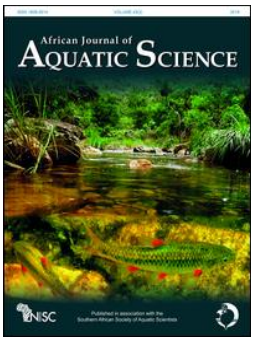

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Predictor variables for moggel (*Labeo umbratus*) biomass and production in small South African reservoirs

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The biomass and production of moggel, *Labeo umbratus*, in five small previously unexploited Eastern Cape reservoirs were estimated and related to environmental conditions. Biomass and production estimates varied widely between the reservoirs. Whilst the production/biomass ratio was not a good indicator of fishery potential, conductivity, mean reservoir depth and surface area proved to be the most suitable predictors of moggel biomass and production, whereas chlorophyll *a* concentration was somewhat less suitable. Results suggested that reservoirs with high conductivity (>50mS.m^{-1}), small area (<50ha) and shallow depth (<3m) would have the highest moggel biomass and production.

Keywords: age and growth, empirical modelling, moggel, small water bodies

Introduction

South Africa has approximately 3 100 registered reservoirs, ranging in size from 1–1 000 hectares, with a surface area totalling 84 439 hectares (SADC Surface Water Body Database, unpublished data). Within southern and eastern Africa, Lindqvist (1994) estimated the number of small reservoirs to be between 50 000 and 100 000. Given Bernacsek's (1986) estimate of the total fishery potential of small reservoirs in Africa at between 1 and 2.3 million tons, this number of reservoirs clearly could provide fishery opportunities for rural communities.

Fisheries information for small reservoirs in South Africa is not available. This is partly due to the lack of traditional harvesting of freshwater fish in South Africa (Andrew *et al.* 2000) and to the scientific focus on larger reservoirs and lakes such as Le Roux Reservoir (Allanson and Jackson 1983), Gariep Reservoir (Hamman 1981), Hartbeespoort Reservoir (Cochrane and Robarts 1986) and Lake Sibaya (Bruton and Allanson 1974, Bruton 1979). Since most small reservoirs are situated in poor rural areas, the need for fisheries research and development here is a priority (Andrew *et al.* 2000). To ensure that sustainable fisheries are developed, it is essential to obtain at least basic information for each reservoir. However, the collection of fishery information from the predominantly rural and widely dispersed small reservoirs is time-consuming and expensive.

Empirical modelling of fish production in large inland water bodies has been a focus of scientific research for decades (see, for example, Rawson 1952, Ryder 1965, Jenkens and Morais 1971, Henderson and Welcomme 1974, Melack 1976, Ogelsby 1977, Hanson and Legget 1982, Downing *et al.* 1990, Nissanka *et al.* 2000). Since small reservoirs (<1 000ha) do not conform to these models (Ogelsby 1977), it is necessary to explore alternatives. The low number of species with fishery potential occurring in small African reservoirs (Marshall and Maes 1994) provides an opportunity to explore empirical models that are species-specific. Identifying variables that can be used to predict fish production in unstudied systems is the first step towards developing a model to predict production.

The objective of this study was to identify easily-measurable parameters that could be used to predict biomass and production of moggel in small reservoirs. Moggel, *Labeo umbratus* (Cyprinidae), are widely distributed throughout South Africa (Skelton 1993), occurring in high densities in impoundments (Gaigher 1984). It has been recognised as a commercially important species in Wuras Reservoir (Pieterse and Keulder 1982), Lake Mentz, Kalkfontein Reservoir (Merron and Tømasson 1984) and Bloemhof Reservoir (P de Villiers pers. comm.). Recently, moggel has been the focus of rural fishing projects in small water bodies in the Eastern Cape (Andrew *et al.* 2000), in an effort to establish small-scale fisheries.

Materials and methods

Study area

Five small reservoirs — Katriver, Sinqemeni, Ndlambe, Laing and Dimbaza — in the Eastern Cape Province, South Africa were studied (Figure 1). They varied in size from 9–214ha, had mean depths of between 1.9 and 12.2m at

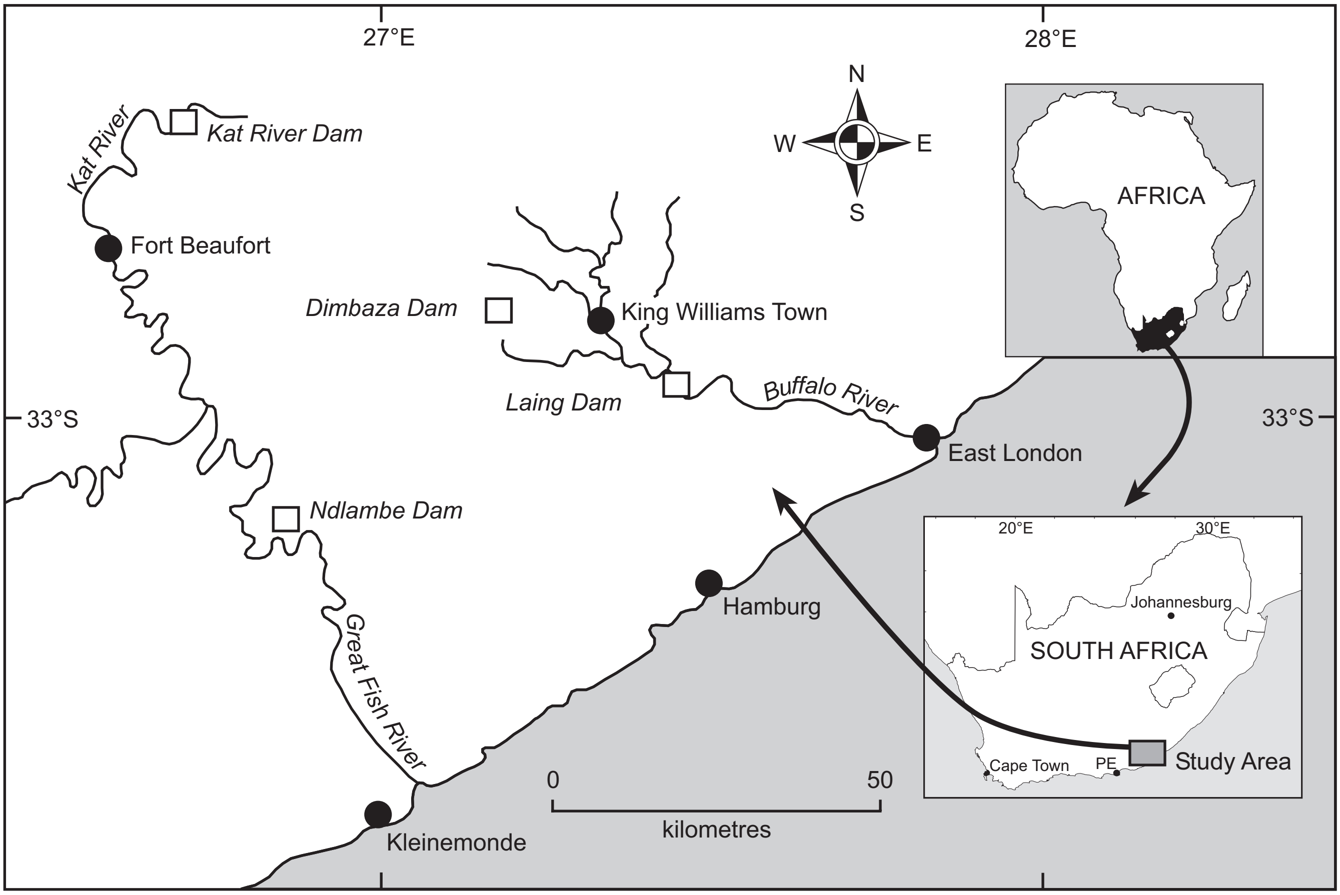

Figure 1: Map showing the location of the four study reservoirs in the Eastern Cape, South Africa

full supply level and catchment areas of from 20–913km^2, and were situated in a fairly narrow range of altitudes (100–740m) in areas with mean annual rainfalls of 500–700mm and mean annual evaporation rates of 1 400–1 700mm. As in most of the Eastern Cape, the bedrock of the catchments of all five reservoirs was sedimentary rock, with a soil type characterised as either sandy or clayey loams (Table 1).

The anthropogenic characteristics of the reservoir catchments varied widely, with the population densities ranging from 90.4–529.9 per km^{-2} and the density of houses between 18.8–124.9 per km^{-2}. In terms of agriculture and industry, the density of farmers and manufacturers ranged from 0.7–2.3 per km^{-2} and 0.3–55.1 per km^{-2}, respectively. The Katriver, Sinqemeni and Ndlambe reservoirs were situated in rural areas, with subsistence livestock farming dominating land use in the catchments. Due to the peri-urban situations of the Laing and Dimbaza reservoirs, the land use in their catchments was varied, including commercial and subsistence farming, industry and domestic utilisation (Table 2).

Five fish species — moggel (*L. umbratus*), carp (*Cyprinus carpio*), river goby (*Glossogobius callidus*), chubbyhead barb (*Barbus anoplus*) and longfin eel (*Anguilla mossambica*) — occur in all five reservoirs. Sharptooth catfish (*Clarias gariepinus*) occur in both the Katriver and Laing reservoirs, and largemouth bass (*Micropterus salmoides*) occurs in the Katriver and Dimbaza reservoirs. Bluegill (*Lepomis macrochirus*) occurs only in the Dimbaza reservoir. Mozambique tilapia (*Oreochromis mossambicus*) is present in the Ndlambe and Laing reservoirs, and flathead (*Mugil cephalus*) and freshwater mullet (*Myxus capensis*) were introduced into the Katriver reservoir in 1988 (Eastern Cape Nature Conservation, stocking records).

Hand-line fishing was practised in all reservoirs, prior to the study. Two throw-net fishermen operated sporadically (± once per week) in the Laing reservoir. No moggel were ever observed in the catches of the hand-line fishermen, whilst the throw-net fishers' catch of this species was negligible (2.1 ± 2.3 fish per fishing trip).

Water quality

Water temperature and dissolved oxygen were measured at a deep offshore stations near the reservoir walls, using a hand-held oxygen meter (Oxygaurd handy MKIII). Turbidity in Formazine Turbidity Units (FTU) (where 1 FTU = 1 Nephelometric Turbidity Unit (NTU)) and conductivity were measured directly near the major inflow, in the middle reaches, and near the wall of each reservoir, using a Hanna 93703 turbidimeter and a Hanna HI 933300

Table 1: Environmental parameters of Katriver, Laing, Sinqemeni, Ndlambe and Dimbaza reservoirs situated in the Eastern Cape Province, South Africa

	Katriver	Laing	Sinqemeni	Ndlambe	Dimbaza
Geographical co-ordinates	32°33'43''S, 26°46'08''E	32°57'32''S, 27°30'05''E	33°11'32''S 26°58'04''S	33°10'14''S 26°58'04''E	32°50'38''S 27°13'37''E
Altitude (m)[1]	750	310	100	100	350
Catchment size (km^2)[1]	258	913	± 20	± 20	± 35
Utilisation[1]	Irrigation	Potable supply, industry	Human and livestock supply	Human and livestock supply	Industry and livestock
Surface area at FSL* (ha)	214[1]	211[1]	9.3	16.2	46.2
Mean depth (m)	12.2	10.4	3.2	3.0	1.9
Maximum depth (m)	48.0	30.0	7.5	8.6	3.9
Catchment geology[1]	Sedimentary	Sedimentary	Sedimentary	Sedimentary	Sedimentary
Catchment soils[1]	Sandy-loams	Clayey loams	Clayey loams	Clayey loams	Sandy-loams
Mean annual rainfall[1]	600–700mm	600–700mm	500–600mm	500–600mm	600–700mm
Mean annual evaporation[1]	1 500–1 600mm	1 400–1 500mm	1 500–1 600mm	1 500–1 600mm	1 400–1 500mm

Superscript indicates reference: 1 = Midgely *et al*. (1994)
* FSL = full supply level

Table 2: Selected anthropogenic catchment characteristics for Katriver, Laing, Sinqemeni, Ndlambe and Dimbaza reservoirs situated in the Eastern Cape Province, South Africa (South African 2001 census, unpubl. data obtained from the Municipal Demarcation Board)

Catchment characteristics	Katriver	Laing	Sinqemeni	Ndlambe	Dimbaza
Number of houses	4 847	36 126	1 185	1 185	4 371
Density of houses (no.km^{-2})	18.8	39.6	47.4	47.4	124.9
Population	23 314	172 718	5 484	5 484	18 545
Population density (no.km^{-2})	90.4	189.2	219.4	219.4	529.9
Number of farmers	600	634	29	29	45
Density of farmers (no.km^{-2})	2.3	0.7	1.1	1.1	1.3
Number of manufacturers	89	4 275	8	8	1 930
Density of manufacturers (no.km^{-2})	0.3	4.7	0.3	0.3	55.1
Number of households without flush toilets	4 542	20 830	1 167	1 167	2 060
Density of households without flush toilets (no.km^{-2})	17.6	22.8	46.7	46.7	58.9

conductivity meter, respectively. Chlorophyll *a* concentration was determined at 1m intervals, from the surface to a depth of 5m.

Due to unavailability of a field fluorometer, the water samples were stored on ice in a black-lined cooler box and, once back at the laboratory, were frozen at –30°C and stored for a maximum of six months before processing. While the degradation of chlorophyll *a* over time and its poor filtration efficiency after freezing are recognised, the standardised method used for all reservoirs ensured that comparisons between the systems were still valid. In the laboratory, samples were defrosted in black containers and filtered (using GF/F filters) with a vacuum pump. Chlorophyll *a* was extracted in 90% acetone for 24h in the dark and concentrations were determined with a Turner 10AU fluorometer before and after acidification with 4N HCL (Holm-Hansen and Riemann 1978).

General sampling

To identify variables that could possibly be used to predict moggel biomass and production in unexploited reservoirs, it was critical to obtain production estimates for moggel in unfished populations. Therefore, the population size structure, growth and mortality rates were estimated from the biological surveys before the experimental gill-net fishing began.

Biological samples of *L. umbratus* were collected monthly from the Katriver and Laing reservoirs between November 1998 and October 2000, quarterly in the Ndlambe and Sinqemeni reservoirs between June 1999 and April 2001, and quarterly in the Dimbaza reservoir between February 2000 and January 2002 according to the methods of Potts *et al.* (2005). After the biological surveys had continued for about a year, experimental community-based fisheries were initiated in each reservoir. Fishermen were given gill-nets and were required to keep accurate records pertaining to the date of capture, number of fish caught and length composition of their catches. At the Katriver and Laing reservoirs, fishermen were given six gill-nets, each 40m in length, with a stretched mesh size of 75mm. Fishing commenced in November and December 1999, in the Katriver and Laing reservoirs, respectively. Fisheries were initiated in the Sinqemeni and Ndlambe reservoirs in May 2000, where each fisherman was given one 40m net with a stretched mesh size of 100mm. The Dimbaza reservoir fishery was initiated in July 2001, where each fisherman was given three gill-nets of 40m with a stretched mesh size of 75mm.

Growth and mortality

The most suitable method of interpreting growth zones in the otoliths was assessed. The lapillae of each fish were either burned or left unburned and then read whole in either water or methyl-salicylate under transmitted or reflected light, using a dissecting microscope. After three readings of each whole otolith, the burned and unburned otoliths were either sectioned longitudinally or transversely through the nucleus with a double-bladed, diamond-edged saw. The sections were mounted onto glass slides with DPX mountant, and read a further three times. It was found that the most consistent readings were obtained using whole, unburned otoliths immersed in methyl-salicylate BP and read under reflected light. This method was then used to age all fish sampled.

The number of translucent zones was counted on three occasions, using transmitted light. If the three readings were the same, the age estimate was accepted. If they differed, the otolith was rejected. To validate the periodicity of ring formation, the outer margin of each otolith was examined. The composition of the outer margin (either opaque or translucent) was noted and expressed as a percentage of the monthly sample. The Von Bertalanffy growth model (Ricker 1975) was fitted to the length-at-age data, using a downhill simplex search (Nelder and Mead 1965), a nonlinear minimisation routine for obtaining model parameter estimates. Model fits were obtained by minimising the negative normal log-likelihood of the observed and predicted lengths at each age. To compare the model fits, a non-parametric one-sample runs test for residual randomness and the Bartlett's test for their homoscedascity (Hughes 1986) were applied. In addition, variance estimates were calculated, using parametric bootstrap resampling (Efron 1982), with 1 000 bootstrap iterations. Standard errors and 95% confidence intervals were constructed from the bootstrap data, using the percentile method described by Buckland (1984). A likelihood ratio test (Cerrato 1990) was used to compare the model parameters between the five reservoirs.

The instantaneous rate of total mortality (Z) was estimated for *L. umbratus* of over 160mm FL (i.e. the minimum size captured in the gill-nets), using catch curve analysis (Ricker 1975). Length frequency distributions from the gill-net catches before the initiation of the fisheries were corrected for selectivity (Potts 2003) and converted to age frequency distributions by means of a normalised age-length key (Butterworth *et al.* 1989).

Population numbers

The number of fish in each population was estimated using the Leslie and Davis (1939) removal method, since the lack of suitable seine netting sites made mark-recapture experiments impossible. A condition for the use of the removal method is a considerable reduction in the catch per unit effort (CPUE). This occurred in all reservoirs after only two years of sampling and one year of experimental gill-net fishing. The numbers of moggel of over 160mm FL were estimated from gill-net CPUE data from the fisheries surveys and the independent, experimental fisheries.

Population structure

Population size structure was estimated from information collected in the fisheries surveys in the first year of study. This was done because the independent, experimental fisheries used one mesh size and removed only larger individuals. The survey gill-net catches from the first year were corrected for selectivity using the length-structured model (Potts 2003), and the proportion of fish in each length class was calculated. The population structure was calculated by multiplying the estimated population number by the proportion of fish in each length class. Only fish above 160mm FL were considered in the biomass and production calculation, since the size selectivity of seine nets and the population number of the small size classes could not be estimated.

Biomass and production

Moggel biomass (B) and production (P) for fish of between 160 and 400mm FL were calculated, using the exponential (single) Von Bertalanffy formulae proposed by Allen (1971):

$$\mathrm{B} = W_{\infty}\sum_{i=160}^{400} N_i\left(\frac{e^{-t_i Z}}{Z}-\frac{3e^{-t_i(Z+K)}}{Z+K}+\frac{3e^{-t_i(Z+2K)}}{Z+2K}-\frac{e^{-t_i(Z+3K)}}{Z+3K}\right)$$

and

$$\mathrm{P} = 3W_{\infty}K\sum_{i=160}^{400} N_i\left(\frac{e^{-t_i(Z+K)}}{Z+K}-\frac{2e^{-t_i(Z+2K)}}{Z+2K}+\frac{3e^{-t_i(Z+3K)}}{Z+3K}\right)$$

where K is the Brody growth coefficient, N_i is the number of individuals in the L_ith length class, W_{∞} is the theoretical maximum fish weight, Z is the mean total mortality rate, and the age of fish of length i is:

$$t_i = \mathrm{t_o} - \tfrac{1}{\mathrm{k}}\ \ln\left[1-\tfrac{\mathrm{L_i}}{\mathrm{L_{\infty}}}\right]$$

W_{∞} in each reservoir was calculated by converting the mean L_{∞} (400mm FL) to weight by using the length-weight relationship for each system. Since the lowest L_{∞} was 358mm FL, the standardisation of L_{∞} was required for comparative purposes, and consequently an upper limit of 400mm FL was set for the calculation of biomass and production.

Influence of environmental variables on production

A number of environmental variables (Table 3) were assessed as predictors of fish biomass and production. Mean depth (Rawson 1952), surface area (Jenkins and Morais 1971) and catchment area (Niassanka *et al.* 2000) have been incorporated into empirical models and thus were included in this analysis. Other variables included were the amount of suitable spawning area, because this has been highlighted as an important factor contributing to reproductive success (Potts 2003), temperature (Schlesinger and Reiger 1982), conductivity (Ogelsby 1977, Henderson and Welcomme 1974) (both commonly used in empirical models) and turbidity, because it has an influence on photosynthesis, which in turn may influence algal biomass and therefore moggel growth (Potts and Khumalo 2005). Human activities in the catchment may influence the physiochemical conditions and algal biomass in reservoirs, and were therefore included in the analysis. Chlorophyll *a* was included, as it has been used in other empirical models (Melack 1976, Ogelsby 1977), as was algal biomass, which has been highlighted as an important factor influencing moggel growth (Potts 2003). The number of predatory and competitor (i.e. phytoplankton feeder) species was included to assess the effect of species interactions on biomass and production.

Pearson product-moment correlations for pairs of dependent (biomass and production) and independent (environmental, water quality, anthropogenic parameters) variables were obtained to investigate the relationship between each independent variable and either moggel biomass or moggel production, after the data was logarithm- transformed to stabilise variance.

Results

Mean surface water temperature ranged from 20.3(± 4.2) –22.1(± 5.2)°C and there were no significant differences between reservoirs (Table 4). High turbidity (61.0–151.2 FTU) was observed in all reservoirs, although significantly higher turbidity values were recorded in the Dimbaza and Ndlambe reservoirs (Table 4). All reservoirs were marginally alkaline, and water conductivity ranged between 11.3 and 112.6mS.m^{-1}. The mean chlorophyll *a* concentration in the reservoirs varied between 1.4 and 18.6µg.l^{-1} (Table 4) and thus, according to Walmsley's (1984) definitions, the Katriver reservoir could be classified as oligotrophic and the remainder as eutrophic.

Despite its extremely low CPUE and low catches, the Katriver reservoir fishery was allowed to continue until the end of the study. CPUE and catches were higher in the Laing reservoir fishery, despite the discontinuation of fishing after the theft of nets in August 2000. The fishermen in the Sinqemeni reservoir fished regularly until the end of the study, capturing large numbers of fish. In the Ndlambe reservoir, fishing was more sporadic. However, a high CPUE resulted in large numbers of fish being captured during the sampling period. Although fishermen seldom fished in the Dimbaza reservoir, the CPUE was extremely high and large numbers of fish were captured (Table 5).

Small fish (<300mm FL) dominated the population in the Katriver and Dimbaza reservoirs, while large fish (>300mm

Table 3: Parameters used to determine predictor variables for *Labeo umbratus* biomass and production in five small reservoirs in the Eastern Cape, South Africa

Dependent variables	Predictor variables			
	Morphometric	Physio-chemical	Anthropogenic	Biological
Biomass (kg.ha^{-1}) Production (kg.ha^{-1}.yr^{-1})	Mean depth (m) Surface area (ha) Suitable spawning area (% shoreline) Catchment area (km^{-2})	Temperature (°C) Turbidity (FTU) Conductivity (µS/cm)	Population density (no.ha^{-1}) Density of farmers (no.ha^{-1}) Density of manufacturers (no.ha^{-1}) Density of houses without flush toilets (no.ha^{-1})	Chlorophyll 'a' (µg.l^{-1}) Number of competitors Number of predatory species

Table 4: Average annual water quality parameters for Katriver, Laing, Sinqemeni, Ndlambe and Dimbaza reservoirs in the Eastern Cape Province, South Africa, between November 1998 and January 2002

	Katriver	Laing	Sinqemeni	Ndlambe	Dimbaza
Temperature (°C)	20.48 ± 5.2	20.30 ± 4.2	21.87 ± 5.4	22.05 ± 5.2	21.09 ± 6.1
Conductivity (µS.cm^{-1})	11.3 ± 4.7	51.3 ± 4.6	112.6 ± 6.7	107.9 ± 8.4	45.0 ± 7.8
Turbidity (FTUs)	65.89 ± 15.7	74.07 ±9.2	61.0 ± 0.4	147.0 ± 13.41	151.2 ± 44.1
pH	7.1–8.1	7.2–9.4	7.0–8.4	7.0–8.0	7.9–8.8
Chlorophyll *a* (µg.l^{-1})	1.4 ± 2.9	8.4 ±15.4	16.6 ± 15.4	15.7 ± 16.8	18.6 ± 17.7

Table 5: Catches of the experimental gill-net fisheries in the five reservoirs. Catch per unit effort (CPUE) expressed as number of fish per 10m of net per night

Reservoir	Dates of fishing records	Total days fished	Total catch (number)	CPUE (no./net/night)
Katriver	Nov 1999–Oct 2000	144	160	0.1 ± 0.1
Laing	Dec 1999–Oct 2000	82	1 257	1.57 ± 2.0
Sinqemeni	May 2000–Oct 2001	217	4 933	6.2 ± 3.0
Ndlambe	May 2000–Oct 2001	32	896	7.1 ± 2.3
Dimbaza	Oct 2001–Jan 2002	20	3 194	9.1 ± 3.9

FL) dominated in the Laing, Sinqemeni and Ndlambe reservoirs (Figure 2). There was wide variation in moggel growth, with ω values ranging between 75.2 in the Dimbaza and 124.8 in the Sinqemeni reservoirs (Table 6). Mean total mortality ranged from 0.14 in the Sinqemeni to 0.40 in the Katriver reservoirs (Table 6).

Moggel population estimates at the time of the first survey ranged from 1 348 in the Katriver reservoir to 7 784 fish in the Dimbaza reservoir, at densities of between 6.6 and 474.1 fish per hectare in the Katriver and Sinqemeni reservoirs, respectively (Table 7).

Moggel biomass estimates ranged between 1.9kg.ha^{-1} in the Katriver reservoir and 1 254.6kg.ha^{-1} in the Sinqemeni reservoir (Table 7), and were positively correlated to the chlorophyll *a* concentration and conductivity, and negatively correlated to mean reservoir depth, surface area and the number of predatory species (Table 8, Figure 3). Production ranged between 0.8 and 174.7kg.ha^{-1}.year^{-1} in the Katriver and Sinqemeni reservoirs, respectively (Table 7), and correlated to the same variables as biomass (Table 8, Figure 4). The P/B ratio ranged from 0.14 in the Sinqemeni reservoir to 0.40 in the Katriver reservoir (Table 7).

Discussion

There was considerable variation in the biomass (1.9–1 254.6kg.ha^{-1}) and production (0.8–174.7kg.ha^{-1}.yr^{-1}) estimates of the five moggel populations. This indicated that conditions in the reservoirs ranged from unsuitable to very suitable for this species. Other estimates of biomass and production for a number of cyprinid species in small reservoirs ranged from 3.3–248.0kg.ha^{-1} and 2.0–107.6kg.ha^{-1}.yr^{-1}, respectively (Downing and Plante 1993). This study therefore shows two extreme cases, one below (Katriver Reservoir) and one above (Sinqemeni Reservoir) the previous highest and lowest biomass and production recorded. This scale of variation has not previously been observed for one species in small reservoirs. The greatest variation in biomass and production has been found in the European perch (*Perca fluviatilis*), which only ranged from 7.7–37.0kg.ha^{-1} and 2.4–22.2kg.ha^{-1}.yr^{-1}, respectively (Downing and Plante 1993). The only other study of this type in Africa focussed on the biomass and production of the cichlid, *Oreochromis shiranus*, in two small reservoirs in Malawi where, while the biomass estimates were lower, production estimates were considerably higher (Mattson and Kaunda 1997), mostly as a result of the extremely high estimates of natural mortality, which were in excess of 2.yr^{-1}.

Since estimates of biomass and production were not obtained for fish smaller than 160mm FL in this study, the actual production estimates may be higher than recorded, as juvenile fish are generally considered to be the most productive component of the population (Balon 1974, Chadwick 1976). While small fish may have influenced the production estimates, the lack of consideration of fish larger than 400mm FL may have resulted in an underestimate of biomass, particularly in the Sinqemeni and Ndlambe reservoirs, which were dominated by larger fish.

The P/B ratios for moggel in these reservoirs were low, as P/B ratios for most species range between 0.48 and 3.4 (Welcomme 2001). The P/B ratio is regarded as an indicator of fishery potential (Welcomme 2001), and thus the results from this study suggest that the Katriver reservoir should have the highest and the Sinqemeni reservoir the lowest fishery potential. However, this was not the case, and therefore the use of the P/B ratio as an indicator of fishery potential may well not apply for these unexploited populations. According to surplus production theory (Quinn and Deriso 1999), the initiation of a fishery would increase the P/B ratio of high-density populations, by decreasing intraspecific competition. An increase in the P/B ratio of moggel in the Sinqemeni, Ndlambe and Dimbaza reservoirs would be more reflective of their fishery potential.

In unexploited systems, it appears that a better indication of fishery potential could be obtained by assessing the relative abundance and population structure of the fish. However, this, as with the P/B ratio, requires exhaustive sampling and consequently simpler, cheaper methods are being sought. Despite its low statistical power ($n = 5$), this study highlighted a number of environmental variables that can be used as predictors of moggel biomass and production.

Biomass and production were positively correlated to chlorophyll *a* concentration (algal biomass) and water conductivity, and negatively correlated to mean reservoir depth, surface area and the number of predator fish species.

The existence of relationships between fish yield and phytoplankton has been shown by a number of investigations (Melack 1976, Ogelsby 1977, Jones and Hoyer 1982, Biró and Vörös 1988, Downing *et al.* 1990, Gomes *et al.* 2002). Potts and Khumalo (2005) showed that growth of moggel appeared to be dependent on the biomass of diatoms, and thus the relationship between fish production and chlorophyll *a* concentration is not unexpected. They also concluded that blue-green algae were considerably less digestible than diatoms. Since algal communities generally change from diatom/green algae-dominated to blue-green algae-dominated in response to eutrophication (Welcomme 2001), there is likely to be an upper critical point where moggel production is no longer correlated with chlorophyll *a*. The use of chlorophyll *a* as a predictor of production, while sounding simple, is not practical. The concentration of chlorophyll *a* fluctuates seasonally and diurnally, and may be severely reduced by washout after flooding. Its use as a predictor of fish production would therefore require an appropriate, intensive sampling programme, which would limit its application.

Conductivity may be a useful alternative as a predictor of moggel production, as it is an indicator of nutrient status of the water, which in turn influences the productivity of phytoplankton and the rest of the food web (Welcomme 2001). In addition, water conductivity fluctuated considerably less than chlorophyll *a* concentration in these reservoirs (Table 4) and could therefore be used as a more reliable predictor of production. Conductivity has been used extensively in fish production models (Henderson and Welcomme 1974, Ogelsby 1977, MRAG 1995) and would be widely accepted as a suitable predictor of moggel production.

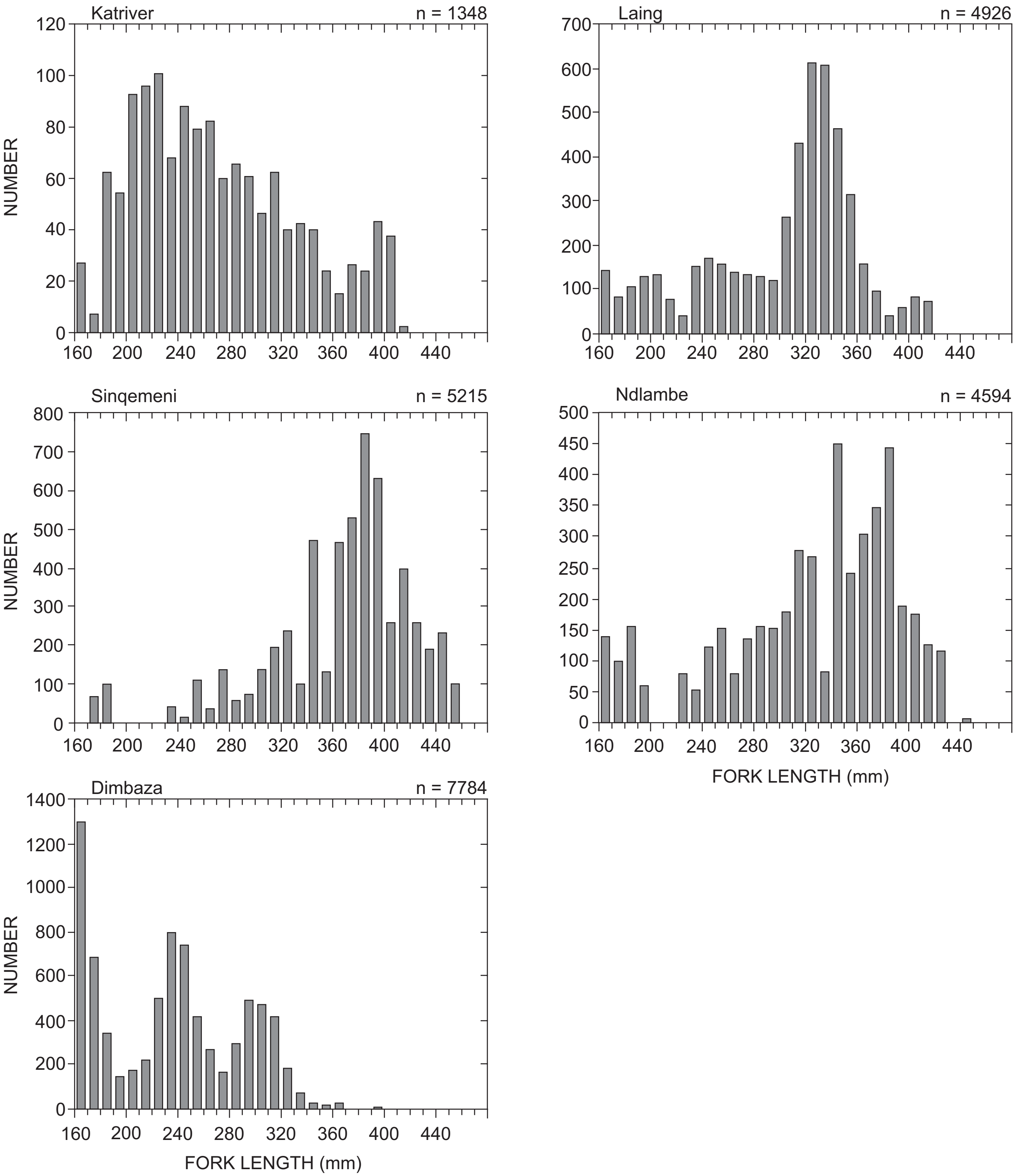

Figure 2: Population size structure of *Labeo umbratus* in five Eastern Cape reservoirs

Table 6: Population estimates and life history parameters used to estimate biomass and production of *Labeo umbratus* in five small reservoirs, Eastern Cape, South Africa

Reservoir	Population estimate	Moggel density (no.ha^{-1})	Mortality (Z)	Mean mass (g)	K	ω
Katriver	1 348	6.3	0.40	1 333.0	0.20	78.5
Laing	4 928	23.5	0.25	1 202.0	0.33	123.1
Sinqemeni	5 215	474.1	0.14	961.1	0.30	124.8
Ndlambe	4 594	287.1	0.21	932.6	0.26	114.3
Dimbaza	7 784	169.2	0.22	1 416.8	0.21	75.2

Table 7: Biomass, production and production-biomass ratios for *Labeo umbratus* in five small reservoirs, Eastern Cape, South Africa

Reservoir	Biomass (kg.ha^{-1})	Production (kg.ha^{-1}.year^{-1})	P/B
Katriver	1.9	0.8	0.40
Laing	33.7	8.2	0.24
Sinqemeni	1 254.6	174.7	0.14
Ndlambe	347.7	72.8	0.21
Dimbaza	214.2	46.8	0.22

There was a significant relationship between mean depth and fish production. This is not surprising, as mean depth has been used in most empirical fish production models (Rawson 1952, Hayes and Anthony 1964, Ryder 1965, Hanson and Legget 1982, Jenkens 1982, Prepas 1983). Generally, shallow reservoirs are considered more productive than deep ones (Brylinsky and Mann 1973, Marshall and Maes 1994). These systems have high surface-to-volume ratios, which results in an increase in photosynthesis and algal biomass production (Vollenweider 1976). Mean depth is a simple and easily measured variable, and is thus considered a suitable predictor variable for moggel biomass and production.

Jenkins and Morais (1971) suggest that there is a correlation between the surface area of a water body and fish production. Smaller systems are generally more productive, mostly due to their large surface area-to-volume ratios, thermal instability and rapid exchange of nutrients between sediments and water (Marshall and Maes 1994). This trend appeared to apply even within these 'small' (<1 000ha) reservoirs, and since this variable is easily measured it also appears to be a good predictor of moggel biomass and production.

The number of predator species in a reservoir was also negatively correlated with biomass and production. Whilst a negative relationship was expected, surplus production theory suggests that production would be higher when predation increases.

This trend, while not apparent from the biomass and production estimates, was visible in the P/B ratios, as reservoirs with the most predatory species (Katriver, Laing and Dimbaza) had the highest P/B ratios. The use of this variable as a predictor of biomass and production is not, however, considered appropriate, since the abundance of predators was not considered. Persson (1997) showed that predatory fish biomass in 32 Finnish lakes influenced the biomass of perch (*Perca fluviatilis*). This suggests that estimates of predator abundance may be used to predict the biomass of moggel. However, estimating the biomass of the predator species would be expensive and time-consuming and should, therefore, not be considered. Eutrophication in Eastern Cape reservoirs is caused primarily by the increased nutrient load from sewage run-off and crop fertilisers (Potts *et al.* 2005). Eutrophication is known to be an important factor influencing fisheries in large lakes and reservoirs (Colby *et al.* 1972, Leach *et al.* 1977, Marshall 1978, Bninska 1985, Cochrane 1985, Wolter *et al*. 2000). A normal consequence of eutrophication due to anthropogenic factors is the disappearance of predators and an overall reduction in the number of species (Colby *et al.* 1972, Bninska 1985). The absence of predators and the increase in plant production results in an increase in herbivorous and phytoplanktivorous species (Bninska 1985). In southern Africa, Marshall (1978) and Cochrane (1985) reported a decrease in the number of species and an increase in fish production in Lake Chivero and the Hartbeespoort reservoir, respectively. Although the process of eutrophication in small reservoirs should be faster than in large reservoirs, its effects on fish populations has not been documented. However, in southern Africa, the fish species composition in small reservoirs is unlikely to change, since these waters are generally dominated by a few tolerant species (Marshall and Maes 1994). In this study, increased algal biomass in these reservoirs resulted in an increase in moggel production and, since they readily digest diatoms (Potts and Khumalo 2005), the trends found in large systems appear to apply to small reservoirs.

A logical extension of this study would be the development of a model to predict moggel biomass and production in small reservoirs. The number of reservoirs in this study was low, and consequently the lack of statistical power prevented the development of a model. Future research in this field should therefore focus on obtaining biomass and production estimates for moggel in other small reservoirs throughout the distribution of this species. Since the reservoirs in this study were fairly uniform in temperature (Table 4) and most had constant water levels, future research should include reservoirs situated at higher altitudes, and therefore with lower temperatures, and in more arid regions.

Table 8: Results of the Pearson product-moment correlation between environmental factors (independent variable) and *Labeo umbratus* production and biomass (dependent variable)

	Production (kg.ha^{-1}.yr^{-1})		**Biomass (kg.ha^{-1})**	
	ρ	p	ρ	p
Biological parameters				
Production (kg.ha^{-1}.yr^{-1})			0.99	<0.01
Biomass (kg.ha^{-1})	0.99	<0.01		
Chlorophyll *a* (mg.m^{-3})	0.95	0.02	0.94	0.02
Number of predatory species	–0.93	0.02	–0.93	0.02
Number of competitor species	–0.87	0.06	–0.87	>0.05
Physiochemical parameters				
Temperature (°C)	0.83	0.08	0.81	0.09
Turbidity (FTU)	0.40	0.51	0.36	0.56
Conductivity (µS.m^{-1})	0.88	<0.05	0.88	<0.05
Morphological parameters				
Surface area (ha)	–0.92	0.03	–0.90	0.04
Mean depth (m)	–0.91	0.03	–0.90	0.04
Suitable spawning area (% shoreline)	0.86	0.06	0.85	0.07
Catchment area (km^{-2})	–0.48	0.41	–0.46	0.44
Catchment characteristics				
Population density (no.ha^{-1})	0.50	0.40	0.48	0.42
Density of farmers (no.ha^{-1})	–0.63	0.25	–0.65	0.24
Density of manufacturers (no.ha^{-1})	0.20	0.75	0.18	0.78
Density of houses without flush toilets (no.ha^{-1})	0.05	0.93	0.05	0.93

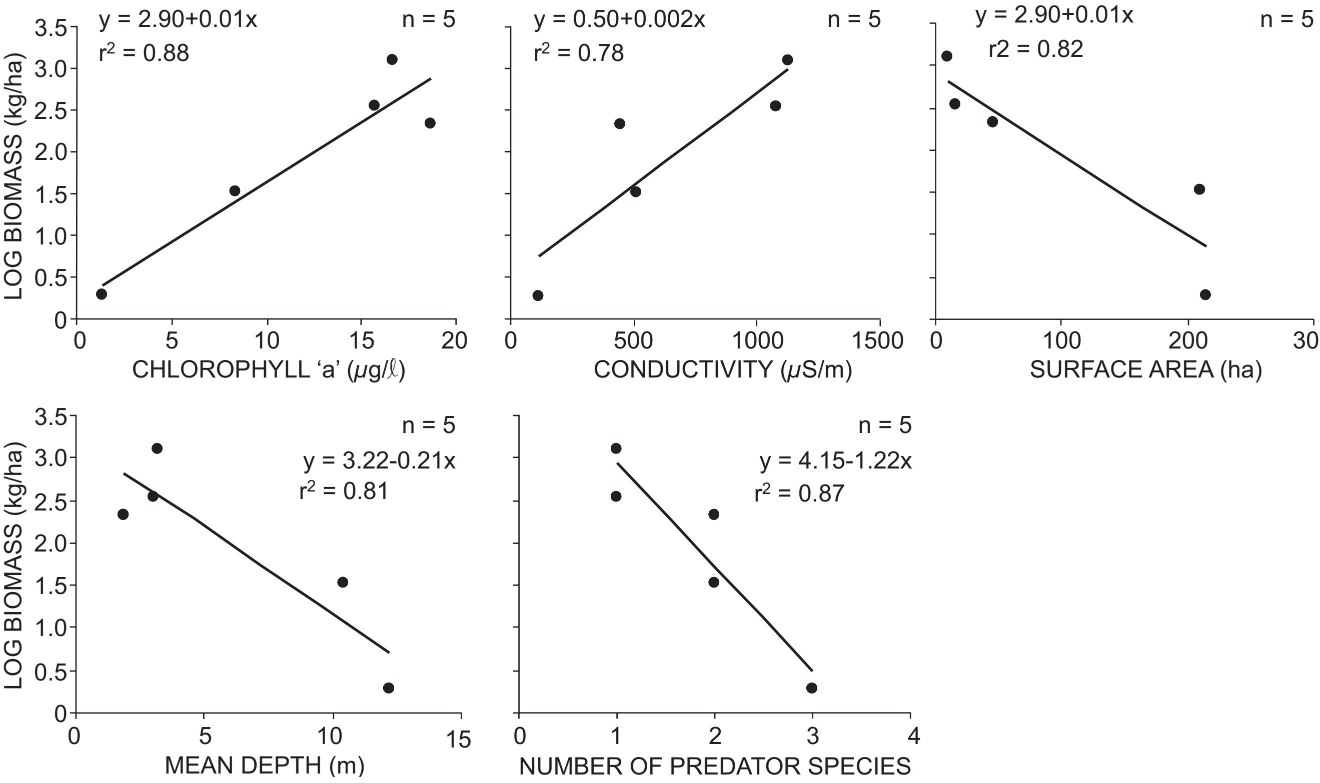

Figure 3: Relationship between *Labeo umbratus* biomass and selected biotic and abiotic variables in five small Eastern Cape reservoirs

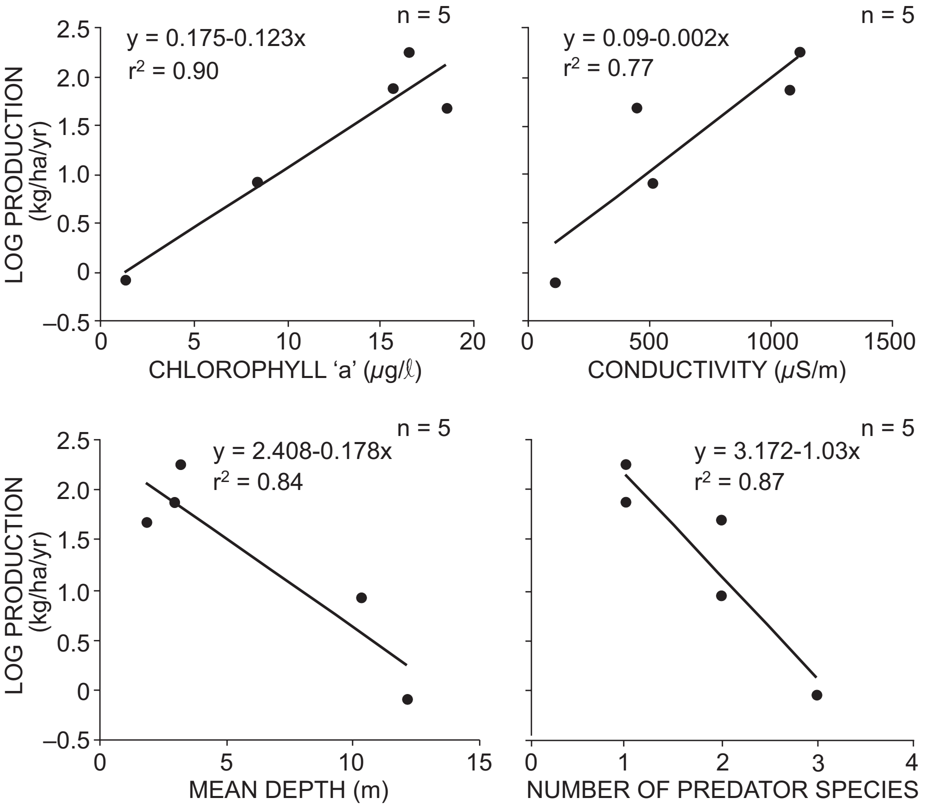

Figure 4: Relationship between *Labeo umbratus* production and selected biotic and abiotic variables in five small Eastern Cape reservoirs

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