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Shark Catch Trends and Effort Reduction in the Beach Protection Program, KwaZulu-Natal, South Africa
(Elasmobranch Fisheries - Oral)

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Abstract

Shark nets have been set off the beaches of KwaZulu-Natal, South Africa, since 1952, to minimise risk of shark attack. Reliable catch data for each of the 14 shark species commonly caught are available from 1978 only. The nets fish in fixed localities very close to shore and there is an absence of fisheries independent data for most species. There is uncertainty about factors such as localised stock depletion and philopatry. Catch rates of seven species show a significant decline, but this figure drops to four with the exclusion of the confounding effects of the annual sardine run. Of the four, two are caught in very low numbers (Java *Carcharhinus amboinensis* and great hammerhead *Sphyrna mokarran*) and it is probable that any decline in population size reflects either local depletion or additional exploitation elsewhere. The other two species (blacktip *C. limbatus* and scalloped hammerhead *S. lewini*) are caught in greater numbers. *C. limbatus* appears to have been subject to local depletion. Newborn *S. lewini* are captured by prawn trawlers and discarded, mostly dead, adding to pressure on this species. As a precautionary measure, and in the absence of clarity on the question of stock depletion, in September 1999 a process of reducing the number of nets per installation was begun, with a view to reducing catches. In addition, a final phase of experimentation with drumlines (set lines, each with a single baited hook) began in March 2001. Once complete, it is hoped that some of the remaining nets will be replaced with drumlines. Drumlines are more selective than nets in terms of shark species caught, and take little non-shark bycatch. An essential consideration throughout the process is that bather safety remains the priority.

Introduction

The KwaZulu-Natal shark control program, that exists to minimise risk of shark attack at selected recreational beaches, constitutes a form of shark fishery (Cliff and Dudley, 1992). The Natal Sharks Board monitors trends in catches of sharks (and other animals) with a view to monitoring the environmental impact of the program. Also, the Board routinely considers alternatives to and modifications of its current shark fishing methods. In two overviews published some years ago, Dudley and Cliff (1993a, b) stated that catch rates of most of the 14 species of shark that are caught regularly declined in the initial years of the program but showed no trend after the mid-1970s. Catch rates of two species, the tiger shark and the spotted ragged-tooth shark, actually increased over the period 1972 to 1990, although the quality of data during the early part of this period was poor.

In this report, an updated set of catch plots and linear regression results is presented and discussed. The possibility that localised stock depletion may occur is also discussed. A process of reducing the number of shark nets per protected beach is described, the objective being to reduce captures while continuing to provide safe bathing. Finally, mention is made of experimentation with drumlines, a more selective type of shark fishing.

Methods

Time series of catch and CPUE are plotted for each of the 14 shark species caught annually in the KZN nets. Total catch and effort data are presented for the period 1966 to 1999, inclusive (Fig. 1), but because species identification is regarded as unreliable pre-1978, catch and CPUE plots for each species are presented for the period 1978-1999 only (Fig. 2). Linear regression lines of CPUE against time, where significant, are included in Figure 2. Actual probability values for regressions of both catch and CPUE against time are given in Table 1. Sexes are combined.

An annual phenomenon that occurs each winter around June and July is the influx into KwaZulu-Natal coastal waters of shoals of sardines *Sardinops sagax,* an event known as the sardine run (Armstrong *et al*., 1991). Annual catches of certain shark species have been influenced historically by two factors associated with the sardine run; (i) variations in the "strength" of each sardine run (i.e., the apparent abundance of sardines and the proximity of the shoals to the coast) and (ii) an improvement over time in the ability of the NSB to monitor movement of the shoals and hence to minimise catches of accompanying sharks (and dolphins) by removing the nets in advance of their arrival (Fig. 3). Hence, time series of catch and CPUE in which data from the months of June and July were excluded are also plotted (Fig. 2). As an indication of the effect of the sardine run, 658 sharks were caught during the months of June and July in 1984. This figure equates to 51% of the mean annual shark catch for the period 1978-99. Isolating the confounding effects of the sardine run on catch and separating them from any underlying trends in actual population abundance is unlikely to be possible, particularly for those species or size classes that are caught primarily during the sardine run. The exclusion of "sardine run" catches eliminates these effects, but also, of course, results in the exclusion of a considerable amount of information about the affected species.

Presented in Table 2 are the signs of the regression slopes, together with their associated probabilities, of precaudal lengths of all sharks dissected (PCL_{all}), all mature males ($PCL_{mat.\ male}$), all mature females ($PCL_{mat.\ female}$) and all pregnant females ($PCL_{pregnant}$), respectively, each against time and for each species. In this case the unit of time was day of capture rather than year. In the case of (PCL_{all}) only, sharks captured in June and July were omitted.

For those regressions for which the slope is statistically significant, predicted values for 1978 and for 1999 (catch and CPUE), or for 1 January 1978 and 31 December 1999 (length), are given in Table 3.

Results

After nets were introduced at a single location, Durban, in 1952, total shark catch and CPUE declined steeply in the first year (Fig. 1). In the mid 1960s effort increased rapidly with the introduction of shark nets at a number of beaches. This resulted in a rapid increase in total catch and CPUE but both had declined by 1970, from when annual catch fluctuated about a mean of 1228 sharks (*S.E.*=69.7). Catches associated with the annual sardine run are included in Figure 1.

(a) Blacktip *Carcharhinus limbatus* ($\bar{x}$=113 sharks per year, incl. sardine run data, 94 sharks per year, excl. sardine run data, 1978-99; Fig. 2a): About two thirds of the catch consists of mature animals. There is a significant decrease in catch and CPUE but no apparent change in size. The decrease in catch therefore may not be biologically significant, but the extent of the decrease is marked. This is a species in which localised stock depletion may occur. When shark nets were first installed at the relatively remote locality of Richards Bay (84 km from the nearest existing net installation) in 1980, the catch rate in the first year was 28 sharks.km-net^{-1} and dropped to 15 sharks.km-net^{-1} in the second year (Fig. 4a). Since 1981 the average annual catch rate has been 3 sharks.km-net^{-1}.

(b) Copper *Carcharhinus brachyurus* ($\bar{x}$=117 sharks (incl.), 34 sharks (excl.); Fig. 2b): The catch consists primarily of late adolescents and adults, is very seasonal and variable and is markedly affected by the sardine run. There is no trend in catch or CPUE but there is a decrease in size of animals caught outside the sardine run. There is a slight but significant increase in size of mature males. This species is exploited commercially in Cape waters and so is impacted by two fisheries (shark nets and the commercial line fishery) across its southern African range.

(c) Dusky *Carcharhinus obscurus* ($\bar{x}$=256 sharks (incl.), 175 sharks (excl.); Fig. 2c): This species is caught in largest numbers in the shark nets, with the catch consisting of a wide range of size classes, from newborn to adult. There are no significant trends. The dusky shark is impacted relatively heavily by recreational anglers, who target juveniles, as well as by the shark nets. There is occasional exploitation of juveniles by the commercial linefishery. Govender and Birnie (1997), in a mark-recapture study of juvenile dusky sharks, expressed concern that fishing mortality exceeds natural mortality, which suggests overfishing. They noted, however, that a recent increase in conservation awareness amongst recreational anglers has led to an increase in the release of sharks, which should alleviate pressure on the stock.

(d) Great hammerhead *Sphyrna mokarran* ($\bar{x}$=11 sharks (incl.), 10 sharks (excl.); Fig. 2d): The catch consists primarily of adolescents and adults. This species shows mixed indices, with declining catch and CPUE but increasing size of mature females. While the apparent change in size is probably a statistical artefact (n=15), the decline in catch appears to be a genuine trend. This species is a summer migrant and is widely distributed in the southwest Indian Ocean (Cliff, 1995). It seems unlikely that an annual catch of less than 20 animals could lead to a decline in the stock, unless a sub-group is being locally impacted.

(e) Great white *Carcharodon carcharias* ($\bar{x}$=38 sharks (incl.), 30 sharks (excl.); Fig. 2e): There is widespread interest in the conservation status of the great white shark. It has received legal protection in a number of countries, including South Africa, although the local protection was not conferred on the basis of evidence of declining stocks (Compagno, 1991). More recently, Cliff *et al*. (1996) argued that initial estimates of fishing mortality rates did not suggest overfishing, although they acknowledged that these estimates need to be improved before any relaxation of the legislation is considered. The animals caught in the KwaZulu-Natal shark nets consist largely of adolescents. In the present analysis, catch shows a non-significant declining trend and CPUE a significant decline. With the exclusion of catches taken in June and July, however, the sign of the catch trend changes from negative to positive (still non-significant) and the CPUE trend is no longer significant. Despite these mixed signals, the data do tend to support the suggestion that protection of the white shark should continue.

(f) Java *Carcharhinus amboinensis* ($\bar{x}$=13 sharks (incl.), 13 sharks (excl.); Fig. 2f): This is a low-catch species, the catch consisting primarily of adolescents, that shows a significant declining trend in catch, CPUE and PCL_{all}. The trends in catch and CPUE are heavily influenced by an outlier data point (1980), the exclusion of which renders the slopes no longer significant. The outlier is explained by the introduction of nets at Richards Bay in 1980; 25 of the 42 Java sharks caught on the coast in 1980 were caught at Richards Bay. The catch trend is no longer significant after the exclusion of catches in June and July but this change is unrelated to the sardine run, the Java shark being caught primarily in summer and on the north coast (Cliff and Dudley, 1991a). If declining catch, CPUE and size reflect a decline in local abundance of the species, it is possible either that one or more local sub-groups have been impacted by net catches on the north coast or that a more widespread population is being impacted by artisanal gill netting in southern Mozambique. Localised stock depletion is indicated not only by the Richards Bay example (Fig. 4b) but also by the capture in 1984 of 47 Java sharks during three weeks of temporary netting at Mtunzini, which is situated between Richards Bay and Zinkwazi (Cliff and Dudley, 1991a).

(g) Shortfin mako *Isurus oxyrinchus* ($\bar{x}$=14 sharks (incl.), 10 sharks (excl.); Fig. 2g): This is a low-catch, oceanic species, the catch consisting primarily of late adolescents and adults, with a significant decline in total CPUE but, conversely, a significant increase in PCL_{all} and PCL_{pregnant}. As in the case of the Java shark, the exclusion of a single influential point (1979) from the CPUE data renders the slope no longer significant. The size regression for pregnant females was based on a sample of three and thus cannot be regarded as biologically significant.

(h) Spotted ragged-tooth *Carcharias taurus* ($\bar{x}$=214 sharks (incl.), 171 sharks (excl.); Fig. 2h): Catches of this relatively high-catch species appear cyclical, with three distinct periods (low-high-low) between 1978 and 1999. It was the second period of low catches that ensured that the increasing trend reported by Dudley and Cliff (1993a,b) did not persist into the late 1990s. Although the catch trend is no longer significant, there are small but significant declines in $PCL_{\text{mat. female}}$ and PCL_{pregnant}. This species has a very low fecundity (two young, possibly produced every two years only) and hence may be particularly susceptible to exploitation pressure. Concerns about the stock,

expressed by South Africa's Marine Linefish Management Association, led to the species being decommercialised through the Marine Living Resources Act of 1998. Fortunately, ragged-tooth sharks survive well in the KZN shark nets and about 40% of the annual catch has been released over the last decade. Concerns have been expressed about the conservation status of this species elsewhere in the world (e.g. Pollard *et al*., 1996).

(i) Sandbar *Carcharhinus plumbeus* ($\bar{x}$ =23 sharks (incl.), 22 sharks (excl.); Fig. 2i): This species is caught in low numbers, consisting of both adolescents and adults, and shows no significant trends. It has been impacted heavily by fishing activities elsewhere in the world, i.e., off the US Atlantic coast (Musick *et al*., 1993).

(j) Scalloped hammerhead *Sphyrna lewini* ($\bar{x}$ =158 sharks (incl.), 145 sharks (excl.); Fig. 2j): There is a substantial and statistically significant decline in catch and CPUE but, by contrast, a concurrent increase in PCL_{all}. Most of the animals caught in the nets are juvenile or adolescent, with males outnumbering females by 2.3:1 overall. Fennessy (1994) reported large catches of newborn scalloped hammerhead sharks by prawn trawlers on the Tugela Bank, ranging from an estimated 3288 sharks in 1989 to 1742 in 1992 and with a mortality of nearly 98%. This fishery continues to operate. The declining catch in the shark nets may give cause for concern about the status of the population (de Bruyn, 2000).

(k) Smooth hammerhead *Sphyrna zygaena* ($\bar{x}$ =74 sharks (incl.), 50 sharks (excl.); Fig. 2k): The catch consists almost exclusively of juvenile animals moving into the netted region from the south in winter. There is no significant trend in catch or CPUE but a small but significant increase in PCL_{all}.

(l) Spinner *Carcharhinus brevipinna* ($\bar{x}$ =137 sharks (incl.), 112 sharks (excl.); Fig. 2l): A species with no significant trend in catch or CPUE and with slopes changing from negative to positive with the exclusion of the sardine run. The catch consists primarily of adults. There are significant increases in PCL_{all}, $PCL_{mat.\ female}$ and $PCL_{pregnant}$. This, therefore, is the species with the most compelling evidence of increasing size. The cause of this is unknown, but, as with the tiger shark (see below), perhaps the spinner shark has some sort of competitive advantage over the other shark species exploited by this multi-species shark fishery. Alternatively, or perhaps additionally, it may be better able to accommodate other changes within the multi-impacted nearshore environment of KZN.

(m) Tiger *Galeocerdo cuvier* ($\bar{x}$ =48 sharks (incl.), 41 sharks (excl.); Fig. 2m): The bulk of the catch consists of adolescent animals, although some adults are caught. The tiger shark and the smooth hammerhead shark are the only two species with a positive catch trend (sardine run catches included), although in neither case is the trend significant. If the low catches of 1998 and 1999 are omitted from the tiger shark regression, however, the positive slope becomes significant. In addition, there was a significant increase in PCL_{all} from 1978 to 1999, the average size increasing from 171 cm to 194 cm. Increases in tiger shark catches have also been reported in the two Australian shark control programs (Dudley, 1997 and references therein) and may indicate local increases in abundance. It is unclear whether this would have been an indirect effect of the programs themselves but, if so, it is possible that *G. cuvier* enjoys a competitive advantage within a multi-species shark fishery. Although just one of the factors that affect the vulnerability of a stock, the productivity estimate for the tiger shark ranks higher than the dusky, Zambezi, scalloped hammerhead and sandbar sharks but lower than the ragged-tooth and blacktip sharks (Smith *et al*., 1998). In the KZN program any advantage enjoyed by the tiger shark, if it exists, may have been enhanced since the late 1980s by the release of all live sharks (Cliff and Dudley, 1992). Over the period 1987-97, 41% of the total catch of *G. cuvier* was released. Although 74% of those released were smaller than 200 cm, and hence posed limited immediate danger to humans, the fact that the tiger shark is one of the potentially most dangerous species in KZN waters may necessitate the review of this practice (Wintner and Dudley, 2000).

(n) Zambezi (bull) *Carcharhinus leucas* ($\bar{x}$ =50 sharks (incl.), 46 sharks (excl.); Fig. 2n): The bulk of the catch consists of adolescent animals. In similar manner to the ragged-tooth shark, there is some evidence of a cycle between 1978 and 1999, with catches moving from low to high to low. There is no significant trend overall in catch, but a significant decline in CPUE. The decline is no longer significant after the exclusion of catches from June and July, although, because catches are lowest in winter (Cliff and Dudley, 1991b), this is unlikely to be related to the sardine run. There is a significant decrease in PCL_{all}. Localised stock depletion may occur in this species. In 1991

nets were installed at Mbango, situated between the existing installations of Umtentweni (5 km to the north) and St Michael's-on-Sea (10 km to the south). In the first six weeks of operation the new installation caught 11 large Zambezi sharks, an exceptional catch for the region (Cliff and Dudley, 1991b). It appeared that an isolated group of Zambezi sharks may have survived at Mbango despite more than two decades of netting to both north and south.

There appears to have been a very marked decrease in catch from the mid-1960s through to the early 1970s, although poor species identification at the time means this cannot be confirmed. If Zambezi shark catches genuinely did decline as shown, and if, as is likely, this represented a decline in local abundance, this may explain much of the effectiveness of shark control measures. Zambezi sharks were probably responsible for most nearshore attacks on bathers in the pre-netting era.

Discussion

Shark catch, CPUE and size trends

Trends in total shark catch during the early years of netting have been discussed elsewhere (Cliff and Dudley 1992, Dudley and Cliff 1993a, 1993b). The focus of this discussion is on individual species over the period 1978-1999.

Catch

There is considerable fluctuation in catch from year to year. Regressions of catch against time for four of the 14 shark species show a significant decline over the 22 year period 1978-1999. These are the blacktip shark *Carcharhinus limbatus*, the Java shark *C. amboinensis*, the great hammerhead shark *Sphyrna mokarran* and the scalloped hammerhead shark *S. lewini*. Two species show an increasing trend, albeit non-significant - the tiger shark *Galeocerdo cuvier* and the smooth hammerhead shark *S. zygaena*.

The predicted catch drops by about 50% for the blacktip, Java and scalloped hammerhead sharks and by over 75% for the great hammerhead shark. Of these, both the Java and the great hammerhead are relatively low-catch species.

After the June and July catches are eliminated, the slopes of the regressions for three species (blacktip, great hammerhead and scalloped hammerhead sharks) remain significant, but not for the Java shark. No other regressions are significant but the signs of the slopes for four species (copper shark *Carcharhinus brachyurus*, dusky shark *C. obscurus*, spinner shark *C. brevipinna* and great white shark *Carcharodon carcharias*) change from negative to positive.

CPUE

Regressions of CPUE against time for seven of the 14 shark species show a significant decline between 1978 and 1999. These were the blacktip, Java, great hammerhead and scalloped hammerhead sharks, as above, as well as the great white shark, shortfin mako shark *Isurus oxyrinchus* and Zambezi shark *Carcharhinus leucas*. The exclusion of June and July catches, however, resulted in the declines remaining significant for only the original four species, the Java shark no longer dropping out. In addition, the signs of the non-significant slopes for four species (copper, smooth hammerhead, spinner and tiger sharks) changed from negative to positive.

Size

There was a significant reduction in size (PCL_{all}) of three species, the copper, Java and Zambezi sharks. Of these the Java and Zambezi had also exhibited significant declines in catch and/or CPUE. Another five species exhibited a significant increase in size (PCL_{all}), including one (the scalloped hammerhead) for which both catch and CPUE had conversely decreased significantly.

There were five species in which size of mature males, mature females and/or pregnant females either increased or decreased significantly, but in each of these cases either there was no significant change in catch or CPUE, or there was a change but of the opposite sign.

The question of residency

Holden (1977) noted that there appeared to be separate “resident” shark stocks at Durban and nearby Brighton Beach in the early 1950s and 1960s, respectively. This seemed unlikely for large, highly migratory animals and unfortunately the quality of data available to Holden was poor, primarily with regard to species identification. The possibility raised by Holden has considerable significance, however, for the assessment of the impact of shark nets on local stocks of sharks of a given species. Does one combine all the catches for the whole coast, or might individual installations, particularly the more remote ones such as Richards Bay, impact separate sub-groups? The answer may vary according to species. Some recent evidence supports Holden’s suggestion, such as the examples of the blacktip, Java and Zambezi sharks described above.

Hueter (1998) discussed the subjects of *philopatry*, *natal homing* and *localised stock depletion* in sharks. He gave the definition of *philopatry* as the drive or tendency of an individual to return to, or stay in, its home area, birthplace or another adopted locality. *Natal homing* is an extreme form of philopatry in which an animal migrates back to its birthplace, usually to reproduce. *Localised stock depletion* refers to the depletion of a species in a highly restricted part of its geographic range. Hueter concluded that, if philopatry is true for most shark species, it would fundamentally affect studies of shark population dynamics and the way shark populations are managed. He challenged shark biologists to investigate the extent to which philopatry exists in sharks.

If philopatry exists in KZN’s shark stocks, the fact that the net installations are in fixed localities may mean that they have had a major impact on local sub-groups of sharks of a given species but a considerably smaller impact on the stock as a whole. This largely remains conjecture, however, and would probably be clarified only by means of an intensive (and expensive) tagging and tracking program using sonic and other electronic tags.

Of interest are the numerous anecdotal reports received at certain times of the year of frustrated skiboat anglers losing hooked gamefish, such as king mackerel *Scomberomorus commerson*, to sharks. Despite the apparent abundance of these sharks on the fishing grounds at such times, concurrent catches in nearby shark net installations are frequently extremely low.

OLRAC’s findings

In the mid-1990s resource assessment consultants, OLRAC cc, were asked by the Natal Sharks Board to study the relationship between shark attack risk and netting strategy and to attempt to quantify the additional risk associated with deploying fewer nets per protected beach. They were asked to base the study on the organisation’s database of monthly catch and effort data. After investigating the data OLRAC expressed concern about interpretations of shark attack risk in relation to the catch rate (CPUE) of sharks. Their findings do, however, provide insight into the evaluation of catch trends.

OLRAC concentrated their efforts on the three shark species regarded as being of the greatest potential danger to humans, the great white, the tiger and the Zambezi (OLRAC, 1996). Unfortunately, the poor quality of the early data compelled them to consider only the period 1979-1994, i.e., a period beginning long after most installations were established. They used a variety of analytical techniques, with the reliability of trends in shark catches being assessed via a combination of a General Linear Modeling approach and a Monte Carlo simulation procedure. In investigating the presence of significant year-to-year trends in the data, OLRAC first eliminated the systematic effects of month, capture site and frequency of gear inspections.

OLRAC found no statistically significant trend either in catch or CPUE for great white sharks. Tiger sharks increased in both catch and CPUE but there was poor statistical precision so the trends could not be regarded as biologically significant. There was a significant decline in catch and CPUE of the Zambezi shark. OLRAC argued that it is not possible to draw strong conclusions about the population dynamics of these sharks from observed trends in catches or CPUE taken in the shark nets. This argument was based partly on the difficulty of distinguishing inter-annual catch trends from random noise.

With regard to residency, four installations were established during the study period. There was evidence of local residency in tiger and Zambezi sharks at Richards Bay, the most remote of the new installations and possibly, although not conclusively, in all three species at Mbango.

OLRAC found that an increased frequency of daily gear inspections led to an increase in both catch and catch per unit effort. This probably reflects fewer losses from the nets through decomposition or scavenging, but there may also be an increased probability of capture in a net cleared of previous captures.

In an earlier analysis, OLRAC (1994) found no significant change in the mean size of captured sharks, and in some cases that mean size had even increased.

Conclusions

OLRAC expressed the opinion that catch trends in the shark nets may not be useful in the study of local shark population dynamics. In addition to OLRAC's observation that spurious features may arise in the data by chance as a result of small sample sizes and the statistical nature of the entanglement of sharks in nets, there are uncertainties about factors such as localised stock depletion and philopatry. The shark nets fish in fixed localities very close to shore and for most species there is an absence of fisheries independent data from the region.

In the absence of corroborating indices, however, the Sharks Board has no option but to use data derived from the protective net "fishery" as a means of monitoring the population status of each of the 14 species of large sharks captured in the nets. Catch rates of seven of the 14 species show a significant decline over the period 1978-1999, but this figure drops to four with the exclusion of the confounding effects of the sardine run. Of these four, two are caught in very low numbers in the nets (Java and great hammerhead) and it is probable that any decline in population size represents either local depletion or additional exploitation elsewhere in the range. The other two species, the blacktip and scalloped hammerhead sharks, are caught in considerably greater numbers in the nets. The blacktip may be subject to local depletion. Newborn scalloped hammerhead sharks are captured and discarded by prawn trawlers, adding to pressure on this species.

The Zambezi shark, one of the species that exhibit a declining catch rate prior to the exclusion of sardine run catches, also exhibits a decrease in size with time. OLRAC also found a decrease in catch and catch rate of this species, but no change in size.

The significance of the above trends in terms of the conservation status of the shark species in question is unknown. If stock depletion is indeed localised for sharks such as the Zambezi, this is consistent with the objective of the Natal Sharks Board to provide bather protection at a local level by means of reducing the probability of an encounter between a bather/board rider and a potentially dangerous shark. If stock depletion is occurring on a more general level, however, the NSB should seek ways of reducing mortalities.

As a precautionary measure and in the absence of clarity on the question of stock depletion, in September 1999 the NSB began a process of reducing the number of nets per installation. After OLRAC's finding that a population dynamics approach was not useful for assessing the risk associated with net reduction, a more qualitative approach was taken. This was based on a comparison of the beach protection methods used in KwaZulu-Natal, New South Wales and Queensland (Dudley, 1997). The goal is to achieve a 27% reduction over the coast as a whole, and by mid-2002 a 22% reduction had been implemented. Additional to this program of reducing the size of individual net installations, a further 3% reduction was effected through the complete removal, for economic reasons, of a single large net installation.

The NSB is continuing to experiment with drumlines (anchored lines, each with a single baited hook), as used in Queensland. An initial evaluation demonstrated that drumlines are more selective than nets in terms of shark species captured and take very little non-shark bycatch (Dudley *et al*., 1998). The objective of the experiment is to quantify the number of lines needed to replace a net, in terms of capture efficiency for great white, Zambezi and tiger sharks. Once complete, it is hoped that some of the remaining nets will be replaced with drumlines, such that a mixture of gear types will be deployed off each protected beach.

References

ARMSTRONG, M. J., P. CHAPMAN, S.F.J. DUDLEY, I. HAMPTON and P.E. MALAN. 1991. Occurrence and population structure of pilchard *Sardinops ocellatus*, round herring *Etrumeus whiteheadi* and anchovy *Engraulis capensis* off the east coast of South Africa. *S. Afr. J. mar. Sci.*, **11**: 227-249.

CLIFF, G. 1995. Sharks caught in the protective gill nets off KwaZulu-Natal, South Africa. 8. The great hammerhead shark *Sphyrna mokarran* (Rüppell). *S. Afr. J. mar. Sci.*, **15**: 105-114.

CLIFF, G. and S.F.J. Dudley. 1991a. Sharks caught in the protective gill nets off Natal, South Africa. 5. The Java shark *Carcharhinus amboinensis* (Müller & Henle). *S. Afr. J. mar. Sci.*, **11**: 443-453.

CLIFF, G. and S.F.J. DUDLEY. 1991b. Sharks caught in the protective gill nets off Natal, South Africa. 4. The bull shark *Carcharhinus leucas* Valenciennes. *S. Afr. J. mar. Sci.*, **10**: 253-270.

CLIFF, G. and S.F.J. DUDLEY. 1992. Protection against shark attack in South Africa, 1952 to 1990. *Aust. J. Mar. Freshwat. Res.*, **43**(1): 263-272.

CLIFF, G., R. P. VAN DER ELST, A. GOVENDER, T. K. WITTHUHN and E.M. BULLEN. 1996. First estimates of mortality and population size of white sharks on the South African coast. *In*: Great white sharks: the biology of *Carcharodon carcharias*. Klimley, A.P. and Ainley, D.G. (eds.). Academic Press. San Diego, 517 p.

COMPAGNO, L. J. V. 1991. Government protection for the great white shark (*Carcharodon carcharias*) in South Africa. *S. Afr. J. Sci.*, **87**(7): 284-285.

DE BRUYN, P.A. 2000. The age, growth, feeding, reproduction and exploitation of the scalloped hammerhead shark, *Sphyrna lewini*, in the coastal waters of KwaZulu-Natal. M.S. thesis, University of Port Elizabeth – Port Elizabeth, 88 p.

DUDLEY, S.F.J. 1997. A comparison of the shark control programs of New South Wales and Queensland (Australia) and KwaZulu-Natal (South Africa). *Ocean Coast. Manage.*, **34**(1): 1-27.

DUDLEY, S.F.J. and G. CLIFF. 1993a. Some effects of shark nets in the Natal nearshore environment. *Environ. Biol. Fish.*, **36**: 243-255.

DUDLEY, S.F.J. and G. CLIFF. 1993b. Trends in catch rates of large sharks in the Natal meshing program. In: Shark Conservation. J.G. Pepperell, West J. and Woon P. (eds.). Proceedings of an international workshop on the conservation of elasmobranchs, Sydney, Australia, 24 February 1991. Zoological Parks Board of NSW. Mosman, NSW, 147 p..

DUDLEY, S. F. J., R.C. HAESTIER, K.R. COX and M. MURRAY. 1998. Shark control: Experimental fishing with baited drumlines. *Mar. Freshwater Res.*, **49**(*7*): 653-661.

FENNESSY, S. T. 1994. Incidental capture of elasmobranchs by commercial prawn trawlers on the Tugela bank, Natal, South Africa. *S. Afr. J. mar. Sci.*, **14**: 287-296.

GOVENDER, A. and S. L. BIRNIE. 1997. Mortality estimates for juvenile dusky sharks *Carcharhinus obscurus* in South Africa using mark-recapture data. *S. Afr. J. mar. Sci.*, **18**: 11-18.

HOLDEN, M.J. 1977. Chapter 9. Elasmobranchs. *In*: Fish Population Dynamics. Gulland, J.A. (ed.). John Wiley & Sons. London, 372 p.

HUETER, R.E. 1998. Philopatry, natal homing and localised stock depletion in sharks. *Shark News*, **12**: 1-2.

MUSICK, J. A., S. BRANSTETTER and J.A. COLVOCORESSES. 1993. Trends in shark abundance from 1974 to 1991 for the Chesapeake Bight of the U.S. Mid-Atlantic coast. *In*: Conservation Biology of Elasmobranchs. Branstetter, S. (ed.). *NOAA Tech. Rep.*, NMFS, **115**, 99 p.

OLRAC. 1994. The feasibility of predicting the risk of reducing or altering shark net configurations on the Natal coast: A preliminary numerical study. Contract report for the Natal Sharks Board, 20 p.

OLRAC. 1996. Important features of data on the capture of great white, tiger and Zambezi sharks in shark nets off KwaZulu-Natal. A confidential submission to the Natal Sharks Board, 12 p + tables + figures.

POLLARD, D. A., M.P. LINCOLN SMITH and A.K. SMITH. 1996. The biology and conservation status of the grey nurse shark (*Carcharias taurus* Rafinesque 1810) in New South Wales, Australia. *Aquat. Conserv.: Mar. Freshwat. Ecosyst.*, **6**: 1-20.

SMITH, S. E., D.W. AU and C. SHOW. 1998. Intrinsic rebound potentials of 26 species of Pacific sharks. *Mar. Freshwater Res.*, **49**: 663-678.

WINTNER, S.P. and S.F.J. DUDLEY. 2000. Age and growth estimates of the tiger shark *Galeocerdo cuvier* from the east coast of South Africa. *Mar. Freshwater Res.*, **51**: 43-53.

Table 1. Trends in catch (number of sharks) and CPUE (number.km-net^{-1}.yr^{-1}) of shark species caught in the KZN shark nets, 1978-1999 inclusive, with and without catches taken in June and July. Slope - sign of the slope of linear regression of CPUE against time (number of years, 1-22). *P* - probability value associated with the slope. Significant slopes ($P \leq 0.050$) are shaded.

	Catch		Catch (excl. June & July)		CPUE		CPUE (excl. June & July)	
Species	Slope	*P*	Slope	*P*	Slope	*P*	Slope	*P*
Blacktip	-	0.009	-	0.019	-	0.001	-	0.003
Copper	-	0.180	+	0.085	-	0.130	+	0.087
Dusky	-	0.381	+	0.993	-	0.198	-	0.780
Great ham.	-	0.000	-	0.001	-	0.000	-	0.000
Great white	-	0.116	+	0.744	-	0.042	-	0.932
Java	-	0.044	-	0.060	-	0.027	-	0.035
Mako	-	0.080	-	0.377	-	0.036	-	0.180
Ragged-tooth	-	0.648	-	0.705	-	0.428	-	0.518
Sandbar	-	0.185	-	0.276	-	0.118	-	0.193
Scalloped ham.	-	0.012	-	0.027	-	0.002	-	0.006
Smooth ham.	+	0.966	+	0.542	-	0.836	+	0.679
Spinner	-	0.890	+	0.506	-	0.544	+	0.706
Tiger	+	0.632	+	0.268	-	0.831	+	0.586
Zambezi	-	0.132	-	0.164	-	0.042	-	0.058

Table 2. Trends in shark length with time for shark species caught in the KZN shark nets, 1978-1999 inclusive. Slope - sign of the slope of linear regression of length against capture date (the latter expressed as a numeric value). *P* - probability value associated with the slope. *n* - sample size (number of animals measured). *PCL* - precaudal length. Significant slopes ($P \leq 0.050$) are shaded (dark – negative; light – positive). All data include catches taken during June and July except PCL_{all}

	PCL_{all} (excl. June & July)			$PCL_{mat. male}$			$PCL_{mat. female}$			$PCL_{pregnant}$		
Species	Slope	*P*	*n*	Slope	*P*	*n*	Slope	*P*	*n*	Slope	*P*	*n*
Blacktip	-	0.261	1487	-	0.225	530	+	0.209	580	+	0.263	186
Copper	-	0.000	415	+	0.024	553	-	0.532	253	+	0.214	56
Dusky	-	0.724	1975	+	0.255	179	+	0.079	659	+	0.286	284
Great ham.	+	0.786	156	+	0.474	31	+	0.015	15			1
Great white	-	0.111	432	-	0.561	7			2			0
Java	-	0.002	198	-	0.254	14	+	0.421	11	+	0.658	8
Mako	+	0.046	171	+	0.191	133	+	0.235	39	+	0.038	3
Ragged-tooth	-	0.710	1799	+	0.325	658	-	0.001	1188	-	0.020	236
Sandbar	-	0.318	358	-	0.855	39	-	0.068	117	-	0.075	78
Scalloped ham.	+	0.003	1782	+	0.254	138	+	0.189	24	-	0.329	11
Smooth ham.	+	0.013	769			1			2			0
Spinner	+	0.000	1444	+	0.362	528	+	0.000	690	+	0.002	291
Tiger	+	0.002	477	+	0.257	16	+	0.117	8			0
Zambezi	-	0.014	615	+	0.146	36	-	0.468	26	-	0.462	3

Table 3. Predicted values for those species in which there was a significant change over time in one or more parameters (dark shading - negative changes; light shading - positive changes) are shaded. Columns marked (excl) exclude catches taken during June and July.

	Catch (number)		Catch (excl) (number)		CPUE (number.km-net^{-1}.yr^{-1})		CPUE (excl) (number.km-net^{-1}.yr^{-1})		PCL_{all} (excl) (cm)		$PCL_{mat.\ male}$ (cm)		$PCL_{mat.\ female}$ (cm)		$PCL_{pregnant}$ (cm)	
Species	1978	1999	1978	1999	1978	1999	1978	1999	1978	1999	1978	1999	1978	1999	1978	1999
Blacktip	151	76	123	65	3.9	1.7	3.2	1.5								
Copper									201	185	198	203				
Dusky																
Great ham.	18	4	16	5	0.5	0.1	0.4	0.1					204	282		
Great white					1.2	0.7										
Java	19	8			0.5	0.2	0.5	0.2	139	123						
Mako					0.4	0.2			199	214					197	305
Ragged-tooth													199	195	202	198
Sandbar																
Scalloped ham.	212	104	191	100	5.5	2.3	5.0	2.2	113	122						
Smooth ham.									89	93						
Spinner									160	177			183	191	186	194
Tiger									171	194						
Zambezi					1.5	0.9			165	157						

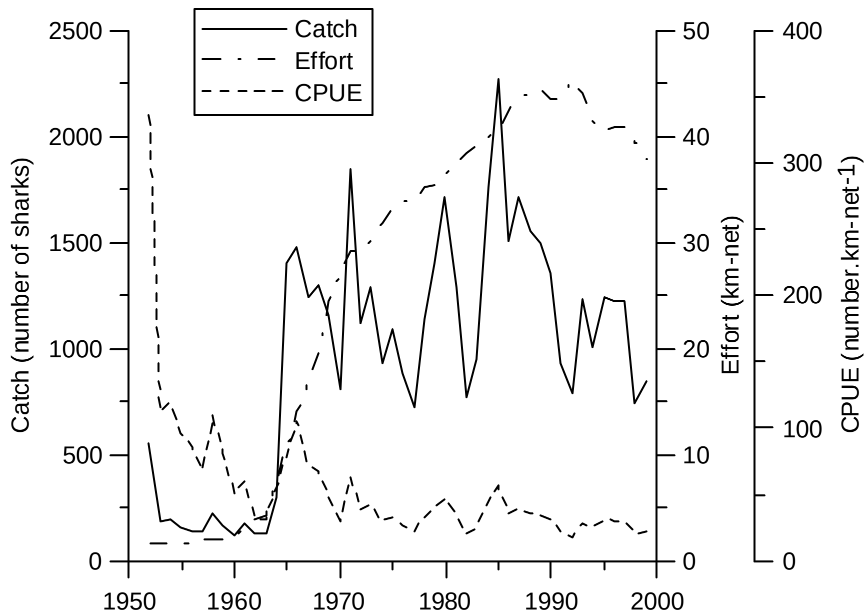
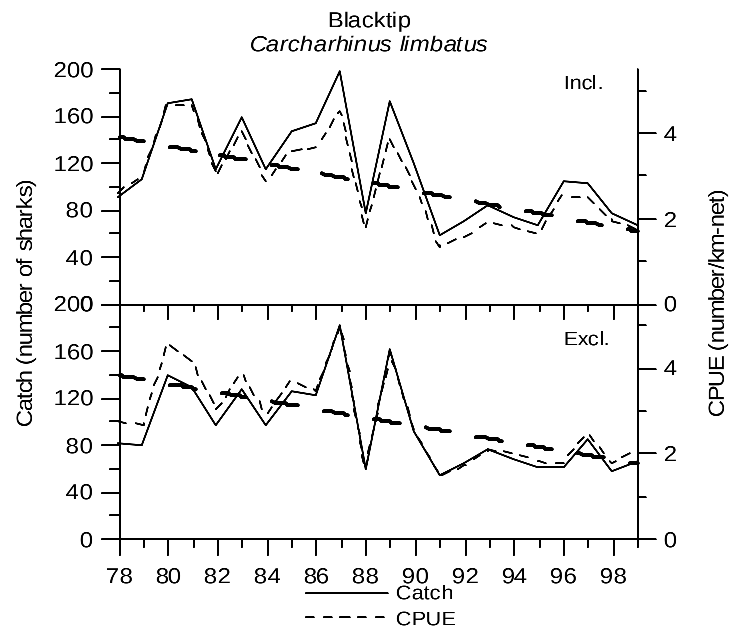


Fig. 1: Total shark catch, CPUE and effort in the KwaZulu-Natal beach protection program, 1952-99.



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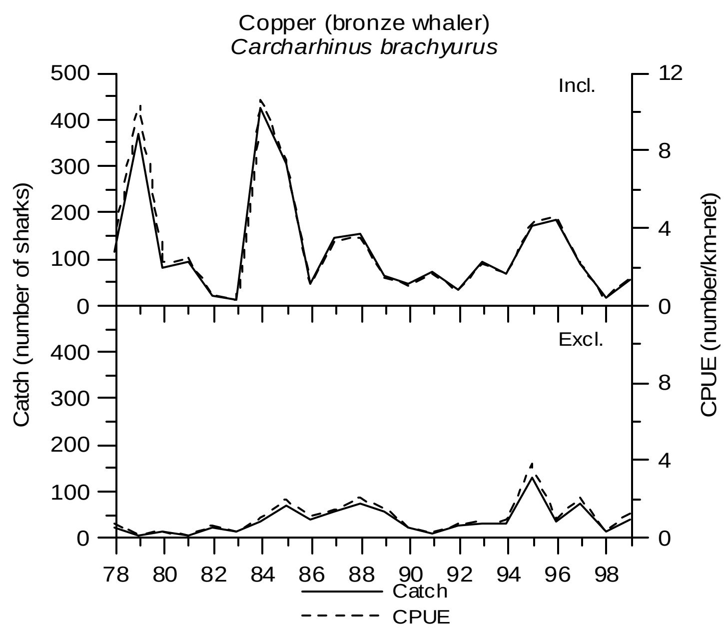
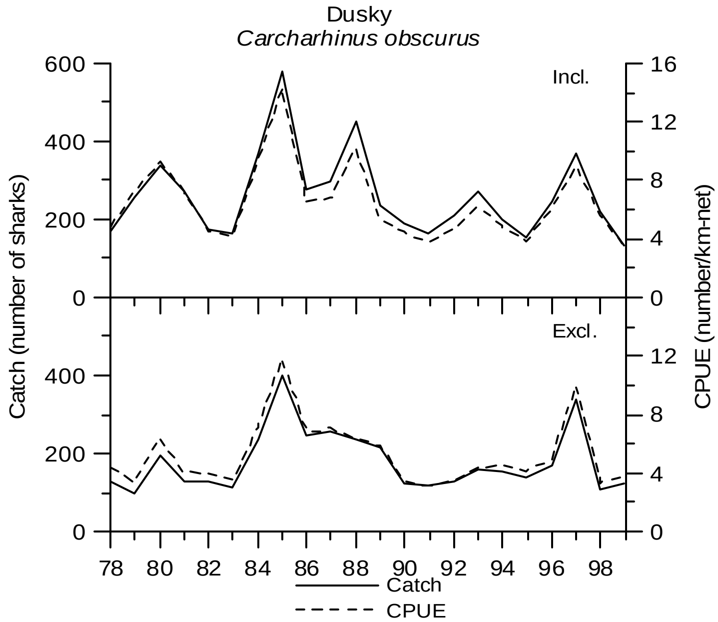


(b)

Fig. 2: Catch and CPUE for each of 14 shark species caught annually in the shark nets, 1978-99. Plots marked "Incl." include all catch data, those marked "Excl." exclude catches taken during June and July. Regression lines of CPUE against time are included where significant (see Table 1)



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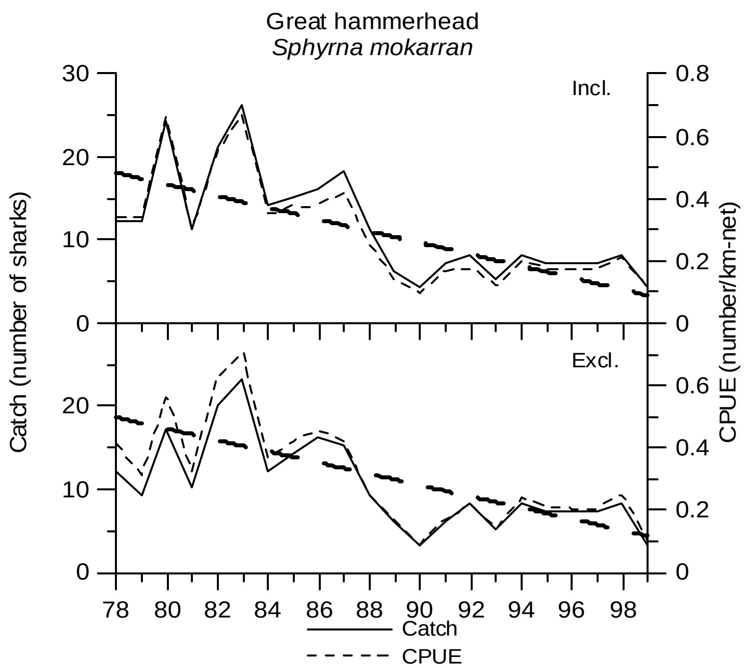

d)

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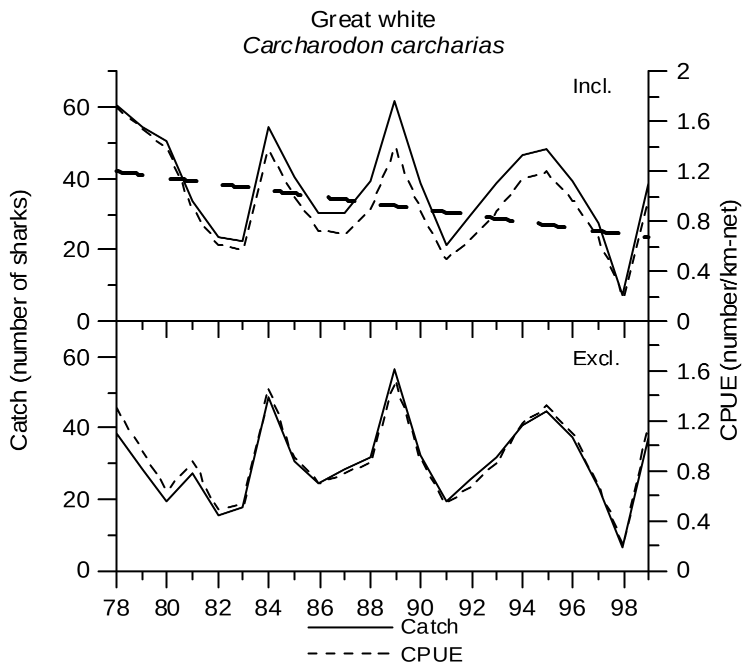

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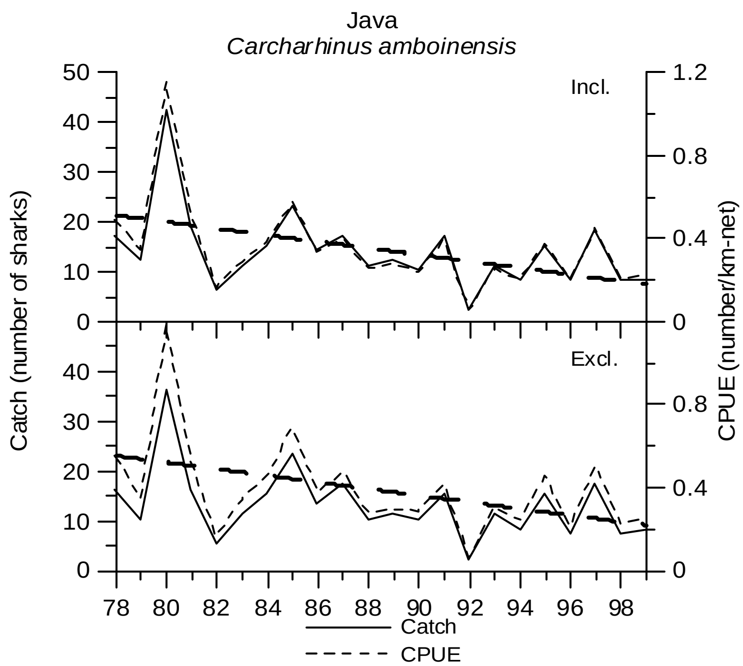

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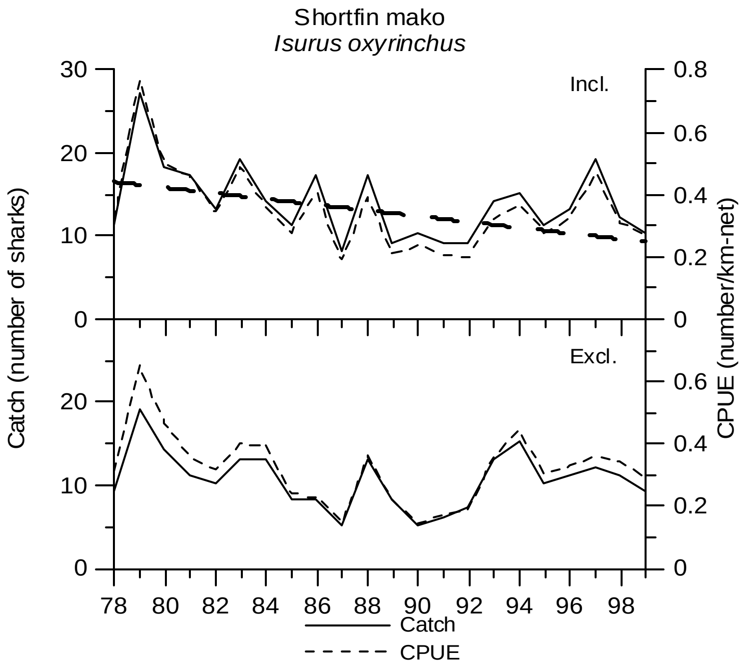

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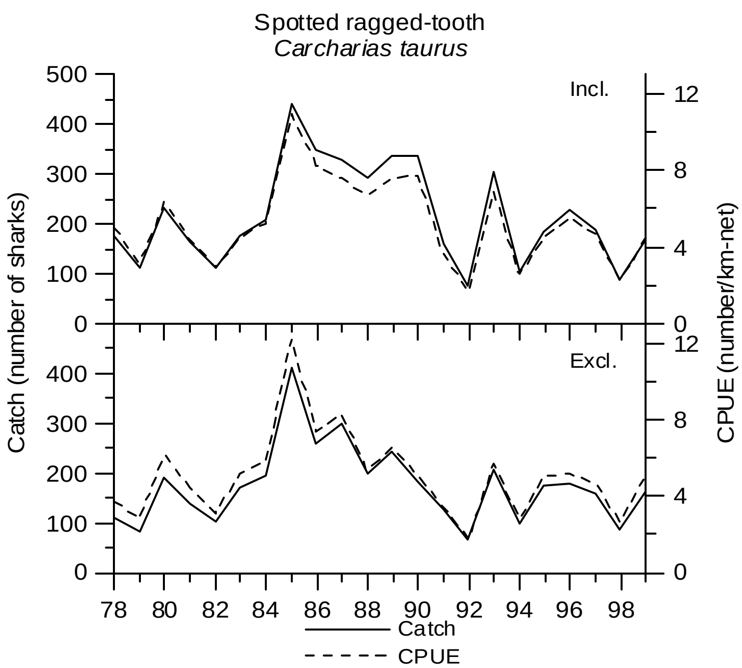

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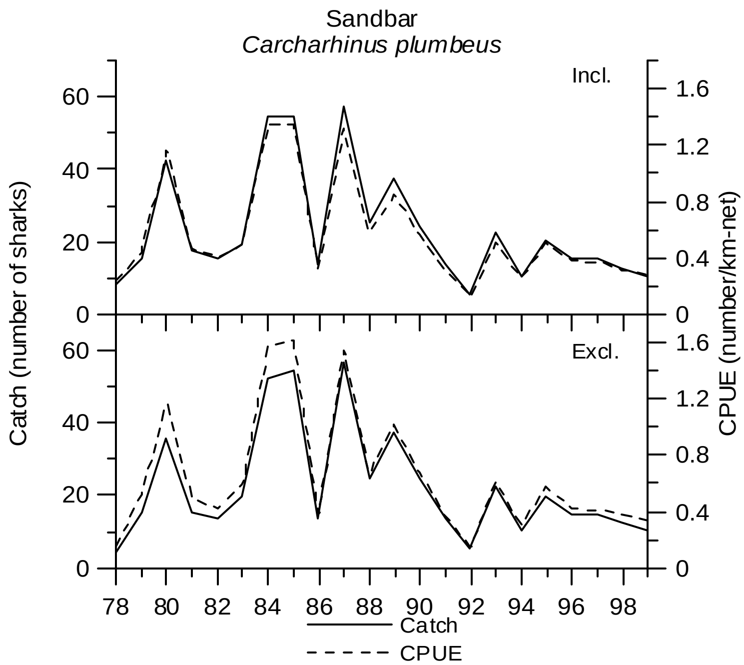

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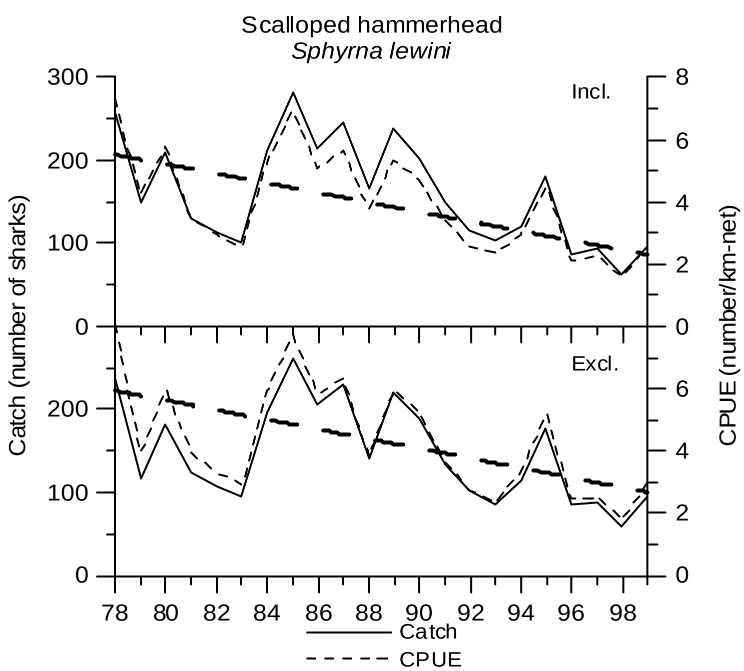

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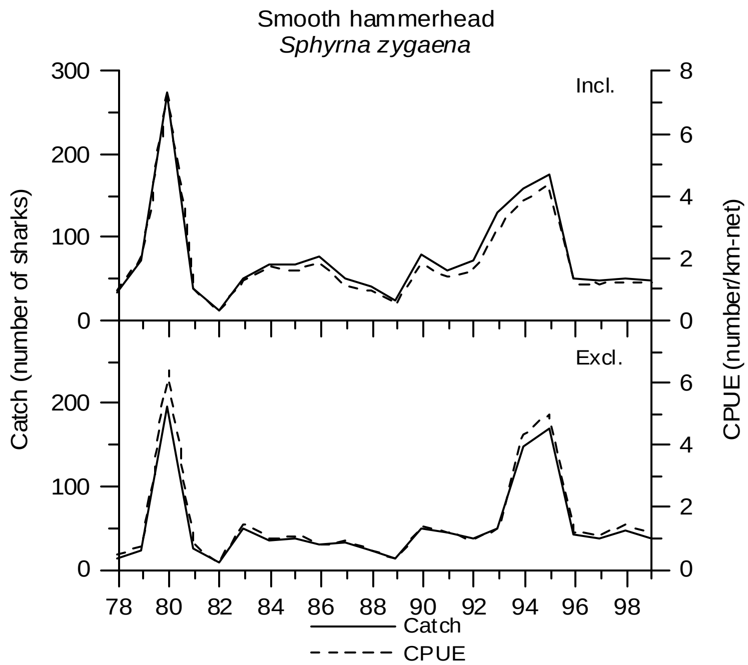

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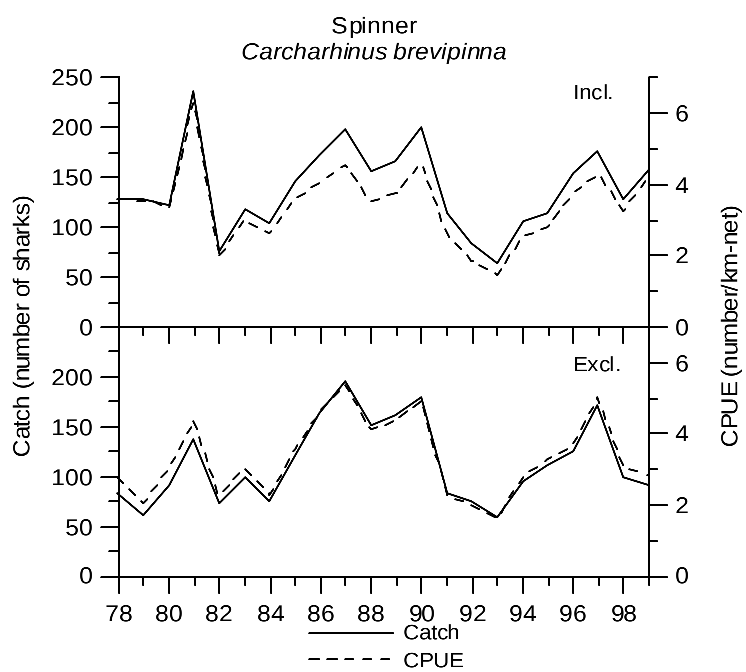

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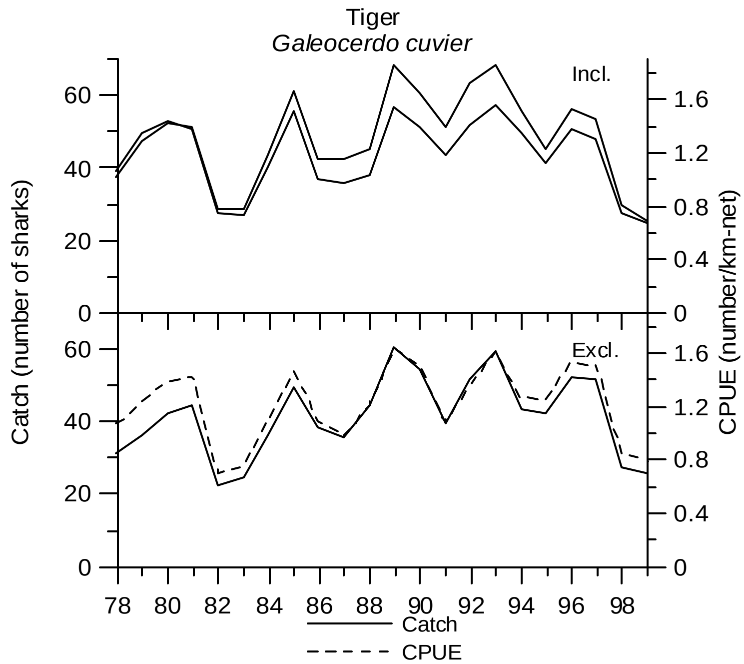

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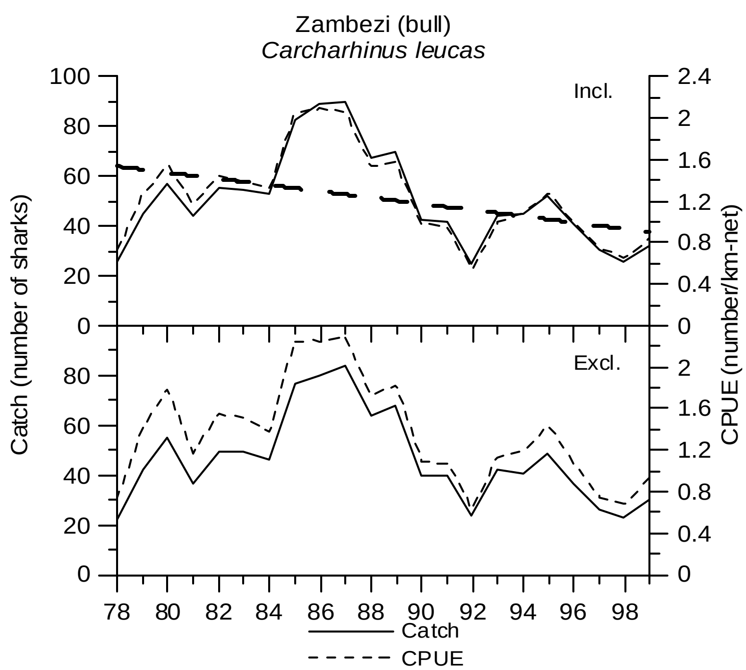

(n)

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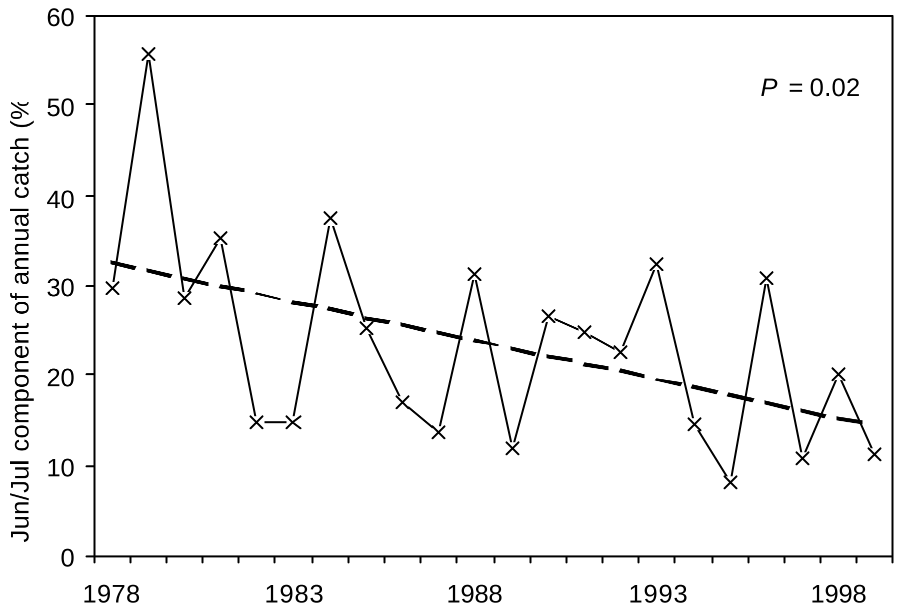
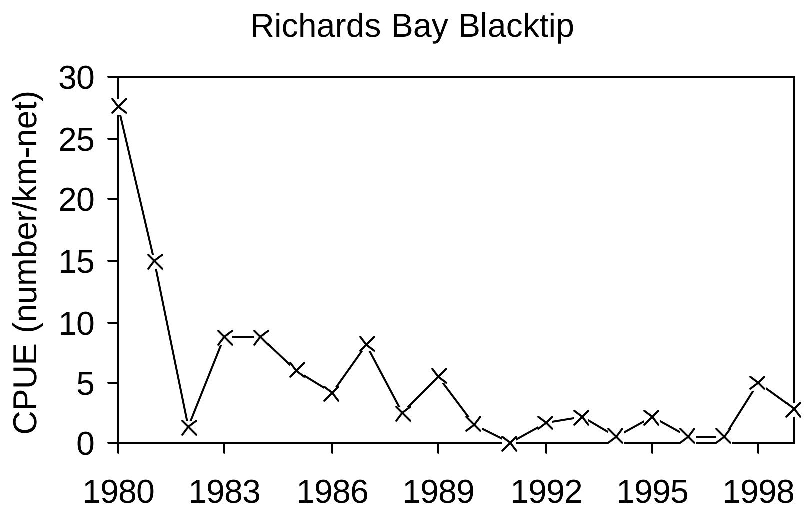
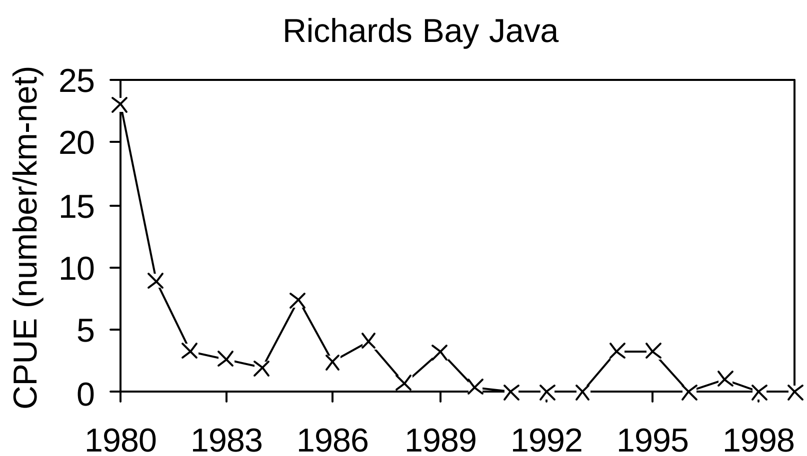


Fig. 3. Progressive reduction in catch associated with the annual sardine run, resulting from temporary net remo val, illustrated by a reduced June/July component of the annual catch.



(a)



(b)

Fig. 4. Possible localised stock depletion of (a) blacktip and (b) Java sharks at Richards Bay, where shark nets were first installed in 1980.