Preliminary estimates of population size and capture rates of mature *Acanthopagrus berda* in the Kosi lakes system, South Africa, using mark-recapture methods

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Population size estimates and capture rates by various fishing techniques of mature estuarine bream, *Acanthopagrus berda*, were determined in the Kosi lakes system using mark-recapture methods. The total population size of mature *A. berda* was estimated to be 45 257 (95% confidence interval: 31 589–74 429) based on fish recaptured in fish traps and 56 112 (95% confidence interval: 25 505–374 080) using recaptures from recreational anglers. Fish traps were estimated to catch about 5% of the mature population of *A. berda* annually, while recreational rod and line angling and traditional spearfishing accounted for about 1% and 0.2% of the mature population respectively. Limited mark-recapture data for other species of fishes in the lakes yielded annual capture rates by fish traps ranging from 2.4% to 5.8%. These levels of fishing appear low enough to be sustainable, but evidence from a long-term monitoring programme indicates an increase in overall fishing effort in the Kosi lakes between 1984 and 1996 and a three-fold increase in the proportion of the *A. berda* population caught annually. However, there is no evidence from available catch per unit effort (CPUE) data that current levels of harvesting of *A. berda* are unsustainable. This needs to be confirmed through modelling of the *A. berda* stocks and continued monitoring of CPUE in all components of the Kosi lakes fishery. In the meantime, an increase in fishing effort directed at this species is not recommended.

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The tagging of fish has been used for decades by scientists throughout the world to investigate many aspects of fish biology and ecology. Valuable information on fish movements, growth rates, mortality rates and population estimates has been obtained through tagging (Blaber 1973; Davis & Anderson 1989; Baker, Lafferty & Quinn 1991; Attwood & Bennett 1994; Cliff, Van der Elst, Govender, Witthuhn & Bullen 1996; Govender 1996). In the Kosi lakes system in KwaZulu-Natal, South Africa, potential conflict arose between indigenous artisanal fishermen, principally using traps, and recreational anglers using rod and line, as the artisanal fishermen believed that the catches of the recreational anglers were reducing their trap catches. The conservation authority responsible for the area was also concerned that fish stocks might be over-exploited. In 1980, a project was designed to investigate the exploitation of fish resources in the Kosi lakes system with a view to determining sustainable levels of fishing and resolving the conflict between recreational and artisanal fishermen (Kyle 1986). This paper describes a mark-recapture experiment which was undertaken as part of this project to obtain population estimates of mature estuarine bream, *Acanthopagrus berda*, and to determine their capture rates by various fishing techniques.

Materials and methods

Study site

The Kosi lakes system is situated on the east coast of South Africa just south of Mozambique (Figure 1). It is a series of interconnected water bodies about 10 km long running parallel to the Indian Ocean immediately behind high vegetated coastal dunes. The estuary is linked to the sea via a mouth in the north. The marine influence generally extends into Lake Nhlange, where salinities are usually less than 6‰ (Begg 1978; R. Kyle, unpublished data). The water in Lake Amanzimnyama is entirely fresh (Begg 1980). Various aspects, including the fishes and fisheries, of the system have been described (Tinley 1964; Felgate 1965; Begg 1978, 1980; Blaber 1978; Blaber & Cyrus 1981; Kyle 1981, 1986, 1993,

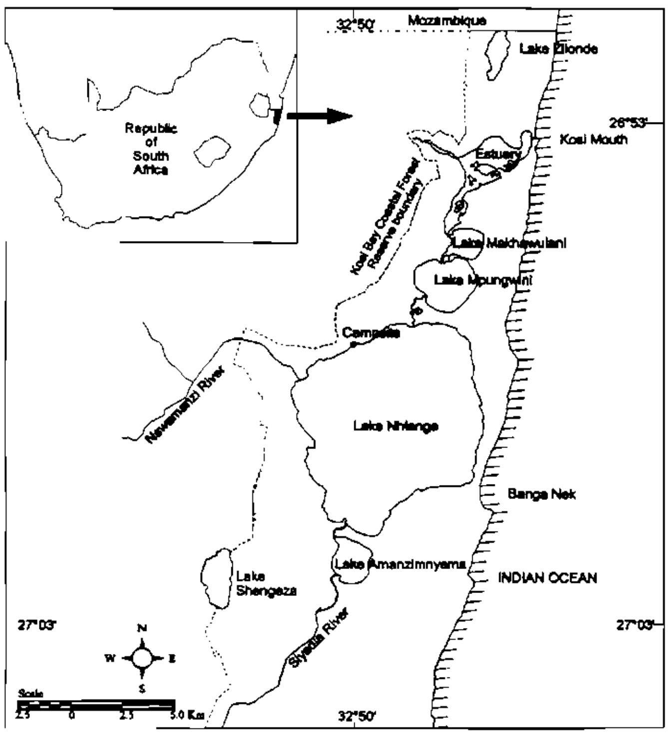

Figure 1 Map of Kosi Bay lakes system.

1995, 1996; Cyrus & Blaber 1984a,b). Most of the fish species in the system which are of importance to man are of marine origin (Blaber & Cyrus 1981; Kyle 1986, 1993). Recreational angling is restricted to Lakes Makhawulani, Mpungwini and Nhlange, while traditional fish traps are situated in the estuary and Lake Makhawulani. The fish traps consist of a fence which stretches from the channel towards the bank and guides fish into funelled baskets. The fish are collected from the baskets with the aid of a spear (Kyle 1986). The number of baskets per trap varies but averages three (R.Kyle, unpublished data). Fish are mostly caught in the fish traps as they migrate from the lakes to their spawning grounds at the mouth or in the sea (Kyle 1986).

Tagging programme

The principle of the programme was to tag fish in the lakes just prior to their spawning migration to the mouth (Garratt 1992). In this way, tagged fish would initially be available for capture by the recreational anglers and later, as they moved through the estuary, they would be caught in the traps. An efficient tag recovery system was essential and, as a precursor to the tagging programme, the concept was explained to the local fishermen at a series of meetings which culminated with a visit by the local Nkosi (Chief) to the lakes where he tagged and released the first fish. The endorsement by the Nkosi guaranteed local support for the scheme, and a small financial reward for each tag returned ensured that recoveries were reported. Leaflets distributed to campers and a notice in the campsite tourism office informed recreational anglers of the tagging programme and encouraged them to report tag recoveries.

Tagging effort was concentrated on the estuarine bream, *Acanthopagrus berda*, as it fitted most of the criteria important to the success of the scheme, i.e. it is abundant, it is caught regularly by artisanal and recreational anglers, and it will usually survive the trauma of tagging. Floyd FD 67 spaghetti-type tags bearing a unique number and a postal address were used. The tags were applied below the rear of the dorsal fin about midway between the dorsal surface and the lateral line, using a standard applicator. All tagging was carried out by the first author to avoid differences in tagging methods.

During 1983/4, the year before the intensive *A. berda* tagging project, many fishes of various species were also tagged in the Kosi system. Similar tagging and recovery methods to those described above were used. Tags were recovered over the period of a year.

Data analysis

The population size of mature *A. berda* was estimated using Chapman's formula (Ricker 1975):

$$N = \frac{(M+1)(C+1)}{R+1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where M = number of marked animals, C = total number of captured animals and R = number of tagged animals recaptured. The total number of fish caught in the traps was monitored routinely between 1980 and 1984 as part of the larger study of fish populations in the system (Kyle 1986). Estimates of total recreational catches were made from voluntary visitor catch return cards, which were also analysed as part of the larger study, and from monitoring of catches at the launch site. The proportion of the number of tagged fish recaptured by each fishing technique to the total number of fish tagged was used as an estimate of the exploitation or capture rate by each technique (Ricker 1975). Ninety-five percent confidence limits of population estimates and recapture rates were obtained by substituting 95% confidence limits of the number of tags recovered (obtained from a table of fiducial limits for the Poisson distribution) for R in the respective formulae (Ricker 1975).

Results

A total of 500 *A. berda* was tagged in the Kosi lakes upstream of the fish traps between mid-November 1984 and March 1985. Of the fish tagged, 279 were caught on rod and line, 157 were purchased live from local fishermen and the remainder were caught by seine and gill netting. Twenty-three tagged *A. berda* were recovered from the traps, a further three by recreational anglers and one by a traditional spear-fisherman, during the year following tagging (Table 1). Most recoveries were made between April and June 1985 and the mean period between tagging and recapture was 37.2 days (range 1–123 days).

All fish tagged were larger than 22 cm total length (TL), the size at which 50% of *A. berda* are mature (Wallace 1975). Fish traps mostly catch fish larger than this because of the way the traps are constructed (Kyle 1986), and recreational anglers only reported catches of fish larger than 25 cm TL as this is the minimum legal length for *A. berda*. Population size estimates and capture rates were thus based on the mature *A. berda* population.

The recovery rate of tagged fish from the fish trap catches indicated a capture rate by the fish traps of about 5% of mature *A. berda*. The total mature *A. berda* population was estimated to be 45 257 fish with 95% confidence limits of 31 589 and 74 429 (Table 1). The same calculations made from recreational angling returns gave a capture rate of about 1% and a population estimate of 56 112 (Table 1). The 95% confidence interval (25 505–374 080) for this population estimate was greater than that for the fish trap data because recoveries and total catch were lower. A tagged fish was also

Table 1 Summary of results of the 1984/5 *Acanthopagrus berda* mark-recapture programme with estimates of capture rates and population size, including 95% confidence intervals (C.I.). Number of fish tagged (M) = 500

	Fish traps	Recreational fishing	Spearfishing
Total catch (C)	2168	447	*
Recaptures (R)	23	3	1
95% C.I.	14.6–34.4	0.6–8.8	**
Capture rate (R/M) %	4.6	0.8	0.2
95% C.I.	2.9–6.9	0.12–1.76	**
Population estimate	45 257	56 112	–
95% C.I.	31 589–74 429	25 505–374 080	

*No accurate estimate available for total spearfishing catch.

**R too low to allow unbiased estimate of 95% C.I.

caught by a local spearfisherman using a traditional spear. This enabled a rough estimate to be made of the percentage catch by this method (Table 1), but, as total spear catches were not known, no estimate of total population size could be made.

During the 1983/4 tagging programme, 27 tagged fish of four different species were recaptured in the fish traps (Table 2). Annual capture rates ranged from 2.4% for *Gerres rappi* to 5.8% for *Rhabdosargus sarba*, with upper 95% confidence

Table 2 Numbers of fish tagged and recaptured from fish traps and estimates of capture rates with 95% confidence intervals (C.I.) for the 1983/4 tagging programme

Species	Total tagged (M)	Recaptures (R)	Capture rate (R/M) % Rate	95% C.I.
Pomadasys commersonni	88	4	4.5	1.1–11.5
A. berda	172	9	5.2	2.3–9.9
Rhabdosargus sarba	191	11	5.8	2.8–10.3
Gerres rappi	126	3	2.4	0.5–6.7

limits ranging from 6.7% to 11.5%. The capture rate of 5.2% estimated for *A. berda* from the 1983/4 tagging is similar to the 4.6% obtained for fish traps using the 1984/5 data (Table 1).

Discussion

If mark-recapture data are to produce useful estimates of fish populations, some important problems need to be addressed. Several factors could depress the number of tagged fish available to be caught subsequently, or otherwise distort the computation. Ricker (1975) summarised the most important factors which are outlined below.

The natural mortality rate of mature *A. berda* is not known. Although numbers of *A. berda* dying between the time of marking and recapture would not affect estimates of adult populations, provided tagged and untagged fish died at the same rates, they would, nevertheless, distort recovery rates. The same would be true if some mature fish did not migrate to the mouth, although available evidence (Garratt 1992) suggests that all mature *A. berda* undertake this annual migration. Although every effort was made to tag all the fish in as short a time period as possible, an extended capture period became unavoidable owing to the difficulty in capturing large numbers of *A. berda*. A few *A. berda* were captured in the traps before tagging was completed, but none of these fish was tagged. However, there was some overlap of tagging and recaptures by the recreational anglers. This could have resulted in an over-estimate of population size which may partially explain the higher population estimate obtained from the recreational angling data (Table 1). The small number of tagged fish recovered by the recreational anglers also reduces the reliability of the estimates based on these data.

Mortality of tagged fish owing to capture or tagging stress can be a serious problem, but one reason for choosing *A. berda* was that it is a robust fish which usually survives rough handling. Any tagged fish which showed signs of distress was put in a holding pen over night and, if not fully recovered by morning, was killed. It is also possible that tags could make the fish more easily visible to predators and thus increase mortality in the clear waters of the Kosi lakes. However, the tags chosen were small and not easily visible under water and they soon became covered with algal growth which further reduced their visibility. Thus, increased predation owing to the tags should have been minimal.

Capture by rod and line or by traps should not be influenced by tags as there was no evidence that tagged fish behaved differently from untagged fish. On two occasions, tagged fish were recaught on rod and line immediately after initial tagging, and several times they were caught again the following fishing day, suggesting that feeding was not affected by tagging. All tagged fish recovered were found nearer the sea than their position of release, indicating that they continued their spawning migration after tagging. It appears that *A. berda* has a strong spawning drive and even the trauma associated with tagging does not deflect this. Since it was virtually impossible to see a tag on a fish in the shallows, spearfishing catch success should not have been influenced by the tags.

Loss of tags will also affect estimates of population size and capture rate (Ricker 1975). Tag loss can be minimised through the correct choice of tags and by careful tagging in a suitable position. The tags used for *A. berda* were small and strong, and a tag inserted behind the medullary rays of *A. berda* was very difficult to remove. This tag site was found to be the most effective for *Tilapia* spp. (Chilvers & Gee 1969). Blaber (1973) also used the same tags and tag site on juvenile *Rhabdosargus holubi*, and his control experiment showed tag loss to be minimal over a nine-month period. A control experiment to quantify tag loss was attempted at Kosi Bay, but *A. berda* did not survive well in enclosures. In the field, however, tagged fish from earlier tagging programmes were still being recovered well over a year after initial tagging. The longest period to date between tagging and recovery for *A. berda* with these tags is just over six years.

It is likely that adequate mixing of tagged and untagged fish occurred, as the fish were tagged throughout the lakes over a period of several weeks. Tagged fish were regularly recaught in the traps together with untagged fish, but no more than one tagged fish was caught per trap in one day.

Detection of tagged fish in the traps should have been almost total, as virtually all the trap catches were being monitored on a daily basis during the period of recoveries as part of another study (Kyle 1986). The publicity associated with the trap monitoring also meant that local spearfishermen knew of the project, or at least the reward, and their rate of reporting should have been good. Recreational fishermen were aware of the scheme and the reward system, and most catches were also monitored at the principal boat launching site.

Evidence from this project and from Garratt (1992) suggests that the population of *A. berda* in the Kosi lakes system is fairly isolated from populations in other estuaries in the region, as the species is rarely seen or caught in the sea adjacent to the system. Therefore, it is believed that no immigration into the pre-spawning mature population of *A. berda* should have occurred during the recapture period. However, a small proportion of fish may have been recruited from smaller size classes into the mature population during the capture period, thus affecting the population estimate slightly.

Although the number of recaptures was fairly low, most of the criteria for a successful mark-recapture experiment were met, and the population size and recapture rates are considered to be reasonable first estimates. The close agreement between the population estimates of *A. berda* based on fish trap and recreational catches, and between recapture rates of *A. berda* in fish traps for two consecutive years, increases the credibility of the results.

Conservation and management

Results from the 1984/5 tagging study suggest that combined annual capture rates of *A. berda* for all fishing techniques assessed are under 10% of mature fish (based on upper confidence limits). Data from earlier (1983/4) tagging of *A. berda* produced similar results and those for other species suggest similar levels of capture, with upper 95% confidence limits of all offtake rates being less than 12%. Unavoidable factors, such as the tagging overlapping the recovery period, and mortality of tagged fish, will depress estimates of capture rates below actual levels but, even in the unlikely event that the results were underestimated by 100%, this still represents an annual capture rate of only 25% of mature fish. It seems unlikely that this level of harvesting would be unsustainable. Further, the impact of recreational anglers on trap catches should be minimal as recreational anglers catch a very small proportion (1–2%) of the adult population. The traps mainly catch fish in the estuary after they have left the lakes where they are accessible to recreational anglers, so there should be little conflict of interest between trap and recreational anglers. Other fishing techniques, such as illegal gill netting (Kyle 1986), were not assessed. The results of this study suggest that levels of fishing in the early 1980s were probably sustainable and that catches by recreational anglers were unlikely to affect the catches by trap fishermen.

However, evidence from a long-term monitoring programme covering various components of the Kosi lakes fishery (to be discussed in detail in separate publications) suggests that overall fishing effort in the Kosi lakes has increased substantially since 1984. The number of traps in the Kosi system showed a gradual increase from 66 traps in 1981 to 90 traps in 1993, followed by a sudden increase to 121 traps in 1995 (R. Kyle, unpublished data). Trap catches increased from about 40 000 fish in 1981 to an estimated 93 000 fish in 1993. The number of recorded outings by recreational anglers in the Kosi system rose from 1 887 angler outings in 1986 to 6 635 angler outings in 1995, and recorded annual catches (of which about 6% were *A. berda*) increased from 2 300 to 4 200 during this period (J. Mann-Lang, Oceanographic Research Institute, unpublished data extracted from National Marine Linefish System database). These recorded changes in recreational angling are partly attributable to improved data collection, but there is little doubt that effort has increased in this component of the Kosi lakes fishery. Gill nets have been used illegally in the Kosi system since the 1950s (Tinley 1964), but an experimental gill net fishery was initiated by the conservation authorities in 1990 (Kyle 1995). Five permits were issued in 1992 and this number had risen to 35 by 1995. Total legal catches of fish in gill nets increased from 4 800 in 1992 to 60 900 in 1996. *A. berda* constituted 3 to 6% of these catches (R. Kyle, unpublished data). Catches by illegal gill netters are unknown but are undoubtedly substantial (R. Kyle, pers. obs.). Traditional spearfishing also contributes significantly to fishing effort in the lakes with annual catches between 1990 and 1995 averaging 8 700 fish in 1 930 fisherman days (R. Kyle, unpublished data). Unfortunately, the proportion of *A. berda* in these catches is not known.

A. berda is known to constitute about 6% of the total catches of recreational anglers and 3 to 6% of the catches of gill netters (see above). If it is assumed that *A. berda* makes up 7% of the catches of trapfishermen (as was the case in 1981–1984; R. Kyle, unpublished data) and about 6% of the catches of spearfishermen, and that illegal gill netters catch similar numbers of fish to legal gill netters, then the total annual catch of *A. berda* by the four major components of the Kosi lakes fishery is currently about 14 600 fish. If it is further assumed that the total population of *A. berda* has remained unchanged at about 50 000 fish (Table 1), then the current annual capture rate of *A. berda* is about 29%. This is about three times higher than the upper limit of the estimated capture rate for this species in 1984/5 (Table 1).

If the population of *A. berda* was being progressively eroded by over-fishing, a decrease in the catch per unit effort (CPUE) of this species would be expected. CPUE data for the various components of the Kosi lakes fishery are available for several years, but their usefulness in detecting trends in catch rates of *A. berda* is limited for various reasons. The catch rate of *A. berda* in traps decreased between 1981 and 1984 (Figure 2a). However, only a small proportion of the traps were monitored after 1984 and very few *A. berda* were caught in these traps, so subsequent trends in CPUE of trap-caught *A. berda*

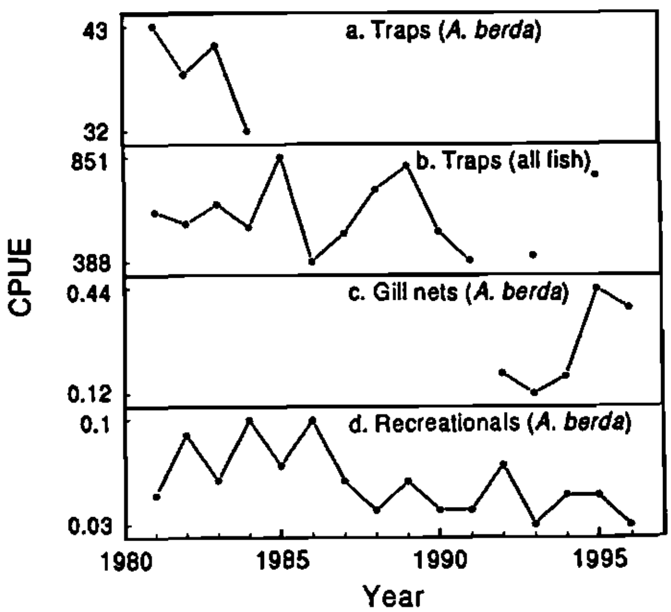

Figure 2 Catch per unit effort (CPUE) of fish in various components of the Kosi lakes fishery: (a) fish traps (*Acanthopagrus berda* only); (b) fish traps (all fish); (c) gill nets (*A. berda* only) and (d) recreational anglers (*A. berda* only). Units of CPUE are number of fish/trap/year for traps, number of fish/net/night for gill nets and number of fish/angler/day for recreationals.

are unknown. The CPUE of trap fishermen, based on estimated total catches in all traps, has fluctuated considerably but has shown no consistent downward trend since 1981 (Figure 2b), suggesting that the complaints of these fishermen regarding decreasing catches were probably unfounded. The CPUE of *A. berda* in gill nets rose sharply in 1995 (Figure 2c), but it remains to be seen whether these catch rates can be maintained. The catch rate of recreational anglers appears to have decreased markedly after 1986 (Figure 2d), but this is thought to be largely owing to improved recording of unsuccessful (zero catch) fishing trips (J. Mann-Lang, Oceanographic Research Institute, pers. comm.). Since 1987, the CPUE of *A. berda* by recreational anglers has shown no obvious downward trend. Thus, there is no clear evidence from available CPUE data that current levels of harvesting of *A. berda* are unsustainable.

Continued monitoring of all the components of the Kosi lakes fishery in a standardised manner is essential to the wise management of the resources in this system. This is particularly important in view of the degraded state of many other estuarine systems in KwaZulu-Natal, which is believed to have contributed to the decline in catches of many estuarine species, in particular *A. berda* (Grindley & Heydorn 1979). The recently introduced gill net fishery in the Kosi lakes merits close monitoring as its long-term effects are as yet unknown. Consideration should also be given to recording catches in some fish traps closer to the mouth where the catches of *A. berda* are likely to be higher and therefore more useful as an index of abundance of this species.

Little is known about growth and mortality rates of South African populations of *A. berda*, but a study of populations in Kuwait suggests that it is a fast-growing, long-lived (14 years) species with a low mortality rate (Samuel & Mathews 1987). It is also a protandrous hermaphrodite (Garratt 1993; Tobin, Sheaves & Molony 1997) which could make it particularly vulnerable to over-fishing. Modelling of the *A. berda* stocks in the Kosi lakes needs to be undertaken to ensure that present levels of harvesting of this species are sustainable. In the meantime, a further increase in fishing effort directed at this species is not recommended.

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