment opportunities.

Sampling methods

Three sampling trips were conducted in March, May and August 2007 when gill nets, longlines, fyke nets and a seine net were used to sample fish. Sampling gear was set in all available habitat types to ensure representative sampling. Habitat types included muddy and sandy substrates over both steep and shallow banks. Experimental multifilament gill net fleets, comprising 9 m long × 3 m deep panels of netting with 44 mm, 60 mm, 75 mm, 100 mm and 144 mm stretched mesh size were set at the surface overnight. Longlines with circle hooks (Mustad sizes 5/0–11/0) spaced at 2–3 m intervals and baited with fish were set overnight. To supplement samples for age and growth, a 15 m seine net with 10 mm mesh size was used to sample shallow habitats and five fyke nets were deployed during the first sampling trip. The soak time of each gear was recorded.

Environmental data such as water temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO) and Secchi depth were recorded at each sampling site (Table 1). Dam level data were obtained from the Department of Water Affairs and Forestry. Physicochemical characteristics were found to be similar to those recorded by Schramm (1993).

Table 1: Physical and chemical parameters (means ± standard deviations) measured in the surface waters of Xonxa Dam at each sampling site during 2007

Parameter	Month			Average
	March	May	August	
Temperature (°C)	21.3 ± 1. 8	17.6 ± 0.5	12.3 ± 2.5	16.5 ± 4.0
Dissolved oxygen (mg l^{-1})	7.5 ± 0.3	8.3 ± 0.2	9.3 ± 0.3	8.5 ± 0.8
Oxygen saturation (%)	94 ± 7	95.0 ± 3.0	97.0 ± 6.0	96.0 ± 5.0
pH	8.3–8.5	8.4–8.6	6.9–7.6	6.9–8.6
Secchi depth (cm)	33.0 ± 5.0	38.0 ± 8.0	34.0 ± 5.0	35.7 ± 7.0
Electrical conductivity (μS cm^{-1})	258.0 ± 7.0	252.0 ± 19	260.0 ± 6.0	257.0 ± 13.0
Total dissolved solids (mg l^{-1})	131.9 ± 3.6	132.7 ± 1.7	130.3 ± 4.1	132.0 ± 3.0
Sample size	10	15	15	40

Potential yield estimation

In the absence of prior fisheries data, direct estimates of fish production could not be determined. First estimates of the total potential fish yield were obtained from the Schlesinger and Regier (1982) global, temperature-adapted morphoedaphic index (MEI) model as

$$\text{Yield}\,(\text{kg ha}^{-1}\,\text{y}^{-1}) = 10^{0.044T + 0.482\log_{10}\frac{\text{TDS}}{\text{MD}} + 0.021}$$

and the Marshall and Maes (1994) model as

$$\text{Yield}\,(\text{kg ha}^{-1}\,\text{y}^{-1}) = 23.281 \times \left(\frac{\text{EC}}{\text{MD}}\right)^{0.447}$$

where T is the mean annual water temperature in °C, TDS is the total dissolved solids (mg l^{-1}), EC is electrical conductivity (μS cm^{-1}) and MD is the mean depth of the reservoir in metres. The empirical yield models were selected based on their widespread use and contrasting outputs. Data used in the analyses are summarised in Table 1.

Catch rate and target species

Upon capture, fish were identified to species level and the total catch for each species component in each gear recorded in terms of number and weight (nearest 10 g).

Mean catch per unit effort (CPUE) was calculated as

$$\text{CPUE} = \frac{\sum_{i=1}^{n}\left(C_i / E_i\right)}{n}$$

where C_i is the catch (either in weight or number of fish) of by gear i, E_i is the effort expended by gear i and n is the number of different types of gear. Effort units were standardized to net $night^{-1}$ for gillnets and 10 hooks $night^{-1}$ for longlines. CPUE between gears and within sampling events was compared using one-way analysis of variance. A Tukey's *post hoc* test was used to determine pairwise differences.

Target species were identified as those that collectively comprised more than 80% of the catch in either the gill net or the longline samples.

Length at age

Four fish species (*L. aeneus*, *C. carpio*, *C. gariepinus* and longfin eel *Anguilla mossambica*) were collected, with *L. aeneus* and *C. gariepinus* contributing 23% and 74% of total mass, respectively.

Of all fish sampled, *Labeobarbus aeneus* and *Clarias gariepinus* were considered to be the target species. All *L. aeneus* and *C. gariepinus* sampled were weighed to the nearest gram, measured to the nearest millimetre for fork length (FL, for *L. aeneus*) or total length (TL, for *C. gariepinus*), otoliths were removed and, where possible, the fish were sexed.

Otoliths were set in clear casting resin and sectioned transversely at a thickness of 0.3 mm for *L. aeneus* and 0.4 mm for *C. gariepinus*, using a double-bladed diamond-edged saw; sections were mounted on microscope slides using DPX mountant.

Growth zones were counted under reflected light for *L. aeneus* and transmitted light for *C. gariepinus* (Figure 2). Sections were read three times, twice by TR and once by OLFW. The consistency of the otolith readings was assessed using an index of average percent error (IAPE) (Beamish and Fournier 1981) as

$$\text{IAPE} = \frac{1}{n}\sum_{j=1}^{n}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{\left|X_{ij} - \overline{X}_j\right|}{\overline{X}_j}\right] \times 100$$

where there are n fish aged, R is the number of times each fish j was aged, X_{ij} is the ith age determined for the jth fish, and $\overline{X}_j$ is the average age calculated for the jth fish.

The periodicity of growth zone formation was not directly validated for either species. Annulus deposition has, however, been validated by marginal zone analysis for *L. aeneus* in van der Kloof Dam (Orange River system) (Tomasson 1983) and for *C. gariepinus* in Glen Melville Dam (Great Fish River system) using fluorochrome-marked wild fish (Weyl and Booth 2008). Van der Kloof Dam (29°59′29.22″ S, 24°43′55.81″ E) and Glen Melville Reservoir (33°11′44.58″ S, 26°38′59.75″ E) are situated 308 km and 160 km from Xonxa Reservoir, respectively, and are subject to similar temperature and day-length regimes. It was, therefore, assumed that both species in Xonxa Dam also deposited annuli.

Length-at-age, L_t, was modelled using the von Bertalanffy growth function as

$$L_t = L_\infty(1 - e^{-K(t - t_0)})$$

where L_∞ is the asymptotic length, K is the growth coefficient and t_0 is the age-at-zero length. Parameter variability was estimated using a parametric bootstrapping (Efron 1982)

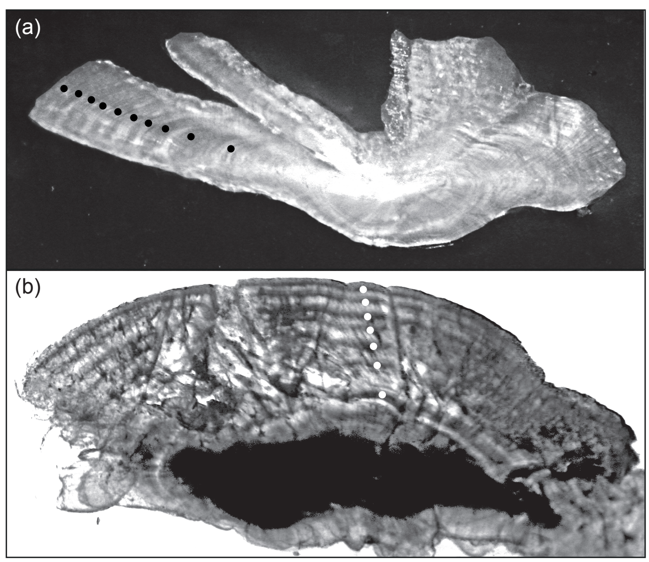

Figure 2: Photographs of sectioned otoliths showing annuli, indicated by dots: (a) *Labeobarbus aeneus* otolith viewed under reflected light; (b) *Clarias gariepinus* otolith viewed under transmitted light

with 1000 iterations. Confidence intervals were calculated using the percentile method (Buckland 1984).

Maturity

Labeobarbus aeneus maturity was assumed to be 'knife-edged', with all fish below the average length of the smallest mature female and the largest immature individual being considered to be immature and all larger fish mature. Age-at-maturity for *C. gariepinus* was obtained from the literature (Bruton 1977).

Mortality

Natural mortality (M) was estimated by both catch-curve analysis (Ricker 1975) and Pauly's (1980) empirical equation. For this analysis it was assumed that, in the absence of a formal fishery, total mortality was equal to natural mortality.

As *L. aeneus* was primarily sampled using size-selective gill nets, a correction was made for gear selectivity. The observed age and length frequencies were multiplied by the age- and length-specific gill net correction factor, which is the inverse of the sum of the age- and length-specific capture probabilities of each gill net mesh size (Millar and Holst 1997).

For *C. gariepinus*, catch curve analysis was applied directly to age frequency data, but nine-year-old fish were excluded from the catch-curve analysis, as this year class was found to be exceptionally strong and would introduce negative bias. Only one 11-year-old fish was sampled. This age class was also excluded from the analysis.

Pauly's (1980) empirical estimate of natural mortality is

$$M = \exp\left(-0.0152 - 0.279\ln L_\infty + 0.6543\ln K + 0.463\ln T\right)$$

where T is the mean annual water surface temperature (°C), and L_∞ (mm) and K are the estimated von Bertalanffy growth parameters.

Selectivity

Few *L. aeneus* were caught in the larger gill net mesh sizes. Selectivity was therefore estimated only for the 44 mm and 60 mm mesh sizes, using the SELECT method proposed by Millar and Holst (1997) and Booth and Potts (2006). For *C. gariepinus*, hook selectivity was assumed to be best explained by a logistic curve with 100% selection being the asymptote of the first ascending limb of the age frequency of sampled fish.

The selectivity of a gill net with mesh size i catching a fish of age t, S_t^{GN}, is described as

$$S_t^{\mathrm{GN}_i} = \exp\left(-\frac{\left(t - t_r^{\mathrm{GN}_i}\right)^2}{2\left(\delta^{\mathrm{GN}_i}\right)^2}\right)$$

and the selectivity of a longline catching a fish of age t, S_t^{LL}, is described as

$$S_t^{\mathrm{LL}} = \left(1 + \exp\left(-\left(t - t_r^{\mathrm{LL}}\right)/\delta^{\mathrm{LL}}\right)\right)^{-1}$$

In both selectivity curves, t_r^* denotes the age at selection, and δ^* either the standard deviation of the gill net curve or the inverse rate of selection for the logistic ogive.

Per recruit analysis

A yield and spawner biomass per recruit was calculated using input parameters summarised in Table 2. Yield per recruit (YPR) and spawner biomass per recruit (SBR) as a function of fishing mortality F and selectivity at age S_t, was calculated as

$$\mathrm{YPR}\left(F, S_t\right) = \sum_{t=0}^{\max} W_{t+1/2}\tilde{N}_t \frac{S_t F}{M + S_t F}\left(1 - e^{-M - S_t F}\right)$$

and

$$\mathrm{SBR}\left(F, S_t\right) = \sum_{t=0}^{\max} W_t \tilde{N}_t \psi_t$$

where W_t is weight of fish at age t, ψ_t is the maturity at age t and max is the age of the oldest aged fish in the population. The relative number of fish at age t, $\tilde{N}_t$, is calculated as

$$\tilde{N}_t = \begin{bmatrix} 1 & \text{if } t = 0 \\ \tilde{N}_t e^{-M - S_{t-1}F} & \text{if } 0 < t < \max \\ \dfrac{\tilde{N}_{\max-1} e^{-M - S_{\max-1}F}}{1 - e^{-M - S_{\max}F}} & \text{if } t = \max \end{bmatrix}$$

Five reference points were investigated. These were $F_{\max}$ (the fishing mortality corresponding to the maximum of the YPR curve), $F_{0.1}$ and $F_{0.2}$ (where the slope of the YPR curve is 10% and 20% of that at the origin, respectively), and F_{SB40} and F_{SB30} (those fishing mortalities that correspond to a reduction of SBR to 40% and 30% of pristine levels, respectively). The variability of the reference point estimates was assessed using Monte Carlo simulation. For each simulation, a random normally-distributed variate was drawn and all five BRPs estimated. Natural mortality was assumed to be normally distributed around the mean natural mortality rate with a CV of 15%, such that for *L. aeneus*

$$M_{\mathrm{La}} \sim N\left(0.30, \left(0.30 \times 0.15\right)^2\right)$$

and for *C. gariepinus*

$$M_{\mathrm{Cg}} \sim N\left(0.20, \left(0.20 \times 0.15\right)^2\right)$$

Confidence intervals from the resultant BRP vectors were calculated using the percentile method (Buckland 1984).

Results

Target species and experimental CPUE

A total of 677 fish from four species were sampled. Species composition and CPUE per gill net mesh size and in longline catches are summarised in Table 3. At all sampling sites *Labeo aeneus* dominated the gill net catches and *C. gariepinus* the longline catches. Gill net and longline CPUE did not differ significantly between months. Gill net CPUE by number was significantly higher for 44 mm and 60 mm mesh sizes than for all others but by weight the 60 mm mesh size had a significantly higher CPUE than all other mesh sizes (ANOVA, n = 18, $p < 0.05$).

Table 2: Biological and fishery parameters used for the application of yield and spawner biomass per recruit models for *Labeobarbus aeneus* and *Clarias gariepinus* in Xonxa Dam (FL = fork length; TL = total length)

Parameter	Species	
	L. aeneus	*C. gariepinus*
L_∞ (asymptotic length) (mm)	276.25 FL	1121.34 TL
K (brody growth coefficient) (y^{-1})	0.25	0.2
t_0 (age at zero length) (y)	–0.63	-0.24
a (length–weight parameter) (mm)	0.000012	0.0000064
b (length–weight parameter) (g mm^{-1})	2.99	3.00
ψ (age-at-50% maturity) (y)	4.6	1.49
δ_ψ (inverse rate of maturity curve) (mm y^{-1})	0.2	0.2
t_r (age-at-50% selection) (y)	5.94 and 8.11	4.92
δ_{tr} (inverse rate of selectivity curve) (mm y^{-1})	1.11 and 1.51	0.05
M (natural mortality rate) (y^{-1})	0.30	0.26
σ_M (standard deviation of M) (y^{-1})	0.06	0.05
max (maximum age considered) (y)	12	12

Table 3: Summary of species composition and experimental CPUE of experimental catches during 2007 from Xonxa Dam (CPUE for gill nets is expressed as per 9 m net per night and longlines expressed as per hook per night)

Gear	Species composition (%)				Total	CPUE	*n*
	Anguilla mossambica	*Cyprinus carpio*	*Clarias gariepinus*	*Labeobarbus aeneus*		Mean ± SE	
				Number (fish)			
44 mm gill net	0	1	0	99	214	11.9 ± 3.0	18
60 mm gill net	0	2	2	96	229	12.7 ± 2.1	18
75 mm gill net	0	5	0	95	61	3.4 ± 0.7	18
100 mm gill net	0	56	11	33	9	0.5 ± 0.2	18
144 mm gill net	0	40	60	0	5	0.3 ± 0.1	18
All gill net meshes	0	3	2	95	518		
Longline	2	0	98	0	54	0.2 ± 0.1	11
				Weight (kg)			
44 mm gill net	0	<1	0	99	20.1	1.1 ± 0.3	18
60 mm gill net	0	1	2	97	46.5	2.6 ± 0.4	18
75 mm gill net	0	3	0	97	18.0	1.0 ± 0.2	18
100 mm gill net	0	62	11	27	7.9	0.4 ± 0.2	18
144 mm gill net	0	18	82	0	18.1	1.0 ± 0.5	18
All gill net meshes	0	8	15	77	110.6		
Longline	1	0	99	0	281.9	1.0 ± 0.3	11

Potential yield

Potential yield, at full dam levels, varied considerably between the two different empirical models and was estimated to range between 18.7 kg ha^{-1} (Schlesinger and Regier 1982) and 95.7 kg ha^{-1} (Marshall and Maes 1994), corresponding to a total yield of between 27 and 139 t y^{-1} at full capacity.

Target species biology

The relationship between length and weight was $W = 0.000012L^{2.99}$ mm FL (n = 430, r^2 = 0.99) for *L. aeneus* and $W = 0.0000049L^{3.04}$ mm TL (n = 49, r^2 = 0.98) for *C. gariepinus*.

Growth zones were clearly noticeable in sectioned otoliths (Figure 2) and were consistently interpreted with an IAPE of 11.4% for *L. aeneus*, and 8.5% for *C. gariepinus*. Length-at-age was described as $L_t = 278.3(1 - e^{-0.25(t+0.64)})$ mm FL for *L. aeneus* and for *C. gariepinus* as $L_t = 1178.97(1 - e^{-0.2(t+0.37)})$ mm TL (Table 4, Figure 3).

Length-at-50% maturity was estimated at 204 mm FL for *L. aeneus* and 330 mm TL for *C. gariepinus*. Age-at-50% maturity was estimated at 4.8 years and 1.5 years for *L. aeneus* and *C. gariepinus*, respectively.

First estimates of natural mortality for *L. aeneus* were 0.30 y^{-1} using both the catch curve and Pauly (1980) methods (Figure 4). For *C. gariepinus*, natural mortality was estimated at 0.20 y^{-1}, an average of 0.22 y^{-1} using catch curve analysis and 0.18 y^{-1} by Pauly's (1980) method.

Gear selectivity

Observed and SELECT-predicted age frequencies are illustrated in Figure 4. Gill net selectivity for *L. aeneus* ($t_r \pm \delta$) was estimated at 5.98 ± 1.11 years for the 44 mm mesh size and 8.16 ± 1.51 years for the 60 mm mesh size (Table 2). Age-at-50% selectivity for *C. gariepinus* was estimated at 6.40 years. The inverse rate of selection was 1.34 y^{-1} (Table 2).

Table 4: Maximum likelihood estimates (MLE) and summary statistics derived from a parametric bootstrap procedure for von Bertalanffy growth model fitted to observed age and length data for *Clarias gariepinus* and *Labeobarbus aeneus* sampled during 2007 from Xonxa Dam

Species	Parameter	MLE	CV (%)	95% CI
L. aeneus	L_∞ (mm FL)	278.03	3.71	[260.08, 299.43]
	K (y^{-1})	0.25	12.14	[0.20, 0.31]
	t_0 (y)	–0.64	31.00	[–1.08, –0.27]
C. gariepinus	L_∞ (mm TL)	1178.97	19.03	[978.44, 1701.40]
	K (y^{-1})	0.20	34.44	[0.08, 0.35]
	t_0 (y)	–0.37	175.88	[–2.03, 0.54]

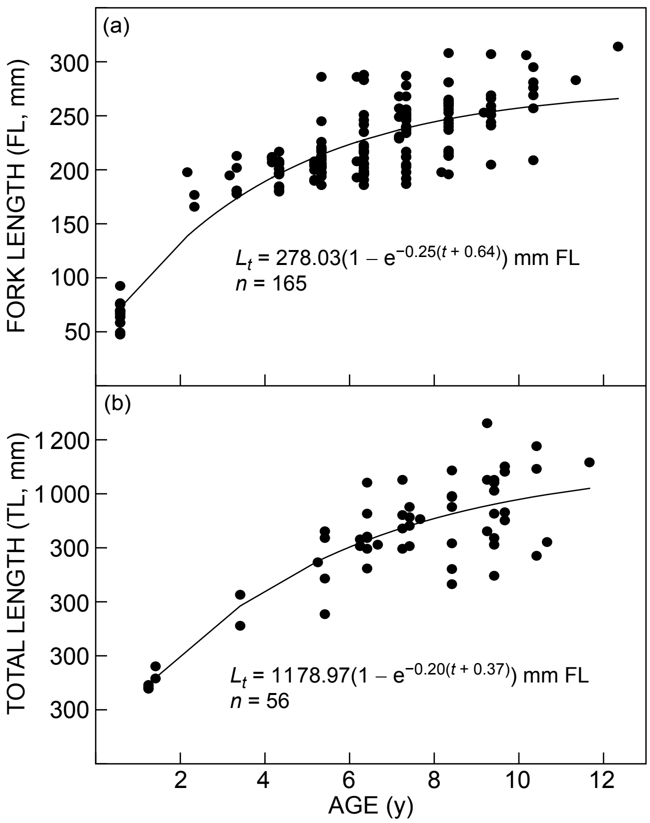

Figure 3: Observed lengths-at-age and fitted von Bertalanffy growth functions for (a) *Labeobarbus aeneus* and (b) *Clarias gariepinus* sampled during 2007 from Xonxa Dam

Per-recruit analysis and reference points

The YPR and SBR isopleth diagrams, showing the responses of YPR and SBR to different selectivity and *F* scenarios, are shown in Figure 5. Results of the estimated BRPs that included random variation in the assumed natural mortality rate are summarised in Table 5.

Labeobarbus aeneus YPR is maximised when selected between 4.5 and 7 years at relatively high levels of fishing mortality. At 4.5 years, SBR was, however, rapidly depleted to below 30% of pristine levels. At higher ages of selection (>7 years), SBR is maintained at above 40% of pristine levels at high levels of fishing mortality.

Selectivity by the 44 mm mesh experimental gill net allowed for a greater YPR than using the 60 mm gill net, but with decreased SBR. This is because of per recruit effects of harvesting considerably more, but smaller, immature fish. The 60 mm mesh size is therefore favoured as a potential gear for a new fishery. The BRPs in Table 5 clearly show that it is almost impossible to obtain maximum YPR due to the monotonic shape of YPR vs *F* curve. However, at fishing mortalities of c. 0.6 y^{-1}, at least 90% of maximum YPR is obtained without reducing SBR below 40% pristine levels. Selection by the 60 mm gill net at 8.11 years resulted in the maintenance of SBR above F_{SB40} at all levels of fishing mortality.

Clarias gariepinus YPR was maximised at ages of selection between of between four and six years. At these ages, SBR would be maintained at ≥30% of pristine levels. The SBR is only depleted to below 30% of pristine levels selecting fish younger than 4 years. As age-at-selection increases, the risk of depleting spawner biomass to unacceptable levels decreases rapidly, but realises less YPR. At current longline selectivity patterns (harvesting fish at 6.39 years of age), fishing moralities needed to attain the $F_{0.1}$ and $F_{0.2}$ TRPs did not exceed either F_{SB40} or F_{SB40}.

Results from the per recruit simulation exercise summarised in Table 5 clearly show that the most poorly estimated BRP is F_{max}; the estimates were both excessively high and extremely variable with high CVs. The SBR-based BRPs had slightly higher CVs than the marginal yield-based equivalents and provided a limit beyond which fishing should be halted. For example, dropping SBR below 30% of pristine levels has been shown to increase the risk of reproductive failure dramatically. Ideally, SBR should not be fished below 40% of pristine levels. Therefore, given the lower 95% confidence limit, fishing mortality for *L. aeneus* should not exceed 0.74 y^{-1} for the 60 mm gill net fishery, and for *C. gariepinus*, fishing mortality should not exceed 0.31 y^{-1} for a longline fishery harvesting fish from six years of age.

Discussion

Xonxa Dam fulfils Weyl et al.'s (2007) criteria for the development of a community-managed subsistence fishery, as the community's land borders the dam and both the local municipality and members of the community have expressed an interest in developing a fishery (Rouhani 2002).

Based on the two MEI estimates considered, annual potential yield was estimated to range between 27 and 139 t y^{-1}. To remain precautionary, we therefore suggest that the lower estimate of 27 t y^{-1} is probably more appropriate, given the lack of an existing fishery on the dam and that no data are available on biomass trends in response to harvesting.

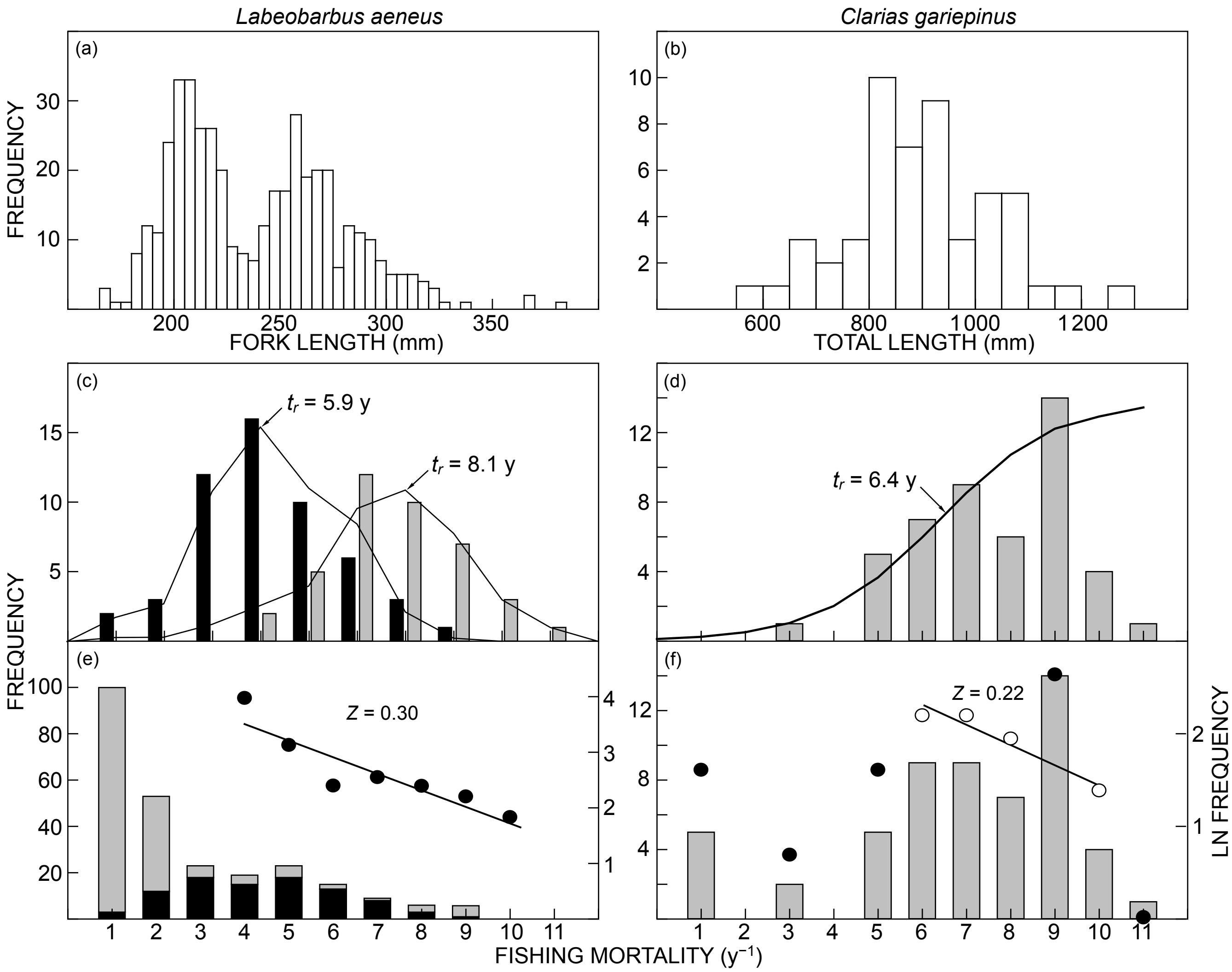

Figure 4: Length frequencies for (a) *Labeobarbus aeneus* and (b) *Clarias gariepinus*; (c) age frequencies of *L. aeneus* caught in 44 mm gill nets (black bars) and in 60 mm gill nets (grey bars) with SELECT model predicted frequencies (line); (d) age frequency of *C. gariepinus* caught on longlines (bars) and logistic selectivity function (line) fitted to the first ascending limb of the age frequency histogram; (e) *L. aeneus* age frequency corrected for selectivity and catch curve; and (f) *C. gariepinus* age frequency and catch curve based on all fish caught using various gears. All samples were collected from Xonxa Reservoir in March, May and August 2007

The MEI yield estimates were originally developed to provide 'first-estimates' on the potential yield from a fishery and it is suggested that these be updated as additional data become available (Ryder et al. 1974). The proposed yield estimates for Xonxa Dam must, therefore, be viewed in this context and be adjusted accordingly as data are collected through monitoring of the fishery.

The initial MEI yield estimates are also species non-specific. Given the dominance of two species in the dam, both being alien to the Kei River catchment, it is suggested that the annual harvest would comprise both *C. gariepinus* and *L. aeneus*. Fortunately, no IUCN red-listed species that may be vulnerable to exploitation was present.

Experimental fishing showed that the two potential target species would form the basis of two distinct fisheries; a gill net fishery targeting *L. aeneus* and a long-line fishery targeting *C. gariepinus*. Harvest strategies should be developed to avoid growth overfishing (where recruits are caught before they can contribute significantly to the biomass) and recruitment overfishing (where spawner stock levels are depleted to levels at which the stock cannot replenish itself). These harvest levels can only be estimated using more complex stock-assessment approaches.

Historical catch and effort data are unfortunately not available, given the 'new fishery' status of Xonxa Dam. A per-recruit approach to simulate the response of the *L. aeneus* and *C. gariepinus* resources to different exploitation strategies was considered appropriate. These MEI estimates are provisional and will require additional sampling surveys to investigate changes in catch rate and to determine the relationship between catches and fishing mortality. As

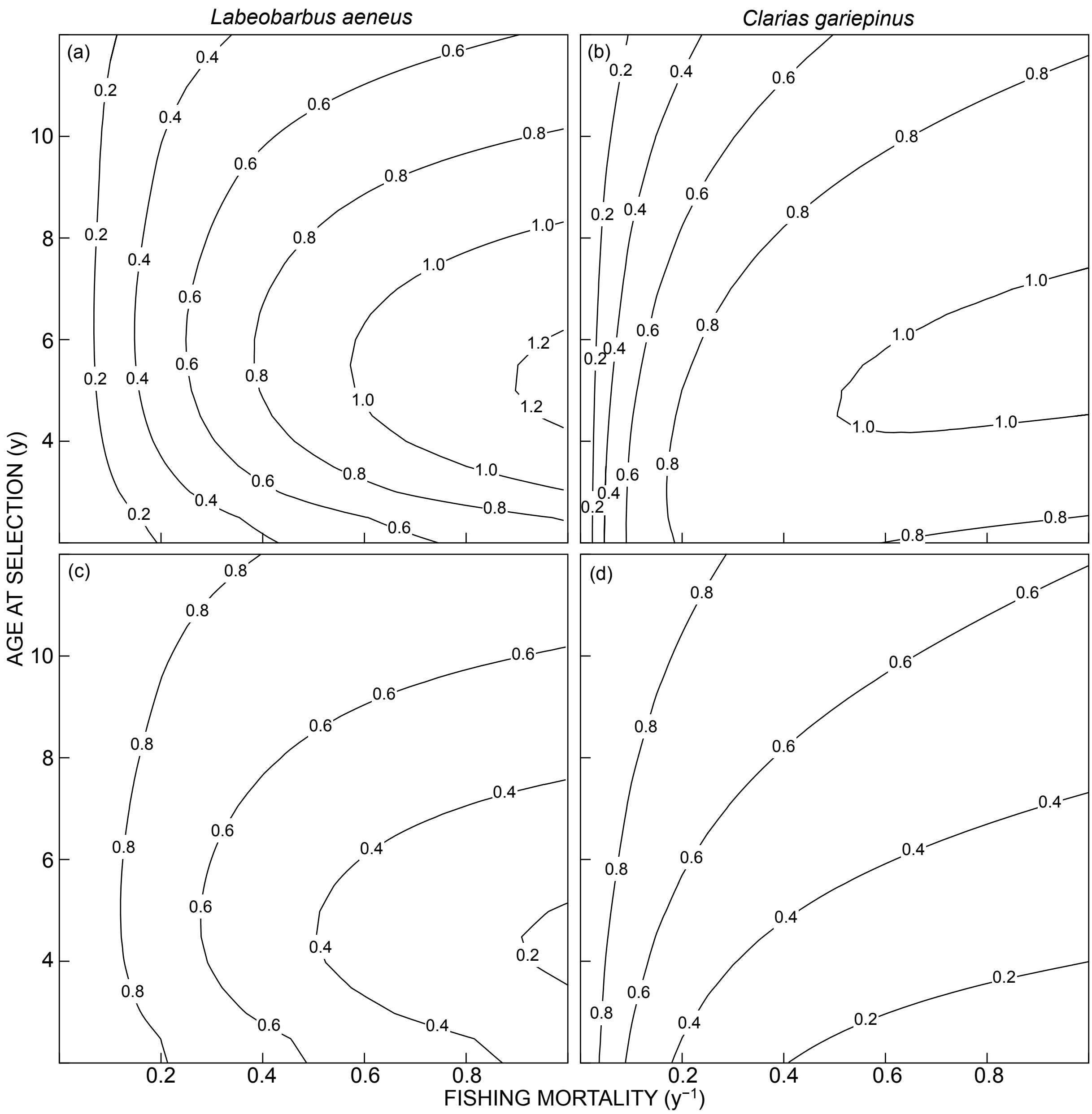

Figure 5: Isopleth diagrams describing the responses of yield per recruit for (a) *Labeobarbus aeneus* and (b) *C. gariepinus,* spawner biomass per recruit for (c) *Labeobarbus aeneus* and (d) *C. gariepinus* under different combinations of fishing mortality and age at selection. Contours represent the proportion of maximum yield per recruit and the proportion of pristine spawner biomass per recruit

such monitoring data become available, more complicated assessment methods can be employed to refine annual harvest rules. The motivation for a new fishery is to provide additional employment to a poor rural community and it is essential that this should be sustainable in the short- to medium-term. The consequences of over-harvesting and the need for harvesting rules must also be carefully articulated to the community.

Both the YPR and SBR analyses suggest that it is not possible to maximise *L. aeneus* yield while maintaining SBR above F_{SB30}. As exploitation using a 44 mm mesh gill net resulted in a rapid decline in SBR to below F_{SB30}, the 60 mm gill net mesh size is recommended. Harvesting of older fish resulted in a slightly lower YPR but maintained SBR at above 30% of pristine levels, even at very high levels of fishing mortality. For *C. gariepinus*, selection by longlines at ages approximating those in the experimental gear allowed for the maintenance of SBR above the 30% level at realistic fishing mortality values.

In the absence of an established fishery, the relationship between harvesting levels and fishing mortality could not be ascertained. An alternative approach was therefore required to set initial effort levels for the longline and gillnet fisheries. Using the conservative MEI estimate of 27 t y^{-1} derived from the Schlesinger and Regier (1982) model and experimental

Table 5: Biological reference points and their associated estimates of variability derived from Monte-Carlo simulation for *Labeobarbus aeneus* and *Clarias gariepinus* in Xonxa Dam

Species	t_r	BRP	Summary statistics			
			Point	Mean	CV (%)	95% CI
L. aeneus	5.94	F_{max}	16.64	24.24	156.30	[2.77, 182.89]
		$F_{0.1}$	0.99	1.00	6.62	[0.87, 1.15]
		$F_{0.2}$	0.67	0.67	5.02	[0.61, 0.75]
		F_{SB30}	0.84	0.85	11.46	[0.67, 1.07]
		F_{SB40}	0.58	0.59	9.63	[0.48, 0.71]
L. aeneus	8.11	F_{max}	134.51	144.91	117.97	[16.74, 309.69]
		$F_{0.1}$	0.90	0.91	11.06	[0.74, 1.13]
		$F_{0.2}$	0.57	0.58	8.09	[0.50, 0.67]
		F_{SB30}	3.04	3.15	33.81	[1.43, 5.45]
		F_{SB40}	1.38	1.46	32.91	[0.74, 2.54]
C. gariepinus	6.39	F_{max}	0.90	0.91	23.68	[0.56, 1.4]
		$F_{0.1}$	0.29	0.29	16.33	[0.21, 0.39]
		$F_{0.2}$	0.19	0.19	15.40	[0.13, 0.24]
		F_{SB30}	1.00	1.01	28.67	[0.54, 1.66]
		F_{SB40}	0.54	0.55	27.27	[0.31, 0.89]

gill net fleet CPUE for each species as a 'first-estimate' of relative biomass, we recommend an initial harvest level of 23 t y^{-1} for *L. aeneus* and 4 t y^{-1} for *C. gariepinus*. Using average CPUE for the 60 mm gill net mesh size and for experimental longlines, it was calculated that the initial yield estimate could be attained by using 5 × 100 m gillnets with a 60 mm mesh size, and 2 × 12-hook longlines, each operated for 150 fishing nights y^{-1}. It must, however, be recognised that in fished populations CPUE will diminish rapidly. This effect of harvesting therefore requires monitoring as, once CPUE drops below 40–50% of initial CPUE, then harvesting levels could depress the intrinsic rate of increase in the population, which is typically maximised as these values. Schramm (1993) noted that the dam's water level does not fluctuate greatly and that there is sufficient habitat for both target species to spawn. Maintenance of spawner biomass should be prioritised to prevent recruitment failure from harvesting, rather than from environmental effects.

Rapid assessment has shown that a small gill net fishery for *Labeobarbus aeneus* and longline fishery for *Clarias gariepinus* is feasible. It must however be recognised that any fisheries development should take into account both the biological limitations to yield and the social and economic factors that may influence fisheries development. As a result, assessments need to be undertaken to: (1) identify demand and possible markets for harvested fish, (2) determine the social and economic reasons why previous attempts to initiate a gill net fishery on Xonxa Dam (Duncan-Brown 1980, Rouhani 2002) appear to have failed, and (3) identify potential impacts of a fishery on other livelihood strategies in the area.

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References

Beamish RJ, Fournier DA. 1981. A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 982–983.

Beverton RJH, Holt SJ. 1957. On the dynamics of exploited fish populations. *Fisheries Investigational Series II (London)* 19: 1–533.

Booth AJ, Potts WM. 2006. Estimating gill-net selectivity for *Labeo umbratus* (Pisces: Cyprinidae), and an evaluation of using fyke-nets as a non-destructive sampling gear in small reservoirs. *Fisheries Research* 79: 202–209.

Booth AJ, Weyl OLF. 2004. Investigations into a potential directed fishery for *Labeo cylindricus* in Lake Chicamba, Mozambique. *African Zoology* 39: 77–90.

Bruton MN. 1977. The biology of *Clarias gariepinus* (Burchell, 1822) in Lake Sibaya, KwaZulu, with emphasis on its role as a predator. PhD thesis, Rhodes University, South Africa.

Buckland ST. 1984. Monte Carlo confidence intervals. *Biometrics* 40: 811–817.

Duncan-Brown R. 1980. Xonxa Fisheries Project: An attempt to stimulate fishing in a rural community in Transkei. In: Transkei and Ciskei Research Society, Proceedings of the 6th biennial meeting, Umtata, 7–9 March 1980. pp 160–161.

DWAF (Department of Water Affairs and Forestry). 1997. MS-EXCEL Database of Water Resources (unpublished report). Pretoria: DWAF. Available at www.dwaf.gov.za.

Efron B. 1982. The jackknife, the bootstrap and other resampling plans. Society for Industrial and Applied Mathematics, Philadelphia.

Kapetsky JM, Petr T. 1984. Status of African reservoir fisheries. Rome: FAO. CIFA Technical Paper 10.

Kanyerere GZ, Booth AJ, Weyl OLF. 2005. Management for the *Diplotaxodon limnothrissa* (Teleostei: Cichlidae) resource in the south-east arm of Lake Malawi, based on per-recruit analysis. *African Journal of Aquatic Science* 30: 151–155.

Marshall BE, Maes M. 1994. Small water bodies and their fisheries in southern Africa. Rome: FAO. CIFA Technical Paper 29.

Millar RB, Holst R. 1997. Estimating gillnet and hook selectivity using log-linear models. *ICES Journal of Marine Science* 54: 471–477.

NEPAD (New Partnership for Africa's Development). 2005. The NEPAD action plan for the development of African fisheries and aquaculture. NEPAD Fish for All summit, Abuja, Nigeria, 23 August 2005. Available at http://www.fishforall.org/ffa-summit/English/NEPAD_ActionPlan.pdf [accessed 18 November 2008].
Pauly D. 1980. On the interrelationship between natural mortality, growth parameters and mean environmental temperature in 175 stocks of fish. *Journal du Conseil* 39: 175–192.
Ricker WE. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board Canada* 191: 1–382.
Rouhani QA (ed.). 2002. A report on the feasibility of inland fisheries and oyster farming in the Emalahlani and Mbashe Municipalities respectively. Special report, Rural Fisheries Programme, Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown.
RSA (Republic of South Africa). 1998a. National Water Act No. 36 of 1998. *Government Gazette* 398(19182).
RSA (Republic of South Africa). 1998b. National Environmental Management Act No. 107 of 1998. *Government Gazette* 401(19519).
Ryder RA, Kerr SR, Loftus KH, Regier HA. 1974. The morphoedaphic index, a fish yield estimator — review and evaluation. *Bulletin of the Fisheries Research Board Canada* 31: 663–688.
Schlesinger DA, Regier HA. 1982. Climatic and morphoedaphic indices of fish yields from natural waters. *Transactions of the American Fisheries Society* 111: 141–150.
Schramm M. 1993. A comparison of cyprinid fish populations in three large Transkei reservoirs with respect to abundance and reproduction. *Southern African Journal of Aquatic Sciences* 19: 74–88.
Scott LEP, Skelton PH, Booth AJ, Verheust L, Harris R, Dooley J. 2006. Atlas of Southern African Freshwater Fishes. *Smithiana Monograph*.
Thompson TB, Allison EH. 1997. Potential yield estimates of unexploited pelagic fish stocks in Lake Malawi. *Fisheries Management and Ecology* 4: 31–48.
Tómasson T. 1983. The biology and management considerations of abundant large cyprinids in Lake Le Roux, Orange River, South Africa. PhD thesis, Rhodes University, South Africa.
Van Der Knaap M. 1994. Status of fish stocks and fisheries of thirteen medium-sized African reservoirs. Rome: FAO. CIFA Technical Paper 26.
Weyl OLF, Booth AJ. 2008. Validation of annulus formation in otoliths of a temperate population of adult African sharptooth catfish, *Clarias gariepinus* (Burchell, 1822), using fluorochrome marking of wild fish. *Journal of Fish Biology* 73: 1033–1038 DOI: 10.1111/j.1095-8649.2008.01975.x.
Weyl OLF, Booth AJ, Mwakiyongo KR, Mandere DS. 2005a. Management recommendations for *Copadichromis chrysonotus* (Pisces: Cichlidae) in Lake Malombe, Malawi, based on per-recruit analysis. *Fisheries Research* 71: 165–173.
Weyl OLF, Booth AJ, Mwakiyongo K, Banda MM. 2005b. Per-recruit simulation as a rapid assessment tool for a multi-species small-scale fishery in Lake Malombe, Malawi, Africa. In: Kruse GH, Gallucci VF, Hay DE, Perry RI, Peterman RM, Shirley TC, Spencer PD, Wilson B, Woodby D (eds), Fisheries assessment and management in data-limited situations. Alaska Sea Grant Program AK-SG-05-02. University of Alaska Fairbanks. pp 235–254.
Weyl OLF, Potts WM, Rouhani Q, Brits P. 2007. The need for inland fisheries policy in South Africa: a case study on the Northwest Province. *Water SA* 33: 497–504.