Shark nets in KwaZulu-Natal - an evaluation of catches and alternatives

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Declaration

Construction and maintenance of experimental fishing gear and collection of field and laboratory data were carried out by technical and field staff of the Natal Sharks Board. The feeding analysis summarised in Table 1.II was conducted by Geremy Cliff, and Mike Murray produced the model output summarised in Appendix 4.I. Experimental design, all other analysis and the writing of this thesis were my own work.

Signed by candidate

11 December 1995

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Beulah Davis, former Director of the NSB, initiated the collection of catch and biological data. Private contractors and subsequently the field staff of the Natal Sharks Board (NSB) maintained the nets and provided the specimens. Research technician Rod Haestier constructed all drumlines, installed them at Zinkwazi, La Mercy and Mzamba and also carried out daily monitoring of the equipment at Zinkwazi and, for most of the main study, at La Mercy. The willing co-operation of the field staff, who conducted much of the experimental field work and without whom projects such as this would be impossible, is gratefully acknowledged. Particular thanks are due to Craig Hosken and Grant Webster who performed most of the experimental meshing and who kept excellent records of their activities. Daily monitoring of the drumlines at Mzamba was conducted by Kevin Cox. Others who assisted included Tony Beneke, Neale Bense, John Booker, Dale Chaplin, Mike Kerns, Trevor Krige, Mike Le Roux, Grayson Love, Grant Melville, Paul McMullen, Brendan O'Leary, Darryl Smith, Peter Streicher and Paul von Blerk. Derek Groger and Mike Anderson-Reade facilitated operations in their respective areas of jurisdiction. The NSB net-making team, led by Bogaat Manzini, assembled the experimental panels. Patrick Mthembu and Phillip Zungu took many of the laboratory measurements. The dive survey of the La Mercy drumline site was conducted by Geremy Cliff, Rod Haestier and Vic Peddemors. Dennis Everitt, former contractor at Umhlanga Rocks, made available his personal catch records. Comment on earlier versions of Chapter 1 was provided by Doug Butterworth of the Applied Mathematics Department, University of Cape Town, Mike Bruton, former Director of the J.L.B. Smith Institute of Ichthyology, Grahamstown and Leonard Compagno of the South African Museum, Cape Town. The provision of data for Chapter 2 by the following is gratefully acknowledged: Baden Lane (Queensland Shark Control Program, Queensland Department of Primary Industries), Martin Krogh (Environment Protection Authority, New South Wales), Dennis Reid (New South Wales Fisheries), Andy Short (Coastal Studies Unit, Department of Geography, University of Sydney), Ern Grant (E.M. Grant Pty. Limited), Colin Simpfendorfer (Fisheries Department of Western Australia) and Anton McLachlan (Zoology Department, University of Port Elizabeth). John West of the Taronga Zoo, Sydney, supplied data from the Australian Shark Attack File. Baden Lane provided details of drumline design and supplied a complete drumline and Ern Grant provided historical perspective on the introduction of drumlines in the Queensland Shark Control Program. Anesh Govender of the Oceanographic Research Institute introduced me to the model-fitting capabilities of spreadsheets and showed me how to set up both the Kirkwood & Walker model and the likelihood profile method. Mike Murray of the Department of Mathematical Statistics, University of Natal, provided assistance with statistical analysis of the drumline data. Philippa Logan drew the maps and diagrams. Barbara Cunningham captured the historical catch data on computer. Graeme Charter, present Director of the NSB, is thanked for his support for this work, as are my fellow-biologists in the Research Department of the NSB, Geremy Cliff, Vic Peddemors and Sabine Wintner, with whom I have discussed ideas over the years. Finally, I am grateful to my supervisor, Charles Griffiths, of the University of Cape Town, for providing direction during this study.

Contents

ABSTRACT

Shark nets in KwaZulu-Natal - an evaluation of catches and alternatives

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Abstract

Protective gillnets (shark nets) have been successful in reducing the frequency of shark attacks on the coast of KwaZulu-Natal (KZN), South Africa. This is achieved primarily through a reduction in numbers of large sharks. The nets also take a by-catch of dolphins, sea turtles, batoids and teleosts. Catch rates of most shark species declined initially but have shown no trend since the mid-1970s. Turtle and teleost stocks do not appear to be threatened by net mortalities, but there is concern about the sustainability of catches of the humpback dolphin. Certain batoids may have declined despite a high release rate. A published contention that shark netting has resulted in a proliferation of small sharks through reduced predation is re-examined and considered to be exaggerated. Reduced predation on dolphins, as a result of shark netting, is estimated. Considerably less fishing effort is applied in the shark control programs of New South Wales and Queensland, Australia, than in that of KZN. On the basis of a comparison of factors such as the nearshore physical environments and trends in shark catch and catch rate, it is concluded that the number of nets used in KZN could be reduced. To test whether a 70 cm mesh would continue to capture potentially dangerous sharks, while at the same time reducing by-catch, a gamma distribution model was used to determine length-specific selectivities in 50.8 cm and 70 cm mesh nets respectively. A reduction in relative selectivity from 81% to 25% for a shark of 1.6 m *PCL* would result from an increase in mesh size from 50.8 to 70 cm. Despite a probable reduction in catch of dolphins and certain other by-catch species, the introduction of the larger mesh would constitute an unacceptable reduction in levels of bather safety. Baited lines, or drumlines, were tested as possible alternatives to gillnets. They demonstrated greater species selectivity for sharks, including a higher catch of two of the target species, *Carcharhinus leucas* and *Galeocerdo cuvier*, and also a reduced by-catch of non-shark animals. The probability of the bait being scavenged, or a shark being caught, was modelled in relation to a number of physical factors. Although there were insufficient data for a quantitative comparison of catch rates between nets and drumlines, the results indicated that an optimal solution may be to deploy a combination of nets, using the existing 50.8 cm mesh, and drumlines, using 14/0 shark hooks.

GENERAL INTRODUCTION

General introduction

The Natal Sharks Board (NSB) maintains a series of gillnets, known as shark nets, at various bathing beaches on the KwaZulu-Natal coast in order to reduce the risk of shark attack. In response to a series of shark attacks, netting began at Durban in 1952 and subsequently spread to other KwaZulu-Natal beaches, with the majority of net installations coming into being in the 1960s (Davies 1961, 1963, 1964, Wallett 1983, Davis *et al*. 1989, Cliff 1991, Cliff & Dudley 1992a). The NSB was formed in 1964 and initially had an advisory and supervisory rôle, but today is solely responsible for the installation and maintenance of all shark nets (Wallett 1983, Davis *et al* 1989). In addition to carrying out these core functions, the NSB monitors catches and conducts research into the biology and ecology of captured sharks (Cliff *et al*. 1988a, 1989, 1990, Cliff & Dudley 1991a, 1991b, 1992b, Dudley & Cliff 1993a, 1993b, Cliff 1995, Wintner & Cliff 1996) and dolphins (Peddemors 1995 and references therein), and investigates alternatives to the existing netting operation.

The basic *modus operandi* of the shark control program has remained constant, yet, despite a high success rate in terms of bather protection, there are two reasons to downscale and modify the operation:

i. Cost

Shark netting is an expensive process, with the projected NSB budget running at approximately R14.5 million for the 1995-96 financial year. The bulk (about 66%) of this money comes from state funds, but increases in the state contribution have not matched inflation in recent years. With inflation running at between 10 and 15% per annum, the NSB is forced to seek the escalating balance from alternative sources.

ii. Environmental impact

Shark nets are fishing devices, believed to protect bathers primarily by reducing shark numbers. Although the extent of this reduction is not well understood, any reduction in numbers of top predators carries, in principle, a high ecological risk. Sustainability of the existing shark catch is also a concern, given that the life-history patterns of elasmobranchs are consistent with those of so-called *K*-selected species in *r*/*K* selection theory (Hoenig & Gruber 1990). Furthermore, gillnets are not species-selective within a given size range and take a by-catch of animals such as dolphins, sea turtles, batoids and teleosts, as well as harmless shark species. Little is known about the effects of this by-catch, both on the inshore ecosystem and on most of the individual species caught. An assessment of catches is therefore required but also it is assumed, *prima facie*, that methods of effort reduction should be sought.

The aim of the study is to assess the environmental impact of the present operation and to consider modifications to the operation which will result in a reduction both of costs and impact, but without a substantial reduction in bather safety.

Environmental impact is addressed in Chapter 1 by means of a comparison of relative catch rates of all species caught and of trends in catch and catch rates for selected species of shark taken during the NSB shark control program. In Chapter 2 the shark control programs of New South Wales and Queensland, Australia, are compared with that of KwaZulu-Natal, to determine whether the fishing effort applied in the local program could be reduced. The remaining two chapters are devoted to experimentation with shark fishing gear. Chapter 3 details an experiment to determine the relationship to express relative selectivity of gillnets as a mathematical function of mesh-size of gillnets and length of shark for the larger coastal species, in order to determine whether a larger mesh could be introduced as a means of reducing by-catch. Chapter 4 consists of an assessment of drumlines, which have lower catchabilities than gillnets for the by-catch species, as an alternative type of shark fishing gear.

CHAPTER 1: SOME EFFECTS OF SHARK NETS IN THE KWAZULU-NATAL NEARSHORE ENVIRONMENT

Chapter 1: Some effects of shark nets in the KwaZulu-Natal nearshore environment

1.1 Introduction

In response to a history of shark attacks on the KwaZulu-Natal coast, protective gillnets were installed off the beaches of Durban in 1952 (Davies 1964), and the laying of two nets at Amanzimtoti in August 1962 (Wallett 1983) marked the beginning of shark netting at other beaches. By 1990 44.4 km of gillnets set at fixed positions covered 14% of the 326 km coastline between Richards Bay and Mzamba (Fig. 1.1). A more comprehensive history of the shark netting operation in KwaZulu-Natal is provided elsewhere (Wallett 1983, Davis *et al.* 1989).

Shark nets have been successful in providing protection against shark attack. For example, 21 attacks, seven of which were fatal, occurred off Durban between 1943 and 1951 (Wallett 1983). In the 38 years since the introduction of nets there have only been five incidents at Durban's netted beaches (Wallett 1983, Cliff 1991), despite increasing bathing populations. Injuries resulted from four of the incidents and in each case consisted of minor lacerations, probably inflicted by small sharks of less than 1.5 m precaudal length (Cliff 1991).

Netted animals include sharks (Squalomorphea), batoids (Batoidea), sea turtles (Cryptodira), dolphins (Delphinidae) and teleosts (Teleostei). The ecological impact of the netting operation has been a subject of considerable controversy. Scientists, conservationists and anglers have attributed a variety of effects detrimental to the inshore ecosystem of KwaZulu-Natal to the nets (e.g. van der Elst 1979, Mara 1986, Richards 1988). Although these claims are not all substantiated, concern about the ecological effects of anti-shark measures is not limited to the South African situation (Paterson 1990) and the topic demands consideration.

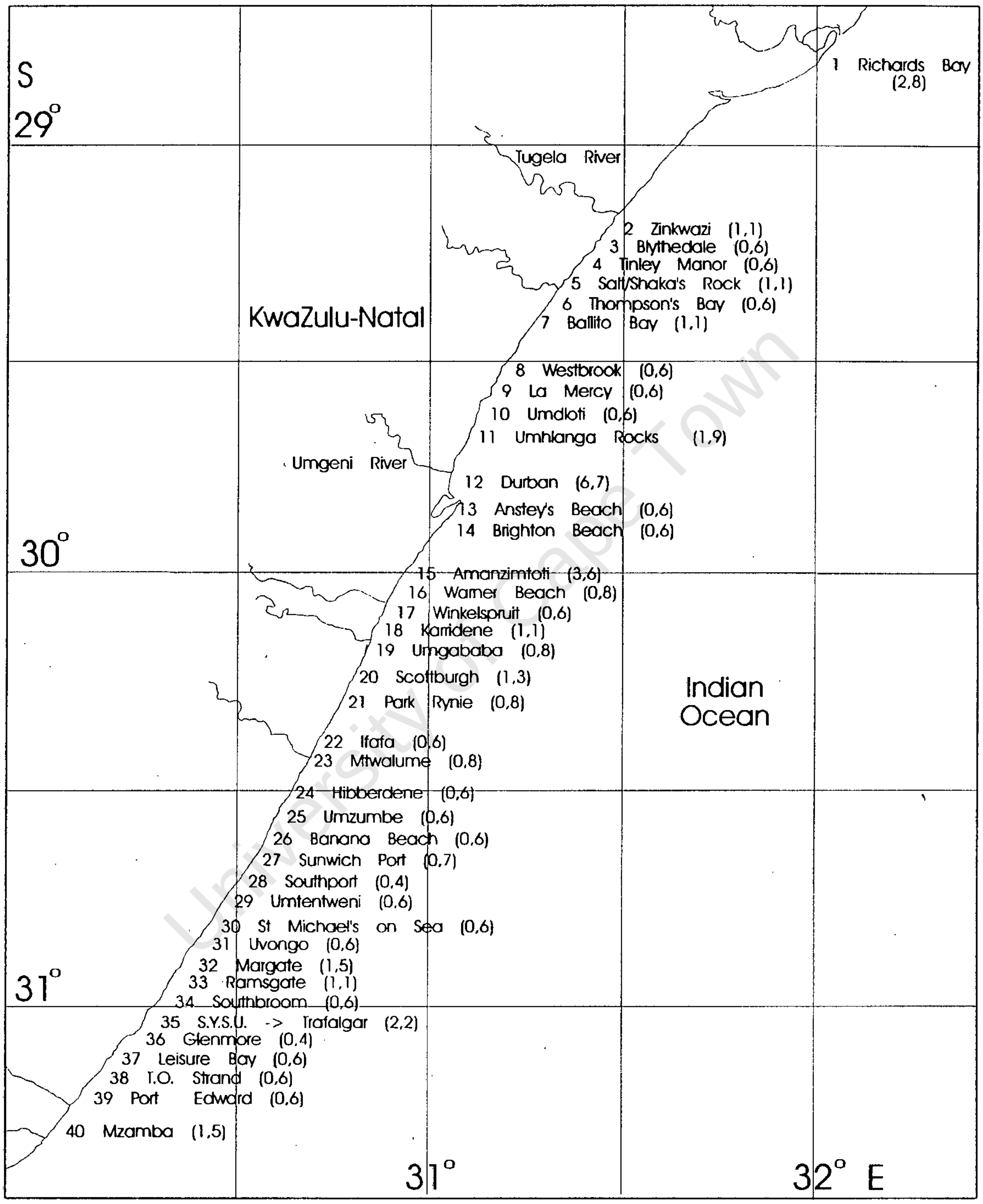

Figure 1.1: Netted beaches on the KwaZulu-Natal coast and, in parentheses, the length of nets in kilometres in January 1990

The purpose of this chapter is to quantify catches and to re-evaluate certain aspects of the effects of netting. While each of the five groups of animals caught in the nets is discussed, the emphasis is on sharks, the group caught in greatest numbers. Shark fisheries have a history of collapse (e.g. Holden 1968, 1974, Cailliet & Bedford 1983, Bedford 1987, Richards 1987, Hoenig & Gruber 1990), and it is through catches of sharks that the KwaZulu-Natal nets are likely to have had the greatest ecological effect, both directly and indirectly, because sharks are top predators.

1.2 Methods

In this chapter total annual shark catch records from most netted beaches are considered for the period 1966-1990, over which time the quality of data improved. Contractors, who had received limited training in shark identification by Natal Sharks Board (NSB) scientists, were responsible for servicing the nets and reporting catches until the mid-1970s, from which time they began to be replaced by more fully trained NSB field staff. Replacement was completed in 1982. Throughout 1966-1990 NSB scientists had access to a percentage of the total shark catch for dissection and confirmation of identity. From 1983 an average of 63% of the annual catch was examined at the NSB laboratory. The other 37% consisted of those sharks which were found alive in the nets and released, some being tagged, those which were dissected in the field, not necessarily by research staff, and those which were too decomposed to dissect.

Shark identification in the field was regarded as having been reliable to species level from 1978 onwards but catches of species similar in appearance were combined for the analysis of trends over the entire study period. Such combinations included the bull shark *Carcharhinus leucas* with the Java shark *C. amboinensis*, the dusky shark *C. obscurus* with the sandbar shark *C. plumbeus*, and the blacktip shark *C. limbatus* with both the spinner shark *C. brevipinna* and the copper shark *C. brachyurus*. Three hammerhead sharks, the great *Sphyrna mokarran*, the scalloped *S. lewini* and the smooth *S. zygaena*, were also combined.

Catch per unit effort (CPUE) is expressed as the number of sharks caught per kilometre of net per annum. A year is considered an appropriate unit of time because, apart from the short-term removal of some nets during the annual sardine run (see Section 1.3.2.1), the nets are in the water permanently. For the purpose of quantifying effort, a homogeneous distribution of each species, or species group, within the netted region was assumed, excluding the remote locality of Richards Bay. For the period 1966-1972, Wallett (1973) considered the quality of catch rate data from six localities to be unacceptably poor. For that period total reported catch data are therefore presented, but those localities were omitted from the catch rate data. Continuous data series from Durban, Anstey's Beach and Brighton Beach were not available and these localities were omitted from all catch and catch rate series.

Leslie's method, as described by Ricker (1975), provides a means of estimating population size using catch and effort data. The method is valid when the catch is sufficient to reduce CPUE substantially, CPUE is proportional to abundance, the population is closed to emigration and immigration and natural births and deaths remain negligible or in balance. The Leslie equation is given by Ricker (1975) as

$$C_t/f_t = qN_o - qK_t,$$

where C_t is catch taken, f_t is fishing effort and C_t/f_t is CPUE, all during time interval t, q is catchability, N_o is the original population size, and K_t is the cumulative catch to the start of interval t plus half of that taken during the interval.

Reliable catch data for animals other than potentially dangerous sharks were available from all net installations from 1981 only, but a single complete data series, in which similar species were grouped, existed for one installation, Umhlanga Rocks, from the establishment of nets at that beach in 1964.

The precaudal length (*PCL*) of sharks was measured in centimetres as a straight line from the tip of the snout to the precaudal notch. The shark feeding analysis covered the period 1983-1988. Stomach contents were identified to the lowest possible taxonomic group and quantified in terms of percentage frequency of occurrence, defined as the proportion of stomachs which contained each group. Empty stomachs and those containing cephalopod beaks and teleost sagittae but with no associated flesh or bone, were excluded from the analysis. It was assumed that the proportional representation of each prey category was unaffected by any regurgitation of stomach contents which occurred during capture.

1.3 Results and discussion

1.3.1 By-catch of animals other than potentially dangerous sharks

Of the approximately 350 batoids (mostly comprising six species of rays and guitarfish), taken annually 1981-1990, about 245 were released alive (Table 1.I), although the survival rate of released animals is unknown. Few data were available for batoid catches in the shark nets prior to 1980. Discussion of long-term trends is therefore restricted to the Umhlanga Rocks data series, in which species identification is limited. All rays, with the exception of the manta ray *Manta birostris* and the devil rays *Mobula* spp., were combined in Figure 1.2. It is probable that the majority of these were myliobatids. The peaks in CPUE in 1964, 1966 and 1975 probably indicate natural fluctuations in local abundance. The overall trend appears, however, to be one of initial decline followed by relative stability. Other than a catch of zero in the first year, the catch rate of mobulid rays also indicates an initial period of decline (Fig. 1.2).

Table 1.I: Average annual catches in the KwaZulu-Natal shark nets, 1981-1990, of animals other than potentially dangerous sharks

Species	Common name	Caught (number)	Released (%)
Birds			
Sula capensis	Cape gannet	1.3	0
Phalacrocorax sp.	Cormorant	0.1	0
Spheniscus demersus	Jackass penguin	0.1	0
Turtles			
Eretmochelys imbricata	Hawksbill	1.8	28
Lepidochelys olivacea	Olive ridley	1.1	27
Caretta caretta	Loggerhead	42.6	35
Chelonia mydas	Green	14.0	34
Cheloniidae	Unidentified turtle	1.1	73
Dermochelys coriacea	Leatherback	6.8	35
Cetaceans			
Sousa plumbea	Indo-Pacific humpbacked dolphin	6.1	2
Delphinus delphis	Common dolphin	36.3	4
Tursiops truncatus	Bottlenose dolphin	34.9	1
Stenella coeruloealba	Striped dolphin	0.3	33
Stenella longirostris	Spinner dolphin	0.1	0
Lagenodelphis hosei	Fraser's dolphin	0.1	0
Pseudorca crassidens	False killer whale	0.1	0
Delphinidae	Unidentified dolphin	0.9	0
Balaenoptera acutorostrata	Minke whale	0.4	25
Sharks			
Rhizoprionodon acutus	Milk	4.6	6
Mustelus mosis	Hardnosed smooth-hound	0.2	50
Halaelurus lineatus	Banded cat	0.1	0
Rhincodon typus	Whale	0.7	57
Squatina africana	African angel	32.9	45
Batoids			
Aetobatus narinari	Spotted eagleray	14.0	80
Myliobatis aquila	Eagleray	3.7	54
Pteromylaeus bovinus	Bullray	37.8	61
Rhinoptera javanica	Flapnose ray	41.1	58
Manta birostris	Manta	52.5	66
Mobula spp.	Devilray	14.2	60
Dasyatidae	Unidentified stingray	6.5	74
Dasyatis chrysonota chrysonota	Blue stingray	0.8	88
Gymnura natalensis	Backwater butterflyray	49.6	78
Himantura gerrardi	Sharpnose stingray	1.4	93
Himantura uarnak	Honeycomb stingray	1.9	84
Torpedo sinuspercici	Marbled electric ray	0.4	25
Torpediniformes	Electric ray	0.6	100
Rhina ancylostoma	Bowmouth guitarfish	0.1	100
Rhynchobatus djiddensis	Giant guitarfish	122.0	75
Pristis microdon	Largetooth sawfish	0.2	100
Pristis pectinata/zijsron	Smalltooth/green sawfish	0.9	67
Pristis spp.	Sawfish	1.0	70

Table 1.I (continued): Average annual catches in the KwaZulu-Natal shark nets, 1981-1990, of animals other than potentially dangerous sharks

Species	Common name	Caught (number)
Teleosts		
Sphyraena spp.	Barracuda	0.3
Trachinotus blochii	Snubnose pompano	1.2
Lichia amia	Garrick	11.5
Scomberoides spp.	Queenfish	1.8
Caranx ignobilis	Giant kingfish	0.2
Carangidae	Unidentified kingfish	0.2
Thunnus albacares	Yellowfin tuna	4.6
Euthynnus affinis	Eastern little tuna	2.0
Katsuwonus pelamis	Skipjack tuna	4.3
Scomberomorus commerson	King mackerel	0.6
Scomberomorus plurilineatus	Queen mackerel	0.5
Scombridae	Unidentified tuna, bonito	1.2
Rachycentron canadum	Prodigal son	0.9
Argyrosomus japonicus	Kob	3.2
Atractoscion aequidens	Geelbek	1.5
Makaira indica	Black marlin	0.9
Istiophorus platypterus	Sailfish	0.1
Elops machnata	Ladyfish (springer)	1.0
Epinephelus lanceolatus	Brindlebass	0.4
Epinephelus tukula	Potato bass	0.1
Sparodon durbanensis	White musselcracker	0.3
Cymatoceps nasutus	Black musselcracker	0.7
Oplegnathus spp.	Knifejaw	0.2
Tripterodon orbis	Spadefish	0.1
Pomadasys kaakan	Javelin grunter	0.3
	Unidentified fish	1.0
Crustaceans		
Panulirus homarus	Crayfish	0.1

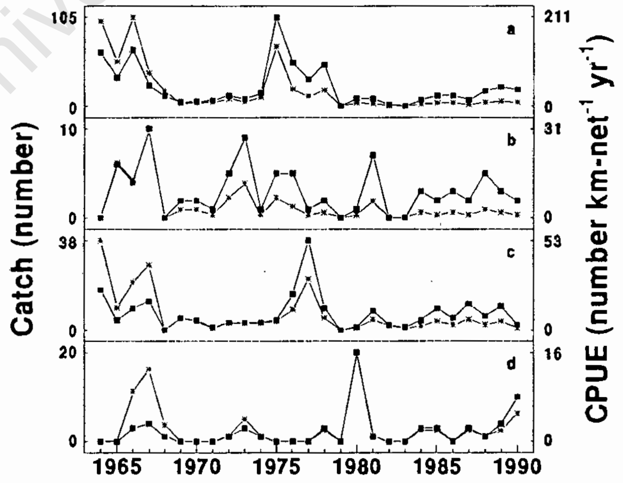

Figure 1.2: Annual catch (squares) and catch per unit effort (asterisks) at Umhlanga Rocks: a-rays, other than mobulids, b-manta and devil rays, c-giant guitarfish, d-turtles

Myliobatid life history characteristics of relatively slow growth rate, late age at maturity and low fecundity (Smith & Merriner 1986, 1987, Martin & Cailliet 1988a, b) may have led to stock depletion from net fatalities, despite the high release rate (62%) of those caught in the KwaZulu-Natal shark nets. Neither the myliobatids nor the mobulids are known to be exploited elsewhere in eastern African waters, so any impact on stocks is likely to be localised. The giant guitarfish *Rhynchobatus djiddensis* was caught in large numbers ($\bar{x}$=122 y^{-1}) along the netted coast but an average of 92 was released alive (Table 1.I). Again, the long-term trend in CPUE was one of slight decline, but superimposed on this was considerable fluctuation (Fig. 1.2). This species is locally exploited by recreational anglers (van der Elst 1988a).

An average of 67 turtles, of which about 23 were released alive, were caught annually (Table 1.I). The loggerhead turtle *Caretta caretta* and leatherback turtle *Dermochelys coriacea* are likely to be the most vulnerable to mortalities in the nets because they nest within 250 km of the netted region, yet the numbers of females nesting in KwaZulu-Natal were stable or increasing (Hughes 1989a, b). The average annual catch of the green turtle *Chelonia mydas* in the nets between 1981 and 1990 was only 14 individuals, of which five were released. Between 10 000 and 18 000 females nest annually at the tropical island of Europa (22°21'S, 40°21'E) (Le Gall *et al*. 1985 cited by Hughes 1989a), the closest green turtle breeding locality to South African waters (Hughes 1974). Although all turtle species were combined, the lack of trend in turtle catch rate at Umhlanga Rocks tends to support the contention (Hughes 1989b) that mortalities in the nets are not affecting turtle stocks to any great extent (Fig. 1.2).

From 1981 to 1990 the average annual teleost catch amounted to less than 50 individuals (Table 1.I). This figure may be conservative, as it does not allow for scavenging from the nets. The large mesh (50.8 cm stretched) of the nets seemed, however, to result in catches which were negligible in terms of exploitation pressure. Captured teleosts tended to be large; for example the average garrick *Lichia amia* measured 91 cm *FL* (*n*=83) and the average yellowfin tuna *Thunnus albacares* 93 cm *FL* (*n*=33).

Three species of dolphin were caught in the nets at a combined average rate of 77 per annum (1981-1990; Table 1.I). Common dolphin *Delphinus delphis* catches were small relative to the total population size (Cockcroft & Peddemors 1990), but marine mammalogists have expressed concern about net mortalities of the bottlenose dolphin *Tursiops truncatus* and the humpback dolphin *Sousa plumbea* (Ross *et al*. 1989, Cockcroft 1990, Durham *et al*. in prep.). A recent study which demonstrated that 63% of the catch of *T. truncatus* consists of non-residents implies, however, that catches of this species may be sustainable (Peddemors 1995).

1.3.2 Catches of potentially dangerous sharks

1.3.2.1 Catch and catch rate; all species combined

While the total shark catch at all beaches showed considerable annual variation between 1966 and 1990, there was a steep decline from 1966 to the early 1970s, followed by an increase until 1990, when it was at a level similar to that when records commenced in 1966 (Fig. 1.3). Highly variable catches of seasonal migrants directly associated with the 'sardine run', the annual winter influx of Cape pilchard *Sardinops ocellatus* (Wallett 1983, Armstrong *et al*. 1991), explain much of the fluctuation. Catches at the remote locality of Richards Bay (Fig. 1.1) are shown separately. The NSB began tagging sharks found alive in the nets in 1978 and releases approximately 15% of the annual catch. If sharks caught at Durban, Anstey's Beach and Brighton Beach, which were omitted from Figure 1.3, are included and all those released alive excluded, an average of 1 326 sharks, weighing a total of about 106 tons, was removed annually over the 13 year period 1978-1990.

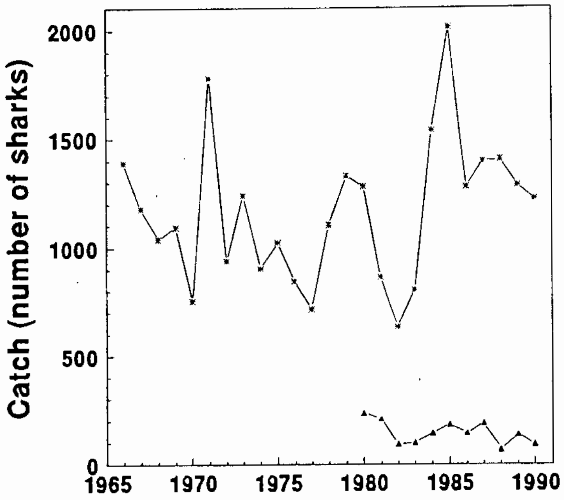

Figure 1.3: Annual catch, all shark species combined, at all installations (asterisks: Durban, Anstey's Beach, Brighton Beach and Richards Bay excluded), and at Richards Bay (triangles)

If total shark catch is related to fishing effort it becomes apparent that after an initial very steep decline in CPUE from 1966 to 1970 there was annual fluctuation, but little or no trend (Fig. 1.4). The initial decline has been interpreted as representing the removal of a resident community, followed by the

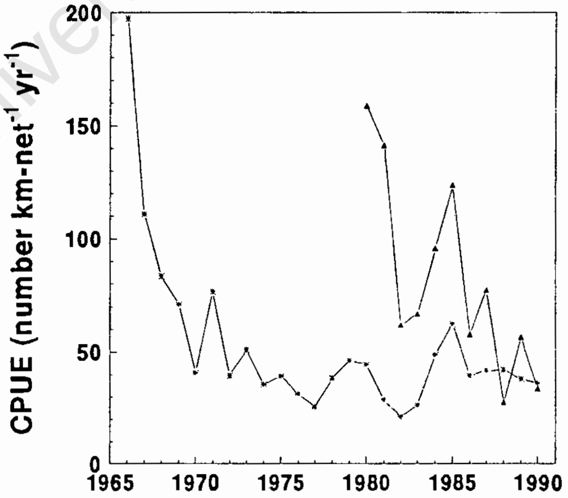

Figure 1.4: Catch per unit effort, all shark species combined, at all installations (asterisks: Durban, Anstey's Beach, Brighton Beach and Richards Bay excluded) and at Richards Bay (triangles)

relatively constant annual harvesting of immigrants (Wallett 1973, Cliff *et al.* 1988b). These immigrants would be either short-term seasonal visitors, or potential residents moving into the netted region to exploit the habitat vacated by those removed. The immigrants would comprise several species, which might variously move in from north, south or offshore of the netted region. Implicit in this interpretation is the assumption that there is a multi-species pool of sharks outside the netted region large enough to continuously provide immigration at the level of the net mortalities. All the shark species caught in the KwaZulu-Natal nets have a considerably wider distribution in the western Indian Ocean than the netted region (Compagno 1984a, b). Furthermore, the width of the continental shelf off the netted region varies from 10 to 45 km (shelf break depth 80-112 m; Martin & Flemming 1988), and the nets, set only 500 m offshore, are probably at the inshore edge of the range of most of the species caught.

1.3.2.2 Stock identity

Holden (1977) suggested that CPUE data from Durban and Brighton Beach, which are some 10 km apart, showed independent trends. In 1991 nets were installed at Mbango, a new locality between two existing installations (Umtentweni and St. Michael's on Sea) situated 15 km apart. An exceptionally large catch of bull sharks was taken in the new installation during the first six weeks, suggesting that a group of individuals of this species had survived despite more than two decades of netting activity to both north and south (Cliff & Dudley 1991a).

Conversely, Wallett (1973) showed that, during the period of numerical decline in the late 1960s, when nets were newly installed at beaches located between existing installations, the new nets began to fish at the same rate (all species combined) as the existing nets. As most of the existing installations were more than 10 km apart, this indicates that the effect of fishing was not necessarily limited to their immediate vicinity. Furthermore, 12 of the 14 shark species regularly caught in the nets were tagged in varying numbers and there were one or more recaptures of 10 of these species. The species with the lowest mean distance travelled before recapture was the bull shark ($\bar{x}$=28 km, *n*=6 recaptures), followed by the blacktip shark ($\bar{x}$=35 km, *n*=12) (van der Elst & Bullen 1990). Maximum individual distances travelled were 1409 km by a spotted ragged-tooth shark *Carcharias taurus* and 1320 km by a copper shark (van der Elst & Bullen 1990). The various shark species therefore moved distances at least as great as those between adjacent installations. This suggests that it is reasonable to combine CPUE data from the various beaches, despite the observations of Holden (1977) and Cliff & Dudley (1991a). The exception is Richards Bay, 84 km north of Zinkwazi, where nets were installed in 1980. CPUE at Richards Bay in 1980 was considerably higher than on the remainder of the coast (Fig. 1.4).

1.3.2.3 *Stock assessment*

Assessment of the impact of the netting program depends on being able to quantify the decrease in numbers of sharks. The following conceptual definition was assumed to describe the multi-species shark 'stock' or 'population' (strictly a community) exploited by the nets:

> The stock is much more widespread and abundant than the component in the KwaZulu-Natal nearshore environment. However, during 1966-1970, it is reasonable to assume that local reduction of this component took place under netting as if it were a closed population, and immigration effects took a greater time to provide appreciable compensation.

The assumption of constant catchability *q* in Leslie's method precludes territoriality, migration and learned net avoidance. In reality, these factors may all play a rôle, and will vary from species to species. Migration into and out of the entire netted region is the most likely to be a source of error in the present study, and this error will be compounded by combining catch data for all species. Learned net avoidance (discussed below) may also contribute substantially to invalidating the assumptions.

A first estimate of 5 483 sharks was obtained for N_o (95% confidence limits 4 227 and 9 991), based on the period 1966-1970 (Fig. 1.4). N_t, the population at the time K_t sharks had been caught (obtained by subtracting K_t from N_o), was estimated to be 889 sharks in 1970, after which time immigration may have begun to take effect. The fact that CPUE remained relatively stable from the early 1970s (Fig. 1.4) suggests that, notwithstanding the argument of Musick (1995) that even "open" marine fish populations are vulnerable to extinction, the multi-species catch taken annually after that time may have been sustainable.

Anecdotal evidence from skiboat anglers, in the form of sightings and of losing hooked teleosts, suggest that sharks may be considerably more numerous offshore of the nets than the CPUE analysis indicates for inshore waters.

1.3.2.4 Catch rates of individual species/species groups (Durban, Anstey's Beach, Brighton Beach and Richards Bay excluded)

The combined catch rate of Java and bull sharks, both regarded as resident, inshore species, showed a pronounced initial decline (Fig. 1.5). After 1978, when separate catch data for all individual species became available, CPUE of both the Java shark (Cliff & Dudley 1991b) and the bull shark (Cliff & Dudley 1991a) remained relatively constant. Other species for which steep declines in CPUE were initially apparent were the hammerhead sharks (Fig. 1.5) and the spotted ragged-tooth shark (Fig. 1.5), although the ragged-tooth began to increase again slightly from 1982. The dusky/sandbar shark pairing declined from 1966 to 1976, after which there was no trend (Fig. 1.5). Fluctuations were probably amplified by influxes of the dusky shark during sardine runs. The dusky was reported as constituting 86% of the catch of the pair from 1966 to 1977 and 92% from 1978 to 1990. The necessity to group the blacktip, spinner and copper sharks

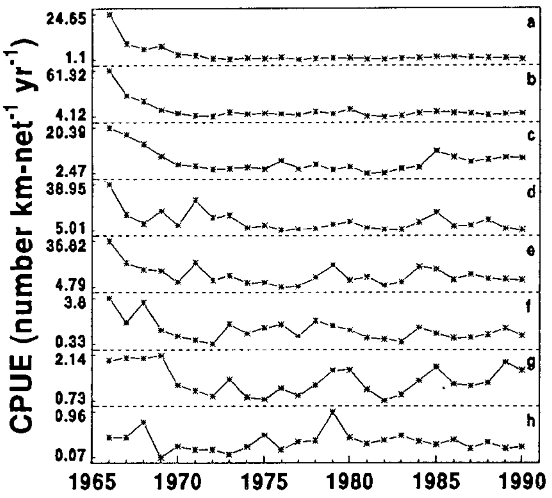

Figure 1.5: Shark catch per unit effort, by species or species group, at all installations: a-Java/bull, b-hammerhead, c-spotted ragged-tooth, d-dusky/sandbar, e-blacktip/spinner/copper, f-great white, g-tiger, h-shortfin mako

(Fig. 1.5) was unfortunate because the copper shark tends to enter the netted region from the cooler waters to the south during the winter months, whereas the other two species occur throughout the year. Thus reliable inferences could not be drawn from the trend in the combined catch rate. An initial decline in catch rate was evident even for those species which were caught in relatively low numbers since the start of the netting program, including the great white shark *Carcharodon carcharias* and the tiger shark *Galeocerdo cuvier* (Fig. 1.5), with the tiger showing a recovery from the mid 1970s. The only shark for which no trend in CPUE was apparent was the shortfin mako shark *Isurus oxyrinchus* (Fig. 1.5), a pelagic species which is probably an incidental visitor to the extreme inshore waters in which the nets are located (Cliff *et al.* 1990). Investigation of the biology of each species of shark caught in the nets is under way (Cliff 1995, Cliff *et al.* 1988a, 1989, 1990, Cliff & Dudley 1991a, b, 1992b, Dudley & Cliff 1993a), as a precursor to an improved assessment of the direct effects of netting on these species, and regression analyses of trends in catch rates are given by Dudley & Cliff (1993b).

1.3.2.5 Net avoidance

The assumption that CPUE data from inshore-set nets are more or less proportional to total stock size of a given species may not necessarily be justified in all cases. Sharks have been shown under experimental conditions to be capable of "rapidly" learning "a wide variety of tasks" (Myrberg 1987, p46). Although considered unlikely, it is not impossible that sharks resident in an area may learn that the nets represent an obstacle and may actively avoid them.

1.3.3 The consumption of small sharks by large sharks

Van der Elst (1979) showed that from 1968 there was a sharp increase in the CPUE of small sharks, especially the juvenile dusky shark and the milk shark *Rhizoprionodon acutus* in KwaZulu-Natal's shore-based sport fishery. He concluded that "reduction in numbers of the large inshore shark species along the KwaZulu-Natal coast, as achieved by intensive gillnetting, has resulted in reduced predation on small sharks and is the cause of their proliferation" (p358). This conclusion, which has been given scientific prominence (Castro 1987, Compagno 1987, Compagno *et al*. 1989, Gruber & Manire 1989, Paterson 1990) and has been accepted by anglers (e.g. Mara 1986), is re-examined below using stomach content data from sharks caught in the nets.

Of the 2 860 stomachs containing food which were examined between 1983 and 1988, 16.9% contained sharks of all sizes, approximately 14.8% contained small sharks of all species and approximately 4.7% contained small dusky sharks. Small sharks were defined as being less than 1 m *PCL*, this being the size discussed by van der Elst (1979). The frequencies of occurrence of selected dietary items are shown in Table 1.II. Net scavenging cannot be discounted, although this will if anything elevate the incidence of elasmobranchs as they are more frequently trapped in the nets than are teleosts (Table 1.I).

Table 1.II: Frequency of occurrence of certain dietary items in sharks caught in the Natal nets. All figures are percentages of non-empty stomachs in which the item was present, with the exception of "Annual catch", "Stomachs" and "Non-empty", which are counts. Annual catch represents the mean for the period 1978-1990 and includes sharks released alive. Dietary information is summed over the period 1983-1988. "Total" represents frequency of occurrence in the diet of the entire annual catch.

	Predator														Total
	Blacktip	Spinner	Copper	Dusky	Sandbar	Bull	Java	Tiger	Great white	Shortfin mako	Spotted ragged-tooth	Great hammerhead	Scalloped hammerhead	Smooth hammerhead	
Annual catch	136	146	138	283	30	59	16	46	41	14	246	15	190	65	-
Sample size															
Stomachs	631	615	685	1164	175	283	74	181	177	71	877	72	788	241	-
Non-empty	316	153	167	473	92	166	41	137	61	36	491	60	522	145	-
Prey															
Teleosts	83.9	83.0	87.4	59.6	58.7	57.2	65.9	35.0	31.1	33.3	82.7	40.0	80.1	83.4	72.7
Elasmobranchs	18.4	2.0	4.8	31.3	17.4	53.6	46.3	54.7	47.5	69.4	31.2	88.3	10.9	0.7	23.2
Sharks	14.6	2.0	4.2	21.6	9.8	32.5	24.4	32.8	42.6	66.7	24.4	53.3	8.8	0.7	16.9
C. obscurus	7.3	0.0	0.0	6.0	2.2	7.5	9.8	5.1	21.5	15.9	6.9	24.2	0.0	0.0	4.7
C. sealei	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1
R. acutus	3.6	0.0	0.0	1.3	0.0	9.0	9.8	2.6	4.3	31.7	6.6	12.1	0.3	0.0	2.9
Sphyrna spp.	1.8	0.0	0.0	6.0	0.0	4.5	4.9	2.6	4.3	7.9	1.7	0.0	0.0	0.0	2.2
Scyliorhinidae	0.9	0.0	1.8	0.9	6.5	4.5	0.0	2.6	0.0	0.0	6.2	12.1	8.4	0.0	3.1
Squalidae	0.0	0.0	1.8	0.0	0.0	1.5	0.0	2.6	4.3	0.0	1.0	0.0	0.0	0.0	0.6
Unident. >1 m	0.9	0.7	0.0	5.5	1.1	3.6	0.0	12.4	3.3	5.6	0.6	3.3	0.0	0.0	2.1
Other sharks	0.0	1.3	0.6	1.9	0.0	1.8	0.0	5.1	4.9	5.6	1.0	1.7	0.2	0.7	1.2

From shark consumption rates published in the literature, together with the findings of this study, it was possible to obtain an estimate of the number of small sharks which would have been consumed by the sharks removed by the nets. Members of the family Carcharhinidae, together with the spotted ragged-tooth shark (Odontaspididae), constitute nearly 80% of the annual catch. Estimates in the literature of daily ration of various carcharhinids and the spotted ragged-tooth shark, expressed as a percentage of body weight, included: sandbar shark 1% (Medved *et al.* 1988), 0.3-0.5% (New England Aquarium cited by Kohler 1987) and 0.5% (Schmid *et al.* 1990); bull shark 0.5% (Schmid *et al.* 1990); blue shark *Prionace glauca* 0.6% (Kohler 1987); lemon shark *Negaprion brevirostris* 1.5-2.1% (Cortes 1987 cited by Wetherbee *et al.* 1990) and spotted ragged-tooth shark 0.3% (Schmid et al. 1990). From these values the mean daily ration for the sharks caught in the KwaZulu-Natal nets was assumed to be 0.8% of body weight.

A reduction in numbers of large sharks was assumed to have occurred over 5 years at a rate of 919 sharks per year, after which predator numbers stabilised (Appendix 1.I). On this basis, it is estimated that some 286 000 small sharks probably escaped predation by large sharks from 1966 to 1976, the period considered by van der Elst (1979). If the reduction in number of predators was assumed to have been unlimited (i.e. no compensatory immigration), the estimate becomes some 419 000 small sharks. Each of these figures is less than one sixth of van der Elst's (1979) estimate of 2.8 million small sharks. There was no evidence from net captures (Fig. 1.5) of the approximately 40-fold increase in the number of adult dusky sharks predicted by van der Elst (1979) for the early 1980s, further indicating that his estimate was exaggerated.

Van der Elst (1979) extrapolated his observations of the captive feeding preferences of two species of shark, the bull and the spotted ragged-tooth, to the entire catch taken in the shark nets. These two together represented only 21% of the annual catch of 14 species, each species having its own dietary characteristics (Table 1.II). Further, if the proportions of small sharks in the diet of wild-caught bull and ragged-tooth sharks as determined in this study were similarly extrapolated, this would not fully explain the difference between the estimate of predation escapement obtained here and that obtained by van der Elst (1979), indicating that he assumed a much higher proportion.

1.3.4 Possible relationships between catch rates of small sharks and teleosts

Van der Elst (1989) modified his earlier position by suggesting that shark nets were only partially responsible for the increased number of small sharks and that exploitation of teleosts by shore-based anglers may have led to replacement by cartilaginous fish, particularly those which had been competing for food. He also reported that, with no change in fishing strategy, catches made during beach angling competitions in the waters of both the Eastern and Western Cape Province (where there are no shark nets) displayed a progressive increase in their elasmobranch component, in conjunction with a decrease in teleosts (van der Elst 1989).

A converse argument is that the increase in small sharks may have led to a decrease in teleosts. Van der Elst (1979) demonstrated that between 1956 and 1976 the catch per unit effort (CPUE) of teleosts by KwaZulu-Natal's shore-based anglers declined steadily, and he pointed out that there was a significant negative correlation between this trend and the increase in CPUE of small sharks. While he did concede that this was not necessarily causal, causality was subsequently assumed by anglers, explicitly linking shark netting with declining teleost catches (Mara 1986). During an interview published in a popular magazine, A.P. Bowmaker stated that "the pleasure of thousands of anglers has been destroyed because (shark) nets have played havoc with the balance of the fish population" (McCracken 1989).

The inverse relationship between CPUE trends of teleosts and small sharks cannot be linked to shark netting alone because the teleost decline reported by van der Elst (1979) had already been evident for at least six years (1956-1961) before nets were installed at any KwaZulu-Natal beach other than Durban. Overall CPUE in the KwaZulu-Natal offshore linefishery declined by 85% from 1933 to 1983 as a result of overfishing (van der Elst 1988b). While the offshore target species differ from the inshore, this trend indicates that KwaZulu-Natal's linefish stocks have been under pressure for much of this century.

1.3.5 The refuge concept

KwaZulu-Natal anglers frequently assert that juvenile dusky sharks aggregate inshore of net installations, and suggest that the nets provide refuge from predation. NSB field staff attempt to determine for each captured shark whether the direction of travel at the time of capture was inshore or offshore. The fact that some 35% of captured sharks were moving offshore from within the netted area indicates that any refuge effect is limited. The intermittent availability of food in the form of netted batoids and teleosts may, however, lead to temporary aggregations of scavenging small sharks.

1.3.6 Shark predation on other groups

Sharks prey both on dolphins (Cockcroft *et al.* 1989, Cliff *et al.* 1989, Cliff & Dudley 1991a) and on turtles (Bass *et al.* 1975, Cliff & Dudley 1991a), and, although the nets kill dolphins and turtles, reduction in shark numbers eases natural predation pressure. This argument has already been presented in the case of turtles for both the Australian (Paterson 1990) and South African (Hughes 1989b) anti-shark programs.

Cockcroft *et al.* (1989) found that, of the shark species caught in the nets, only the dusky (*PCL*>170 cm), bull (*PCL*>140 cm), great white (*PCL*>180 cm) and tiger sharks (*PCL*>190 cm) showed evidence of having killed dolphins. This was determined by the presence of dolphin flukes and/or vertebrae in the stomach contents; any other dolphin remains may have represented scavenging. The majority of the remains were from young dolphins (Cockcroft *et al.* 1989). In the present study, 3.8% of the non-empty stomachs of the above four shark species were found to contain such remains. Assuming a mean mass of 60 kg for a young dolphin, it is estimated that the average of 220 large sharks of these four species killed in one year, each with an average mass of 157 kg, would have consumed 63.8 dolphins per year i.e.

(220 x 157 kg x 0.008 day^{-1} x 365 days x 0.038)/60 kg = 63.8 young dolphins

The Leslie analysis indicated, however, a reduction of 4 594 sharks in KwaZulu-Natal's inshore waters. Assuming that the 16.6% contributed by the above four shark species, of the given sizes, to the annual number of sharks currently killed in the nets was proportional to original abundance, there may have been a reduction of 763 of these predators on dolphins. This number of sharks would have eaten 221 dolphins per annum, which is 2.9 times the current annual catch of 77 dolphins. Compounding over 1966-1990 and assuming a limited reduction in predator numbers, in similar manner to the application of the Leslie figures to small sharks (Appendix 1.I), over 5 000 dolphins may have escaped predation. By comparison, 1 675 dolphins were netted 1966-1990, assuming an average annual catch of 77 dolphins.

This analysis is crude in that it ignores factors such as density dependent limitations on the potential dolphin population size, possible changes over the years in the species composition of large sharks and also possible changes in the numbers of netted dolphins. It also groups the three local species of dolphin. It does, however, indicate that reduction in shark predation on dolphins may partially compensate for the netting of dolphins.

Appendix 1.I: Calculation of predator escapement by small sharks

Consumption of small sharks by large sharks

Average mass of netted large shark (predator): 80 kg

Average mass of small shark (prey): 5 kg

Mean daily ration (percentage of body weight): 0.8%

Occurrence of small sharks in diet of large sharks: 14.8%

Occurrence of small dusky sharks in diet of large sharks: 4.7%

Reduction in number of predators

Initial number of predators N_o = 5 483 large sharks

Final number of predators N_t = 889 large sharks

Depletion of predators $N_o - N_t$ = 4 594 large sharks

Depletion assumed to occur over 5 y (1966-1970) at 919 large sharks y^{-1} after which time number of predators assumed to stabilise

Annual consumption by 919 large sharks

(919 x 80 kg x 0.008 per day x 365 days x 0.148)/5 kg = 6 354 small sharks

(919 x 80 kg x 0.008 per day x 365 days x 0.047)/5 kg = 2 018 small dusky sharks

Number of small sharks estimated to have escaped predation 1966-1976 (11 y)

i). Assuming a cumulative but limited reduction in predator numbers:

$$\left(\sum_{n=1}^{4} n(6354)\right) + (7(5x6354)) = 285930 \textit{ small sharks}$$

ii). Assuming a cumulative and unlimited reduction in predator numbers:

$$\sum_{n=1}^{11} n(6354) = 419364 \textit{ small sharks}$$

CHAPTER 2: A COMPARISON OF THE SHARK CONTROL PROGRAMS OF NEW SOUTH WALES AND QUEENSLAND (AUSTRALIA) AND KWAZULU-NATAL

Chapter 2: A comparison of the shark control programs of New South Wales and Queensland (Australia) and KwaZulu-Natal

2.1 Introduction

Shark control programs exist to reduce the probability of attack from sharks on humans at the major recreational beaches of three regions; New South Wales (NSW) and Queensland, Australia, and KwaZulu-Natal (KZN) (formerly Natal), South Africa (Fig. 2.1). The programs are administered by New South Wales Fisheries, the Queensland Department of Primary Industries and the Natal Sharks Board (NSB), respectively. In all three regions, it is assumed that the shark control measures achieve their protective function through reducing the populations of large sharks and hence the probability of an encounter between a shark and a bather (e.g. Anon 1935, Davies 1961, Springer & Gilbert 1963, Paterson 1979, Cliff & Dudley 1992b, Last & Stevens 1994). These authors emphasise that sharks are not prevented from entering a protected area. Yet despite this general agreement on the mechanism, markedly different amounts of fishing effort are applied in the three regions. Further, fishing gear is permanently deployed in KZN and (in season) in Queensland, but is intermittently deployed, in season, in New South Wales. The reasoning underlying these differences is not known, yet the success of all three programs in terms of reducing the incidence of shark attack appears comparable (Collins 1972, Wallett 1983, Cliff 1991, Anon 1992, Reid & Krogh 1992, Simpfendorfer 1993).

The purpose of this chapter is to review the literature pertaining to the respective programs in an attempt to determine whether effort in the KZN program could be reduced.

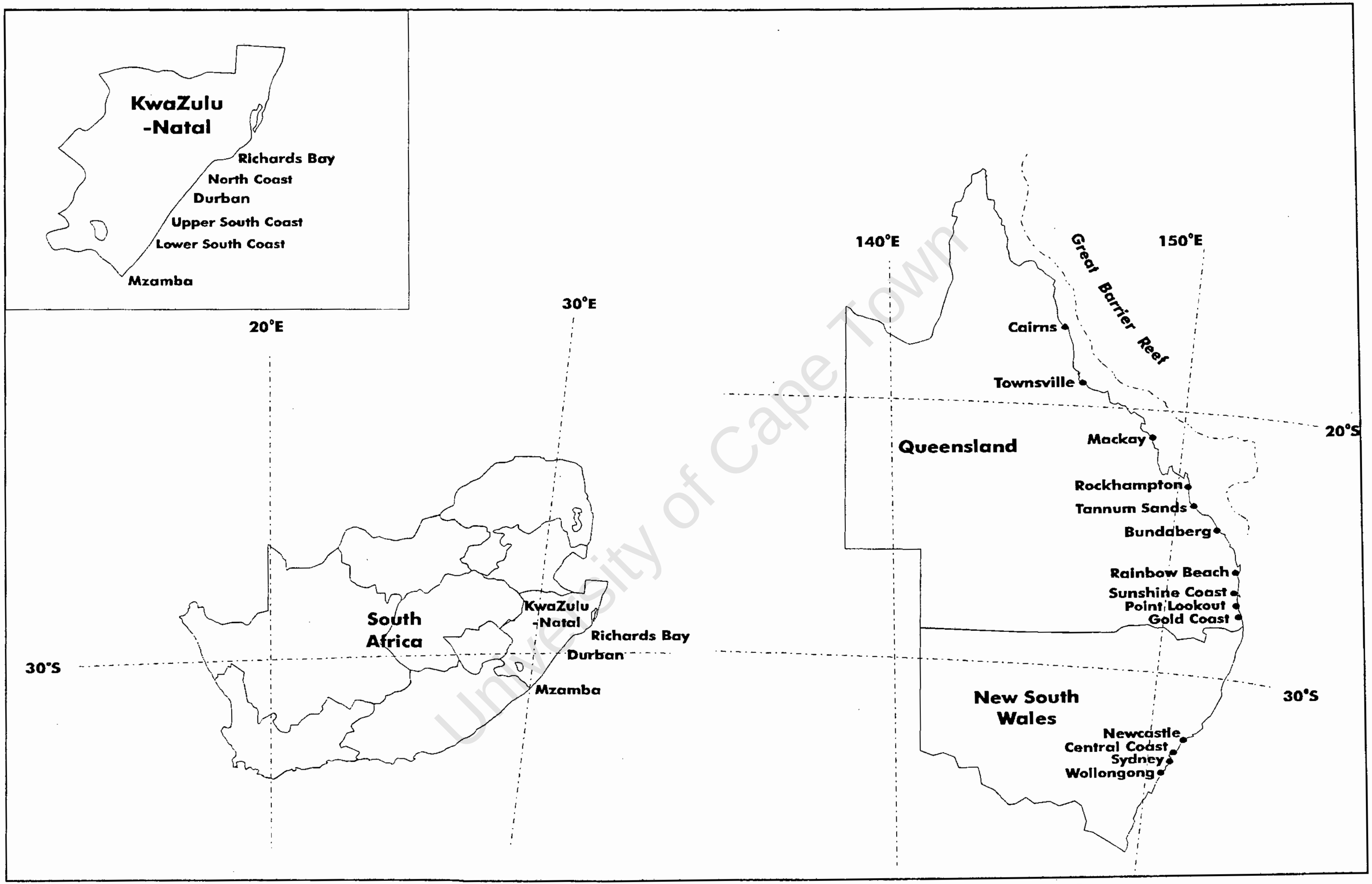

Figure 2.1: The netted regions of KwaZulu-Natal, Queensland and New South Wales

2.2 The nearshore physical environments

2.2.1 New South Wales

The influence of a southward-flowing western boundary current, the warm East Australian Current, extends along the NSW coast (Last & Stevens 1994). Shark nets are confined to the area between Newcastle (32°56´S) and Wollongong (34°25´S) (Reid & Krogh 1992), where the beaches are all exposed to the open ocean, and where waves tend to be moderate or high (Short & Wright 1984). The average wave height is 1.6 m, but extreme conditions may occur - a wave of 17 m being recorded at Newcastle in January 1978 (Short 1993). Mean monthly sea surface temperatures at Manly, Sydney, vary from 21.8°C in February to 14.6°C in August (Short 1993, Fig. 2.2). Temperatures off Newcastle tend to be slightly higher than off Sydney and Wollongong (Reid & Krogh 1992). Water clarity is generally high, with estimated visibility (as assessed by a SCUBA diver) ranging from 6-8 m in summer to more than 15 m in winter, clarity tending to decline after rainfall or during plankton blooms (M. Krogh pers. comm.).

Most of the beaches with shark nets are of the "transverse bar and rip" type, with the bars usually attached to the beach; in this beach type channels or troughs are shore-normal (Short 1993). Some of the beaches alternate between this and the "rhythmic bar and beach" type; in the latter case the bars become detached and a shore-parallel trough forms (Short 1993). Less common beach types are the "low tide terrace" type and the "reflective" type. At low tide on a low tide terrace beach, and at all times on a reflective beach, there is deep water close to the water's edge (Short 1993).

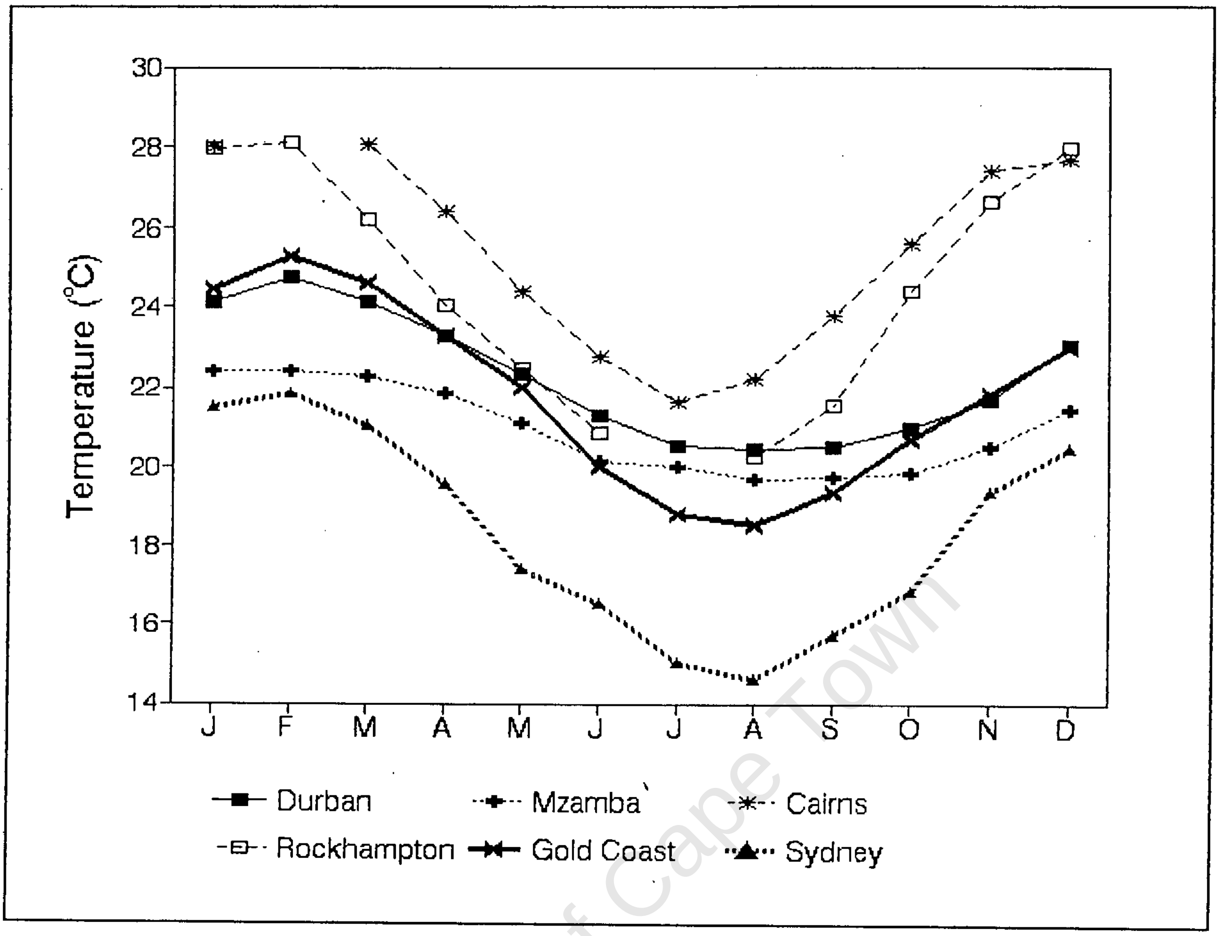

Figure 2.2: Mean monthly sea surface temperatures at Durban and Mzamba (KwaZulu-Natal), Cairns, Rockhampton and the Gold Coast (Queensland) and Sydney (NSW) (Sources; NSW - Manly Surf Club, cited by Short (1993); Queensland - B.H. Lane (pers. comm.))

2.2.2 Queensland

The east coast of Queensland is also affected by the East Australian Current. The netted area extends from Cairns (16°55´S) to the Gold Coast (28°10´S).

Winds in the Cairns/Townsville area are mostly coast-parallel, from northwest or southeast, except for occasional calm periods or tropical cyclones (Wolanski & Pickard 1985). From Bundaberg (24°S) north, surf conditions on mainland beaches are moderated by the Great Barrier Reef (GBR) (Anon 1992). The average wave height in this northern area is 0.5 m and the intertidal zone is wide, low and usually featureless (A.D. Short pers. comm.). Bars and rips are present below low tide on the higher energy beaches only and there are never any longshore bars and troughs (A.D.

Short pers. comm.). Coastal waters inshore of the GBR are turbid because of the resuspension of bottom sediment by wind waves (Wolanski 1994), with estimated visibility seldom exceeding 5 m (E.M. Grant pers. comm.). Visibility drops to 3 m or less in late summer, during seasonal heavy rain (E.M. Grant pers. comm.).

Below 25°S, where there is no reef protection, waves tend to be moderate (1-2.5 m) to occasionally high (>2.5 m) (Short & Wright 1984). Extreme conditions may occur, with, for example, a 6 m swell being recorded on the south Queensland coast in early January 1992 (Anon 1992). The Gold and Sunshine coast beaches usually consist of a double bar system, with an intermediate rip-dominated inner bar and a shore-parallel trough and outer bar with more widely spaced rips (A.D. Short pers. comm.). Water clarity is higher than in the north, occasionally reaching 20 m visibility in midwinter, but may drop to 3 m or less during summer rains (E.M. Grant pers. comm.).

Average monthly sea surface temperatures at Cairns range from 28.0°C in January to 21.6°C in July, and at the Gold Coast from 25.3°C in February to 18.5°C in August (Fig. 2.2).

2.2.3 KwaZulu-Natal

The province of KZN lies on the east coast of South Africa, where it is bordered by the warm, southward-flowing Agulhas Current, a major western boundary current (Schumann 1988). The netted region extends from Richards Bay (28°48´S) to Mzamba (31°05´S). Winds are coast-parallel, blowing with almost equal distribution from northeast or southwest (Hunter 1988). A wave clinometer stationed at Margate (between Durban and Mzamba) from September 1972 to August 1974 showed that swell heights of ≤2 m occurred 92% of the time, with swells of >4-5 m occurring only 1% of the time (Anon 1975). Sea surface temperatures are slightly warmer in the north (e.g. Durban), ranging from an average of 24.8°C in February to 20.4°C in August, than in the south (e.g. Mzamba), where they range from 22.4°C in February to 19.6°C in August (Fig. 2.2). Discharge of sediment by rivers into the ocean occurs in summer after heavy rains (Schumann 1988), and raises nearshore turbidity. Water clarity at the nets, estimated using the meshes of the nets as a guide, ranges from an average of 2.9 m in February to 4.5 m in July, but it may approach zero near the mouths of flooding rivers (NSB unpubl. data, 1981-1992).

All the beaches are exposed to the open ocean, none being protected by reef. The sand on most beaches is either medium- or coarse-grained, although on a few in the south it is fine-grained (Anon 1975, Dye *et al.* 1981). The dominant beach type in the north is the "longshore bar - trough" (as defined by Short & Wright 1984), although this may plane down to the dissipative state in storm conditions or may tend toward a more rhythmic state in calm conditions (A. McLachlan, pers. comm.). For most of the time, therefore, there is a bar some 50 m offshore with a channel between bar and beach. In the south the beach faces tend to be more reflective, although a bar is also frequently present (A. McLachlan, pers. comm.).

2.3 Methods of shark control

2.3.1 New South Wales

Systematic netting, or "meshing", of Sydney's beaches was initially recommended in 1929 (Anon 1935), but was only implemented in September 1937, after which netting spread to the beaches of both Newcastle and Wollongong in December 1949 (Collins 1972), and to the Central Coast beaches in January 1987 (Reid & Krogh 1992). Meshing was interrupted from January 1943 to March 1946 by the Second World War (Collins 1972). By 1992 49 bathing areas were protected (Table 2.I).

Contractors provide vessels, fishing gear and labour. Current net specifications are shown in Table 2.II; until 1946 (Collins 1972) nets were 305 m long. All nets have been bottom set since 1972, prior to which this was not contractually stipulated (Reid & Krogh 1992). Baited lines were not introduced in case these attracted sharks to beaches over an unknown radius (Collins 1972).

From 1983 meshing was suspended, for economic reasons, during June and July, and in 1989 the months of May and August were also removed from the contract (Reid & Krogh 1992). During the remainder of the year, nets are not permanently in the water at any beach (Table 2.III). Until 1972, the contract stipulated the number, which varied from bathing area to bathing area, of overnight sets of a 152 m net per 4-week period, but not how such sets should be temporally distributed (Collins 1972). Subsequent to revisions to the contract made in 1972, the same effort was stipulated for all bathing areas and criteria for distribution of effort through the month were laid down (Reid & Krogh 1992). Thirteen meshings are required per month, with a meshing defined as an overnight (minimum 24 hr) or a weekend (minimum 48 hr) set of a 150 m net; some meshings must be conducted over weekends, and no more than 70% of the monthly meshings should be completed per half month. These stipulations led to an increase of some 20% in nominal effort (Reid & Krogh 1992), with the average monthly effort now being approximately 17 net-days (M. Krogh pers. comm.). Two nets may be set simultaneously at a bathing area and, as this constitutes two meshings, nets tend to be in the water for an average of only nine days per bathing area per month.

Live harmless animals are released, live sharks are killed and dead animals are disposed of at sea (Reid & Krogh 1992, M. Krogh pers. comm.) (Table 2.III). Catches are recorded but classification tends to be by taxonomic group rather than at species level (Reid & Krogh 1992). Some biological parameters are recorded (Table 2.III).

Table 2.I: Distribution of shark control gear. (NSW - identification of meshed areas from Reid and Krogh (1992), length of net 150 m; Queensland - numbers of nets and drumlines from B.H. Lane (pers. comm.), length of net 189 m; KwaZulu-Natal - net length 213.5 m except [a] 320.25 m, [b] 304.8 m, adjacent meshed areas protected by continuous net installations were treated as single areas for the calculation of mean inter-area distances)

Locality name	Latitude	Number of meshed bathing areas	Gear deployment per bathing area ± S.E. (n=net, d=drumline)	Mean distance between meshed areas ± S.E. (km)	Length of locality (km)	Distance to next locality (km)
New South Wales						
Newcastle	32°56´S	10	1-2n	2.8 ± 0.9	25	12
Central Coast	33°17´S	9	1-2n	4.5 ± 0.5	36	8
Sydney	33°52´S	25	1-2n	3.3 ± 0.8	78	10
Wollongong	34°25´S	5	1-2n	3.0 ± 1.2	12	-
Queensland						
Cairns	16°55´S	6	1n & 3-9d, or 3d	3.4 ± 0.5	17	280
Townsville	19°16´S					
Magnetic Island		6	1n & 3d, or 5-12d	4.2 ± 0.5	-	-
Mainland		2	3-6d	7.0	7	355
Mackay	21°09´S	4	2n & 9d, or 1n, or 6d	5.3 ± 1.6	16	325
Rockhampton	23°16´S	9	5-10d	1.6 ± 0.4	13	93
Gladstone	23°51´S	1	12d	-	-	175
Bundaberg	24°52´S	5	3-6d	3.2 ± 0.5	13	150
Rainbow Beach	25°56´S	1	3n & 12d	-	-	42
Sunshine Coast	26°23´S					
Noosa-Caloundra		18	1-2n, or 1-2n & 3-6d, or 3-6d	2.6 ± 0.5	45	36
Woorim (Bribie)		1	6d	-	-	55
Point Lookout	27°26´S	2	12d	2.0	2	59
Gold Coast	27°58´S	20	1n, or 2-6d	1.4 ± 0.1	29	-
KwaZulu-Natal						
North Coast	28°48´S					
Richards Bay		2	7.0n or 1.0n[a]	0.5	2	84
Zinkwazi-Umhlanga		10	3.4n ± 0.3	7.1 ± 1.5	50	10
Durban	29°49´S					
Durban		14	1.5n[b]	(continuous)	6	8
Anstey's-Brighton		2	2.0n[b]	2.0	2	15
Upper South Coast	30°03´S					
Amanzimtoti-Karridene		7	3.8n ± 0.2	3.3 ± 0.3	10	18
Scottburgh-Park Rynie		3	3.3n ± 0.3	4.0	4	18
Lower South Coast	30°35´S					
Hibberdene-Mzamba		24	3.1n ± 0.2	3.6 ± 0.5	71	-

Table 2.II: Net specifications and position details. (Sources; NSW - Hamer (1993), Reid and Krogh (1992), Illawarra shark meshing contract; Queensland - Anon (1992), B.H. Lane (pers. comm.))

	New South Wales	Queensland	KwaZulu-Natal (Durban in parentheses)
Net length	150 m	189 m	213.5 m (304.8 m)
Net depth	6 m	5.6 m (some 4.5 m or 3 m)	6.3 m (7.6 m)
Mesh size - stretched	50-60 cm	50 cm	51 cm
Net body material	3 ply black polyethylene twist; 2 mm diameter 70 kg breaking strain, 3 mm diameter 140 kg	2.7 mm nylon cord; breaking strain 276 kg	black (yellow) polyethylene flat braid with (without) blue rogue line; breaking strain 159 kg
Surround rope	10 mm white ("silver") rope; breaking strain ≥900 kg	12 mm black/green polypropylene rope; breaking strain - top 1 530 kg, bottom 1 450 kg	14 mm black polyethylene rope with blue rogue line; breaking strain 1 360 kg
Hang-in coefficient (excess webbing/total stretched webbing x 100)	33.3%	50.0%	40.0%
Net flotation	10 cm diameter polystyrene floats, set every 5 m	8.8 cm diameter polystyrene floats, buoyancy 1 712 g, set every 13 meshes	plastic keg-type floats, buoyancy *ca* 680 g, set at 4 m intervals
Weights	90 g leads, set every 0.9 m but with 2 leads under each float	390 g leads, set every 8 meshes	roller leads, mass *ca* 560 g, set at 3 m intervals
Anchors	2 x 13 kg Danforth anchor	2 anchors, either 40 kg CQR, 20 kg CQR or 17 kg Danforth	4 (6) x 35 kg stockless naval type or Danforth sand anchors
Water depth	*ca* 10 m	3.5-15 m	10-14 m (6-7 m)
Distance from shore	*ca* 500 m	*ca* 200 m from surfline	300-500
Orientation to shore	parallel	parallel only	parallel
Setting in water column	bottom	top	top/mid-water

Table 2.III: Meshing procedures (Sources; NSW - Reid and Krogh (1992), M. Krogh (pers. comm.); Queensland - Anon (1992))

	New South Wales	Queensland	KwaZulu-Natal
Gear used	Nets	Nets and drumlines	Nets
Gear permanently in the water (in season)	No	Yes	Yes, except locally during sardine run
Gear inspections per bathing area per month	7	17	15-20
Disposal of captures	Live bycatch species released, live sharks killed. Dead animals dumped at sea.	Live bycatch species, including harmless sharks, released, potentially dangerous sharks killed. Dead animals dumped at sea.	Live sharks and bycatch species released, live sharks tagged. Dead animals to laboratory for dissection, unless decomposed.
Capture bonus/incentive	No	Yes	No
Identification of species	Sharks to taxonomic group, some species to species level; bycatch to taxonomic group	Sharks to taxonomic group, some species to species level; bycatch to taxonomic group	Sharks and most bycatch species to species level
Biological parameters recorded at sea	Classification, fork length, alive/dead, number of embryos. Sharks <1 m often recorded as bycatch	Classification, length (total?), sex, stomach contents, no., size & sex of embryos	Classification, precaudal length, sex
Biological parameters recorded at the laboratory	Nil	Nil	Various morphometrics, mass, reproductive state, stomach contents etc.
Physical parameters measured/estimated at sea	Nil	SST, description of sea conditions	SST, wind direction and strength, current direction and strength, water clarity, swell

2.3.2 Queensland

The shark meshing program began in 1962, with the Queensland Government deciding (Paterson 1979) to use both nets (Table 2.II) and, where conditions were unsuitable for nets, baited drumlines (Fig. 2.3). The Queensland Department of Primary Industries provides the shark catching equipment and bait, and maintains records, and contractors - who install and maintain the equipment - supply vehicles, boats and labour (Anon 1992). In November 1994 74 bathing areas in 10 contract areas were protected by means of 36 nets and 296 drumlines (B.H. Lane pers. comm.).

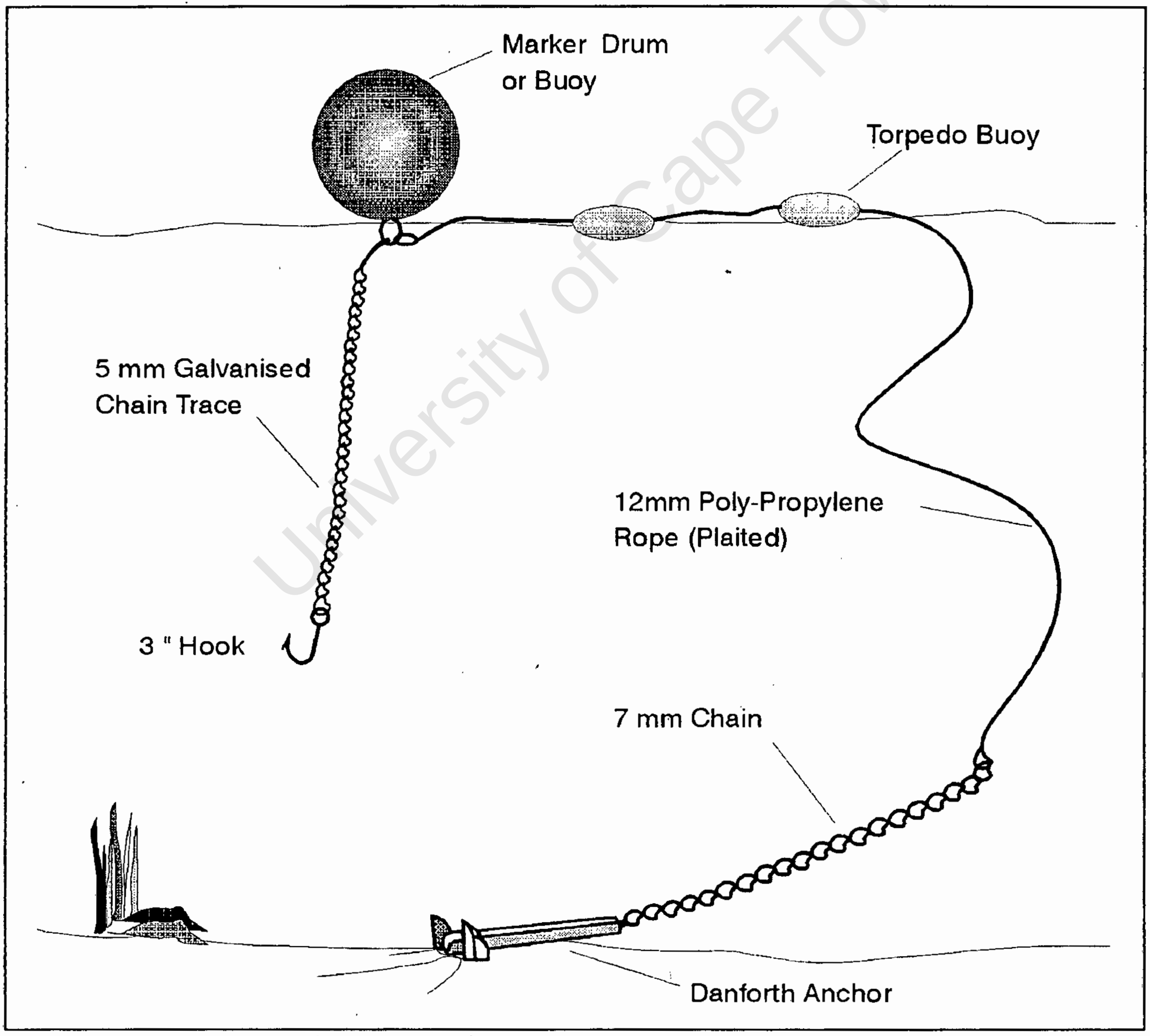

Figure 2.3: Drumline used in the Queensland shark control program (after Anon 1992)

The nets were originally bottom set, but this led to a high catch of rays which resulted in shark scavenging and hence net damage. Hence they were raised within months of the start of the program (E.M. Grant pers. comm., Paterson 1979). Net panels were originally manufactured from No. 72 filament nylon, a soft, white, 3-stranded twine with a breaking strain of 100 kg. This proved very difficult to repair when damaged by sharks and so the change was made, also soon after the program started, to braided nylon cord (E.M. Grant pers. comm.). Another early change was from a hang-in coefficient of 50% to one of 30% (E.M. Grant pers. comm.), although at some later stage this reverted to 50% (B.H. Lane pers. comm.).

At one time fishing effort in June and July was reduced throughout the netted region (Paterson 1986, 1990). There is still a winter closed season from Mackay to Bundaberg, but netting now occurs throughout the year from Rainbow Beach southwards (B.H. Lane pers. comm.). From 1979 there was no netting in February at Cairns or Townsville due to the presence of box jellyfish, or "stingers", *Chironex fleckeri* (Paterson 1986) and cyclones (B.H. Lane pers. comm.). Today, "stinger nets" are used to protect bathers in summer, but the cyclone-induced summer closed season for shark meshing persists in these two areas.

Servicing, or meshing, of the gear entails hauling it to the surface, removing and recording the catch, attending to the bait (in the case of drumlines) and effecting repairs. Contracts typically stipulate that gear must be attended on 20 days per 28 day cycle, weather permitting (Anon 1992). Each set of gear is changed every 21 days and taken ashore for cleaning and repair (Anon 1992). Live harmless animals, recently including harmless sharks, are released, potentially dangerous sharks are killed and dead animals are dumped at sea; some biological parameters are recorded (Anon 1992, B.H. Lane pers. comm.) (Table 2.III). No tagging takes place. Species identification of sharks has historically been poor (Last & Stevens 1994), although since 1992 contractors have been trained in shark identification (B.H. Lane pers. comm.). The catch and effort data from the Queensland program are in the process of being re-computerised and revalidated (B.H. Lane pers. comm.).

2.3.3 KwaZulu-Natal

Encouraged by the success of the New South Wales meshing program (Wallett 1983), the City Engineer of Durban installed 12 gillnets (shark nets) in 1952 (Davies 1964, Hands 1970). The first record of netting at beaches other than those under the control of the Durban City Council was the introduction of two nets at Amanzimtoti in August 1962 (Wallett 1983). The Natal Anti-Shark Measures Board (NASMB) was formed in 1964, and was renamed the Natal Sharks Board in 1986. The NASMB acted initially as an advisory and funding body, channelling state subsidies to local authorities which already used some form of shark control measure, whether nets or physical barriers. In 1973 NASMB staff took over the maintenance of two net installations and by 1982 were responsible for the installation and maintenance of all shark nets on the KZN coast. In November 1994 there was a total of 41 km of netting in the water, protecting bathers at some 64 bathing areas between Richards Bay and Mzamba (Fig. 2.1, Table 2.I).

Net specifications, which have been modified slightly since the 1960s, are given in Table 2.II and Figure 2.4. Green braid with a breaking strain of 79.5 kg was used initially, but in 1967 this was changed to the stronger black braid (Wallett 1973). In the early 1980s the use of "double" nets of 213.5 m was phased in.

The nets at Durban, Anstey's Beach and Brighton Beach differ from those used elsewhere. They were originally 137 m long and 7.6 m deep, but in 1963 the length was increased to 304.8 m (Hands 1970). Manilla trawl twine was used for the manufacture of net panels, but, after experimentation with a number of synthetic materials, the change was made to braided polyethylene (Hands 1970).

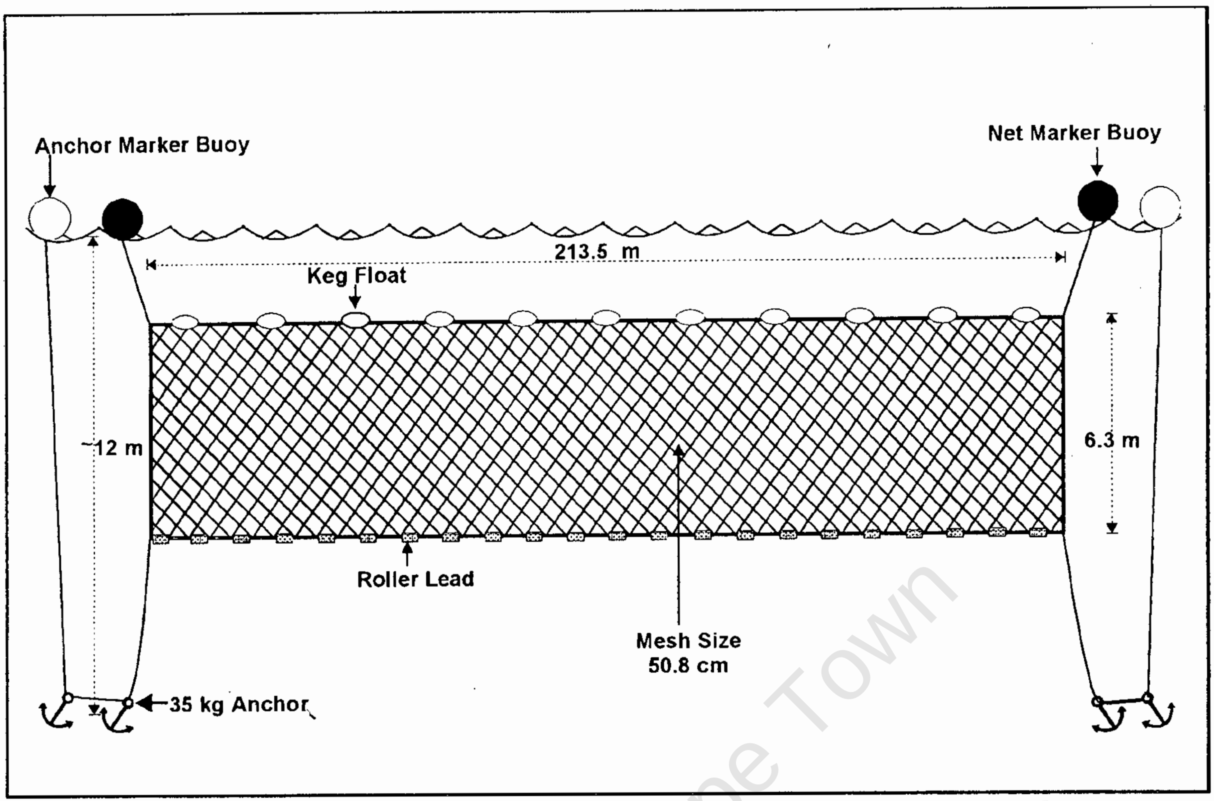

Figure 2.4: Net used in the KwaZulu-Natal shark control program

The nets in an installation are set in two rows parallel with each other and with the beach, the rows being approximately 20 m apart and staggered with an overlap of some 20 m. They are laid at the surface, but tend to sink as they become fouled with organic and inorganic matter (Wallett 1983).

The nets have, since inception, remained in the water throughout the year, except that from 1975 it became policy to lift some nets temporarily during the annual "sardine run", or winter influx of pilchard into southern KZN waters (Cliff & Dudley 1992a, 1992b). Meshing entails the manual hauling of each net to the surface for inspection for damage and also for any captures, which are identified to species level and recorded (Table 2.III). Each net is replaced with a clean one approximately every ten days. All captured animals are removed from the nets. Live animals are released, and, in the case of sharks and giant guitarfish *Rhynchobatus djiddensis*, tagged. All dead sharks and dolphins, other than those which are decomposed, are sent to NSB headquarters for biological examination. Details on improvements in the quality of data with time, including improved species identification, are given in Chapter 1, and by Cliff & Dudley (1992b) and Dudley & Cliff (1993b).

Average meshing frequency was no more than weekly until the early 1970s, but increased to 10 meshings per month by 1974. The frequency has been between 15 and 20 times per month since the late 1970s (Cliff *et al.* 1988). Weekend meshing takes place only if sea conditions prevented adequate weekday meshing.

2.4 Effectiveness of control measures against shark attack

2.4.1 New South Wales

At Newcastle's meshed beaches there were 11 attacks (four fatal) between 1918 and 1949 (Collins 1972). After the initiation of meshing in December 1949 (Collins 1972), there were only two attacks, both at Merewether Beach. A fatality occurred in 1951 and a surfer received minor injuries in 1957 (Coppleson & Goadby 1988). At Sydney's meshed beaches 18 attacks (10 fatal) occurred between 1897 and 1936 (Collins 1972). After nets were installed in September 1937 there were two attacks, one at Cronulla in January 1938, for which the fate of the victim is not recorded, and the other a non-fatal attack at Bondi in February 1951 (Collins 1972). Coppleson (1950) claims that no attacks occurred at meshed beaches from the time nets were installed until 1950, so the Cronulla incident appears doubtful. Reid and Krogh (1992), who differ slightly with Collins (1972) in their interpretation of attack records, exclude this incident (M. Krogh pers. comm.). Despite its large bather population, shark attacks in the Wollongong area have been "almost unknown" (Coppleson & Goadby 1988, p.97) both before and since the installation of nets, although one attack occurred at Coledale in February 1966, prior to the installation of nets (Gorman & Dunstan 1967, Coppleson & Goadby 1988).

2.4.2 *Queensland*

There were 42 attacks (27 fatal) on the Queensland coast between 1919 and 1961 (Anon 1992). After 1962 there were a further 39 attacks (nine fatal), but it is believed that none took place at beaches inshore of protective devices, except during closed seasons when those devices were not in the water (Anon 1992). At Townsville there were 11 attacks (nine fatal) between 1919 and 1962, but none after meshing was introduced in 1962 (Simpfendorfer 1993). The pre-netting attack rate may have been affected by abattoir discharge (Townsville) and whaling (Near North Coast and Gold Coast). These factors are now absent (Paterson 1986).

2.4.3 *KwaZulu-Natal*

Wallett (1983) listed attacks in KZN waters from 1906 until March 1983, and the Natal Sharks Board has maintained the South African Shark Attack File from 1974 (Cliff 1991) until the time of writing (November 1995). The records of KZN shark attacks prior to 1940 are regarded as being incomplete (Davies 1963), so the following figures pertain to the period from 1940 onwards. Prior to the installation of nets 21 shark attacks were recorded at Durban's beaches and 32 at other meshed bathing areas; these frequencies dropped to three and eight respectively after nets were installed. These data include a wide spectrum of incidents, however, ranging from fatal attacks to ones in which minor lacerations were inflicted by small sharks, probably juvenile *Carcharhinus obscurus*, against which the nets, with their 50.8 cm stretched mesh, have little effect (Cliff 1991). Further, minor incidents are likely to have been less well documented in the first half of the century. A more realistic measure of the effectiveness of nets is therefore obtained by considering only fatal attacks or attacks which resulted in serious injury, defined here as the loss of a limb or of muscle bulk. Applying these criteria to shark attacks at meshed bathing areas, there were seven fatal attacks in the pre-netting period at Durban, and 16 fatal attacks and 11 resulting in serious injury at other netted beaches. After nets were installed in 1952 at Durban there were no further incidents of this nature at that locality, and after nets were installed elsewhere in the early to mid 1960s there were no fatal attacks and only three attacks resulting in serious injuries. Two of these occurred at Amanzimtoti, in 1974 and 1975, and the third at Ballito in 1980 (Wallett 1983).

The cessation of fatal/serious attacks at Durban after nets were installed in 1952 took place despite the fact that whaling, which was known to attract large sharks to the vicinity of Durban harbour (Davies 1964), continued until 1975 (Best & Ross 1989).

2.5 Shark species responsible for attacks

2.5.1 *Queensland and New South Wales*

In only two of the fatal attacks which occurred on the Queensland coast prior to 1962 were the sharks identified. The species were believed to be the tiger shark *Galeocerdo cuvier* and the dusky shark *C. obscurus* respectively (Paterson 1986). Similarly, *C. obscurus* was implicated in the only two of the pre-1935 attacks on the New South Wales coast in which the species was identified (Anon 1935). More recently, Last and Stevens (1994) have pointed out that, globally, nearly all fatal attacks in coastal waters can be attributed to three species, the bull shark *Carcharhinus leucas*, *G. cuvier* and the great white shark *Carcharodon carcharias*. These authors suggest that *C. leucas* may well be the most dangerous of the three, but that it has rarely been recorded from the sea off Australia, due possibly to its resemblance to other members of the genus *Carcharhinus*. They also suggest that it has probably been responsible for most of the attacks in and around the Sydney Harbour area. *G. cuvier* also occurs throughout the netted regions of both Australian states (Last & Stevens 1994), but is probably most abundant in the north (C. Simpfendorfer pers. comm.). *C. carcharias* is captured by shark control devices from Mackay southwards (Paterson 1986), to New South Wales (Reid & Krogh 1992). Last and Stevens (1994) confirm that *C. carcharias* is more common from southern Queensland southwards, although catches are higher in the

Newcastle nets than in those of Sydney, and the species is rarely caught at Wollongong (Reid & Krogh 1992). Both *C. carcharias* and *G. cuvier* have been implicated in shark attacks in New South Wales (Gorman & Dunstan 1967, Australian Shark Attack File, unpubl. data).

2.5.2 KwaZulu-Natal

C. leucas, known locally as the Zambezi shark, is believed to have been responsible for most KZN shark attacks between 1960 and 1990, followed by *C. carcharias* (Cliff 1991). Most attacks resulting in serious injury or death were probably due to these two species. Others positively identified in one or two incidents each include the spotted ragged-tooth *Carcharias taurus*, *C. obscurus*, the blacktip *C. limbatus*, and *G. cuvier*, with only the latter inflicting serious injuries (Cliff 1991).

2.6 Trends in catch per unit effort

2.6.1 New South Wales

Catch data are incomplete prior to 1950. Stevens and Paxton (1992) report that more than 1 000 sharks were caught in the first year of meshing (Fig. 2.5), although Coppleson (1950) gives a figure of only 517 sharks. In 1950, the annual catch was 354 sharks (Collins 1972), and the average catch from 1985-1990 was 162 sharks (Reid & Krogh 1992). Catch per unit effort (CPUE) data are available only from 1950 and as such the initial decline is not depicted. There was no trend in CPUE between 1951 and 1972, but the changes to gear specifications and deployment in 1972/3 led to an increase from a pre-1972 mean of 44.6 sharks.1 000 sets^{-1} to 107.4 sharks.1 000 sets^{-1} in the 1972/3 season (Reid & Krogh 1992). This then declined during the 1970s and there was no trend in the 1980s (Reid & Krogh 1992).

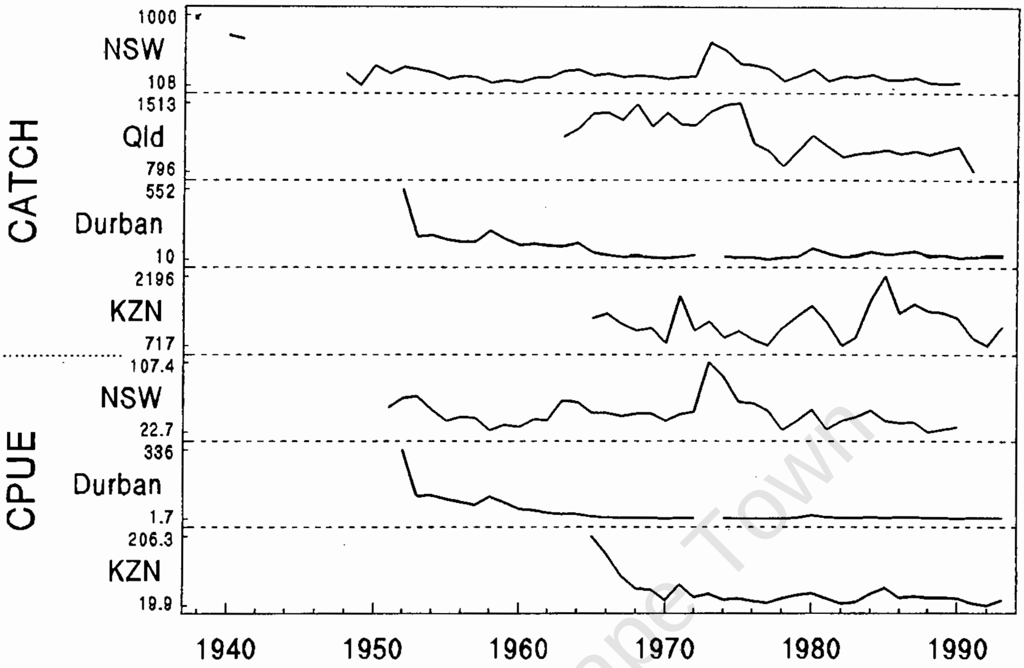

Figure 2.5: Total shark catch (number of sharks) and CPUE (NSW - number.1 000 sets^{-1}.y^{-1}, KwaZulu-Natal - number.km-net^{-1}.y^{-1}). Durban data shown separately from rest of KwaZulu-Natal. (Sources; NSW - Coppleson 1950, Collins 1972, Reid & Krogh 1992, Stevens & Paxton 1992; Queensland - Anon 1992)

Some catch data by species or species group are available for the period prior to 1950 (Coppleson 1950), but Coppleson expressed doubts about their accuracy and both Collins (1972) and Reid and Krogh (1992) chose not to use them. The catch rate of *C. carcharias* declined in both Period 1 (1951-1972) and Period 2 (1973-1990), as did that of whalers (*Carcharhinus* spp.)[a] (Figs 2.6a, b; Reid & Krogh 1992). The whaler group includes *C. leucas*. *G. cuvier* CPUE declined at the beginning of Periods

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[a] The term "whalers" is used ambiguously in the literature, sometimes referring to all locally occurring *Carcharhinus* spp. and sometimes excluding the "blacktip" whalers, primarily *C. limbatus* and *C. brevipinna*.

1 and 2 but (Reid & Krogh 1992) subsequently increased to a peak in 1987 (Fig. 2.6c). An attempt to relate the effort data of the NSW program to those of KZN has recently been published (Krogh 1994), but average catch rates, expressed as number km-net.$^{-1}$yr.$^{-1}$, were calculated for the entire period October 1972 to December 1990 and so the declines at the beginning of that period were not quantified. Average catch rates for white and tiger sharks were 0.167 and 0.159 sharks km-net.$^{-1}$yr.$^{-1}$ respectively (Krogh 1994).

On a localised basis, the total shark CPUE declined during Period 1 in both the Sydney and Wollongong areas, but not in the Newcastle area. During Period 2 it declined in all three areas (Fig. 2.7a). CPUE was generally higher at Newcastle than in the other two areas (Reid & Krogh 1992), although was similar at all three areas in the 1980s. CPUE of *C. carcharias* declined in Periods 1 and 2 at Sydney, and in Period 2 only at Newcastle. This species was rarely caught at Wollongong (Fig. 2.8a). Whaler CPUE declined in Period 1 at Sydney and Wollongong, but fluctuated at Newcastle. A decline was evident in Period 2 at Newcastle and Sydney, but there was subsequently an increase at Sydney in the 1980s (Fig. 2.8a). CPUE of *G. cuvier* declined in Periods 1 and 2 at Newcastle, and in Period 1 at Wollongong, where the species was subsequently infrequently caught (Fig. 2.8a). *G. cuvier* was infrequently caught at Sydney until the mid-1980s, when there was a steep rise in CPUE, peaking in 1987.

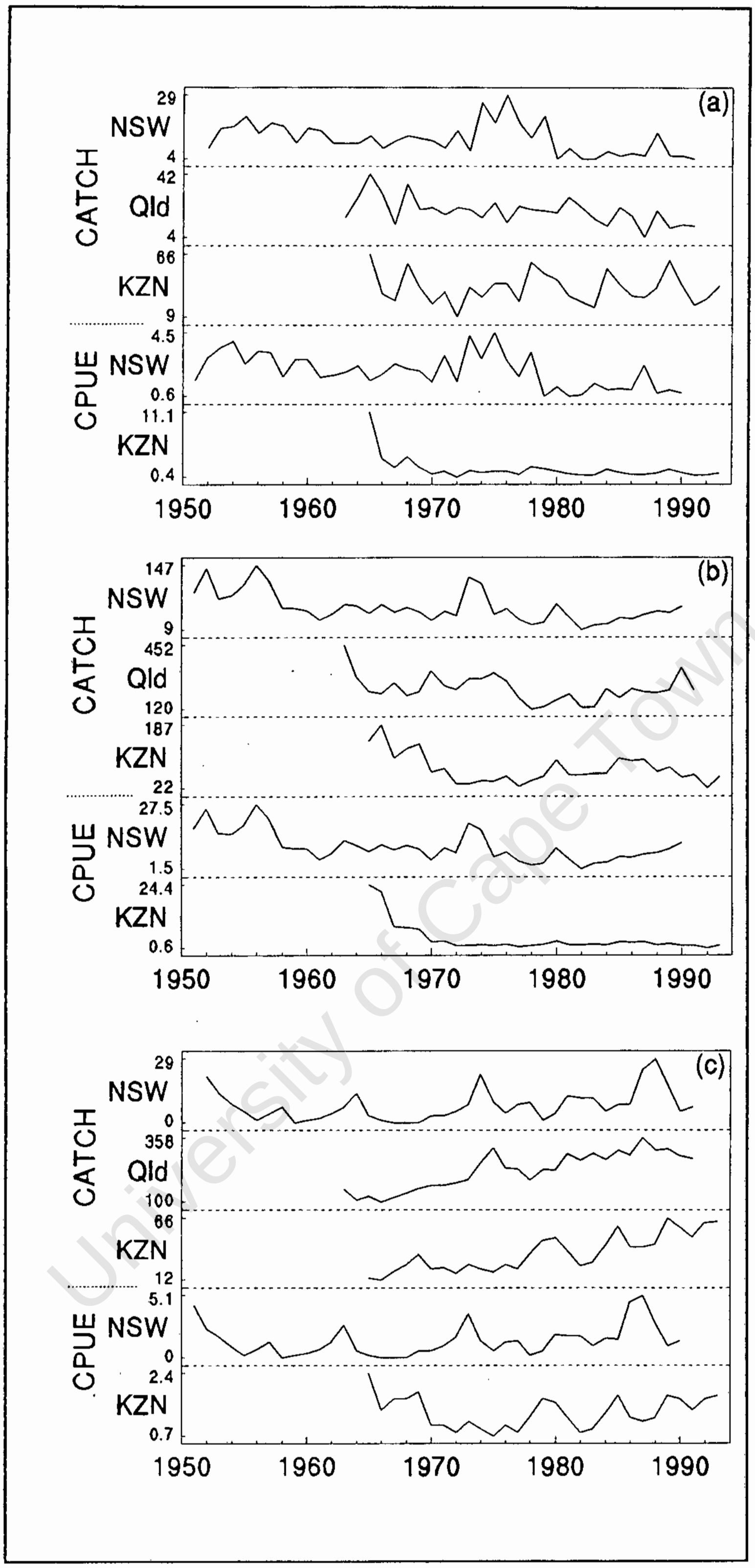

Figure 2.6: Catch (number of sharks) and CPUE (NSW - number.1 000 sets^{-1}.y^{-1}, KwaZulu-Natal - number.km-net^{-1}.y^{-1}) of (a) *Carcharodon carcharias* (b) whalers (NSW and Queensland) or *Carcharhinus leucas/C. amboinensis* (KwaZulu-Natal) and (c) *Galeocerdo cuvier*. KwaZulu-Natal data exclude Durban, Anstey's Beach and Brighton Beach. (Sources; NSW - Reid & Krogh 1992; Queensland - Anon 1992)

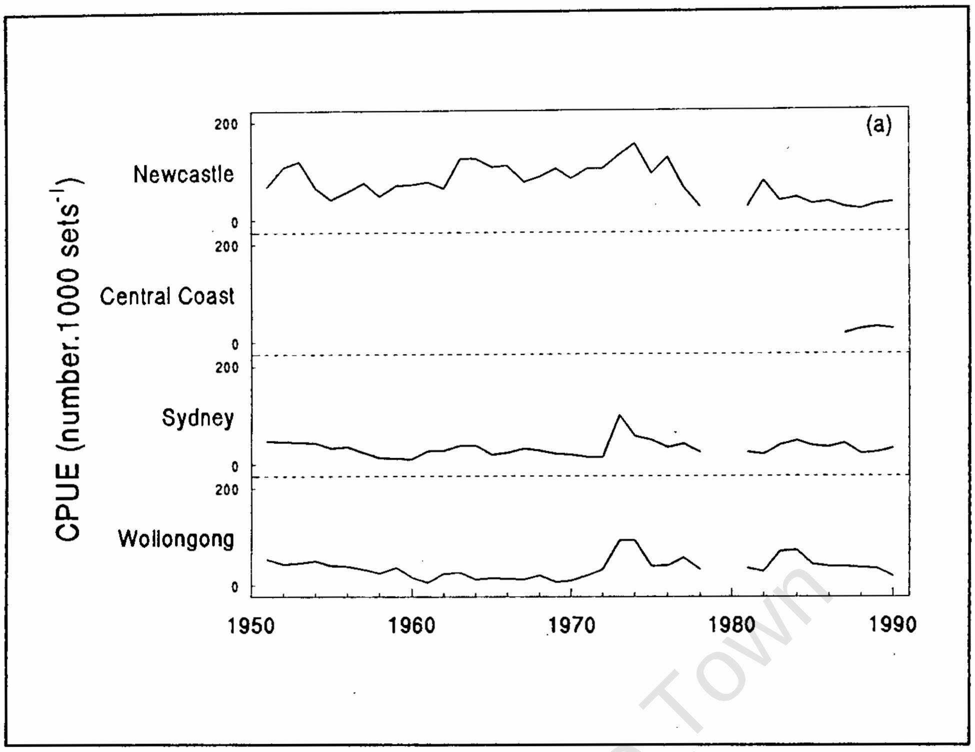

Figure 2.7a: Total CPUE by locality in NSW (Source; Reid & Krogh 1992)

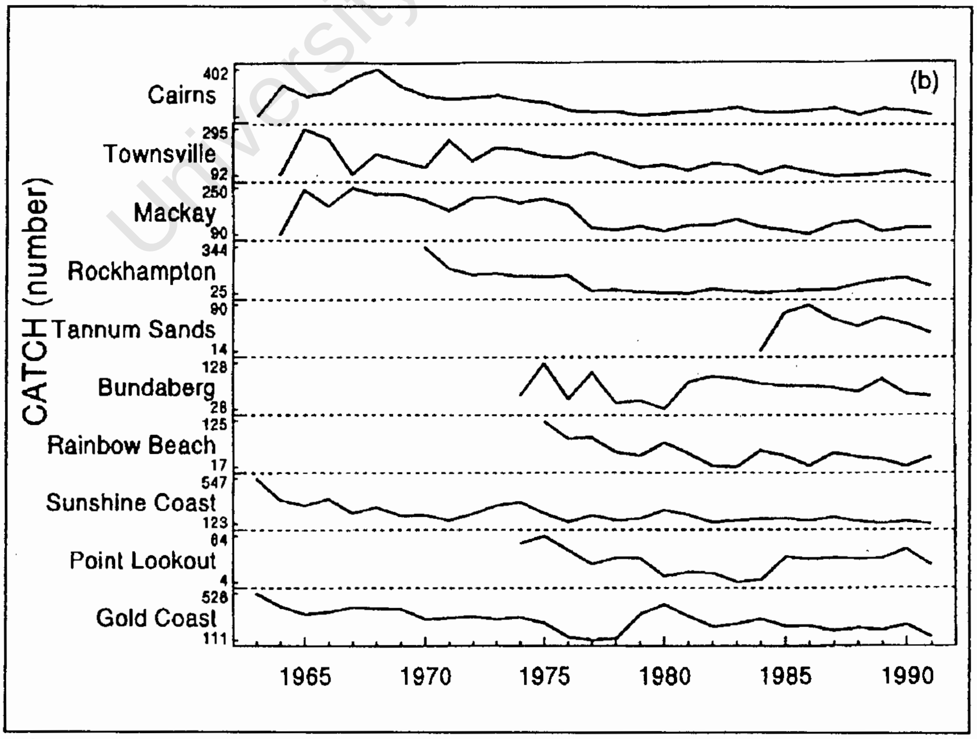

Figure 2.7b: Total catch by locality in Queensland (Source; Anon 1992)

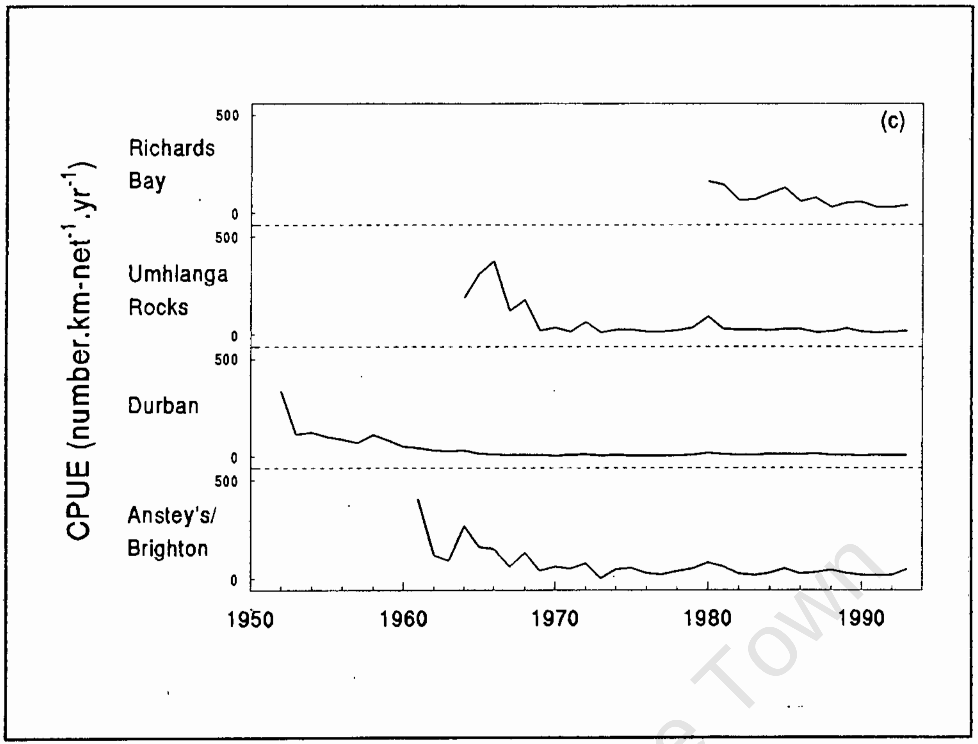

Figure 2.7c: Total CPUE by locality in KwaZulu-Natal (selected localities only)

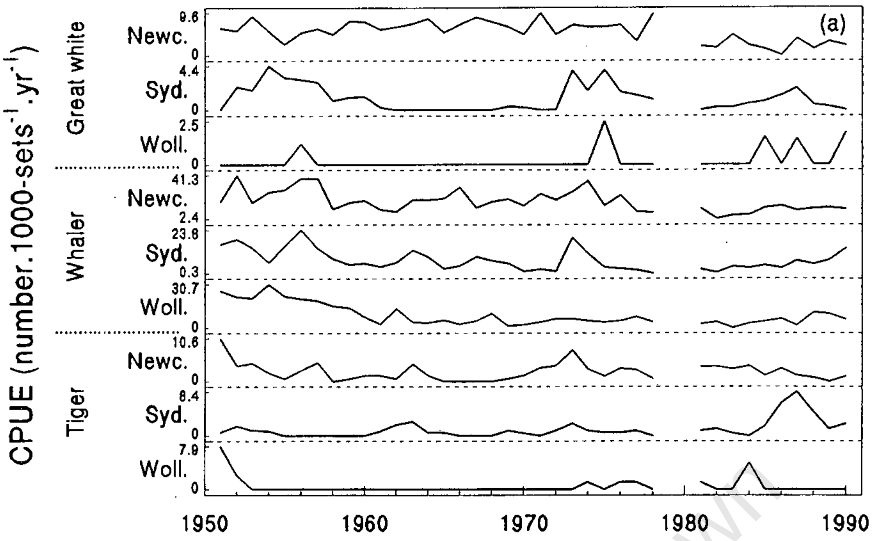

Figure 2.8a: Localised CPUE of *Carcharodon carcharias*, whalers and *Galeocerdo cuvier* in NSW (Source - Reid & Krogh 1992)

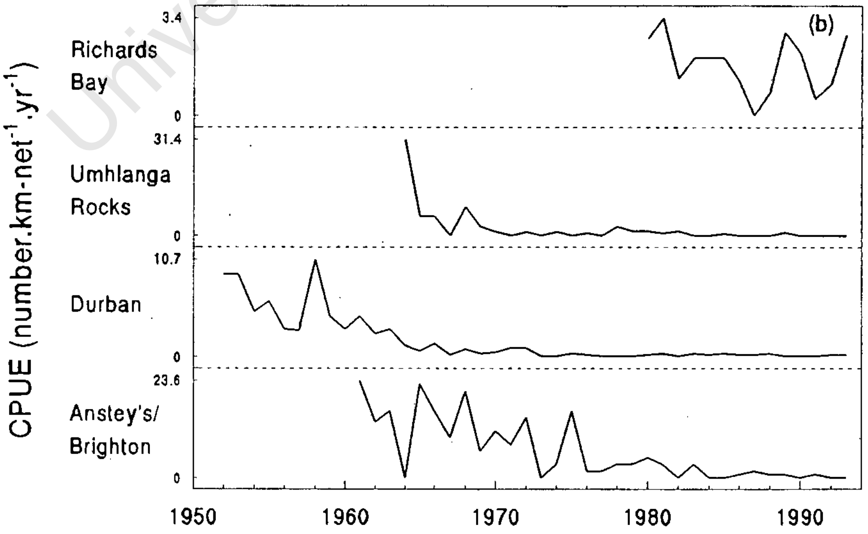

Figure 2.8b: Localised CPUE of *C. carcharias* in KwaZulu-Natal (selected localities only)

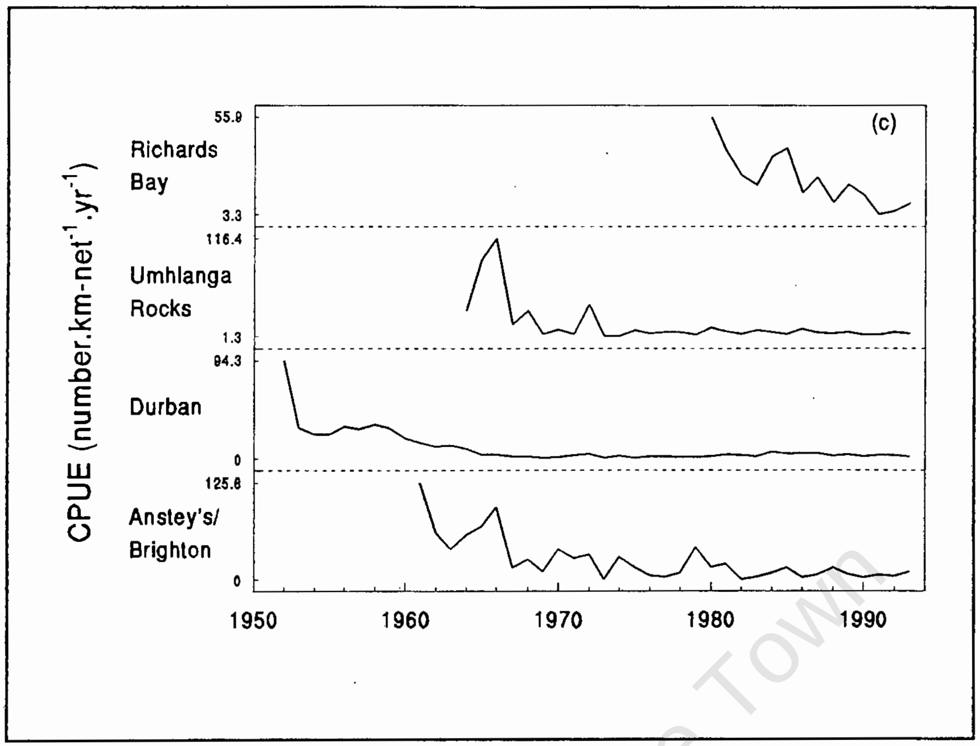

Figure 2.8c: Localised CPUE of *Carcharhinus* spp. (including *C. leucas*/*C. amboinensis* but excluding *C. limbatus*/*C. brevipinna*) in KwaZulu-Natal (selected localities only)

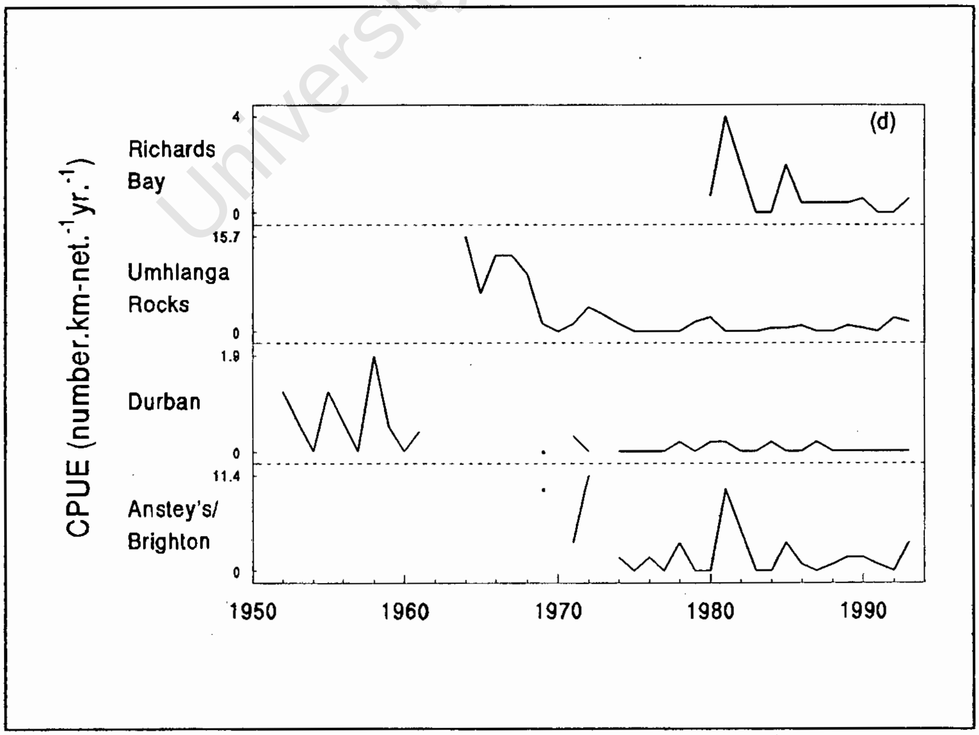

Figure 2.8d: Localised CPUE of *G. cuvier* in KwaZulu-Natal (selected localities only)

2.6.2 Queensland

The total shark catch (all species, both gear types combined) in the Queensland shark control program declined over time (Fig. 2.5), as did the catch rate in the nets (Paterson 1990). Total catch taken by the drumlines increased, however (Paterson 1990), although catch rate data have not been published. *C. carcharias* and whaler (including *C. leucas*) catches (both gear types combined) declined (Figs 2.6a, b), whereas the catch of *G. cuvier*, 61% of which was taken on drumlines (Paterson 1990), increased (Fig. 2.6c). It is not clear whether this increase indicates increasing abundance or increasing drumline effort.

At Townsville, for which area a separate analysis has been published (Simpfendorfer 1993), combined catch rate data from both nets and drumlines indicate that hammerheads, whalers and blacktip whalers may have been reduced in number by 80% since the inception of shark control measures, whereas numbers of *G. cuvier* may be increasing. *C. carcharias* is not caught at Townsville.

Independent trends in total shark catch (both gear types) were evident at the various Queensland localities with shark control measures (Fig. 2.7b).

2.6.3 KwaZulu-Natal

Trends in catch and catch rate of the total shark catch and also of individual species, or species groups, have been described elsewhere (Chapter 1, Cliff *et al.* 1988a, b, Cliff *et al.* 1989, 1990, Cliff & Dudley 1991a, b, 1992a, b, Dudley & Cliff 1993a, b). The essential feature, in terms of shark control, was a steep initial reduction in catch rate (Fig. 2.5). This was followed by the apparent establishment of a new equilibrium, with catches being sustained by the influx of sharks from waters adjacent to the netted region. This pattern was evident for the total shark catch, but also for most individual species, including two of those regarded as potentially the most dangerous to bathers, *C. carcharias* (Fig. 2.6a) and *C. leucas*, which has been combined with the Java shark *Carcharhinus amboinensis* because of poor differentiation in the early data (Fig. 2.6b). *G. cuvier* is an exception in that, after the initial decline, catch rate increased from the mid-1970s (Fig. 2.6c).

For purposes of comparison with the catch rates calculated by Krogh (1994) for NSW, the average catch rates of white and tiger sharks in KZN, for the entire period depicted in Figure 2.6c (1965-1993), were 1.69 and 1.11 sharks km-net.$^{-1}$yr.$^{-1}$ respectively.

Independent trends in catch rate were evident at certain adjacent installations. Such trends are depicted (Figs 2.7c, 2.8b-d) at the adjacent installations of Umhlanga Rocks, Durban and Anstey's/Brighton, which are spaced about 10 km apart, and at Richards Bay, the remote northernmost installation which was established in 1980 and which is 84 km from the next installation, Zinkwazi (Chapter 1, Dudley & Cliff 1993b).

2.7 Discussion

2.7.1 *The nearshore physical environment*

The KZN netted region falls between those of Queensland and NSW not only in terms of latitude, but also of physical parameters such as water temperature and turbidity. Water temperature is highest at the northern Queensland beaches and lowest at Wollongong, with Durban and the Gold Coast being intermediate and similar to each other. It appears from the more qualitative turbidity information that a similar latitudinal gradient exists, although the water seems to be less turbid at the southern Queensland beaches than in KZN. Summer rainfall leads to an increase in turbidity in all three regions.

Shark attacks on the KZN coast (Wallet 1983, Cliff 1991) and on the Australian east coast (Coppleson & Goadby 1988) are frequently associated with high turbidity. Last and Stevens (1994) suggest that conditions following heavy rain, such as increased coastal turbidity and possibly increased movement of prey species close inshore, may result in sharks becoming overstimulated to bite indiscriminately.

Various authors have suggested that the existence of nearshore troughs or channels, which allow large sharks to approach very close to shallow, inshore water, may be an important factor affecting the frequency of shark attack (Anon 1935, Davies 1961, Baldridge 1973, Wallett 1983, Coppleson & Goadby 1988). Davies (1961) referred to a KZN shark attack which took place in water some 0.6 m deep which was within a "few feet" of a channel which was 3 m deep (p.32). Wallett (1983) noted that 28 KZN attacks were associated with channels, either parallel with or perpendicular to the shore, and a further 19 may have been. He also pointed out that anglers often take sharks in nearshore channels. Similar troughs, or channels, off Sydney beaches such as Bondi are recorded as enabling large sharks to penetrate close to shore (Anon 1935). Species such as *C. leucas* are unlikely, however, to be dependent upon such channels in order to enter the surf zone. From shark attack data presented by Cliff (1991) there appears to be a tendency for attacks by *C. carcharias* to occur beyond the surf zone, where the water is deeper and where channels are less likely to be a factor.

Channels are present, either parallel or perpendicular to the beach, at most of the bathing beaches of KZN, southern Queensland and New South Wales. It is possible that the longshore bar - trough beach type which predominates in KZN provides better conditions for shark penetration than the beach types found in the Australian states.

2.7.2 *Methods of shark control*

The major differences between the three programs, in terms of shark fishing methods, are (i) gear specifications and (ii) fishing effort, as summarised in Table 2.IV.

Table 2.IV: Summarised comparison of shark control programs of NSW, Queensland and KwaZulu-Natal (Sources; NSW - Reid and Krogh (1992), M. Krogh (pers. comm.), Queensland - Anon (1992), B.H. Lane (pers. comm.))

	Gear deployment at "typical" meshed bathing area	Number of meshed bathing areas	Monthly effort (in season) (net-days. bathing area^{-1}.month^{-1}) (100 m standardised net unit)	Months meshed y^{-1}	Annual shark catch (number)	Annual budget (US$ m)
New South Wales	1 or 2 x 150 m nets	49	26	8	*ca* 190	0.3
Queensland	1 x 189 m net or 5 drumlines	75	*ca* 57	10-12	*ca* 990	0.8
KwaZulu-Natal	3 x 213.5 m nets	62	192	12	*ca* 1 410	3.2

2.7.2.1 *Gear specifications*

Net specifications vary between the three regions (Table 2.II), but there are only three factors which may substantially affect catch rates; net colour, hang-in coefficient and the position of the net in the water column. In experiments with captive sharks Wallace (1972) showed that two species, *C. leucas* and *C. taurus*, were able to detect brightly coloured (high reflectivity) nets more easily than dull (low reflectivity) ones, such that the latter would have greater catch efficiency. The body, or webbing, of the NSW nets and of most of the KZN nets (except for those at Durban, Anstey's and Brighton Beaches) is constructed from black material, whereas the Queensland nets are white. Experiments with black nets are under way on the Queensland coast (B.H. Lane pers. comm.).

The second factor is hang-in coefficient, which determines the looseness of a net. A hang-in coefficient of 29.3% would result in the net being hung squared. In all three regions the hang-in coefficient exceeds this (Table 2.II), resulting in the meshes being vertically elongated. The Queensland nets are particularly loose, possibly increasing their potential to entangle sharks. Entangle nets are usually hung more loosely than gillnets (Lusyne 1959).

The third factor is deployment depth, with the nets being deployed on the bottom in NSW, but not in Queensland or KZN. In Queensland the nets were originally bottom-set, but were subsequently raised to reduce damage caused by high catches of rays and, consequently, sharks.

Baited lines (drumlines) are used in Queensland only. A comparison of the species composition of the catch, and of catch rates, taken on drumlines and nets has been conducted for the Townsville locality (Simpfendorfer 1993). Drumlines were more selective, taking fewer non-dangerous sharks, but a higher proportion of the potentially dangerous *G. cuvier*. Unfortunately the absence of *C. carcharias* from the Townsville catch, and the combining of *C. leucas* with the other whalers (*Carcharhinus* spp, excluding the blacktip whalers) (Simpfendorfer 1993), makes it impossible to compare the effectiveness of nets and drumlines in catching these two potentially dangerous species. An advantage of drumlines is that they take a lower by-catch of non-shark species (Simpfendorfer 1993).

Baited lines were not used in NSW in case they attracted sharks (Collins 1972). It could also be argued, however, that sharks are attracted to animals captured in nets. About 4% of the sharks captured in the KZN nets were scavenging on other captured animals, and scavenging on dolphins and dugongs caught in the Queensland nets has been documented (Paterson 1990).

2.7.2.2 *Fishing effort*

The most striking differences between the three shark control programs are the quantity of gear deployed per beach and the length of time the gear spends in the water (Table 2.IV). It appears that, at NSW beaches, nets were deployed "on a roster system" from the outset (Anon 1935, p.25). Both KZN and Queensland drew on the experience gained in NSW when initiating their programs (E.M. Grant pers. comm., Wallett 1983). E.M. Grant, who was given responsibility for initiating the shark control program in Queensland by the Queensland Cabinet, held detailed discussions with a NSW meshing contractor, N. Gorshenin, prior to implementing the program (E.M. Grant pers. comm.). According to Coppleson and Goadby (1988), the Durban City Council initiated their meshing program after reading Coppleson's (1950) account of the NSW program. There is no published explanation as to why the Durban City Council or Queensland Cabinet chose instead to mesh each beach on a permanent basis. Davies (1961) did suggest that the use in NSW of supplementary beach patrols when bathing densities were high may have been a factor, and that the higher turbidity of KZN waters would preclude a similar practice. The question of using a roster system "simply did not arise" during the development of the Queensland program (E.M. Grant pers. comm.).

Although not used in NSW, drumlines were introduced from the start of the Queensland program, apparently largely in response to public suggestions (E.M. Grant pers. comm.).

There is also little documentation detailing how the amount of gear used per beach was determined. At NSW beaches, contracts stipulated the number of overnight sets per beach, which varied from beach to beach (Collins 1972). This was probably related to the number of bathers and the length of each beach (M. Krogh pers. comm.). From 1973, 13 sets per beach per month were stipulated for all beaches (Reid & Krogh 1992). In Queensland, the quantity of gear was originally determined by the operational capacity of the contractors concerned (E.M. Grant pers. comm.). In KZN, decisions on the number of nets to deploy per beach were made on the intuitive basis of "beach coverage". Fewer nets were deployed off a beach situated in a "natural curve of the coastline" (Wallett 1973, p.17), because of the physical restriction on a shark's approach to that beach from the sides, than at a beach on straight coastline. Also, if shallow water inshore dictated that the nets be set further offshore than normal, more nets were set (Wallett 1973). Wallett's stated relationship between coastline topography and number of nets is difficult to test objectively, however, because most of KZN's netted beaches are defined by Cooper (1991a, 1991b, 1994) as embayments, albeit poorly developed.

Gear density per unit length of coastline provides another measure of comparison between the three programs. In NSW, there are 49 meshed bathing areas between Newcastle and Wollongong, a distance of about 200 km. Since 1973 (i.e. after the contract changed), the monthly effort per bathing area (in season) has been about 26 standard net days (based on a 100 m standard net unit). This amounts to 1 274 standard net days per month for the whole region, or 6.4 net days.month^{-1}.kilometre^{-1} (in season).

In Queensland, the calculation is complicated by the presence of drumlines and the distance apart of the localities (Table 2.I), Cairns being some 1 700 km from the Gold Coast. If six drumlines are assumed to equate in terms of fishing effort to a Queensland net (Anon 1992), there are the equivalent of 85 x 189 m nets between Cairns and the Gold Coast, or 161 x 100 m standard net units. With the nets being permanently in the water, in season, this amounts to about 4 830 standard net days per month for the region, or 2.8 net days.month^{-1}.kilometre^{-1}. If each locality is considered in isolation, however, this figure rises to, for example, 36.7 net days.month^{-1}.kilometre^{-1} at Cairns and 29.3 on the Gold Coast.

In KZN, there are 39.17 km of netting in the water, excluding the isolated net installation at Richards Bay (Table 2.I). The distance from Zinkwazi to Mzamba is some 242 km, hence the gear density amounts to 48.6 net days.month^{-1}.kilometre^{-1}, throughout the year.

2.7.3 *Trends in catch per unit effort*

An initial decline in total shark catch and/or CPUE after the installation of shark fishing gear was common to all three regions (Fig. 2.5., Paterson 1990). In NSW there was an increase in CPUE after the changes in effort in 1973, followed by a second decline. There were also declines in catch and/or CPUE of the potentially dangerous species *C. carcharias*, *G. cuvier* and *C. leucas/C. amboinensis*, and of the whaler species complex, which includes *C. leucas* (Fig. 2.6). Declining CPUE is assumed to indicate a reduction in the number of sharks in the vicinity of protected beaches. In all three regions, there have been subsequent increases in catches of *G. cuvier*.

A feature common to two of the regions, NSW (Reid & Krogh 1992) and KZN (Chapter 1, Dudley & Cliff 1993b), is the absence of trend in CPUE (all species combined) after the initial decline. This absence of trend since the early 1970s in KZN has been interpreted as indicating that the multi-species shark catch may be sustainable (Chapter 1). Data presented by Simpfendorfer (1993) for Townsville, Queensland, indicate that CPUE of sharks taken on the drumlines remained relatively stable, possibly dropping slightly, after the initial decline, while that of sharks taken in the nets continued to decline, but at a slow rate.

There is some evidence that shark populations within netted regions are isolated from each other (Figs 2.7 and 2.8, Chapter 1, Holden 1977, Dudley & Cliff 1993b). While this can probably be explained by geographical isolation on the Queensland coast, where localities are 40 - 300 km apart (Table 2.I), it is less easy to explain in KZN, where independent trends were evident at certain installations about 10 km apart (Table 2.I). Holden (1977) suggested that the isolating mechanism may be territoriality, but long-term site fidelity has never been shown in sharks (Wetherbee *et al.* 1994 and references therein). Moreover, apparent isolation is evident even in species known to be highly migratory, e.g. *C. taurus* (Dudley & Cliff 1993b). A possible explanation is that within a population of a migratory species there may be sub-groups which follow specific migratory routes. Thus each sub-group may remain unaffected by shark control measures, until an installation is established on its migratory route.

No detailed stock assessments have been attempted for the shark control programs of the three regions, although preliminary attempts have been made for the KZN region in Chapter 1 and by Holden (1977). The principle shortcoming is the poor quality of catch, effort and biological data for all three regions in the early years of shark control. Problems with species identification persisted until recently in Queensland and are ongoing in NSW. Another reason is the problem of stock identity, illustrated by the apparent isolation of nearby installations. A comparison of the initial and current rates of capture of potentially dangerous sharks in the three programs would indicate whether shark abundance varied prior to the initiation of meshing, or continues to vary in the presence of meshing, between regions. A crude comparison indicates, for example, that average catch rates of white and tiger sharks may be greater in KZN than in NSW. An improved comparison would require improved standardisation of effort data, which would probably entail an exchange of gillnets between programs and generalised linear modelling of CPUE data. Also required would be an estimate of the proportion of the whaler catch in NSW and Queensland which consists of *C. leucas*.

2.7.4 *How do shark control measures work?*

As early as 1929 it was suggested that "regular and systematic netting affords a cheap and effective way of greatly minimising the shark peril" (Anon 1929, p.1). Later, it was suggested that the NSW public would be reassured by a demonstration of declining shark numbers (Anon 1935). The belief that shark control measures achieve their function by reducing shark numbers, and thereby the probability of an encounter between a shark and a bather, has subsequently been reiterated by various authors (Davies 1961, 1964, Springer & Gilbert 1963, Paterson 1979, Cliff & Dudley 1992a, Last & Stevens 1994). An elaboration on this concept is that, by reducing shark numbers, competition for food is reduced and hence remaining sharks are not encouraged to forage close to shore (Anon 1992).

There is still little understanding of the detailed effect of shark control measures on shark populations. It has been suggested that the nets may reduce the number of sharks resident in an area and then harvest immigrants at a steady rate (e.g. Chapter 1, Wallett 1973). The concept of "residency" is, however, not well defined. The multi-species catch taken in KZN, for example, has since inception included species known to be migratory and catch rates of these have also declined (Dudley & Cliff 1993b).

It has been suggested (Chapter 1) that resident sharks may learn that nets represent an obstacle in a given area and may actively avoid them. Wallett (1983) rejected the possibility of learned behaviour, arguing that sharks would die with the knowledge that nets are dangerous, and Reid and Krogh (1992) pointed out that, in NSW, the random temporal placement of nets and also their variable positioning at each bathing area rendered learning unlikely.

The distance over which shark control measures are effective is also poorly understood (Chapter 1, Dudley & Cliff 1993b). Springer and Gilbert (1963) suggested that shark populations were depleted in the vicinity of netted beaches. This suggestion that the effect may be localised is supported by Figures 2.8 and 2.9. Paterson (1986) suggested that shark catches remained relatively high in the Queensland program because of the large distances between protected localities, and, for the same reason, Simpfendorfer (1993) suggested that the effects of the Queensland program were primarily local. There is evidence that as the number of net installations on the KZN coast increased, new installations began to fish at the same rate as nearby ones (Chapter 1, Wallett 1973, Dudley & Cliff 1993b). The distances between installations on the KZN coast are generally of the order of kilometres, whereas those between netted localities in Queensland are of the order of tens or hundreds of kilometres (Table 2.I).

As well as having a fishing effect, nets may have a physical barrier effect, although the fact that 35% of the catch is caught on the shoreward side of the nets (Cliff & Dudley 1992b) is evidence that this is only partial. Davies (1964) suggested that large sharks would probably not remain in an area where there was a barrier between themselves and the sea. Wallett (1983) considered it unlikely, however, that if a shark were aware of a barrier from a distance it would then be captured in that same barrier. The apparently successful use of drumlines, which have no physical barrier effect, on the Queensland coast, and the intermittent placing and removing of nets on the NSW coast indicate that any barrier effect is minor compared with the fishing effect of shark control measures.

2.7.5 *Assessing the success of shark control measures*

A strict comparison of the success records of each of the three shark control programs would entail a detailed analysis of the nature of each documented shark attack, to ensure that the same criteria had been applied in defining an attack. The comparison should also take into account trends in bather densities in each region, which would affect the potential encounter rate. In the absence of such detail, it appears that the three shark control programs have achieved similar success in reducing the frequency of shark attack. At Newcastle's meshed beaches the rate of shark attack (number of attacks per year) fell from 0.35 to 0.04 with the introduction of nets, an 88% reduction, and at Sydney's meshed beaches from 0.46 to 0.04 (90%). The rate at Queensland's meshed beaches fell from 0.98 attacks per year to zero (100% reduction) with the introduction of nets, although there may have been some incidents during the closed season when the nets were out of the water. At Durban the rate of attacks resulting in a fatality or a serious injury dropped from 0.58 per year to zero with the introduction of nets, a 100% reduction, and at KZN's other meshed beaches the decline was from 1.08 to 0.10 (91% reduction).

It was recognised before meshing began that only a complete enclosure would prevent all attacks (Anon 1935). Of the attacks which took place in NSW in the presence of nets, one (of doubtful validity) at Sydney and one at Newcastle took place four months and two years respectively after meshing began at those localities, at which stage it could be argued that the "fishing down" of local shark numbers was still under way (Coppleson & Goadby 1988). The same would apply to a minor incident which occurred at Amanzimtoti in April 1963, just eight months after nets were installed there (Wallett 1983).

2.7.6 Shark species responsible for attacks

The East Australian Current seasonally brings tropical species into more southerly latitudes (Last & Stevens 1994), as does the Agulhas Current on the east coast of South Africa (Compagno *et al*. 1989). The same three species, *C. carcharias*, *C. leucas* and *G. cuvier*, have probably been responsible for most of the attacks in the three regions with shark control programs. The distributions of these species are not uniform through the three regions. All three are found in KZN, southern Queensland and northern NSW, but *C. carcharias* is absent from the catch in northern Queensland (Cairns and Townsville), and, paradoxically, is rarely caught at Wollongong, the southernmost netted locality. *G. cuvier* is also rarely caught at Wollongong.

2.8 Conclusions

The differences in gear type and deployment patterns in the three shark control programs do not appear to have arisen through an analysis of differences in the physical or biological environments of the three regions. Rather, it seems as if the processes of establishing the programs were *ad hoc*.

The water is generally less turbid off NSW than off KZN or northern Queensland, increasing the chances of a shark being seen should it approach a bathing area, but as this is dependent upon human vigilance it is unlikely to explain why the NSW meshing program has succeeded over a 50 year period despite a relatively low level of fishing effort. Nearshore channel characteristics may differ in the three areas, but the degree to which this may affect the rate of shark attacks is uncertain.

There are no data available on trends in comparative bather densities in the three regions, but bather numbers in the major centres such as Sydney, the Gold Coast and Durban are all high. Pre-netting shark attack statistics also appear comparable, although a more detailed analysis of the nature and geographical location of each incident is necessary to confirm this.

Despite the poor quality of available catch and effort data, particularly in the case of the Australian programs, and despite the absence of appropriate quantitative comparisons of catch rates, there are sufficient similarities between the catch and CPUE trends presented in this report to suggest that the effects of the three programs on local shark numbers are similar.

On the basis of this review there does not, therefore, appear to be a sound rationale for maintaining the current level of fishing effort in the KZN shark control program. Specific recommendations on effort reduction would be premature, but there is a strong *a priori* case for considering such a reduction. The NSB is working with consultants to investigate the relationship between shark attack risk and various netting strategies, with a view to deriving a quantitative basis for effort reduction.

Chapter 3: Gillnet mesh selectivity for large coastal sharks in the KwaZulu-Natal shark control program

3.1 Introduction

Since its inception in 1964 the Natal Sharks Board (NSB) has used gillnets with a stretched mesh of 20 inches (50.8 cm) to protect bathers against shark attack. Although the nets do not form a complete physical barrier between the bathing area and the open ocean, they have proved successful in lowering the incidence of shark attack (Chapter 2, Cliff 1991). It is believed that the nets operate by catching and killing sharks, hence reducing the chance of a shark encountering a bather (Chapter 2 and references therein).

Why and how sharks are caught in the nets is not well understood. In clear water sharks may be able to see and avoid nets. Experiments with captive bull, *Carcharhinus leucas* and spotted ragged-tooth, *Carcharias taurus* sharks showed that nets with low reflectivity black twine were less well detected than those with high reflectivity yellow twine (Wallace 1972). Similarly, Wallett (1973) found that clean nets caught more sharks than dirty nets, implying avoidance of the dirty nets. Baranov (1914), cited by Hamley (1975), defined the following ways in which a fish may be caught in a gillnet;

i) wedged - held by a mesh around the body
ii) gilled - held by a mesh caught behind the operculum (gill cover)
iii) tangled - held tightly in the net by teeth or other projections without necessarily penetrating the mesh.

Sharks do not have the bony operculum of teleosts and are either wedged in the meshes or tangled, the latter probably resulting in the suggestion by Wallett (1973) that a billowing net is more likely to catch sharks than is a tight curtain. Entangle nets are usually hung more loosely than gillnets (Lusyne 1959).

Entanglement in the case of large sharks does not always result from a projection being held in the net, but sometimes from the shark becoming rolled up. Thus the word "rolled" may be more useful in this context than "tangled". Sometimes sharks are initially wedged and then become rolled as they struggle.

Shark nets also catch various animals which pose little or no threat to bathers. These include smaller sharks, various batoids, sea turtles, dolphins and large teleosts. There is concern that mortalities of bottlenose dolphins *Tursiops truncatus* may exceed recruitment (Ross *et al*. 1989) and it has been recommended (V.G. Cockcroft, Port Elizabeth Museum, pers. comm.) that consideration be given to increasing the mesh size of the nets to 64 cm to reduce dolphin mortality. Some 43% of the bottlenose catch is smaller than 200 cm and it was suggested that a larger mesh may reduce the capture of these animals.

Gillnets are known to be extremely size-selective. Previous studies of size selectivity for various shark species have been conducted as a precursor to stock assessment (Kirkwood & Walker 1986, Nakano & Shimazaki 1989, McLoughlin & Stevens 1994). In the context of shark control, an understanding of the effect of altering the mesh size on shark catches would be a pre-requisite to any general introduction of a larger mesh. This chapter reports on experiments to determine whether different mesh sizes could reduce mortalities in the nets without jeopardising bather safety i.e. whether a larger mesh would still be effective in capturing potentially dangerous sharks. The three most dangerous species taken by the shark control program are the great white shark *Carcharodon carcharias*, the tiger shark *Galeocerdo cuvier* and the bull shark. The smallest potentially dangerous shark is defined here as being a bull shark of approximately 1.6 m *PCL*.

CHAPTER 3: GILLNET MESH SELECTIVITY FOR LARGE COASTAL SHARKS IN THE KWAZULU-NATAL SHARK CONTROL PROGRAM

3.2 Methods

3.2.1 Netting procedure

All nets were manufactured from black polyethylene flat braid with a blue rogue line and a breaking strain of 159 kg. The surround rope, also black/blue polyethylene, was of 14 mm diameter. Plastic keg-type floats, each with a buoyancy of *ca* 680 g, were set at 4 m intervals (later changed to 3 m - see below) on the head-line, and roller leads with a mass of *ca* 560 g were set every 3 m on the lead-line. Each net was secured by two 35 kg anchors (increased to four when the nets were doubled in length - see below).

Gillnets of 30, 50.8, 70 and 90 cm stretched mesh, respectively, were constructed. The hang-in coefficient (excess webbing/total stretched webbing x 100) was 50% for all but the 50.8 cm mesh, for which it was 40%. The numbers of meshes in each net were varied in order to give approximately equal length and depth when set; the 30 cm mesh was 106.4 m long x 6.6 m (25.5 meshes) deep, the 50.8 cm mesh was 106.8 m long x 6.7 m (16.5 meshes) deep, the 70 cm mesh was 106.1 m long x 6.4 m (10.5 meshes) deep and the 90 cm mesh was 99.4 m long x 5.8 m (7.5 meshes) deep.

The experimental net installations were meshed (as defined in Section 2.3.3) at the same time as adjacent conventional installations, the latter consisting exclusively of 50.8 cm nets used to protect bathers at established bathing beaches. The nets remained in the water 24 hours a day and were inspected for catches at first light on about 20 days a month. Each net was replaced with a clean one approximately every 10 days. All catches, including sharks, batoids, turtles, cetaceans and teleosts, were recorded and identified to species level. The work was carried out from 5.5 m open-decked boats.

From 1991, an attempt was made to determine how each shark caught either during the experiment or in the conventional net installations had been captured. The method of capture was recorded as i) tail only, ii) rolled (entangled) only, iii) wedged then rolled, iv) wedged only or v) caught by an angler's trace. The difference between categories ii) and iii) was usually difficult to determine. Category v) refers to sharks which had previously broken free from an angler's line, and with the trace trailing from the mouth then becoming entangled in the net.

The precaudal length of each shark was measured as a straight line parallel to the long axis, connecting imaginary perpendiculars to the tip of the snout and the precaudal notch. All sharks were measured in the field ("field lengths") and those which were not either released alive or decomposing were subsequently returned to the laboratory where more accurate "laboratory lengths" were obtained. Field lengths were used to maximise sample size, as it was impossible to recover to the laboratory all sharks caught in the experimental nets. Both field and laboratory lengths of sharks caught in the conventional nets were available for the period 1978-1994. From 1992 head girth measurements, taken in the region of the first to third gill slits, were obtained for many of the sharks dissected in the laboratory, but sample sizes remain small for some species.

Field measurements of by-catch animals caught in the experimental nets were taken as follows; batoids (excluding giant guitarfish *Rhynchobatus djiddensis*) - disk width at the widest point, giant guitarfish - precaudal length *PCL*, turtles - carapace length, and dolphins and teleosts - fork length *FL*. Field length data for these animals caught in the conventional nets were considered unreliable.

3.2.2 Pilot study

Two sites were chosen for the pilot study, Mzamba (31°05´S, 30°11´E) and Richards Bay (28°48´S, 32°06´E), these being the southernmost and northernmost beaches respectively where conventional net installations are maintained. These sites were chosen because total shark catch rates there are high compared with those at other installations. At Richards Bay, catch rates of the bull shark are particularly high (Cliff & Dudley 1991a).

3.2.2.1 Mzamba

Winter was chosen as the most suitable season for initial experimentation at Mzamba, because shark catch rates at that locality tend to be particularly high as a result of the annual influx of pilchard *Sardinops sagax* into southern KwaZulu-Natal waters (Armstrong *et al*. 1991). Three nets, one each of 30, 50.8 and 70 cm mesh, were installed at Mzamba in June 1990, at a site several hundred metres south of the conventional shark net installation. The three nets were spaced 100 m apart and, each time the nets were removed for cleaning, the relative positions of replacement nets were rotated. As a result of damage from high catches, the nets were removed after only six days. They were relaid in mid-July and remained in the water until late October 1990.

At the beginning of July 1991 another three nets were laid at the same site, one each of 50.8, 70 and 90 cm mesh. These remained in the water until early August, were relaid at the beginning of October and removed finally at the end of November 1991. Although it would have been desirable to continue work at this site, an increase in the work load of the meshing team concerned, caused by the establishment of a new conventional net installation, made this impossible.

3.2.2.2 Richards Bay

Three nets (50.8, 70 and 90 cm mesh) were laid about 3 km to the north of the conventional installation in late February 1991. They were removed in early September due to storm damage, then replaced in mid-October. The 90 cm mesh net was removed permanently in March 1992. The other nets remained in place until mid-August 1992. As at Mzamba, the positions of the nets were rotated regularly.

Pairs of nets of each mesh size (50.8 and 70 cm) were joined at this time to form "double" nets, measuring 213.5 m (double nets are used in most of the conventional installations). A double net of each mesh size was installed in early September 1992 at a site about 3 km to the south of the conventional installation. This site was chosen in expectation of higher catches than were taken at the northern site. The nets remained in place until late 1993, but several months of fishing time were lost due to storm damage incurred at this exposed locality.

3.2.3 Main study

While the pilot study was ongoing at Richards Bay, it was decided to incorporate nets of 70 cm mesh into conventional installations elsewhere. Although this carried an unknown element of increased risk to bather safety, it was done in order to keep the work load of meshing teams manageable, and in anticipation of increased sample size. The length-frequency distributions obtained from the pilot study had also indicated that the 70 cm mesh was capable of catching potentially dangerous sharks. It was furthermore believed likely that the conventional installations had more nets than was necessary to provide acceptable safety levels (Chapter 2).

Incorporation into conventional installations meant that the practice of simultaneously changing all nets within an installation and alternating their positions at each change could no longer be applied, since the installations were too large.

In late 1993 an additional 16 double nets with 70 cm mesh were manufactured, this time with a hang-in coefficient of 40% to match that of the 50.8 cm nets. These nets each consisted of two joined panels together measuring 213.5 m long x 7.0 m (12.5 meshes) deep. In mid-1994 those original 70 cm nets which were still serviceable were rehung at 40%. The effect of rehanging the original nets was to decrease their depth to 5.9 m (length was cut to the standard 213.5 m).

Once the main study began, the meshing officer at Zinkwazi (see below) reported that the 70 cm nets showed a tendency to sink. This may have been because all these nets had a hang-in coefficient of 40% and, as such, contained less twine than those used in the pilot study (the twine was slightly positively buoyant). To counter the sinking, the interval between keg floats was decreased from 4.27 m to 3 m, resulting in an extra 20 keg floats (13.6 kg of buoyancy) per net. The problem had not arisen when nets with a 40% hang-in coefficient were incorporated into the Richards Bay installation in December 1993 (see below), presumably because additional flotation was routinely used on all nets at that locality to keep them off shallow reef. Extra keg floats were added to all 70 cm nets in 1994.

3.2.3.1 Mbango

In early November 1992 three double nets of 70 cm mesh were installed in the conventional six-net installation at Mbango (30°27´S, 30°45´E), replacing alternate 50.8 cm nets. This site was chosen because of the high initial catches when the installation was established in 1991. High catches did not persist into the experimental period, however, and the 70 cm nets were removed at the end of July 1993.

3.2.3.2 Mzamba (MZ93/94)

In early August 1993 two double nets of 70 cm mesh were incorporated into the seven-net Mzamba installation, replacing two of the 50.8 cm nets. A further two were installed in mid-January 1994 and the total installation was increased to eight double nets. All the 70 cm nets were removed at the beginning of February 1994 for administrative reasons. This phase of the experiment was unique in having unequal fishing time for the two mesh sizes and the catches are referred to below as the MZ93/94 data set.

3.2.3.3 Richards Bay

After the termination of the pilot study at Richards Bay, in mid-December 1993 four 70 cm double nets were installed in the conventional seven-net installation at Richards Bay, replacing alternate 50.8 cm nets. The installation was increased to eight double nets with the addition of a 50.8 cm net. Repeated storm damage finally led to the abandonment of Richards Bay as an experimental site at the end of August 1994.

3.2.3.4 *Zinkwazi*

In early January 1994 three 70 cm double nets were incorporated into the five-net installation at Zinkwazi (29°17´S, 31°26´E), chosen because of a relatively high catch rate of bull sharks (Cliff & Dudley 1991a). The installation was increased to six nets, with the 70 cm nets alternating in position with three 50.8 cm nets. In March 1994 the 70 cm nets were removed for the addition of extra keg floats (see above), and were reinstalled in May 1994. These nets have remained in the water to date (October 1995).

3.2.3.5 *Park Rynie*

At the beginning of November 1994, subsequent to the abandonment of Richards Bay as a test locality, two double 70 cm nets were incorporated into the four-net installation at Park Rynie (30°21´S, 30°43´E). These nets have remained in the water to date (October 1995).

3.2.4 *Statistical analyses and the fitting of selectivity curves*

For all analyses data were pooled across sexes and stations (except where otherwise stated) for the purpose of maximising sample sizes. Pooling across stations was justified for the purpose of fitting selectivity curves to the catch data from the experimental 50.8 and 70 cm nets because these nets were deployed together and could therefore be assumed to have been fishing the same shark populations.

Most statistical analyses were conducted using STSC's Statgraphics Plus 5.2. The null hypothesis that shark length was independent of method of capture was tested for each species and for all species combined using the Kruskal-Wallis One-Way Analysis by Ranks procedure. If shark length did differ according to capture method ($p<0.05$), the length-frequency distributions of pairs of capture methods were then tested using the Mann-Whitney U test and the Kolmogorov-Smirnov two-sample test to determine between which specific capture methods the inequalities lay.

Simple linear regressions were used to model the relationship between head girth and precaudal length for each shark species. Outliers, defined as observations with a standard residual ≥3, were excluded from each regression after being identified using Statgraphics' influence measures option.

With regard to selectivity, the initial objective was to determine whether, for individual species and for all species combined, (a) the median lengths and (b) the length-frequency distributions of sharks caught in the nets of different mesh sizes were significantly different. The difference between medians was tested using the Mann-Whitney U test. The Kolmogorov-Smirnov two-sample test procedure was used to determine whether two samples came from the same distribution.

The next step was the fitting of selectivity curves. Since the structure of the various populations being studied was not known, direct methods of estimating selectivities by comparing the length distributions in the experimental nets with those of the populations (Hamley 1975) could not be used. The prediction of selectivity from girth (e.g. Ehrhardt & Die (1988)) was also considered inappropriate because of (a) factors such as rolling and the entanglement of protuberances such as the head of a hammerhead shark and (b) inadequate samples of girth measurements for some species. Instead, a form of indirect estimate was used. Such methods, as reviewed by Hamley (1975), are based upon a comparison of the length distribution of catches in gillnets of different mesh sizes. Indirect estimates have been employed in studies of mesh selectivities for sharks by Kirkwood & Walker

(1986), Nakano & Shimazaki (1989) and McLoughlin & Stevens (1994).

Given that it is not possible, using catch data from only two sizes of the same gear, to ascertain which of the more common selection curve models is most appropriate (Millar 1995), the gamma distribution model developed by Kirkwood & Walker (1986) and later applied by McLoughlin & Stevens (1994) was used. Small sample sizes precluded model fitting for most individual species, but first attempts were made, respectively, for the catch of the combined-species (excluding hammerheads, with their atypical head shape), the dusky shark *Carcharhinus obscurus* and the ragged-tooth shark. The following description of the model is taken from McLoughlin & Stevens (1994) (pp 522-523):

"An assumed selectivity function is fitted directly to the catch data from the different mesh sizes, with the parameters of the selectivity function being estimated simultaneously across mesh sizes and length classes. Hamley (1975) notes that gillnet selectivity curves are frequently skewed to the right. This is due to the tangling of large fish, with the degree of skewness being a result of fish shape. For this reason, Kirkwood & Walker (1986) developed a method for estimating selectivity that uses a gamma distribution model because this is a convenient, flexible, two-parameter model that can display varying amounts of skewness. The functional form used to model the selectivities as a function of length, l, is

$$(l/\alpha\beta)^{\alpha}\exp(\alpha-l/\beta),$$

where α and β are parameters of the probability density function of a gamma distribution with mode $\alpha\beta$ and variance $(\alpha+1)\beta^2$, and where α and β are specified in terms of the mesh size and length class. The assumptions of the model are that *(1)* the length at maximum selectivity for panel j of mesh size m_j is proportional to the mesh size, so that $\alpha\beta=\theta_1 m_j$, *(2)* the variance is a constant θ_2 over different panels, *(3)* the experiment samples across the whole population, *(4)* catches within each length class for each panel are independent observations from a Poisson distribution, and *(5)* all panels have equal fishing power (otherwise these have to be estimated with the selectivities). Assumptions *(1)* and *(2)* lead to a quadratic equation for positive ß and imply that

$$\text{ß}=-0.5[\theta_1 m_j-(\theta_1^2 m_j^2+4\theta_2)^{0.5}]\text{."}$$

The model was set up on a spreadsheet in each of Borland's Quattro Pro 4.0 and Microsoft's Excel 5.0. Maximum likelihood estimates were used to fit the model to the catch data by means of the Optimizer and Solver tools of these two packages respectively. While the packages returned similar values for the 95% confidence limits on θ_1 and θ_2, Quattro Pro converged on multiple values for θ_1 and θ_2 themselves, depending on the starting values which were seeded, whereas Excel converged on unique values. The Excel values, which yield intuitively reasonable lengths at peak selectivity, are therefore reported.

The 95% confidence limits on θ_1 and θ_2 were obtained using the likelihood profile method of Schnute (1989) and Lebreton *et al.* (1992), as described by Govender & Birnie (in prep.).

For purposes of curve-fitting, the length-frequency data for the combined shark species, the dusky shark and the ragged-tooth shark, respectively, were treated as follows: (i) the MZ93/94 data were excluded, enabling effort for the two mesh sizes to be regarded as unity (ii) length classes were increased to 10 cm to reduce the number of classes with zero catches and (iii) catches of hammerhead sharks were excluded from the combined-species data. For those few length classes in which the catch taken in both mesh sizes was zero, a very small value ($1\text{x}10^{-9}$) was entered for both mesh sizes for the purpose of taking logarithms.

As a precursor to the fitting of selectivity curves, an exploratory technique of Holt (1963), as applied by McLoughlin & Stevens (1994), was used. A plot of the natural logarithm of the ratio of the catch from a pair of mesh sizes would be expected to yield a linear relationship, because the number of sharks caught in the smaller mesh size would be expected to decrease with increasing length class and the converse would be true of sharks caught in the larger mesh size.

3.3 Results

3.3.1 Operational observations

The 30 cm mesh net was heavy and difficult to mesh, even when new and clean. Because of the extra volume of polyethylene twine per unit area, its handling characteristics were similar to those of a very dirty 50.8 cm net. Despite increasing the number of anchors to four, the net had a propensity to bow and the anchors tended to drag under conditions where the larger-meshed nets remained stable.

During the pilot study, the 70 and 90 cm nets were less affected by currents than the 50.8 cm net. The larger-meshed nets continued to be easy to work with even when dirty, except for the sinking problem at Zinkwazi discussed above.

3.3.2 Method of capture of sharks

Of the sharks taken in the 50.8 cm experimental nets from 1991 onwards (1990 data were not in a comparable form), three (2%) were caught by the tail only, 15 (8%) were rolled (entangled) only, 148 (84%) were wedged prior to becoming rolled and 11 (6%) were wedged only. The comparative figures for the 70 cm nets were zero (0%) caught by the tail, 15 (28%) rolled only, 36 (67%) wedged then rolled and three (6%) wedged only. Excluding the "tail only" captures, the effect of mesh size on method of capture was significant (two-way contingency table, χ^2 test, $p<0.05$). No sharks were caught in either experimental mesh through entanglement of a trailing angler's trace.

Of the catch taken in conventional nets, 110 (3%) were caught by the tail only, 271 (8%) were rolled only, 2 401 (69%) were wedged prior to becoming rolled, 574 (17%) were wedged only and 99 (3%) were caught by an angler's trace.

For the combined species catch taken in the conventional nets, as well as for catches of the great white, dusky, copper *Carcharhinus brachyurus*, spinner *C. brevipinna* and scalloped hammerhead *Sphyrna lewini* sharks, there were significant differences, in the field lengths of sharks, between two or more capture methods (Figs 3.1 and 3.2). There were few consistent findings between these species, however. Sharks caught by the tail only tended to be larger than those caught by other methods (great white and dusky). Observations by crews servicing the nets suggest that large sharks are sometimes able to break the net around the head and body, but are unable to free the tail. In three cases (dusky, spinner and scalloped hammerhead), wedged-then-rolled sharks were larger than wedged-only sharks, perhaps because of the increased strength of larger specimens.

Dusky sharks caught by an angler's trace were significantly smaller than those caught by the other methods. This is because juvenile dusky sharks are available to anglers fishing in nearshore waters. Despite this only 35% of dusky sharks ≤95 cm *PCL* were caught by a trace. The capture of the remaining 65% is less easy to explain. Their small girth (see below) renders it impossible for them to become wedged. A method of capture which does occur, but is not amongst the categories used, is the entanglement of the teeth of a small shark in a strand of twine. Such a shark may be recorded by a field officer as "rolled only" or as "wedged only".

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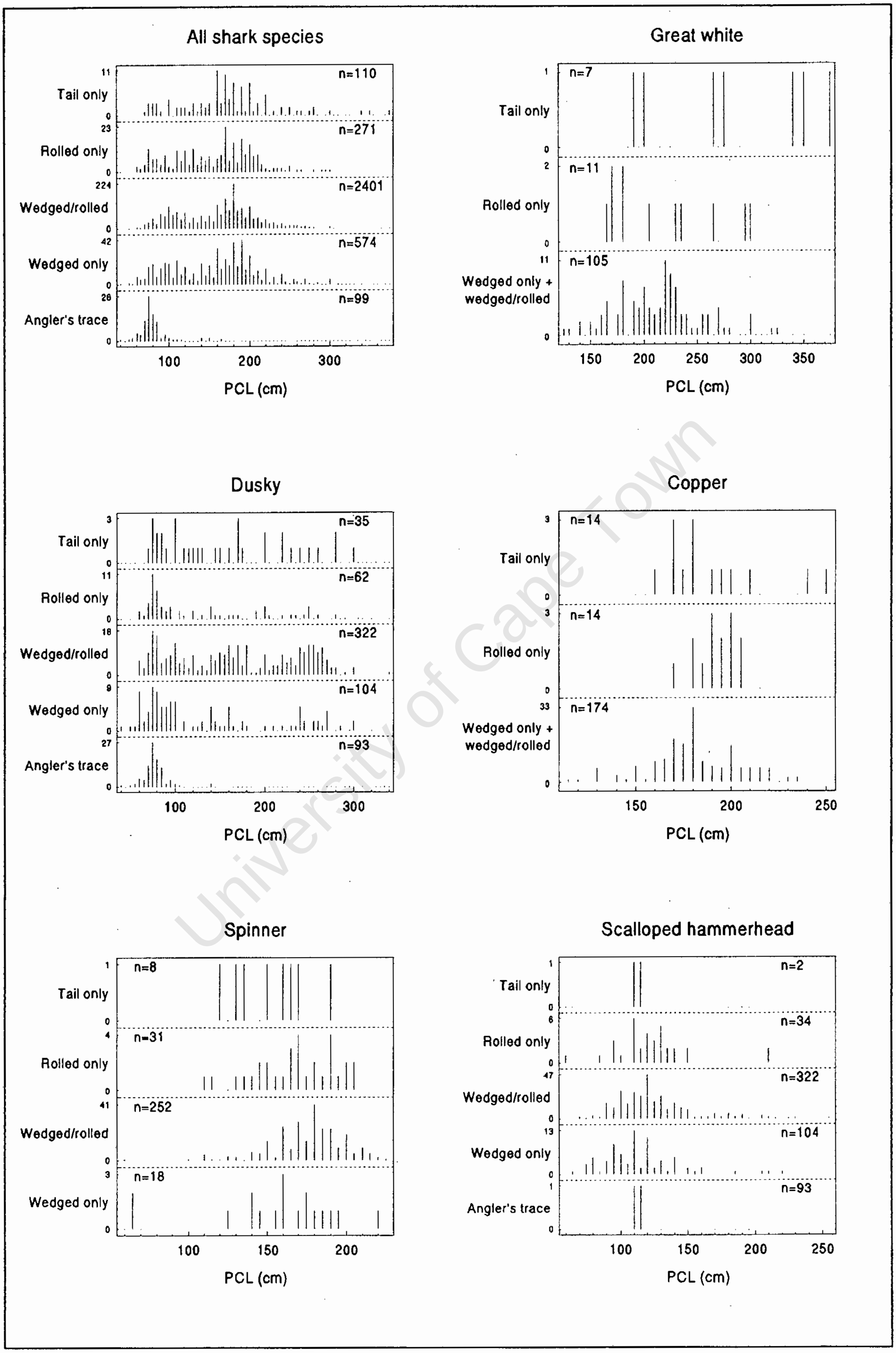
Figure 3.1: Length-frequency distributions (5 cm length classes) by method of capture for all sharks combined and for those shark species caught in conventional nets for which length differences exist between two or more capture methods.


All shark species
11
Tail only
0
n=110
23
Rolled only
0
n=271
224
Wedged/rolled
0
n=2401
42
Wedged only
0
n=574
28
Angler's trace
0
n=99
100
200
300
PCL (cm)
Great white
1
Tail only
0
n=7
2
Rolled only
0
n=11
11
Wedged only + wedged/rolled
0
n=105
150
200
250
300
350
PCL (cm)
Dusky
3
Tail only
0
n=35
11
Rolled only
0
n=62
18
Wedged/rolled
0
n=322
9
Wedged only
0
n=104
27
Angler's trace
0
n=93
100
200
300
PCL (cm)
Copper
3
Tail only
0
n=14
3
Rolled only
0
n=14
33
Wedged only + wedged/rolled
0
n=174
150
200
250
PCL (cm)
Spinner
1
Tail only
0
n=8
4
Rolled only
0
n=31
41
Wedged/rolled
0
n=252
3
Wedged only
0
n=18
100
150
200
PCL (cm)
Scalloped hammerhead
1
Tail only
0
n=2
6
Rolled only
0
n=34
47
Wedged/rolled
0
n=322
13
Wedged only
0
n=104
1
Angler's trace
0
n=93
100
150
200
250
PCL (cm)

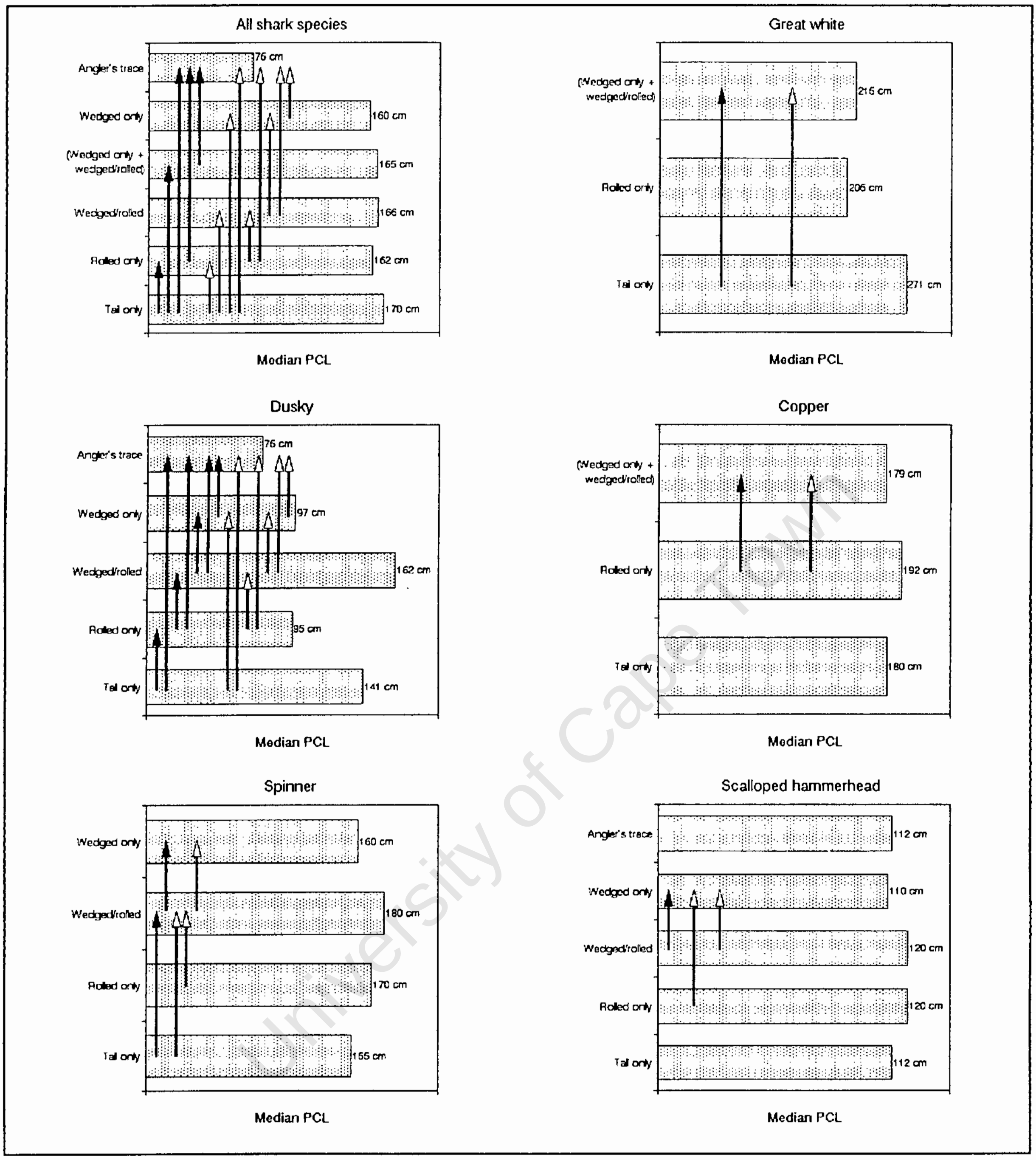


Figure 3.2: Median lengths by method of capture for those shark species, caught in the conventional nets, for which length differences exist between two or more capture methods. Arrows connect the pairs of capture methods between which a difference exists in the median length (Mann-Whitney test; open arrow heads) and/or the length distribution (Kolmogorov-Smirnov test; solid arrow heads)

Hamley (1975) suggested that mesh size is more closely related to the length of wedged fish than to the length of tangled fish. In other studies conducted on mesh selectivities for sharks, entanglement of larger specimens, or in larger mesh sizes, tended to result in a right-skewed selectivity curve (Kirkwood & Walker 1986, Nakano & Shimazaki 1989). Lyle & Timms (1984) fished with nets of 10, 15 and 20 cm mesh and found that the length-frequency distributions of *C. limbatus* caught in the smaller of two mesh sizes were skewed to the right, due to larger sharks rolling up in the nets without first becoming wedged. In the present study, however, there was no consistent evidence of an increase with length in the number of rolled sharks compared with wedged or wedged/rolled sharks caught in the conventional (50.8 cm mesh) installations. This may have been because of difficulty in determining whether a rolled shark had first been wedged. McLoughlin & Stevens (1994) also found inconsistencies in the recording of wedged versus rolled in their study. There was, however, a significant difference in the distribution of capture methods between the experimental 50.8 cm nets and the 70 cm nets, with a higher percentage of sharks being rolled in the larger mesh; hence the use of the Kirkwood & Walker (1986) model (Section 3.3.4.2).

3.3.3 Length/head girth relationships of sharks

A linear regression model was used to describe the relationship between head girth and precaudal length, following the example of Nakano & Shimazaki (1989) for the blue shark *Prionace glauca*. Significant length-head girth model fits were obtained for 12 of the 14 shark species (Fig. 3.3, Table 3.I). Sample sizes were small, however, and in all but one case the intercept was not significant. Thus the comparative plot of length-head girth relationships (Fig. 3.4) should be regarded as preliminary, pending the accumulation of larger samples. The plot tends to confirm that the great white, bull, Java *Carcharhinus amboinensis* and ragged-tooth sharks are the most "robust" species.

The inclusion of the two hammerhead sharks is for completeness only, since in these species head width may be a more relevant index of mesh selectivity than head girth. Bass *et al.* (1975) described non-linear relationships between internasal distance and total length (the latter defined as the sum of the precaudal length and 80% of the upper caudal length) for the scalloped hammerhead, the smooth hammerhead *Sphyrna zygaena* and the great hammerhead *S. mokarran*. A linear approximation has been assumed in plotting relationships between internasal distance and precaudal length (Fig. 3.4). Head width at a given length is considerably less than head girth over the length range for which data are available. Yet the median lengths of smooth and scalloped hammerhead sharks are the smallest of the 14 shark species sampled by the conventional nets (Table 3.II). While it is unclear to what extent this is due to size segregation in the respective populations - a life history characteristic of many shark species (Hoenig & Gruber 1990), and hence availability to the nets, head shape probably increases the likelihood of capture of small hammerheads. Field observations indicate that some hammerheads are caught by means of a part of the net becoming entangled around one side of the head (R. Haestier, Natal Sharks Board, pers. comm.).

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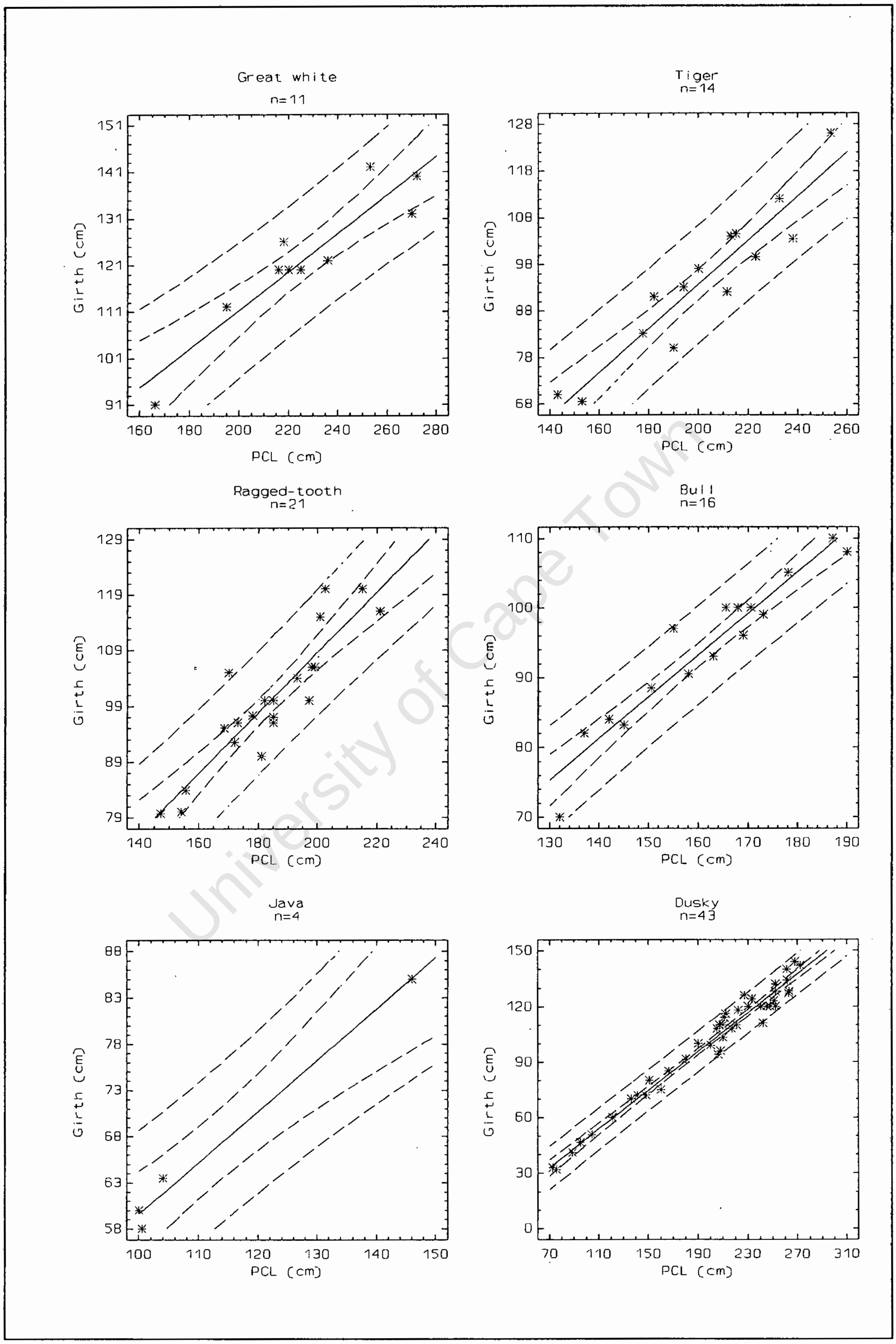
Figure 3.3: Length-head girth relationships, by shark species. Inner and outer dotted lines represent 95% confidence and prediction limits respectively.


Great white
n=11
Girth (cm)
151
141
131
121
111
101
91
160
180
200
220
240
260
280
PCL (cm)
Tiger
n=14
Girth (cm)
128
118
108
98
88
78
68
140
160
180
200
220
240
260
PCL (cm)
Ragged-tooth
n=21
Girth (cm)
129
119
109
99
89
79
140
160
180
200
220
240
PCL (cm)
Bull
n=16
Girth (cm)
110
100
90
80
70
130
140
150
160
170
180
190
PCL (cm)
Java
n=4
Girth (cm)
88
83
78
73
68
63
58
100
110
120
130
140
150
PCL (cm)
Dusky
n=43
Girth (cm)
150
120
90
60
30
0
70
110
150
190
230
270
310
PCL (cm)

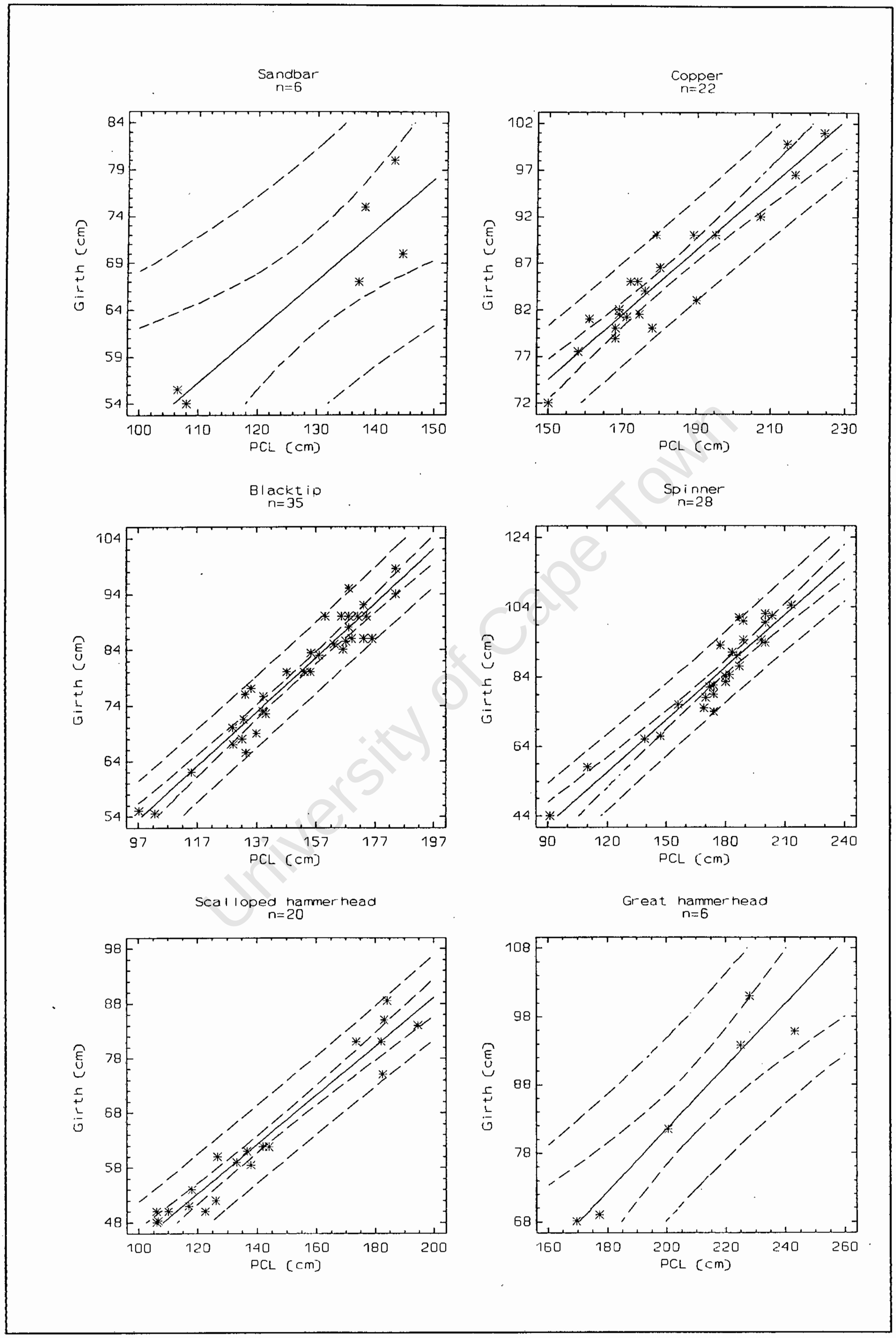

Sandbar
n=6
Girth (cm)
84
79
74
69
64
59
54
100
110
120
130
140
150
PCL (cm)
Copper
n=22
Girth (cm)
102
97
92
87
82
77
72
150
170
190
210
230
PCL (cm)
Blacktip
n=35
Girth (cm)
104
94
84
74
64
54
97
117
137
157
177
197
PCL (cm)
Spinner
n=28
Girth (cm)
124
104
84
64
44
90
120
150
180
210
240
PCL (cm)
Scalloped hammerhead
n=20
Girth (cm)
98
88
78
68
58
48
100
120
140
160
180
200
PCL (cm)
Great hammerhead
n=6
Girth (cm)
108
98
88
78
68
160
180
200
220
240
260
PCL (cm)

Table 3.I: Shark length-girth linear regression results

Shark species	Min. *PCL* (cm)	Max. *PCL* (cm)	Constant	Sig. level	Slope	Sig. level	P-value (full regression)
Great white *Carcharodon carcharias*	166	272	28.78	0.07	0.41	0.00	0.00
Mako *Isurus oxyrinchus*	200	228	-	-	-	-	0.63
Tiger *Galeocerdo cuvier*	143	253	-0.93	0.93	0.47	0.00	0.00
Ragged-tooth *Carcharias taurus*	147	221	0.48	0.96	0.54	0.00	0.00
Zambezi *Carcharhinus leucas*	132	190	-2.27	0.78	0.60	0.00	0.00
Java *Carcharhinus amboinensis*	100	146	4.20	0.51	0.55	0.01	0.01
Dusky *Carcharhinus obscurus*	72	272	-3.73	0.23	0.52	0.00	0.00
Sandbar *Carcharhinus plumbeus*	106	144	-3.68	0.83	0.54	0.01	0.01
Copper *Carcharhinus brachyurus*	150	224	22.13	0.00	0.35	0.00	0.00
Blacktip *Carcharhinus limbatus*	97	184	6.46	0.09	0.48	0.00	0.00
Spinner *Carcharhinus brevipinna*	91	213	-3.64	0.56	0.50	0.00	0.00
Scalloped hammerhead *Sphyrna lewini*	106	194	-0.45	0.90	0.45	0.00	0.00
Smooth hammerhead *Sphyrna zygaena*	75	75	-	-	-	-	-
Great hammerhead *Sphyrna mokarran*	170	243	-10.16	0.51	0.46	0.00	0.00
All (excl. hammerheads)	72	272	5.37	0.02	0.48	0.00	0.00

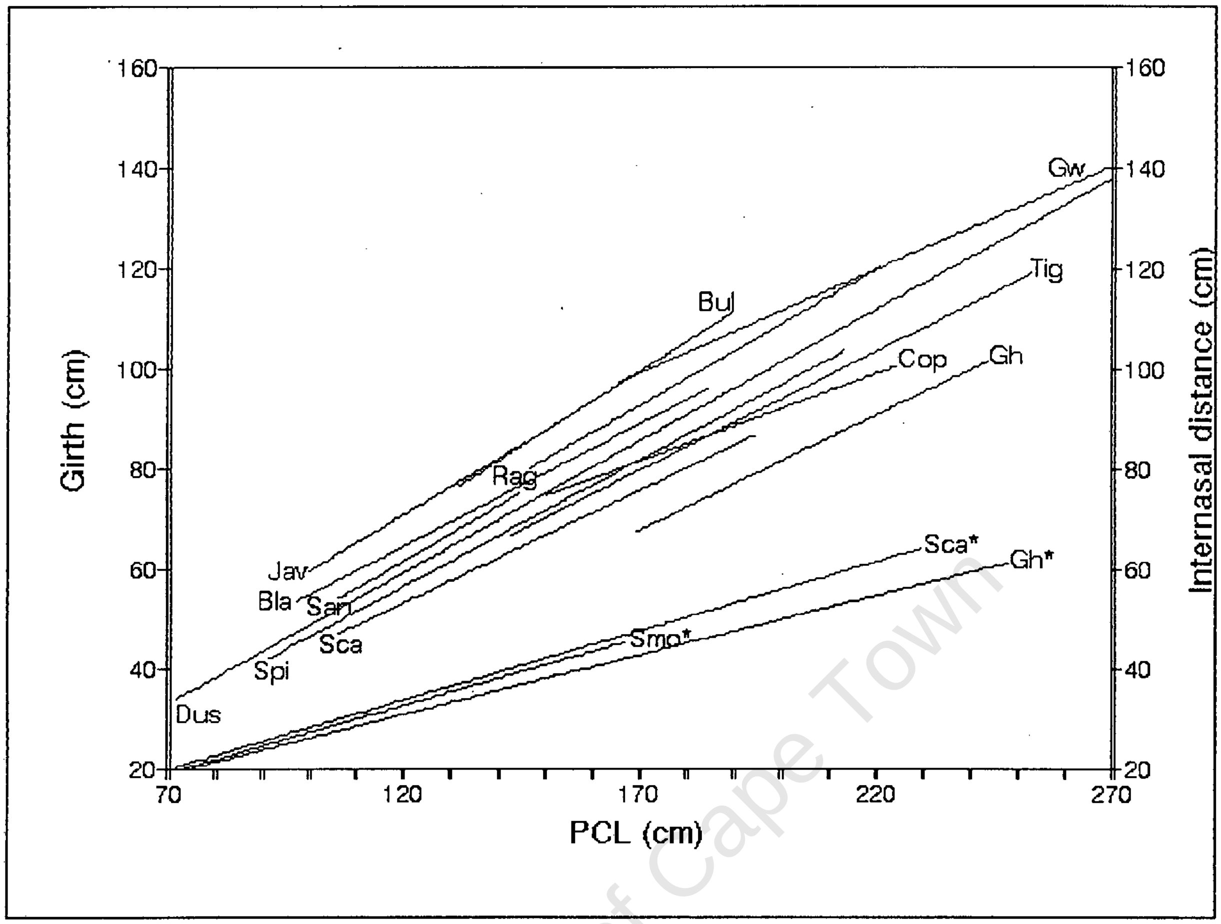


Figure 3.4: Comparative length-head girth relationships, and, for hammerhead sharks, length-internasal distance relationships*. Bla=blacktip, Bul=bull, Cop=copper, Dus=dusky, Gh=great hammerhead, Gw=great white, Jav=Java, Rag=ragged-tooth, San=sandbar, Sca=scalloped hammerhead, Spi=spinner, Tig=tiger

Table 3.II: Summary statistics of the precaudal lengths of sharks caught in the experimental nets with a 30 cm mesh (pilot study only), a 50.8 cm and a 70 cm mesh (pilot and main studies combined) and in the conventional net installations (50.8 cm mesh). (Med.=median, Min.=minimum, Max.=maximum)

	Experimental nets									Conventional nets		
Stretched mesh	30 cm (pilot study)			50.8 cm			70 cm			50.8 cm		
Fishing effort (km-days)	12			1 054			949			-		
Shark species	Med. *PCL* (cm)	Min. *PCL* (cm)	Max. *PCL* (cm)	Med. *PCL* (cm)	Min. *PCL* (cm)	Max. *PCL* (cm)	Med. *PCL* (cm)	Min. *PCL* (cm)	Max. *PCL* (cm)	Med. *PCL* (cm)	Min. *PCL* (cm)	Max. *PCL* (cm)
All	150	107	210	175	51	280	207	70	335	166	48	373
Great white *Carcharodon carcharias*	-	-	-	222	173	280	235	195	300	213	131	373
Mako *Isurus oxyrinchus*	-	-	-	242	242	242	213	213	213	207	84	276
Tiger *Galeocerdo cuvier*	-	-	-	182	131	210	335	335	335	180	90	320
Ragged-tooth *Carcharias taurus*	165	117	200	180	120	220	200	170	220	188	108	229
Zambezi *Carcharhinus leucas*	-	-	-	140	101	184	224	224	224	161	74	220
Java *Carcharhinus amboinensis*	-	-	-	108	96	120	-	-	-	134	978	176
Dusky *Carcharhinus obscurus*	129	112	210	184	51	280	238	74	310	162	57	286
Sandbar *Carcharhinus plumbeus*	-	-	-	140	130	147	145	139	148	120	65	155
Copper *Carcharhinus brachyurus*	150	130	160	170	130	200	-	-	-	192	102	239
Blacktip *Carcharhinus limbatus*	160	130	180	168	119	190	164	160	172	158	60	191
Spinner *Carcharhinus brevipinna*	161	161	161	181	110	221	190	170	209	171	51	220
Scalloped hammerhead *Sphyrna lewini*	130	107	134	130	70	208	168	87	220	111	54	265
Smooth hammerhead *Sphyrna zygaena*	-	-	-	-	-	-	70	70	70	91	48	167
Great hammerhead *Sphyrna mokarran*	-	-	-	210	200	220	212	212	212	206	106	326

3.3.4 Gillnet selectivity for sharks

3.3.4.1 Data description

3.3.4.1.1 Pilot study

During the 1990 phase of the experiment at Mzamba, the combined-species catch taken in the 30 cm mesh differed from that taken in both the 50.8 cm and the 70 cm mesh in terms of both median length and length distribution ($p<0.05$). The combined-species catch taken in the 50.8 cm mesh did not differ from that taken in the 70 cm mesh ($p>0.05$), probably as a consequence of small sample size.

Nets with a 90 cm mesh were in the water at Mzamba for approximately two months and at Richards Bay for 12 months. Despite a total fishing effort of 46 km-days, only one shark (a 196 cm spotted ragged-tooth) was caught.

The difficulty experienced with handling the gillnet with a 30 cm mesh and the low catches taken in the gillnet with a 90 cm mesh led to the abandonment of these mesh sizes.

3.3.4.1.2 Combined pilot/main study

In the combined-species catch, and in the catches of spotted ragged-tooth, dusky and copper sharks, respectively, significant differences in either median length or length distributions, or both, existed between sharks caught in the 30 cm mesh in the pilot study and either the 50.8 cm or the 70 cm mesh, or both, in the combined pilot/main study ($p<0.05$; Figs 3.5 and 3.6, Table 3.II). Given that the 30 cm nets were not used in the main study, however, and hence may not have been fishing the same shark populations as the other nets, these differences cannot be regarded as conclusive.

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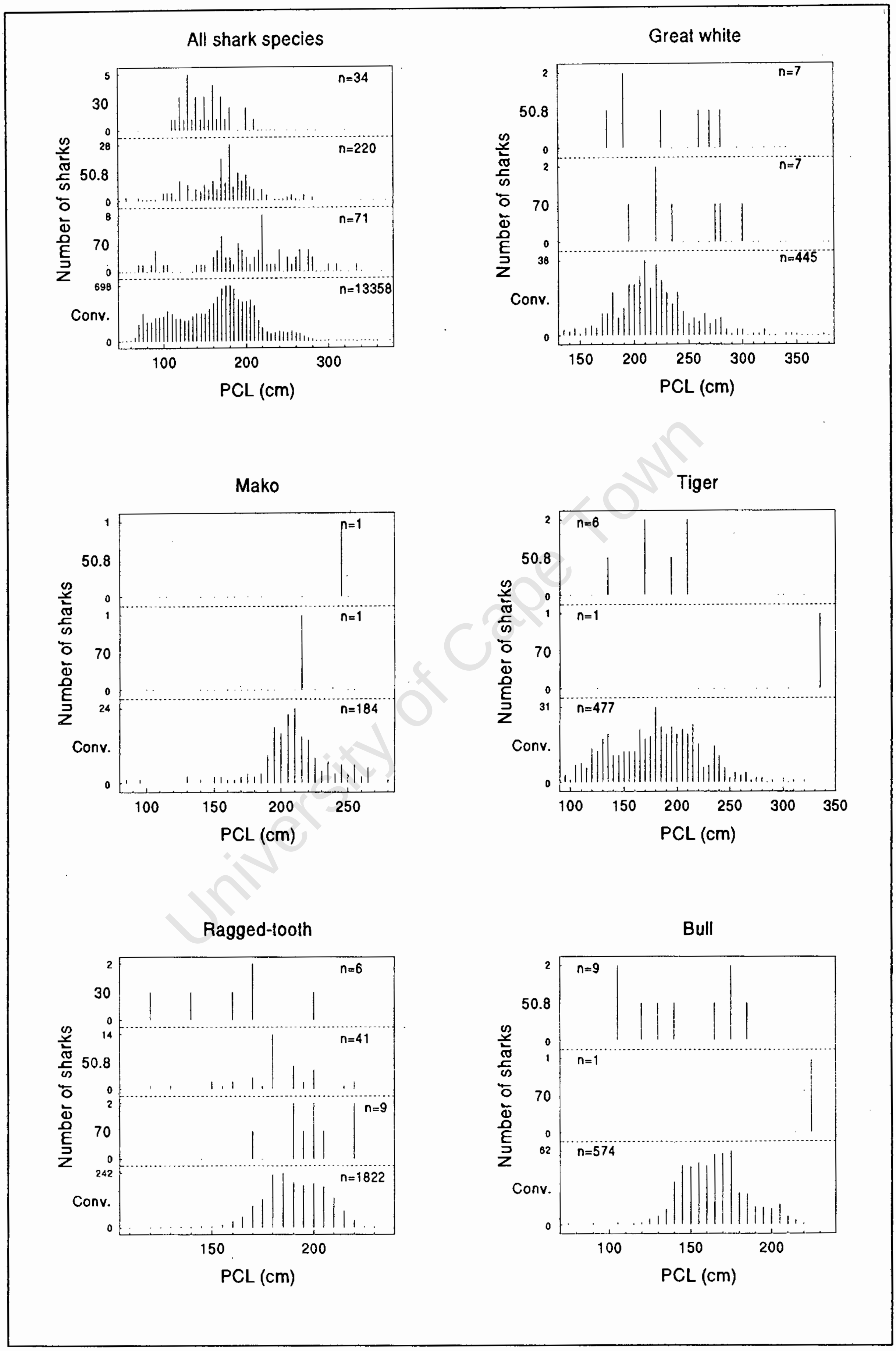
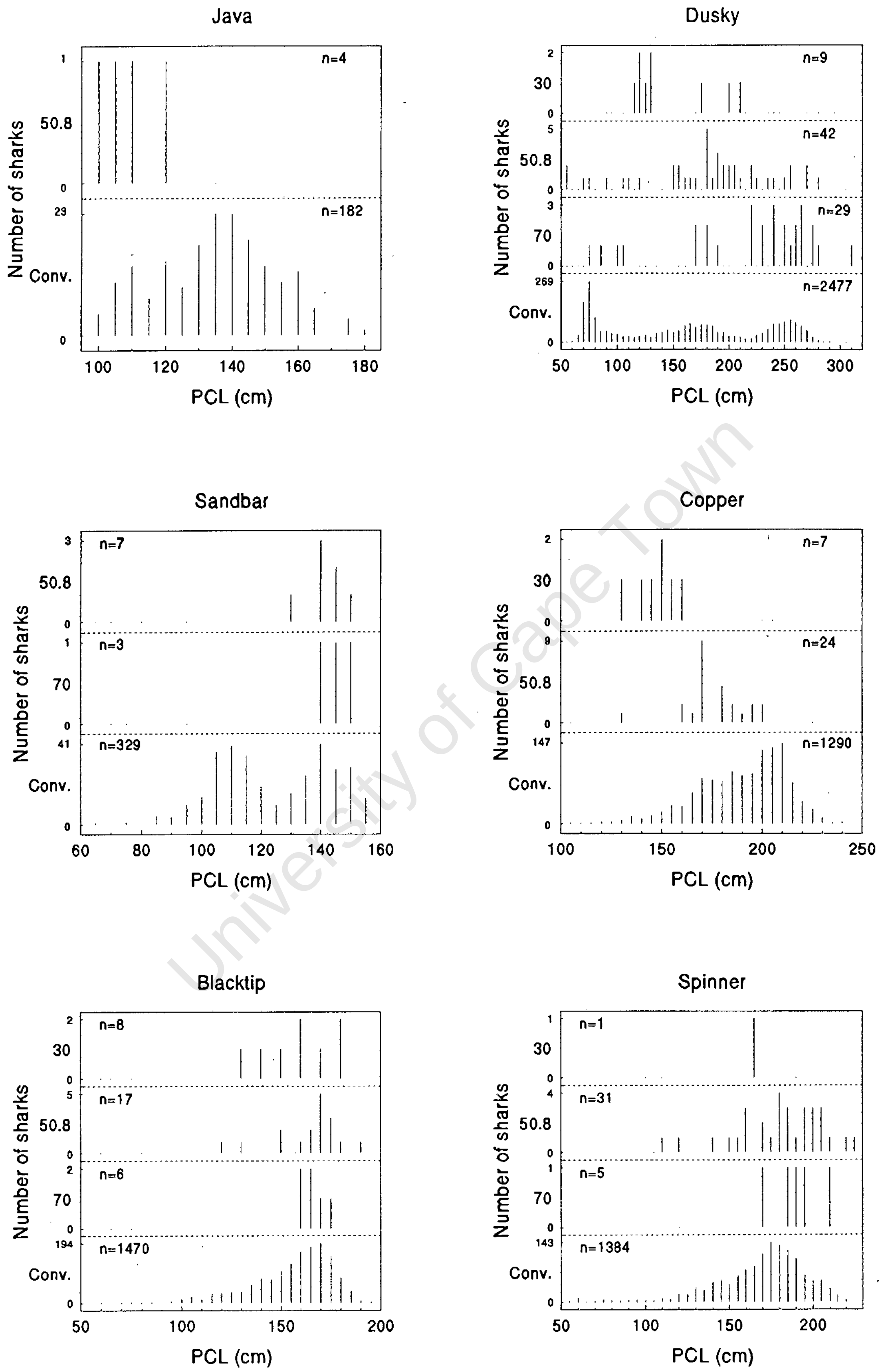
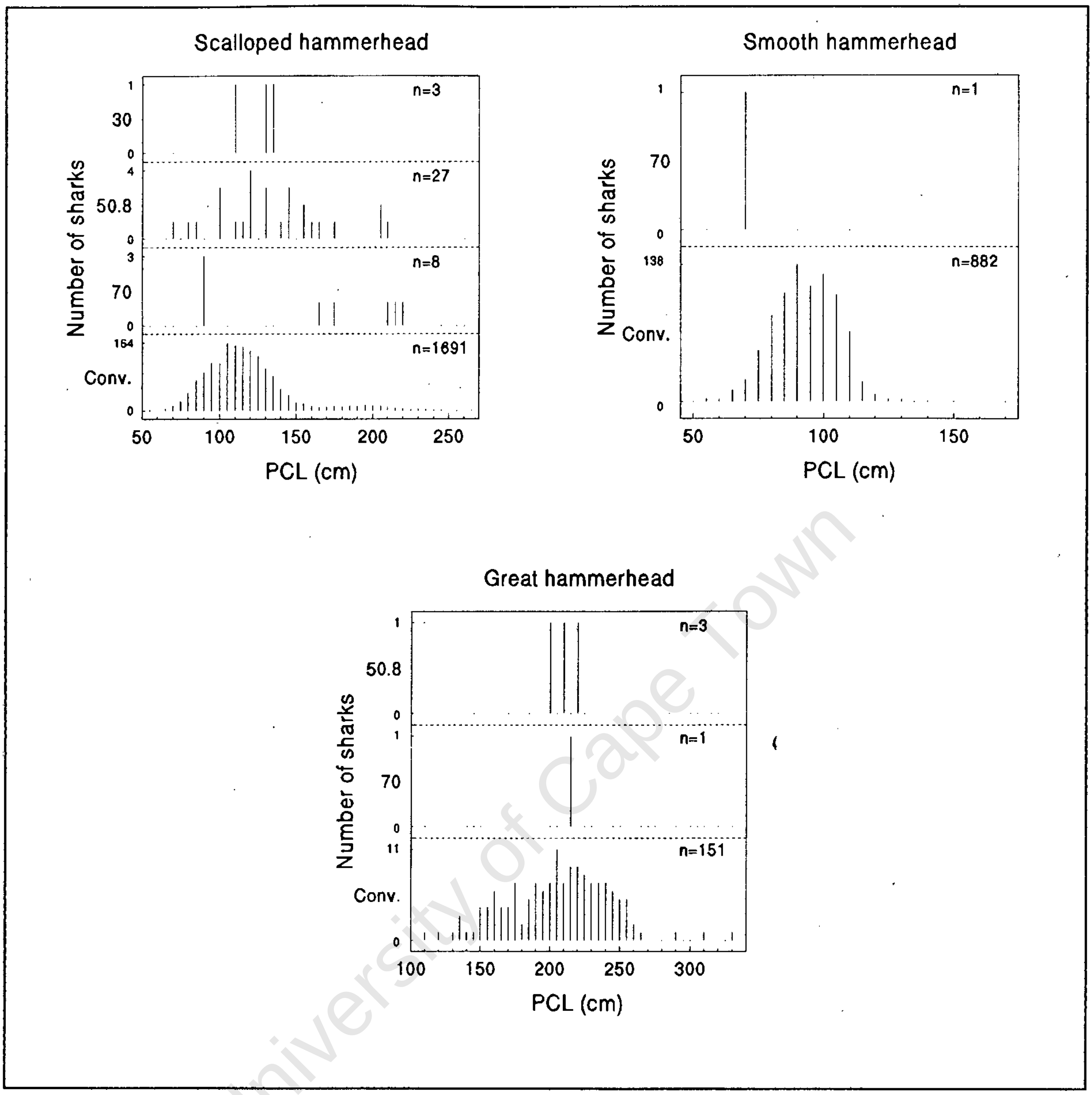
Figure 3.5: Length-frequency distributions (5 cm length classes) of all sharks caught in experimental nets with 30 cm mesh (pilot study only), 50.8 cm and 70 cm mesh (pilot and main studies combined), and in the conventional net installations (50.8 cm mesh)


All shark species
Number of sharks
5
30
0
n=34
28
50.8
0
n=220
8
70
0
n=71
698
Conv.
0
n=13358
100
200
300
PCL (cm)
Great white
Number of sharks
2
50.8
0
n=7
2
70
0
n=7
38
Conv.
0
n=445
150
200
250
300
350
PCL (cm)
Mako
Number of sharks
1
50.8
0
n=1
1
70
0
n=1
24
Conv.
0
n=184
100
150
200
250
PCL (cm)
Tiger
Number of sharks
2
50.8
0
n=6
1
70
0
n=1
31
Conv.
0
n=477
100
150
200
250
300
350
PCL (cm)
Ragged-tooth
Number of sharks
2
30
0
n=6
14
50.8
0
n=41
2
70
0
n=9
242
Conv.
0
n=1822
150
200
PCL (cm)
Bull
Number of sharks
2
50.8
0
n=9
1
70
0
n=1
62
Conv.
0
n=574
100
150
200
PCL (cm)


Java
Number of sharks
1
50.8
0
n=4
23
Conv.
0
n=182
100
120
140
160
180
PCL (cm)
Dusky
2
30
0
n=9
5
50.8
0
n=42
3
70
0
n=29
269
Conv.
0
n=2477
50
100
150
200
250
300
PCL (cm)
Sandbar
3
50.8
0
n=7
1
70
0
n=3
41
Conv.
0
n=329
60
80
100
120
140
160
PCL (cm)
Copper
2
30
0
n=7
9
50.8
0
n=24
147
Conv.
0
n=1290
100
150
200
250
PCL (cm)
Blacktip
2
30
0
n=8
5
50.8
0
n=17
2
70
0
n=6
194
Conv.
0
n=1470
50
100
150
200
PCL (cm)
Spinner
1
30
0
n=1
4
50.8
0
n=31
1
70
0
n=5
143
Conv.
0
n=1384
50
100
150
200
PCL (cm)


Scalloped hammerhead
Number of sharks
1
30
0
n=3
4
50.8
0
n=27
3
70
0
n=8
164
Conv.
0
n=1691
50
100
150
200
250
PCL (cm)
Smooth hammerhead
Number of sharks
1
70
0
n=1
138
Conv.
0
n=882
50
100
150
PCL (cm)
Great hammerhead
Number of sharks
1
50.8
0
n=3
1
70
0
n=1
11
Conv.
0
n=151
100
150
200
250
300
PCL (cm)

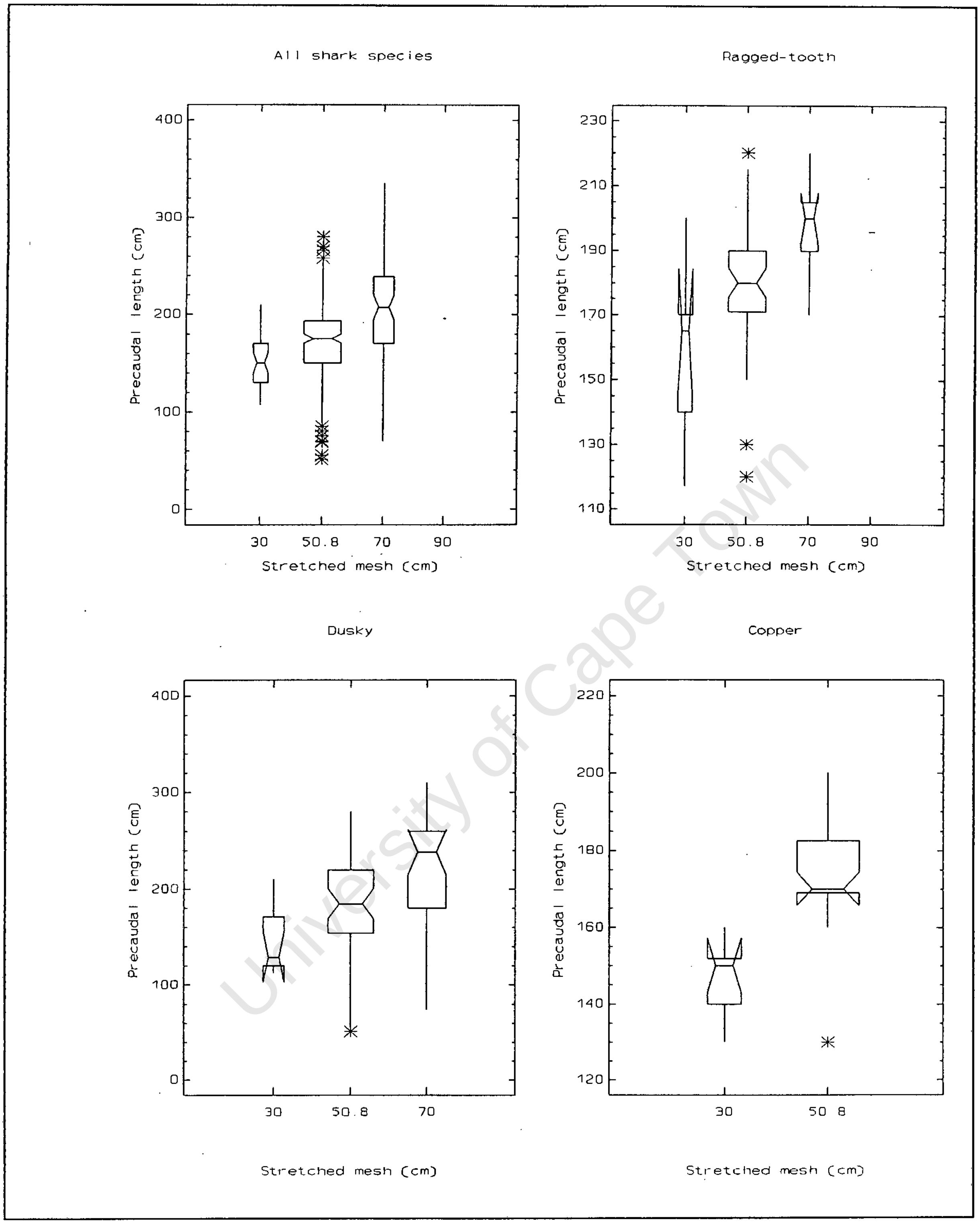


Figure 3.6: Notched box-and-whisker plots for those shark species in which one or more pairs of median lengths differed with mesh size (experimental nets only). (The box encloses the middle 50% of the data; the median is represented by the horizontal line inside each box, the approximate 95% confidence interval for the median by the length of the notch, and the sample size by the width of the box. Non-overlapping notches on pairs of boxes indicate significantly different medians)

The combined-species catch taken in the experimental 50.8 cm mesh differed from that taken in the 70 cm mesh in terms of both median length and length distribution ($p<0.05$; Figs 3.5 and 3.6, Table 3.II). The length-frequency distributions of those sharks caught in the conventional nets during 1978-1994 and subsequently measured accurately in the laboratory are also shown (Fig. 3.5, Table 3.II).

Of the 14 shark species sampled, only two, the dusky shark and the spotted ragged-tooth shark, showed a significant difference ($p<0.05$) between the two mesh sizes (50.8 cm and 70 cm) in terms of both the median length and the length distribution of the catch. In both cases, sharks with a smaller median length were captured in the smaller mesh.

No smooth hammerhead sharks were caught in the 50.8 cm experimental nets and no Java or copper sharks were caught in the 70 cm nets. Of the remaining nine species, the median lengths of seven were larger in the 70 cm than in the 50.8 cm nets, although not significantly so ($p>0.05$). The lack of significance may have been because of small sample size. The two anomalous species in which larger sharks were caught in the 50.8 cm nets were the mako shark *Isurus oxyrinchus*, for which the sample consisted only of two specimens, and the blacktip shark *Carcharhinus limbatus*. In neither case was the difference significant.

3.3.4.2 Selectivity curves

The data sets used for the fitting of selectivity curves are shown in Figure 3.7. In the exploratory log ratio plots (Fig. 3.8), a linear relationship was evident in the combined-species catch for both pairs of mesh sizes, and, although sample sizes were small, appeared to exist also for the dusky and ragged-tooth shark catches.

The Kirkwood & Walker (1986) model was fitted successfully to the catch data from the 50.8 cm and 70 cm experimental nets for (a) the combined shark species and (b) the ragged-tooth shark (Table 3.III).

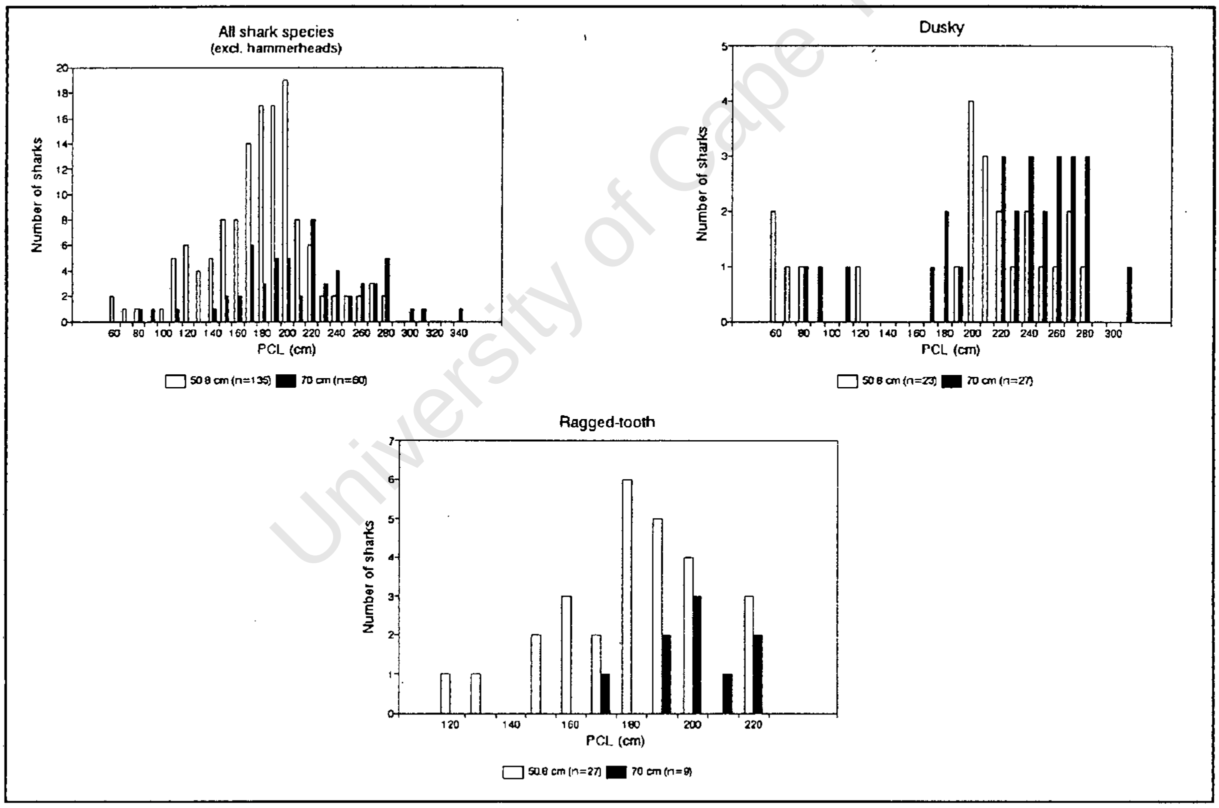


Figure 3.7: Length-frequency data (10 cm length classes) used in the fitting of selectivity curves (experimental nets only; MZ93/94 data excluded)

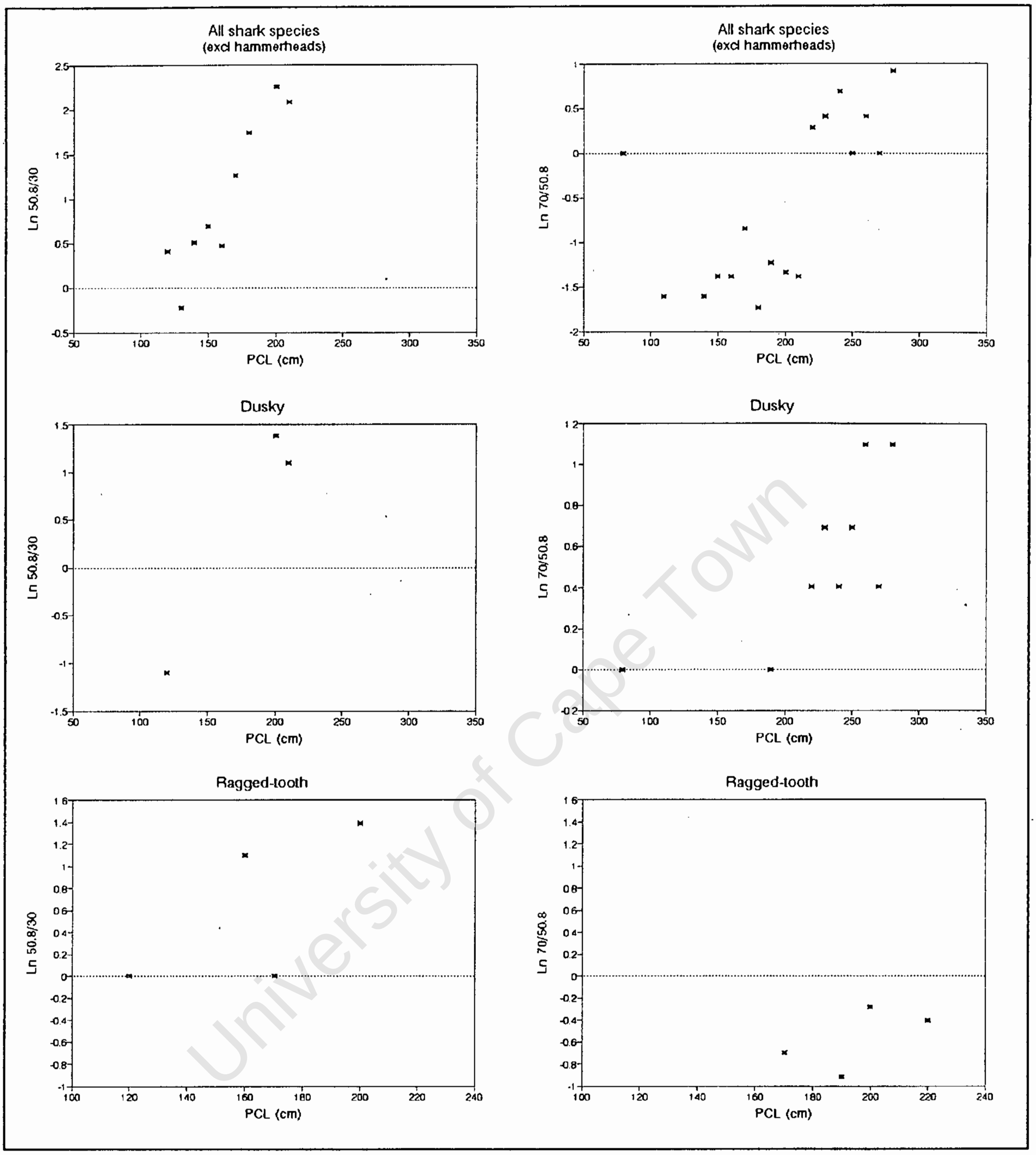


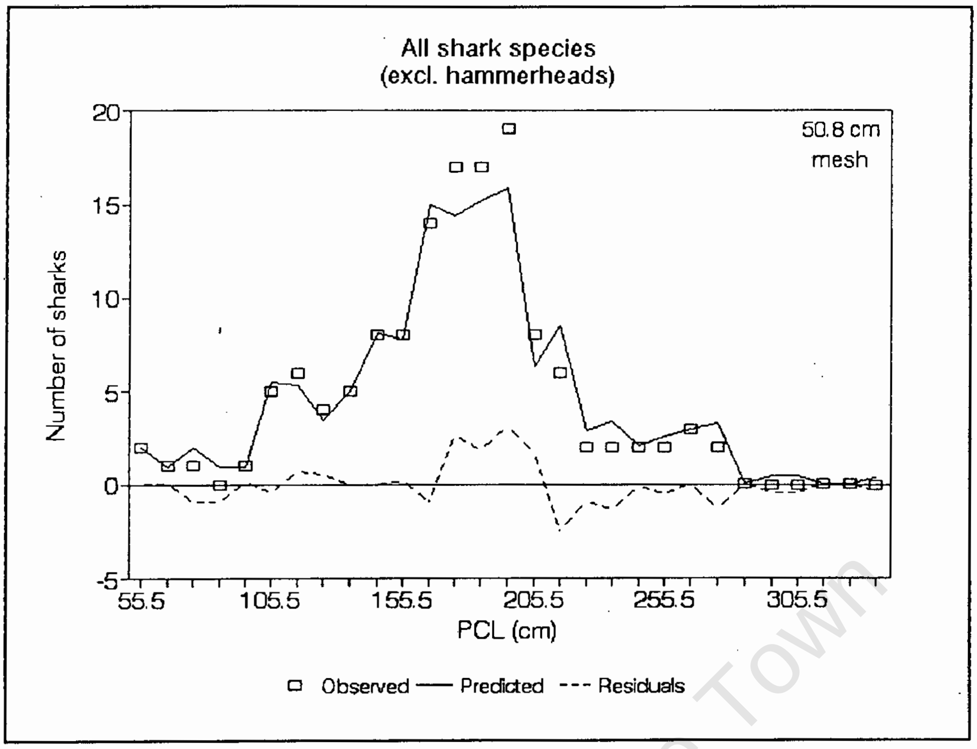
Figure 3.8: Log ratio plots of catches from pairs of mesh sizes against precaudal length (experimental nets only; MZ93/94 data excluded)

Table 3.III: Results of fitting the Kirkwood and Walker (1986) model to the combined shark catch (excluding hammerheads) and the ragged-tooth shark catch taken in the experimental nets with a 50.8 cm and a 70 cm mesh (MZ93/94 data excluded)

	All shark species (excluding hammerheads)				Ragged-tooth	
Length class interval	10 cm		15 cm (and sharks ≤ 95 cm excluded)		10 cm	
θ_1	4.31		3.92		3.45	
95% confidence limits	3.64-6.52		3.53-4.83		3.15-5.95	
θ_2	11 925		5 883		1 717	
95% confidence limits	5 073-66 487		3 154-17 118		667-67 486	
Log likelihood	160.68		243.08		0.71	
Size at peak selectivity (cm)	50.8 cm mesh	70 cm mesh	50.8 cm mesh	70 cm mesh	50.8 cm mesh	70 cm mesh
	218.8	301.6	199.2	274.5	175.2	241.4
95% confidence limits	184.9-331.2	254.8-456.4	179.3-245.4	247.1-338.1	160.0-302.3	220.5-416.5
Girth/mesh perimeter ratio	1.09:1	1.07:1	0.99:1	0.98:1	0.94:1	0.93:1

The model tended to under-predict catches of the modal length classes in both mesh sizes for both the combined species and the ragged-tooth shark (Fig. 3.9). Length classes just smaller than the mode were over-predicted, however, for the combined-species catch taken in the 70 cm mesh. McLoughlin & Stevens (1994) suggested that lack of fit may indicate unequal fishing power (i.e. capture efficiency) of the different mesh sizes, or perhaps that the sharks were not randomly distributed with respect to the different nets. Selectivity curves based on the model results are shown in Figure 3.10. Despite wide confidence limits, peak selectivities shown are reasonable in terms of the girth/mesh perimeter ratio (Table 3.III). Assuming a close relationship between girth and selectivity, peak selectivity would be expected to occur at a length where girth slightly exceeds the mesh perimeter (McLoughlin & Stevens 1994). This was the case for the combined-species catch in both mesh sizes, although for ragged-tooth sharks the ratio was slightly less than unity. The length of the ragged-tooth shark at peak selectivity was smaller than that of the combined species in both mesh sizes. This is consistent with the fact that the ragged-tooth shark is relatively robust (Fig. 3.4).

The attempt to fit the model to the dusky shark data was unsuccessful, presumably because the length distributions were bimodal and hence a gamma distribution of selectivity was inappropriate. For this reason, the method of Ishida (1962), as applied by Nakano & Shimazaki (1989), may be more appropriate, but was not pursued because of the small sample. Unsuccessful attempts were also made to fit the model to the combined-species catch per unit effort data with (a) the MZ93/94 data included or (b) the catches from the 30 cm mesh included. In both cases the lack of success may have been due to disproportionately high catches taken in (a) the 50.8 cm nets and (b) the 30 cm nets respectively. One of the assumptions of Kirkwood & Walker (1986) is that captures occur randomly over time for the duration of the experiment.



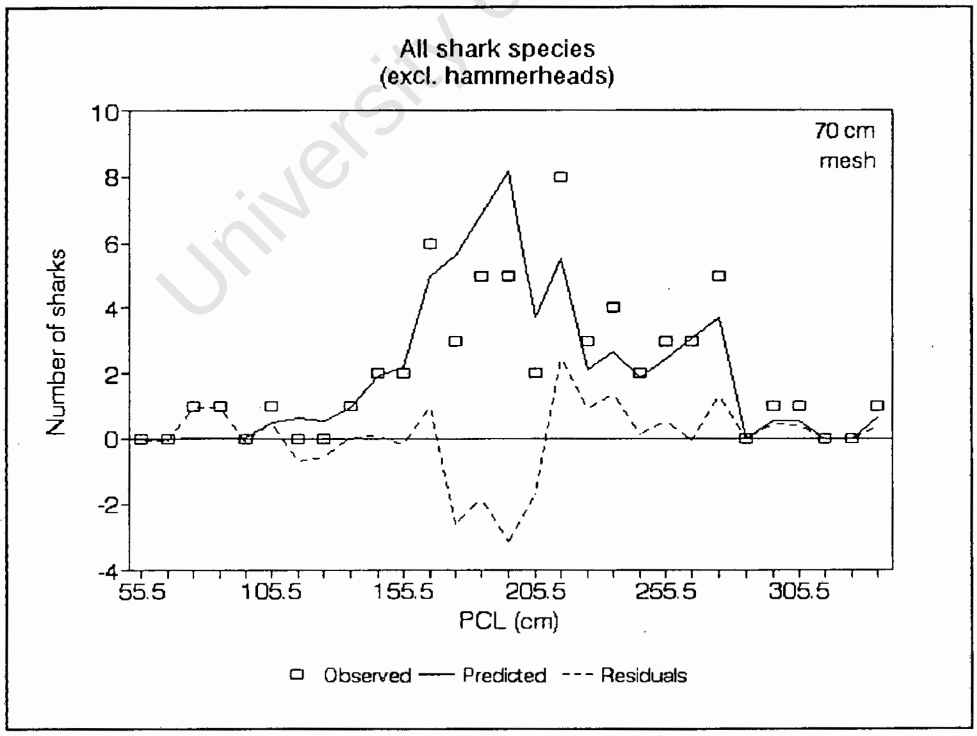
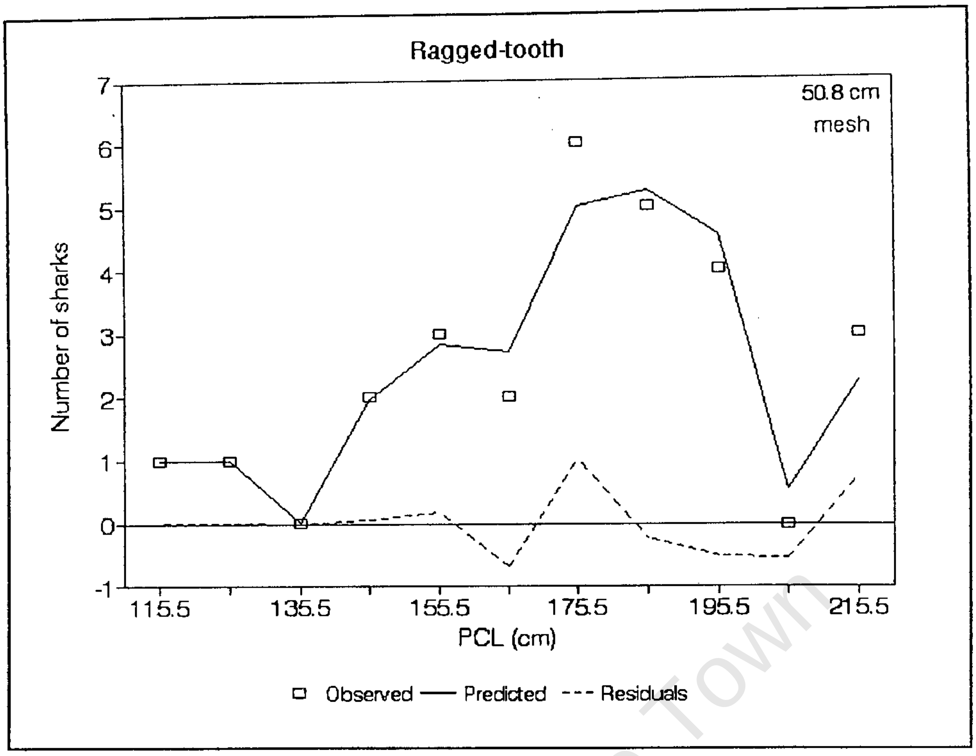


Figure 3.9: Observed combined-species shark catches taken in the experimental 50.8 cm and 70 cm mesh, catches predicted by fitting the Kirkwood and Walker (1986) model, and residuals (MZ93/94 data excluded)



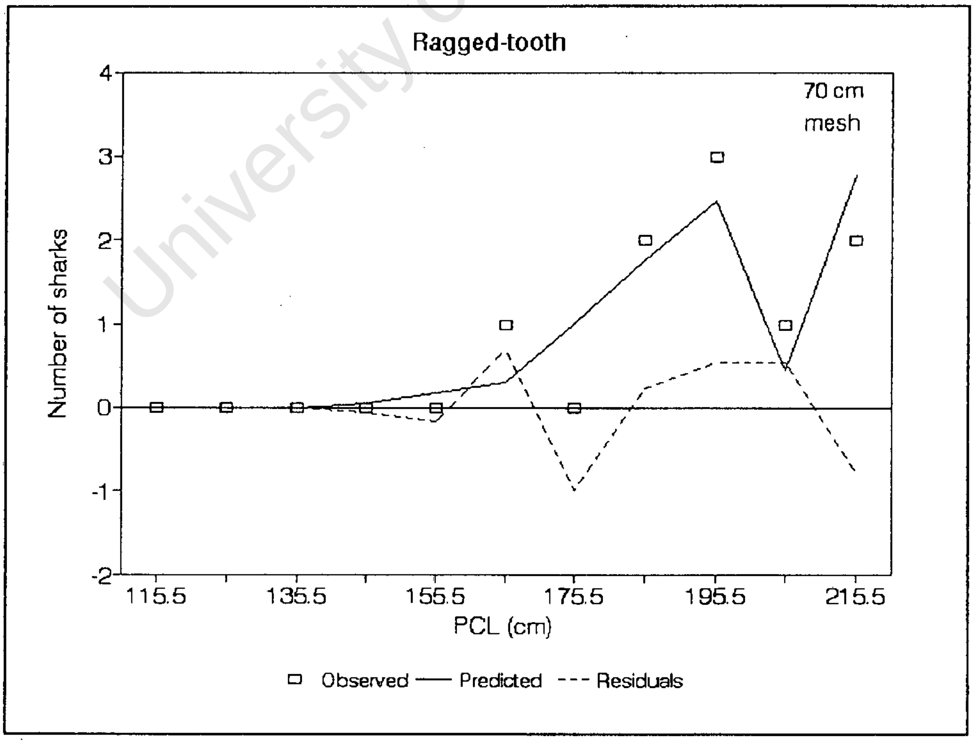
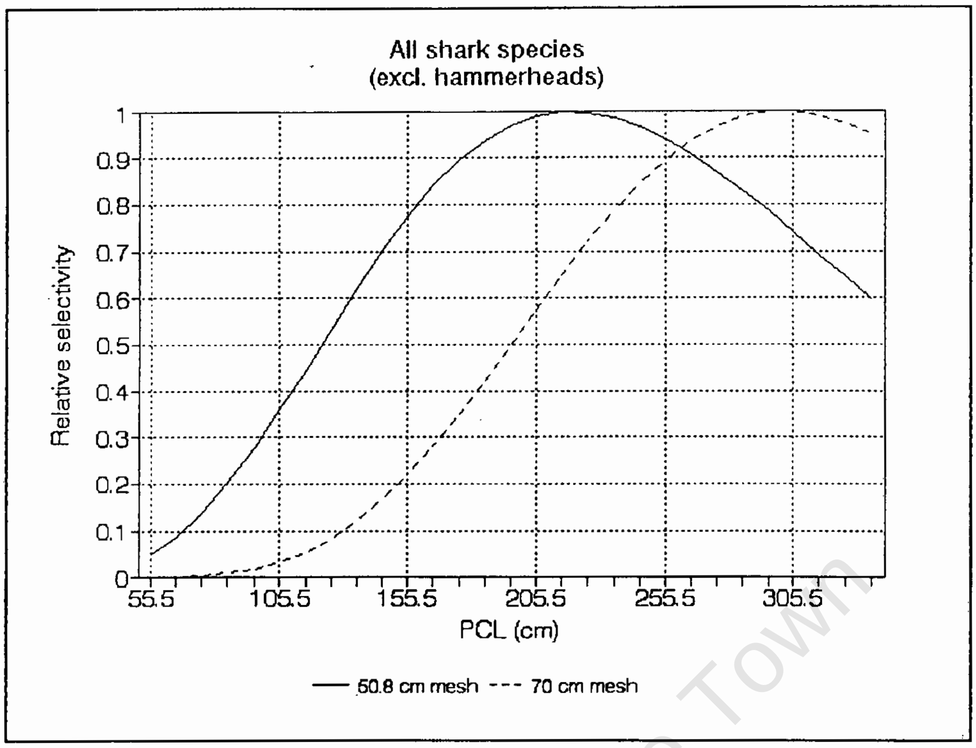


Figure 3.9: Observed ragged-tooth shark catches taken in the experimental 50.8 cm and 70 cm mesh, catches predicted by fitting the Kirkwood and Walker (1986) model, and residuals (MZ93/94 data excluded)



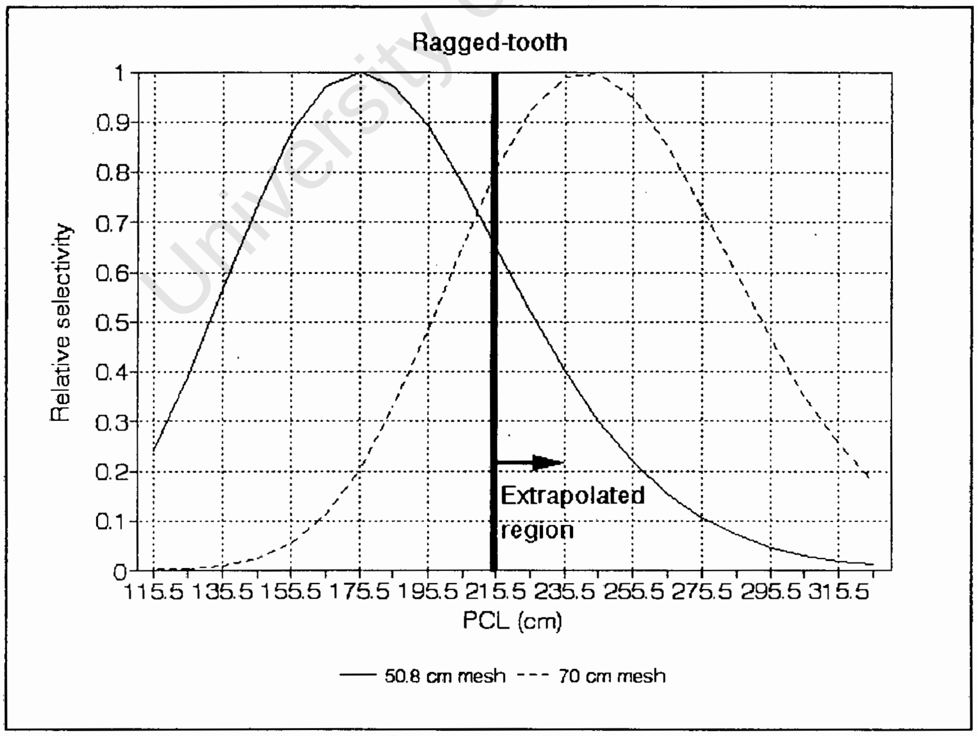


Figure 3.10: Selectivity curves for the combined shark species (excluding hammerheads) and the ragged-tooth shark in the 50.8 cm and 70 cm mesh (MZ93/94 data excluded)

To address a concern that substituting a small number for those length classes with no catch in either net may have markedly affected the model output, the length class intervals for the combined-species data set were increased to 15 cm. Fitting the model to the resultant data, which contained no dual zeroes, led to a marginal narrowing of the 95% confidence limits on θ_1 and θ_2, and hence the confidence limits on length at peak selectivity. Length at peak selectivity itself changed by some 0.8% only.

A second and more serious concern was the effect on the model output of the captures of small sharks, arbitrarily defined as sharks ≤95 cm in length. If these animals were caught by means of the entanglement of either their teeth or anglers' traces, their capture was probably not a function of mesh size in either the 50.8 cm or the 70 cm mesh. The combined-species data were therefore arranged in 15 cm intervals and all sharks ≤95 cm were omitted. Fitting the model to this data set resulted in a substantial narrowing of the confidence limits on the model parameters but also in a 9% reduction in length at peak selectivity for both mesh sizes (Table 3.III). The girth/mesh perimeter ratios at these lengths were less than unity, suggesting that, despite the increased precision of the model fit, the accuracy may have been poorer.

3.3.5 Catches of by-catch species

The 30 cm mesh took no by-catch and the 90 cm mesh only three individuals, one loggerhead turtle *Caretta caretta* and two spotted eaglerays *Aetobatus narinari*. The experimental 50.8 cm mesh caught fewer non-shark animals (70) than did the 70 cm mesh (76) (Table 3.IV). A strict comparison of numbers caught should, however, exclude the MZ93/94 data, in which case the respective totals dropped to 54 and 63 animals. On this basis, the groups/species exhibiting major differences in numbers caught were the "disc-shaped" batoids, for which the respective totals were 25 (50.8 cm mesh) and 46 (70 cm mesh), the giant guitarfish (a "shark-shaped" batoid) - 14 and six, and the dolphins - seven and two. Of the 13 non-shark species which were caught in both the 50.8 cm and the 70 cm nets, a larger median length was taken in the larger mesh in eight cases and in the smaller mesh in four cases. For no species was the difference significant, although the highest probabilities were evident in the spotted eagleray and the diamond ray *Gymnura natalensis* (Mann-Whitney U test; p=0.05 and 0.07 respectively). In all the batoids for which a difference in median was evident, the larger median was obtained in the 70 cm mesh.

Table 3.IV: Summary statistics of non-shark species caught in the experimental nets with a 50.8 cm mesh and a 70 cm mesh respectively. Sample sizes in parentheses exclude MZ93/94 data. For measurement descriptions see text. (Med.=median, Min.=minimum, Max.=maximum)

Stretched mesh	50.8 cm				70 cm			
Species	*n*	Med. size (cm)	Min. size (cm)	Max. size (cm)	*n*	Med. size (cm)	Min. size (cm)	Max. size (cm)
Bottlenose dolphin *Tursiops truncatus*	4 (4)	196	168	237	2 (1)	205	170	241
Common dolphin *Delphinus delphis*	1 (1)	212	212	212	0 (0)	-	-	-
Humpback dolphin *Sousa plumbea*	2 (2)	212	210	215	1 (1)	159	159	159
Loggerhead turtle *Caretta caretta*	4 (4)	86	80	100	4 (3)	92	60	108
Leatherback turtle *Dermochelys coriacea*	2 (2)	160	140	180	3 (3)	140	120	185
African angelshark *Squatina africana*	10 (2)	70	35	90	3 (1)	69	50	70
Eagleray *Myliobatis aquila*	2 (2)	105	100	110	6 (6)	135	100	185
Bullray *Pteromylaeus bovinus*	8 (8)	90	80	130	13 (13)	110	80	152
Spotted eagleray *Aetobatus narinari*	3 (3)	90	90	120	7 (7)	140	116	183
Flapnose Ray *Rhinoptera javanica*	3 (2)	70	60	90	1 (1)	130	130	130
Diamond Ray *Gymnura natalensis*	8 (7)	110	70	180	14 (14)	170	90	230
Manta *Manta birostris*	3 (0)	170	150	170	13 (5)	170	120	500
Devilray *Mobula* spp	3 (3)	60	60	70	0 (0)	-	-	-
Giant guitarfish *Rhynchobatus djiddensis*	15 (12)	150	120	190	7 (6)	160	120	240
Brindlebass *Epinephelus lanceolatus*	0 (0)	-	-	-	1 (1)	182	182	182
Garrick *Lichia amia*	1 (1)	119	119	119	1 (1)	93	93	93
King mackerel *Scomberomorus commerson*	1 (1)	-	-	-	0 (0)	-	-	-

3.4 Discussion

Hamley (1975), in his review of gillnet selectivity, pointed out that various factors other than mesh size may affect selectivity. These include type of twine, hang-in coefficient, method of fishing and the interaction of nets. The 10% difference in hang-in between the 50.8 and 70 cm nets for part of the present study may therefore have had some effect. The type of twine and method of fishing were constant, but, during the main study, the interaction of nets may have been a factor because the positions of the nets were not rotated. Hamley's recommendation that gaps be left between nets was followed.

An improved experimental design would have provided parameter estimates with acceptable standard errors. For a given species such a design would have taken account of (i) the length-range from length at birth to maximum length and (ii) the need to have several mesh-sizes which would between them catch effectively a range of sizes exceeding the actual length-range of the species. In addition, a sample of several hundred individuals would have been required per species, ideally with one hundred or more caught per mesh size. Such requirements could not practically be met, however.

The 30 cm and 90 cm mesh sizes proved to be impractical for reasons of unmanageability (30 cm) and very low catches (90 cm).

The median length of sharks (all species combined) caught in the experimental 50.8 cm mesh was significantly smaller than in the 70 cm mesh. The same applied in the case of dusky and ragged-tooth sharks, and there were indications that, given a sufficiently large sample, a similar finding would have emerged for most of the other species. Yet Hamley (1975) pointed out that length distributions provide limited insight into actual selectivity "because the catch depends on abundance of each length-class, as well as on selectivity" (p. 1955). The fitting of selectivity curves to the data in the present study underscored this point, in that the median lengths of the distributions of the combined-species catch and the ragged-tooth catch respectively (Table 3.II) were considerably less than the calculated lengths at peak selectivity (Table 3.III) in both the 50.8 cm and 70 cm mesh. So large were the discrepancies in most cases that the accuracy, and hence usefulness, of the selectivity curves might be questioned. The girth/mesh perimeter ratios indicate, however, that the peak selectivities may be reasonably accurate, albeit imprecise.

Using the combined-species selectivity curves as the best available approximation for the three most dangerous shark species, the relative selectivity of the 50.8 cm mesh to an animal of 1.6 m *PCL* is 81%, whereas that of the 70 cm mesh to the same animal is only 25% (Fig. 3.10). A comparison of these two percentages is not straightforward, because each is a relative rather than an absolute selectivity. Kirkwood & Walker (1986) defined *absolute selectivity* of a given mesh size to each length of fish as "the probability that, if a fish of that size encounters the net, it is captured and retained in the net" (p. 691). They pointed out, however, because the estimation of these probabilities is usually impossible, *relative selectivity*, which is proportional to absolute selectivity, is determined instead. Although the maximum relative selectivity for each mesh size is, by definition, one, the maximum absolute selectivities of different mesh sizes are only equal if their fishing powers are equal (Kirkwood and Walker 1986). Simultaneous estimation of fishing power and selectivity is considered unlikely to yield robust results, however (Kirkwood & Walker 1986), hence the assumption that fishing powers are equal. On this basis, there appears to be a considerable reduction in absolute selectivity for the smallest shark considered to be potentially dangerous.

Although the sample sizes of non-shark animals are small, the lower catches of giant guitarfish and dolphins in the larger mesh suggest that a reduction in bycatch of these species would be achieved with the general introduction of that mesh. The higher catch of disc-shaped batoids in the 70 cm mesh was unforeseen. About 70% of batoids caught in the conventional nets are released alive (Chapter 1), however, and a similar release rate would presumably be achieved over the long term in the larger mesh.

3.5 Conclusions

The use of only two mesh sizes and the combining of shark species in the fitting of selectivity curves are unsatisfactory. Cost considerations and low catch rates indicate that the introduction of additional experimental mesh sizes and the accumulation of adequate samples of the three major target species (bull, great white and tiger sharks) are unlikely to occur. Although nets of 70 cm mesh continue to be employed in alternate positions with 50.8 cm nets at Zinkwazi and Park Rynie, conclusions with regard to size selectivity must be drawn using the available information. A reduction in selectivity from 81% to 25% for a shark of 1.6 m *PCL* would result from the introduction of a 70 cm mesh. A reduction in the by-catch of dolphins and certain other by-catch species would probably also result. Given that the mandate of the Natal Sharks Board is to protect bathers against shark attack, the introduction of the larger meshed net would constitute an unacceptable reduction in levels of bather safety.

CHAPTER 4: THE EFFECTIVENESS OF DRUMLINES AS POSSIBLE ALTERNATIVES TO GILLNETS IN THE KWAZULU-NATAL SHARK CONTROL PROGRAM

Chapter 4: The effectiveness of drumlines as possible alternatives to gillnets in the KwaZulu-Natal shark control program

4.1 Introduction

Large-mesh (50.8 cm stretched) gillnets are used in the KwaZulu-Natal shark control program to bring about a local reduction in numbers of potentially dangerous sharks. These nets, which were first installed in 1952, have been extremely effective in reducing the frequency of shark attack (Chapter 2, Wallett 1983, Cliff 1991). The most dangerous species taken by the program are the bull shark *Carcharhinus leucas*, the tiger shark *Galeocerdo cuvier* and the great white shark *Carcharodon carcharias*. Other shark species are also caught, however, as are various cetaceans, batoids, sea turtles and teleosts (Chapter 1). Although there are indications that catches of most of these species may be sustainable (Chapter 1), this finding is in most cases based on crude indices of abundance, rather than on detailed stock assessment. For this reason, as well as for humanitarian reasons, a reduction in by-catch is desirable. One means of accomplishing this would be the use of baited lines, or drumlines, as alternative shark fishing gear.

In Queensland drumlines have been used either in conjunction with nets or alone since 1962 (Anon 1992). Despite earlier concerns about the attraction of sharks by drumlines (Anon 1935), the success of the Queensland program in reducing frequency of shark attack is similar to that of the netting programs of New South Wales and KwaZulu-Natal (Chapter 2).

The objective of this study was to test whether drumlines are a viable alternative to gillnets as shark-catching devices. Nets and drumlines were compared in terms of both total catch and species composition of the catch. A key feature was also to determine whether drumlines were capable of catching the large sharks considered dangerous to bathers. Between 1978 and 1994, 95% of sharks caught in the nets had a mass of ≤200 kg, and 99% ≤300 kg. The minimum requirement for a drumline, therefore, was that it should be capable of catching a shark of ≤200 kg, and ideally ≤300 kg.

4.2 Materials and methods

4.2.1 Drumline construction

The drumlines used (Fig. 4.1) were a simplified version of a Queensland design supplied by B.H. Lane (pers. comm.). The cost of a complete drumline, as at May 1994, was R350, excluding VAT. During the pilot studies various float types were used. Two moulded 16 l buoys per line were tried first, but there were doubts as to whether these offered sufficient resistance to properly set the hook in the mouth of a shark. In the third pilot study a pair of 20 l plastic drums, filled with a rigid polyurethane foam, was thus used. In the main study a single 50 l blue drum, also foam-filled, was adopted. The purpose of foam-filling was to reduce the likelihood of theft by persons wishing to use the drums as containers.

The hook type used prior to 1994 was a Mustad Sea Demon 16/0, after which a Mustad Shark 14/0, as used in the Queensland program (Anon 1992), was used. Various configurations were tried, including i) the shackling of two hooks back-to-back, ii) the setting of two hooks 30 cm apart on the same trace, with either both or only the top hook baited, and iii) the attaching of two small "trap" hooks (either Kendal Round 6/0 or Mustad Tuna Circle 8/0) close to the large baited hook. The rationale for the last two configurations was to attempt to hook small sharks which would then act as bait for larger sharks. Although no statistical analysis of the various hook configurations was conducted, it became apparent that small sharks were being captured on 14/0 hooks as well as the 6/0 hooks, and that the use of the latter was therefore unnecessary. There were concerns that the back-to-back configuration would make the release of live harmless sharks difficult and that the survival rate of sharks released with two

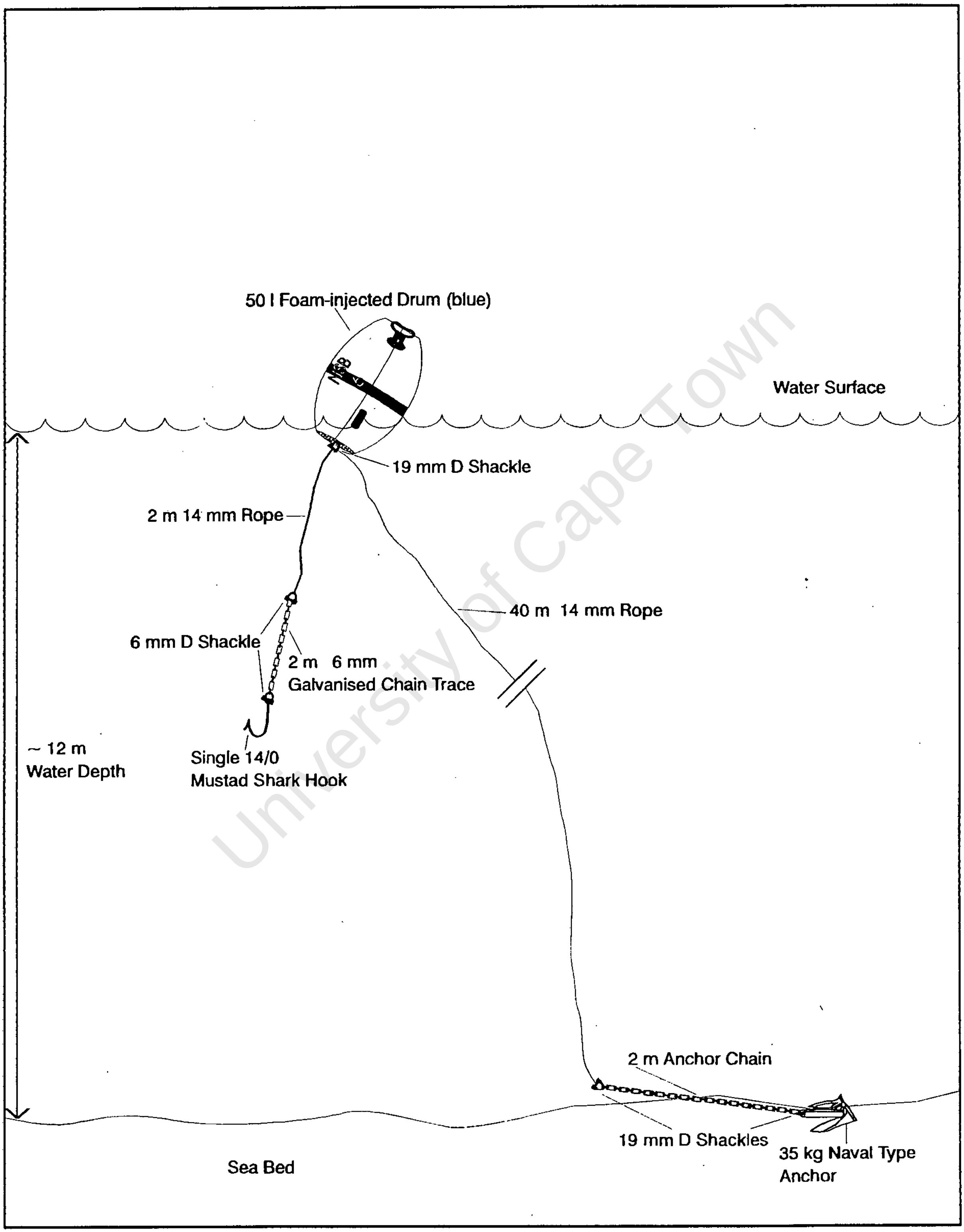


Figure 4.1: Construction of drumline used in the main study at La Mercy and Mzamba

such hooks in their mouths would be reduced. Hence the decision was taken to employ a single 14/0 hook.

4.2.2 Capture records

All captures were recorded to species, except where unidentifiable because of scavenging, and the precaudal length (*PCL*) of each shark was measured.

4.2.3 Bait

Choice of bait was governed by three factors; i) attractiveness to dangerous shark species, ii) cost and iii) availability. Several baits were used, including horse mackerel *Trachurus* sp., mackerel *Scomber japonicus*, southern mullet, or haarder *Liza richardsoni*, flathead mullet *Mugil cephalus* and chokka squid *Loligo vulgaris reynaudi*. Pieces of bullray *Pteromylaeus bovinus* were tried briefly. Eventually the southern rover *Emmelichthys nitidus* was chosen. This species, which is taken as a by-catch in the South African hake fishery, is a suitable size for a 14/0 hook and is reasonably priced, although the price increased from R1.95 kg^{-1} in January 1994 to R2.30 kg^{-1} in July 1995.

4.2.4 Experimental procedures

4.2.4.1 Pilot studies

4.2.4.1.1 Seoula Point; 14-24 January 1992

The first pilot study was run at Seoula Point (29°15´S, 31°29´E), between Zinkwazi and the Tugela River. The objective was to compare the catch rates of three conventional 213.5 m shark nets and six drumlines. The specifications of the nets and the layout of a typical net installation are described in Chapter 2. The net installation and the drumline installation were set 600 m apart in 12 m of water. A distance of 50 m separated each drumline. The gear was inspected at least once each day, usually early in the morning, and on four of the 11 days it was inspected in the afternoon as well. A variety of bait types and hook configurations was used. One drumline broke loose but was recovered and replaced the following day.

4.2.4.1.2 Umdloti/Umhlanga Rocks; 22 April-25 May 1992

The second pilot study was run at Umdloti (29°39´S, 31°08´E) and Umhlanga Rocks (29°44´S, 31°05´E). The objectives were to test the capability of drumlines to catch large sharks and to compare catch rates, particularly of small dusky sharks *C. obscurus*, between drumlines set at different distances from shore.

Two drumlines were set in 20 m of water off Umdloti, two in about 10 m of water (i.e. approximately 500 m from shore) at Umhlanga Rocks and two directly offshore of the latter, about 1 km from shore. A distance of 50 m separated the drumlines of each pair. The lines were installed on 22 April and were baited with southern rover *Emmelichthys nitidus*, although dolphin meat from by-catch taken in the shark nets was used briefly in May. Traces, hooks and baits were removed each Friday and replaced each Monday, to reduce the likelihood of theft.

Three of the lines disappeared during the course of the experiment, one at Umhlanga (14 May) and two at Umdloti (21 and 22 May). This amounted to a 50% loss of equipment in a nine day period. It was impossible to determine whether shackles had failed, large sharks had broken up the gear or fishermen had removed the buoys.

4.2.4.1.3 Zinkwazi; 3 November 1992-16 April 1993

The third pilot study was run 800 m south of the conventional net installation at Zinkwazi (29°17´S, 31°27´E). The objective was to continue to test the capability of the drumlines to catch large sharks.

Three drumlines were set in 12 m of water 200 m apart. Bait was again *E. nitidus*. In this experiment two hooks per line, one large and one small, set close together, were used throughout. Traces, hooks and baits were removed over weekends, as before.

One drumline disappeared on 11 November and was not replaced. A second disappeared on 8 March 1993 and the third on 16 April 1993.

4.2.4.1.4 Umhlanga Rocks; January 1994

A large shark was seen inshore of the net installation on several occasions at the Umhlanga Rocks bathing beach. Two drumlines were installed at the site on 17 January. There were two 14/0 hooks per drumline, set 30 cm apart on the same trace, both baited with dolphin meat.

4.2.4.2 Main study

4.2.4.2.1 La Mercy; 24 March 1994 - 3 April 1995 (non-continuous)

An installation of six 106.75 m nets was established at La Mercy (29°38´S, 31°08´E) on 2 June 1980, having been moved from Genezzano, some 2.5 km to the north, where they had been in place since April 1966. The La Mercy installation was converted to three 213.5 m "double" nets in January 1982, and remained as such until 28 February 1994, when it was removed permanently. A complete record of shark and non-shark catches taken in the La Mercy net installation had been maintained. Drumlines, of the design illustrated in Figure 4.1, were therefore installed at La Mercy in 1994 for the purpose of comparing catches with those previously taken in the nets. It was not possible, for financial and logistical reasons, to retain the net installation during the drumline experiment. The drumlines were serviced using a 4.0 m inflatable boat with a crew of two, whereas nets are serviced using a 5.5 m skiboat with a crew of four.

Based on the Queensland rule-of-thumb that six drumlines represent an equivalent fishing effort to a 200 m net (Anon 1992), 18 drumlines were installed at the site of the former La Mercy net installation on 22 March 1994. They were set in two staggered, parallel rows of nine drumlines, with a distance of approximately 80 m separating adjacent lines. The hooks were baited at first light each weekday, sea conditions permitting.

The bait was usually *E. nitidus*, but *L. richardsoni* or *M. cephalus* was occasionally used.

Sea surface temperature (°C), water clarity (m) and current direction (either south-north or north-south) were recorded on each sea-going day at Westbrook, a net installation 5.1 km north of La Mercy. These parameters were assumed to be applicable to La Mercy.

In May 1994 a team of divers conducted a visual survey of the bottom topography in the vicinity of each of the 18 drumlines. Topography types were qualitatively categorised as sand, flat reef and high-profile reef. The anchors of seven drumlines were situated on sand, three on flat reef and seven on high-profile reef. Line number 17 was missing when the underwater survey was carried out and the topography type could not be determined. During the course of the experiment, replacement drumlines were placed in approximately the same positions as lines which had been lost.

Although the drumlines were in the water for 375 days there were 108 days when no fishing took place because of non-availability of manpower or bait. During the remaining 267 days, the baited lines were inspected on 133 days (this excludes the first day of baiting-up after each period of no fishing). During these 267 days, the average period between inspections was 2 days (± 0.12 S.E., range 1-7 days). The distribution of inspections is depicted in Figure 4.2. For each animal caught, identification to species, condition (alive, freshly dead, rotting/rotten or scavenged remains) and length were recorded. Live animals were released and most dead ones were retained. The hooks were then rebaited.

The ropes and drums were cleaned of encrusting growth in April 1994, a month after installation. In May the ropes were replaced with clean ones and the drums cleaned. The metal components were all regarded as being serviceable, although the galvanised chain

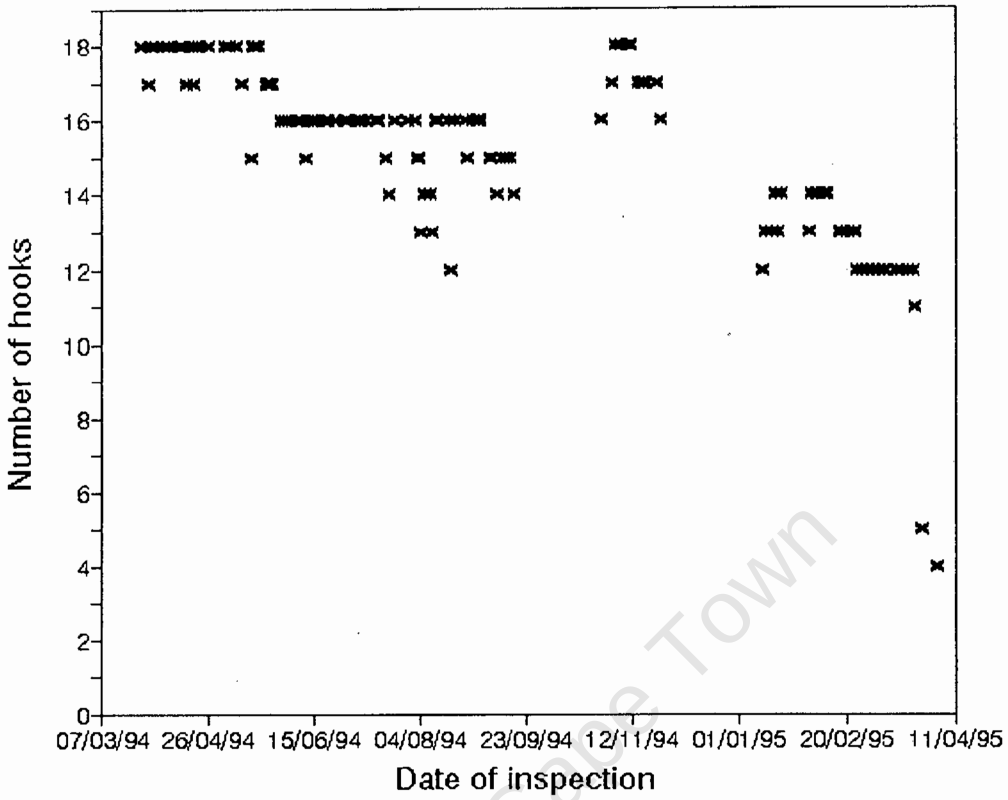


Figure 4.2: Numbers of hooks present and distribution of hook inspections at La Mercy

traces had started to show signs of corrosion within two weeks of installation. In June the original 4 mm chain traces were replaced with 6 mm chain. The 4 mm chains were extensively corroded, particularly the link closest to the hook, although a subsequent static lift test indicated that they were still capable of lifting at least 500 kg.

By mid-September there were 15 lines left in the water. There followed a 34 day period when no inspections of the drumlines took place. By the end of the period eight of these had been lost. The missing lines may have been dislodged by exceptionally heavy seas which persisted for several days; one of the lines was recovered on the beach. New anchor chains, shackles and ropes were attached to the remaining seven lines in late October, and 11 new lines installed. This was the last overhaul of equipment until the experiment ended in early April 1995, by which time only 10 lines remained.

As indicated above, a substantial quantity of gear was lost during the experiment. Of a total of 21 complete drumlines lost, only two were subsequently recovered with ropes, trace and hook still attached. The anchor rope of one of these had chaffed through on reef (see below). A total of 67 hooks, including those on the missing drumlines, was lost. Some of the missing gear was displaced, and some may have been broken by large sharks, while some was known to be stolen. The hooks and traces were cut from six drumlines during the weekend of a large skiboat competition. On two other occasions a drum was found on the beach with all attachments removed. Over a 10-day period from 10-20 January 1995 five hooks were lost, after which the shackles attaching the hooks to the traces were welded shut. Only one hook was lost thereafter until, two months later, the six lines mentioned above were cut just prior to the termination of the experiment.

The anchor ropes of those drumlines which were lost had been in the water for an average of 113.1 days (S.E. 10.7 days, range 13-165 days, *n*=21 ropes).

4.2.4.2.2 Mzamba; started 11 May 1995, ongoing at 30 September 1995

After the termination of the study at La Mercy, six drumlines were installed several hundred metres to the south of the net installation at Mzamba (31°05´S, 30°11´E) on 11 May 1995. The primary objective was to test their ability to catch great white sharks *C. carcharias*, this species being more abundant at Mzamba than at La Mercy (Cliff *et al*. 1989). The lines were set in two rows and were serviced in the same manner as those at La Mercy. Although a dive survey of bottom topography had not been conducted at the time of writing, all the lines were thought to be anchored on sand. The only bait used was *E. nitidus*.

On 12 May, the day after installation, all six traces and hooks and two drums were missing. The experiment was suspended until greater public awareness had been achieved, in anticipation that this would prevent further theft. Letters and posters were sent to local skiboat clubs and the professional fishermen's association, and articles appeared in the local press. The lines were then replaced on 22 May. The publicity appeared to have been partially successful, because no further losses were incurred over the following six weeks. After mid-July, however, six complete drumlines and two hooks were lost. A second public appeal was made in the local press in August.

On four occasions damage to gear appeared to have been caused by large sharks. Damage included a straightened hook, twisted chain traces, a bitten trace rope and a trace entangled around an anchor rope, with the hook embedded in the rope. On two occasions the splicing of the anchor rope was pulled out at the connection with the drum, something which had never occurred at La Mercy.

4.2.5 Statistical analysis of results of main La Mercy study

Each hook inspection was recorded as one of six possible events; 1) bait completely scavenged, 2) bait partially scavenged, 3) bait intact, 4) hook missing, 5) line missing and 6) shark capture. For each event a binary response model was used to analyse the effect of various factor variables on that event. Hook and/or line losses which occurred during the 108 days when no fishing took place were excluded from the model input.

The factor variables included time elapsed since the hooks were previously inspected (days), water temperature (°C), water clarity (m), current direction (coded 1=south-north, 2=north-south), bait type (coded 1=*E. nitidus*, 2=*M. cephalus* and 3=*L. richardsoni*), line number (coded 1-18) and bottom topography (coded 1=sand, 2=flat reef and 3=high-profile reef). For each of events 1-6, in turn, a binary random variable Y_n was introduced taking the value one with the probability p_n if the event had occurred and the value zero with the probability $1-p_n$ if the event had not occurred. For example, $Y_1=1$ if the bait was completely scavenged and $Y_1=0$ if it was not, $Y_2=1$ if the bait was partially scavenged and $Y_2=0$ if it was not, and so forth. The probability that the event $Y_n=1$ would occur was then linked for each of the six different events defined above to the above set of factor variables, which was denoted by $\boldsymbol{x}=(x_1,\ldots,x_k)$, by means of a link function which took the form of a logistic model

$$\ln\left[\frac{p_n}{1-p_n}\right]=\hat{\beta}_{0n}+\hat{\beta}_{1n}x_1+\ldots+\hat{\beta}_{kn}x_k \qquad n=1,\ldots,6$$

Having obtained a suitable set of estimates for $\beta_{0n}\ldots\beta_{kn}$, which was denoted by $\hat{\beta}_{0n}\ldots\hat{\beta}_{kn}$, these estimates could then be substituted back into the above link function to yield the following estimate for p_n

$$\hat{p}_n=\frac{\exp\{\hat{\beta}_{0n}+\hat{\beta}_{1n}x_1+\ldots+\hat{\beta}_{kn}x_k\}}{1+\exp\{\hat{\beta}_{0n}+\hat{\beta}_{1n}x_1+\ldots+\hat{\beta}_{kn}x_k\}}$$

$$=\frac{1}{1+\exp\{-(\hat{\beta}_{0n}+\hat{\beta}_{1n}x_1+\ldots+\hat{\beta}_{kn}x_k)\}}$$

The analysis was conducted using the logistic procedure of SAS, a statistical software package. A stepwise variable selection procedure was run, with those factor variables which met the 0.05 significance level being retained in the final model structure. The SAS output includes an analysis of maximum likelihood estimates, including Chi-square probabilities, for each of the retained factor variables. The effect of each individually retained x_i variable could now be interpreted as follows; a significant positive estimate for $\hat{\beta}_i$ indicated that an increase in the value of x_i would make p_n larger, and the converse applied for a significant negative estimate.

4.3 Results

4.3.1 Pilot studies

4.3.1.1 Seoula Point

Twenty-one sharks were caught in the nets in 27 net-days, i.e. at a rate of 0.8 sharks.net-day^{-1} (Table 4.I). Six sharks were caught on the drumlines in 58 hook-days (a hook-day being crudely defined as one drumline fishing for one day; this is discussed further below), a rate of 0.1 sharks.hook-day^{-1}.

Table 4.I: Total captures in the Seoula Point net/drumline experiment. (Number found alive in parentheses)

Species	Net catch (number)	Size range (*PCL*, cm)	Drumline catch (number)	Size range (*PCL*, cm)
Sharks				
Carcharhinus amboinensis Java	6(2)	110-136	3(1)	78-110
C. leucas Bull	4(2)	136-175	-	-
C. limbatus Blacktip	3(1)	156-160	-	-
C. plumbeus Sandbar	5(2)	90-115	-	-
C. obscurus Dusky	-	-	1(1)	70
Rhizoprionodon acutus Milk	-	-	1(1)	50
Sphyrna lewini Scalloped hammerhead	2(0)	117-167	-	-
Carcharias taurus Spotted ragged-tooth	1(0)	181	-	-
Unknown shark	-	-	1(0)	NA
Non-sharks				
Pteromylaeus bovinus Bullray	51(48)	NA	-	-
Aetobatus narinari Spotted eagleray	1(1)	NA	-	-

The 110 cm *Carcharhinus amboinensis* shark caught on the drumlines was caught while scavenging on an unidentified small shark. The *Carcharhinus obscurus* and *Rhizoprionodon acutus* caught on the drumlines were caught on the small "trap" hooks and were left on as bait. Although both were subsequently scavenged, neither led to the capture of a larger shark. Throughout the experiment, the baits themselves were extensively scavenged.

The sharks caught on the drumlines were all small (≤ 110 cm *PCL*), compared with those caught in the nets (91-181 cm). None of the three most dangerous shark species was caught on the drumlines, although the capture of four *C. leucas* in the nets demonstrated that this species was present in the study area. No non-shark species were caught on the drumlines, in contrast with the capture of 52 rays in the nets.

Seven (33%) of the sharks caught in the nets, and three (50%) of those caught on the drums, were found alive.

4.3.1.2 Umdloti/Umhlanga Rocks

Inadequate effort records were kept during May, but the catch rate in April for all drumlines combined was 0.3 sharks.hook-day^{-1} (Table 4.II).

Table 4.II: Total captures in the Umhlanga/Umdloti drumline experiment. (Number found alive in parentheses)

Species	Umhlanga inshore catch (number)	Size range (*PCL*, cm)	Umhlanga offshore catch (number)	Size range (*PCL*, cm)	Umdloti catch (number)	Size range (*PCL*, cm)
Carcharhinus obscurus Dusky	5(1)	72-80	2(1)	69-75	3(0)	72-80
C. limbatus Blacktip	-	-	-	-	1(1)	130
Galeocerdo cuvier Tiger	-	-	2(1)	128-233	-	-

Of the total recorded catch of 13 sharks, 10 were juvenile *C. obscurus*, of which 2 (20%) were released. All the sharks were caught on *E. nitidus* except for the large *G. cuvier*, which was taken on dolphin meat. Scavenging of baits occurred regularly.

The sample size was insufficient for statistical comparison of inshore and offshore catch rates and so this objective was not achieved. The 233 cm (190 kg) *G. cuvier* was the largest shark caught since drumline experimentation began in January 1992.

4.3.1.3 Zinkwazi

Eleven sharks were caught (Table 4.III) at a rate of 0.09 sharks.hook-day^{-1}.

Table 4.III: Total captures in the Zinkwazi drumline experiment. (Number found alive in parentheses)

Species	Catch (number)	Size range (*PCL*, cm)
Carcharhinus obscurus Dusky	9(0)	70-210
C. leucas Bull	1(0)	153
Isurus oxyrinchus Mako	1(1)	210

Eight of the nine *C. obscurus*, as well as the *Isurus oxyrinchus*, were caught on the small hooks. On all but two of the 115 hook-days on which sharks were not caught the baits had been scavenged, usually in their entirety.

It was not possible to obtain the mass of the 210 cm *C. obscurus* because it was extensively scavenged, and the *I. oxyrinchus* was tagged and released. From a length-mass curve (NSB unpubl. data) the *C. obscurus* probably weighed about 135 kg, and, from a curve in Cliff *et al.* (1990), the *I. oxyrinchus* about 122 kg. The *C. leucas* weighed 69 kg. Although the capture of sharks of this size was encouraging, a shark of >200 kg had yet to be caught.

4.3.1.4 Umhlanga Rocks

On 20 January a female *C. leucas* of 221 cm (238 kg) was caught on the terminal hook and the scavenged remains of a juvenile *C. obscurus* was found on the other hook.

This was not an experiment as such, but a response to a situation in which bather safety was at risk. The *C. leucas* captured was the heaviest shark taken on drumlines in this study.

4.3.2 Main study

4.3.2.1 La Mercy

The results of the binary response model of various factor variables on each possible event recorded for the La Mercy drumlines are tabulated in Appendix 4.I. Various extracts from these results are depicted graphically below. In each graph all but one of the independent variables were held constant for the plotting of each curve.

4.3.2.1.1 Drumline loss relative to bottom topography

On the assumption that each drumline position remained constant relative to bottom topography type, the average number of lines lost per position per topographical type was determined (Table 4.IV).

Table 4.IV: Average number of drumlines lost per position on each type of bottom topography in the La Mercy experiment

Bottom topography	Number of drumline losses per position			
	Minimum	Maximum	Mean	S.E.
Sand	0	1	0.43	0.19
Flat reef	0	3	1.33	0.72
High reef	1	2	1.71	0.17
Undetermined	2	2	2.00	0

The loss of drumlines anchored on high-profile reef occurred nearly four times more frequently than that of lines anchored on sand. The rate of loss on high-profile reef would probably have been even greater if each line had been replaced as soon as it was lost. It could not be determined whether these lines were lost primarily through chaffing of the anchor rope, through theft by anglers fishing on the reef, or through being cut loose by spearfishermen who had expressed objections to their presence. The loss of three lines from one position on flat reef was anomalous.

The binary response model output confirmed the progressive increase in probability of a line being lost with change in bottom topography from sand through flat reef to high-profile reef (Fig. 4.3). Water clarity and time elapsed since the previous inspection were also positively related to probability of loss. The relationship with water clarity was probably spurious, but that with time elapsed may indicate either rough seas both preventing inspections and increasing wear and tear, or a reduced frequency of inspection leading to increased likelihood of theft.

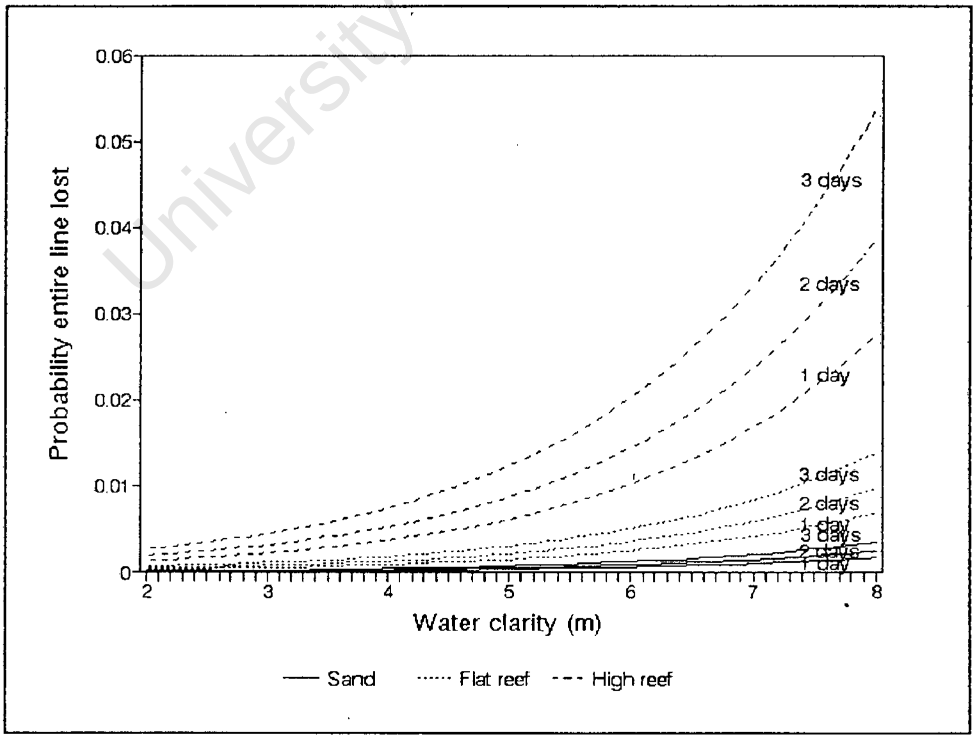


Figure 4.3: Probability of an entire drumline being lost, related to water clarity, bottom topography and time elapsed (days) since the previous inspection

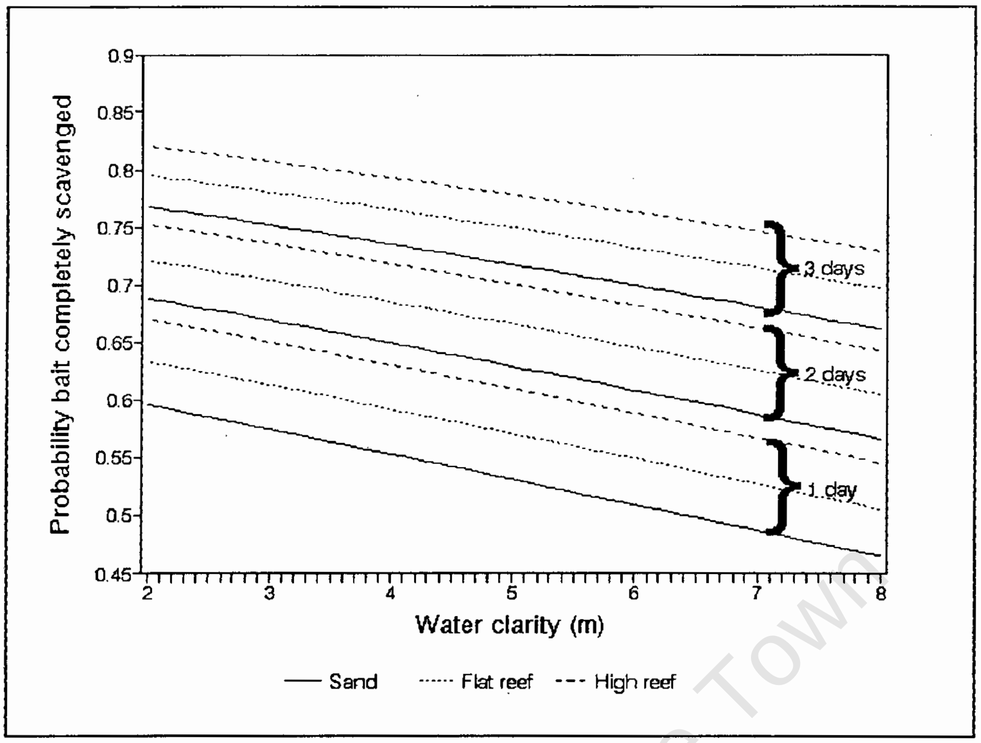


Figure 4.4a: Probability of the bait being completely scavenged, related to water clarity, bottom topography and time elapsed (days) since the previous inspection

4.3.2.1.2 Scavenging of bait

Over the course of the experiment, an average of 60% of baits had been completely scavenged within one day of the hooks being baited and a further 23% were partially scavenged. These figures exclude hooks on which a capture had occurred. Within two days, the respective percentages were 82% and 7%, and within three days, 91% and 2%. All baits were completely scavenged within four days.

The model output showed an increase in the probability of the bait being completely scavenged with change in bottom topography from sand through flat reef to high-profile reef, and confirmed an increase in scavenging with time elapsed since the hooks were baited (Fig. 4.4a). The identity of the scavengers is uncertain although, during the single dive survey, two species of teleost, slinger *Chrysoblephus puniceus* and blacktail *Diplodus sargus capensis*, were observed surrounding the baits of those drumlines anchored on high-profile reef. *C. puniceus* is an opportunistic carnivore (Garratt 1986) and *D. sargus* an omnivore (Joubert &

Hanekom 1980). On the day following the survey slinger were seen approaching a newly baited hook as it was being lowered into the water, and the bait was completely stripped within 30 minutes. In addition to teleosts, juvenile *C. obscurus* were known to take the baits. Many of the *C. obscurus* were hooked as a result and some then constituted bait for larger sharks or teleosts. Of the 76 *C. obscurus* captured, 20 (26%) were subsequently scavenged and, of these, four led to the capture of a larger shark and one to the capture of a large teleost (see below).

An unexpected result was the decrease in probability of bait being completely scavenged with increasing water clarity (Fig. 4.4a). On the assumption that sight is important to these teleosts for prey location, the converse relationship might have been expected. Hypothetically, increased vulnerability to predators may restrict the distance scavenging species will move off the reef in clean water conditions. In a detailed angling account, Schoeman & Schoeman (1990) observed that *D. sargus* is wary and difficult to catch in clear water, but is very active when the sea is rough and the water discoloured.

The conditions associated with partial scavenging of the bait were complementary to those associated with complete scavenging (Fig. 4.4b). In other words, as conditions became less conducive to scavenging, so the probability increased that scavenging would be partial only. An aspect of partial scavenging which was not consistently recorded was the distinction between scavenging by teleosts, which generally entailed the eating of the viscera of the bait fish, and sharks, which generally entailed the bait fish being bitten in two. If such a distinction had been made the conditions associated with these two forms of scavenging may have revealed significant differences.

Several factors were associated with the bait remaining intact. As expected, given the probabilities associated with complete or partial scavenging reported above, an increase in time elapsed since the bait was deployed resulted in a decreased probability of the bait remaining intact (Fig. 4.4c). Similarly, the bait was less likely to remain intact on high-profile reef compared with flat reef, and on flat reef compared with sand (Fig 4.4c). An increase in sea surface temperature resulted in a decreased probability of the bait remaining intact, due probably to a combination of an increased rate of decomposition and increased activity of scavenging fish (Figs 4.4 c-e). Schoeman & Schoeman (1990) noted that *D. sarga* tends to "disappear" (p.242) in abnormally cold water. Buxton & Smale (1989) documented reduced activity and abundance of certain reef-dwelling sparids in low ambient water temperatures.

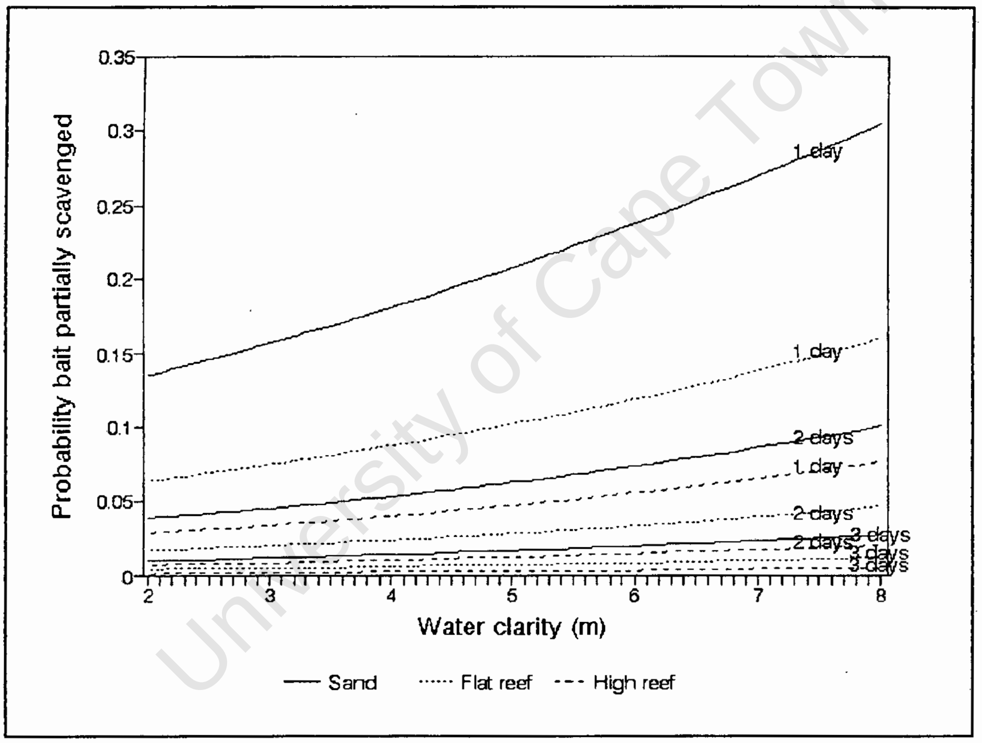


Figure 4.4b: Probability of the bait being partially scavenged, related to water clarity, bottom topography and time elapsed

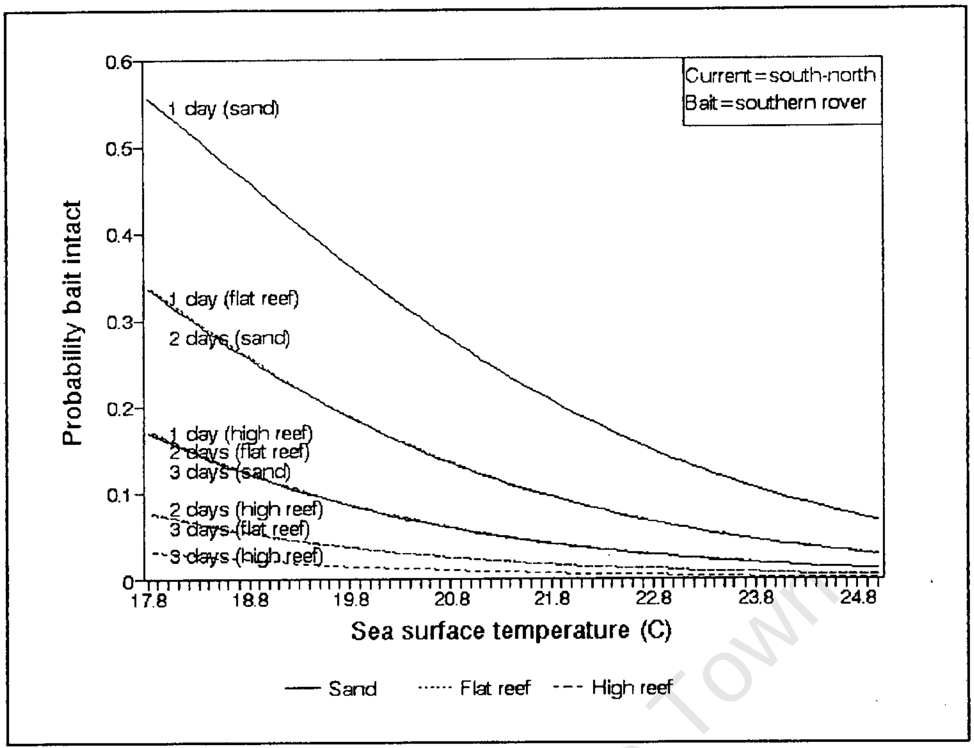


Figure 4.4c: Probability of the bait remaining intact, related to water temperature, bottom topography and time elapsed, with current direction and bait type held constant

The bait was more likely to remain intact in a northward-flowing current than in a southward-flowing current, and the difference was more pronounced on the sand and flat reef than on the high-profile reef (Fig. 4.4d). This was probably because most of the drumlines on sand and flat reef were to the north of the high-profile reef, and a northward current would transport the odour of the bait away from reef-resident scavengers.

Significant differences in the probability of the bait remaining intact existed between the three bait types, with a decrease in probability from *L. richardsoni* through *M. cephalus* to *E. nitidus* (Fig. 4.4e). It is unclear whether this reflects differences in palatability or physical durability, but, given that the *L. richardsoni* had been scaled by the supplier and hence may have had a weakened integument, palatability seems more likely.

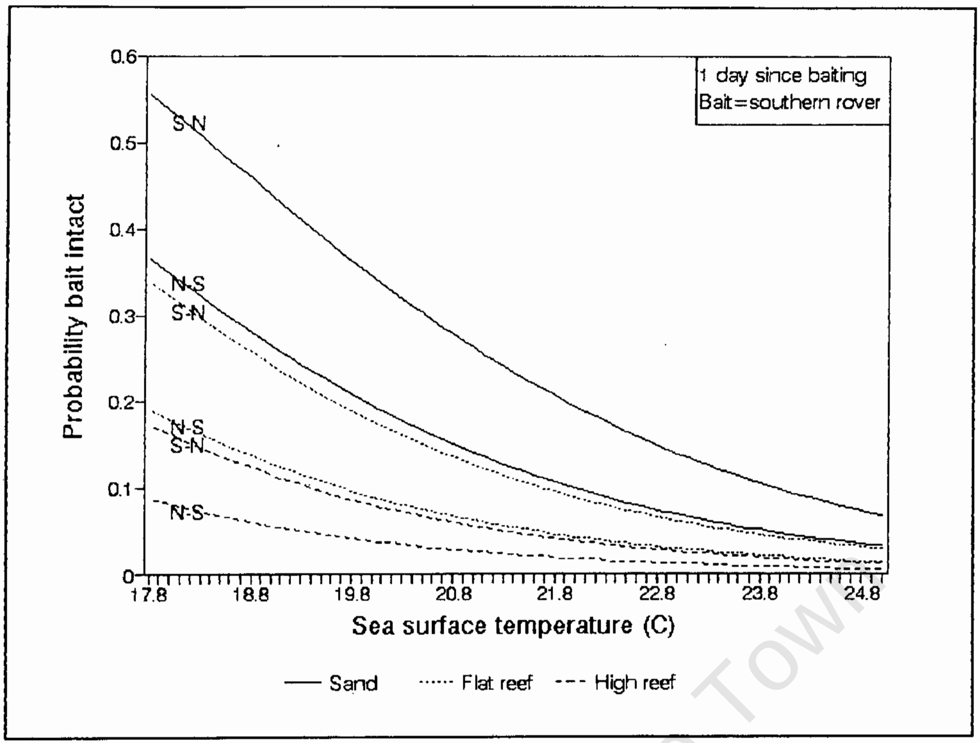


Figure 4.4d: Probability of the bait remaining intact, related to water temperature, bottom topography and current direction, with time elapsed and bait type held constant

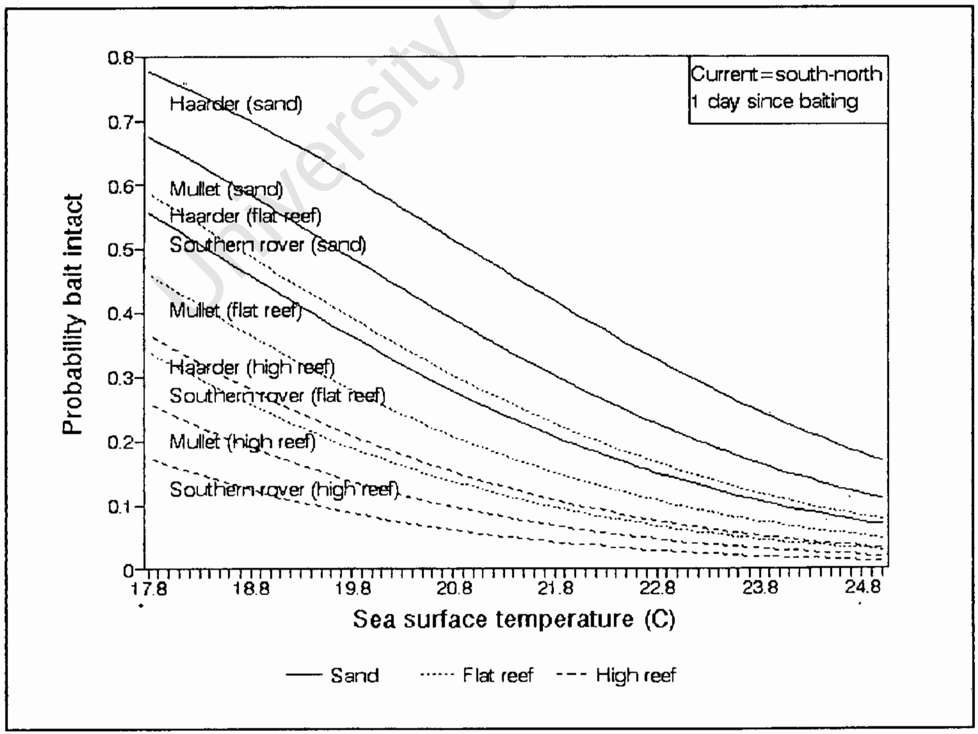


Figure 4.4e: Probability of the bait remaining intact, related to water temperature, bottom topography and bait type, with current direction and time elapsed held constant

4.3.2.1.3 *Definition of effort*

The unit of effort for a net of given specification may be expressed as the length of net fishing per unit time. The implicit assumption is that the net fishes with constant efficiency while in the water. The fact that the efficiency of a net decreases as it accumulates fish or becomes fouled with marine growth or silt (Hamley 1975 and references therein), has always been ignored in the literature pertaining to shark control (Chapter 3 and references therein). Similarly a drumline clearly does not fish with constant efficiency because it becomes saturated as soon as a (large) shark is caught. Also, a drumline is no longer fishing once the bait has been removed through scavenging, or has lost its palatability through leaching or decomposition.

In those cases where baits were not scavenged from the hooks within the first day, the declining proportion of newly-caught sharks with time elapsed since the hooks were baited suggests an apparent loss in palatability. A newly-caught shark was defined as being one which was found alive, or which was subjectively regarded as being freshly dead. On those 74 occasions when the gear was inspected within one day of the hooks being baited, 78% of the 63 sharks caught were newly-caught (Fig. 4.5). On the 16 occasions when gear inspection took place after two days, the figure had dropped to 55% of nine sharks, and after three days (25 inspections), to 21% of 14 sharks. No sharks were found when the gear was inspected four or more days after rebaiting (18 inspections). In the latter case, it was impossible to determine whether sharks had been caught during the four-day period and had subsequently been lost through decomposition or scavenging. Using these figures as an index suggest that the palatability of the bait after two days was 71%, and after three days only 27%, of that after one day. Combining these figures with those for bait scavenging, it is apparent that the lines had lost 69% of their effectiveness within one day of being baited, and 90% within two days (Table 4.V).

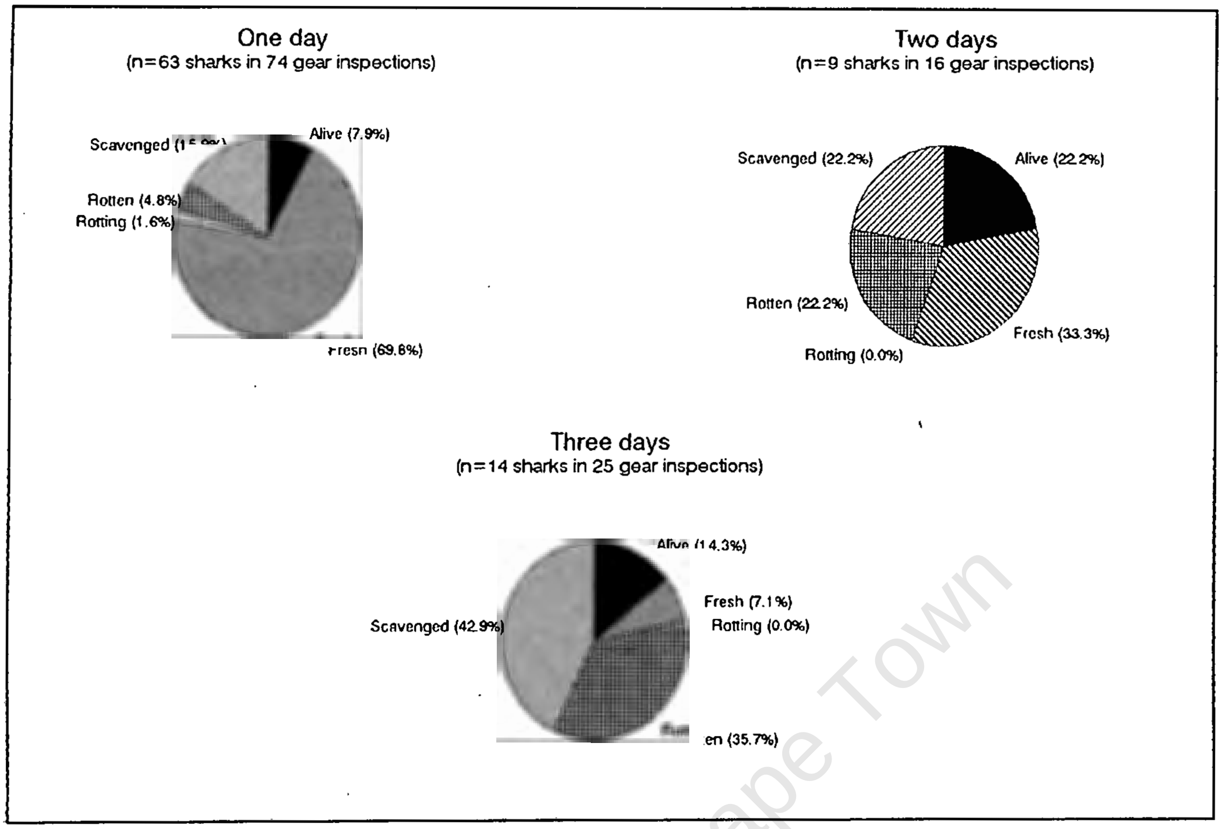


Figure 4.5: Condition of hooked sharks related to time elapsed since the previous inspection

Table 4.V: Loss in fishing power of drumlines at La Mercy with time elapsed since baiting

Time elapsed since hooks baited (days)	Percentage of baits intact or partially intact (A)	Index of bait palatability (percentage of sharks newly-caught) (B)	Percentage relative fishing power of drumlines (BxA)
0	100	100 (theoretical)	100
1	40	78 (actual)	31
2	18	55 (actual)	10
3	9	21 (actual)	2
≥4	0	0 (actual)	0

A unit of effort should therefore incorporate the number of days elapsed since a hook was baited (Table 4.VI). Catch rate declines with an increase in time elapsed, although not as markedly as might be expected from Table 4.V. This is because some sharks found after two days would have been caught during the first day, as would those found after three days.

Table 4.VI: The relationship at La Mercy between time elapsed from baiting to inspection of hooks, and shark catch (double catches on one hook recorded here as single catches)

Time elapsed (days)	Total shark catch (number)	Total number of hooks	CPUE (sharks.hook^{-1})
1	61	1 145	0.053
2	9	238	0.038
3	13	382	0.034
4	0	132	0
5	0	66	0
6	0	45	0
7	0	20	0

The decline in the probability of a shark being captured with time elapsed since the baiting of a hook is illustrated in Figure 4.6. Again, this does not take into account the fact that some of the sharks found at 2- or 3-day inspections may have been caught during the preceding day or days. Despite the fact that no sharks were found after four or more days had elapsed since baiting, the model does not show the probability of capture as being zero.

The probability of shark capture was highest on drumlines deployed on sand, followed by flat reef and then high-profile reef (Fig. 4.6). No distinction was made between shark species in the analysis of probabilities, but most of the catch consisted of juvenile *C. obscurus* (see below). It is apparent from an analysis of stomach contents conducted by van der Elst (1979) that juvenile *C. obscurus* feed on teleost prey associated with a variety of habitats, including both sandy substratum and reef. The higher probability of capture on the sandy substratum was probably therefore a result of the lower rate of scavenging of the bait by reef-associated teleosts.

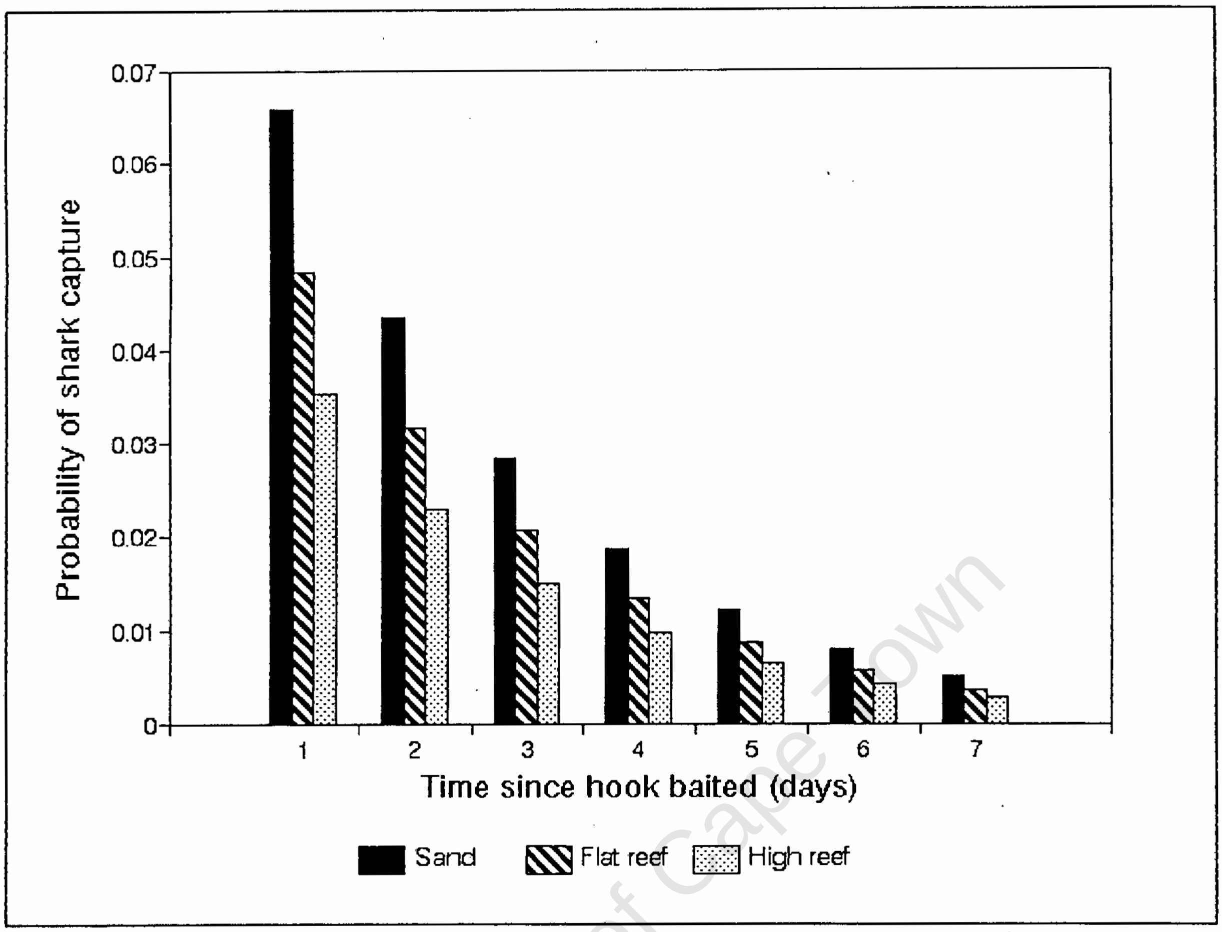


Figure 4.6: Probability of a shark capture, related to bottom topography and time elapsed since the previous inspection

4.3.2.1.4 Comparative catches on drumlines and in nets

Shark catches were low, and mean annual catches in the nets were low but variable (Table 4.VII and Fig. 4.7). This renders statistical comparison of factors such as species composition, size-frequency distribution, overall catch rate and seasonality impossible and comparisons are therefore mostly qualitative.

Eighty-seven sharks were caught on the La Mercy drumlines. One of these, however, a hardnosed smoothhound *Mustelus mosis*, was hooked through the back and had probably been placed on the hook by an angler. Of the remaining 86 sharks, 76 were juvenile *C. obscurus* (median length 75.4 cm), which could be regarded either as by-catch or as scavengers. By contrast, the La Mercy nets caught an average of only 2.6 *C. obscurus* annually between 1981 and 1993. Although most of these also were juveniles, the median length of the catch being 87 cm, some were adult (up to 272 cm).

Of the remaining 10 sharks caught on the drumlines, seven were *C. leucas* or *G. cuvier*, two of the three most dangerous species. The four *C. leucas* were all longer than 180 cm. The median size (198 cm) was considerably larger than that of animals taken in the nets (163.6 cm). Three of the *C. leucas* caught on the drumlines were captured feeding on hooked *C. obscurus*. The total catch of *C. leucas* taken on the drumlines was significantly greater than the mean annual catch taken historically in the La Mercy nets (one-sample t-test, $p<0.05$).

In contrast to *C. leucas*, the median size of the three *G. cuvier* caught on the drumlines (113 cm) was much smaller than that of animals taken in the nets (180 cm). Again, the number caught was greater than the mean annual catch taken in the nets (one-sample t-test, $p<0.05$).

The other three sharks caught were one each of *I. oxyrinchus*, *Carcharhinus limbatus* (caught on a juvenile *C. obscurus*) and *C. amboinensis*.

The percentage of the total shark catch found alive on the drumlines (10.5%) was slightly lower than that found alive in the nets (16.9%).

As had been the case in the pilot studies, the by-catch of non-shark animals on the drumlines was negligible (Table 4.VIII). One green turtle *Chelonia mydas* was hooked through a rear flipper and was released alive and a very large (*ca* 200 cm *FL*) brindlebass *Epinephelus lanceolatus* was caught while attempting to feed on a hooked *C. obscurus*. This fish, which was released alive, had been sighted from an aircraft the previous day and had thus survived on the hook for at least 24 hours. The nets took a mean annual catch of 1.7 turtles, 6.6 batoids, 1.3 teleosts and 1.5 dolphins (Table 4.VIII).

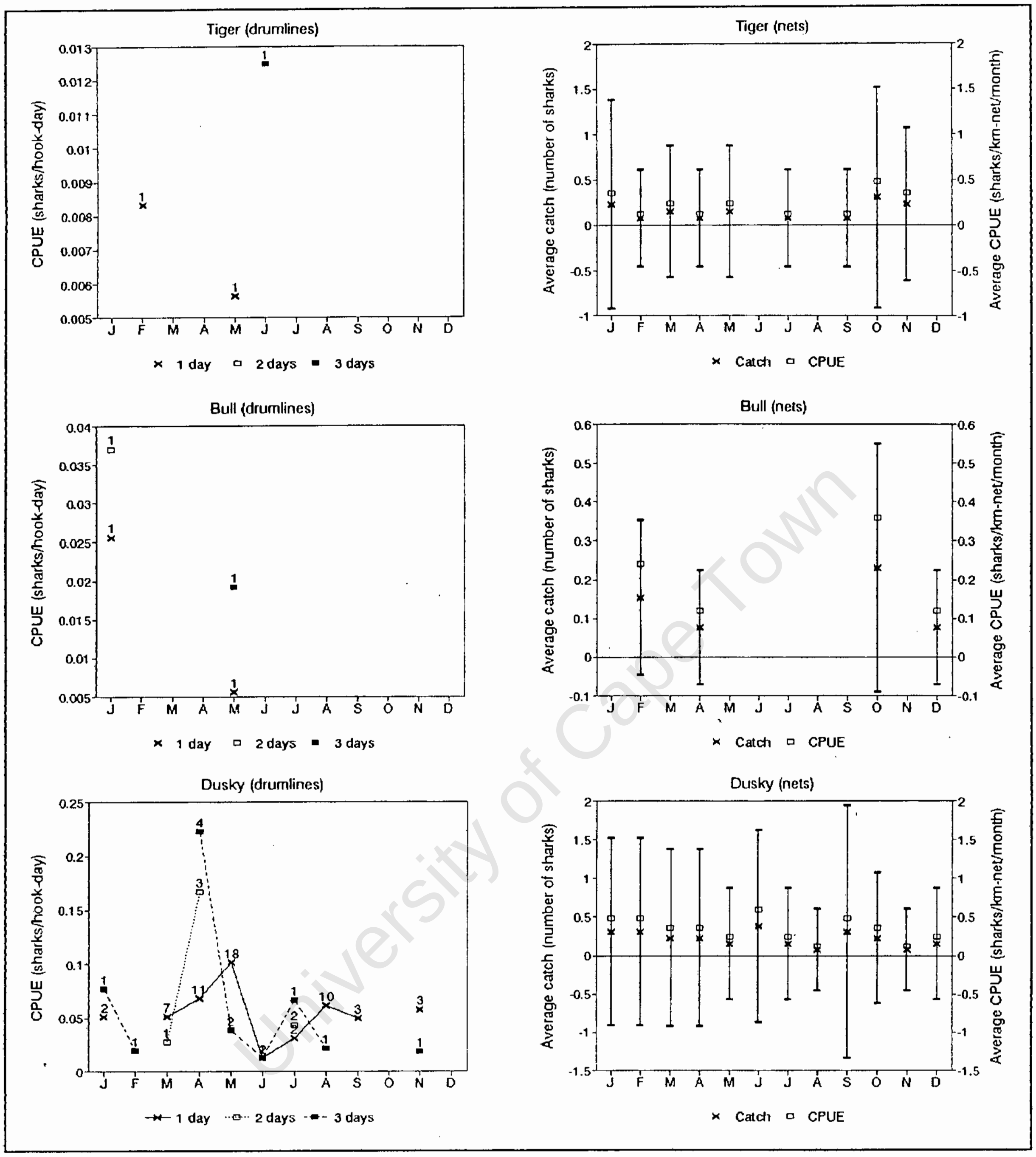


Figure 4.7: *Galeocerdo cuvier*, *Carcharhinus leucas* and *Carcharhinus obscurus* at La Mercy; on the drumlines, monthly catch rate, related to time elapsed since the previous inspection (data labels=catch), and, in the nets 1981-1993, mean monthly catch, with 95% confidence limits, and catch rate

Table 4.VII: Catch and size distribution of sharks caught on the La Mercy drumlines (24 March 1994-3 April 1995), and the average annual catch and total size distribution of sharks caught in the La Mercy nets (1 January 1981-31 December 1993) (Numbers found alive in parentheses)

	Drumlines			Nets					
	Catch (number)	Size (*PCL*, cm)		Annual catch (number)				Size (*PCL*, cm)	
Species		Range	Median	Min.	Max.	Mean	S.E.	Range	Median
Carcharhinus obscurus Dusky	76(6)	60-110	75.4	1	5	2.6(0.2)	0.39	64-272	87
C. plumbeus Sandbar	-	-	-	0	5	0.6(0.2)	0.4	104-141	115
C. limbatus Blacktip	1(0)	162	162	0	10	4.8(0.3)	0.85	73-180	156
C. brevipinna Spinner	-	-	-	0	3	1.2(0)	0.27	67-212	177.1
C. leucas Bull	4(1)	182-214	198	0	2	0.5(0.2)	0.18	130-195	163.6
C. amboinensis Java	1(0)	104	104	0	2	0.4(0)	0.17	120-165	159
Galeocerdo cuvier Tiger	3(1)	105-120	113	0	5	1.4(0.7)	0.43	128-242	180
Sphyrna lewini Scalloped hammerhead	-	-	-	0	5	1.2(0)	0.38	70-194	110.5
S. zygaena Smooth hammerhead	-	-	-	0	1	0.1(0)	0.07	110	110
S. mokarran Great hammerhead	-	-	-	0	2	0.5(0)	0.18	179-300	208
Rhizoprionodon acutus Milk	-	-	-	0	2	0.3(0)	0.17	60-79	68.5
Carcharodon carcharias Great white	-	-	-	0	1	0.3(0.1)	0.13	200-245	208
Isurus oxyrinchus Mako	1(1)	200	200	-	-	-	-	-	-
Carcharias taurus Spotted ragged-tooth	-	-	-	0	11	3.8(1.3)	0.86	151-230	194

Table 4.VIII: Catch of non-shark species caught on the La Mercy drumlines (24 March 1994-3 April 1995), and the average annual catch caught in the La Mercy nets (1 January 1981-31 December 1993) (Number found alive in parentheses)

	Drumlines	Nets			
	Catch (number)	Annual catch (number)			
Species		Min.	Max.	Mean	S.E.
Dermochelys coriacea Leatherback turtle	-	0	2	0.2(0.1)	0.16
Caretta caretta Loggerhead turtle	-	0	2	0.9(0.2)	0.2
Chelonia mydas Green turtle	1(1)	0	2	0.3(0.1)	0.17
Eretmochelys imbricata Hawksbill turtle	-	0	1	0.2(0.1)	0.12
Cryptodira (Unidentified turtle)	-	0	1	0.1(0)	0.07
Pteromylaeus bovinus Bullray	-	0	5	1.1(0.4)	0.41
Aetobatus narinari Spotted eagleray	-	0	2	0.5(0.3)	0.18
Rhinoptera javanica Flapnose ray	-	0	3	0.5(0.3)	0.3
Gymnura natalensis Diamondray	-	0	3	0.2(0)	0.2
Rhynchobatus djiddensis Giant guitarfish	-	0	14	3.8(3.2)	1.18
Manta birostris Manta	-	0	2	0.5(0.3)	0.21
Squatina africana African angelshark	-	0	3	0.4(0.2)	0.26
Makaira indica Black marlin	-	0	1	0.1(-)	0.07
Scombridae (Unidentified tuna)	-	0	1	0.1(-)	0.07
Scomberomorus plurilineatus Queen mackerel	-	0	1	0.1(-)	0.07
Lichia amia Garrick	-	0	1	0.1(-)	0.07
Euthynnus affinis Eastern little tuna	-	0	2	0.2(-)	0.15
Epinephelus lanceolatus Brindlebass	1(1)	0	1	0.1(-)	0.07
Thunnus albacares Yellowfin tunny	-	0	5	0.5(-)	0.37
Cymatoceps nasutus Musselcracker	-	0	1	0.1(-)	0.07
Tursiops truncatus Bottlenose dolphin	-	0	1	0.4(0)	0.13
Delphinus delphis Common dolphin	-	0	9	1.0(0)	0.66
Delphinidae (Unidentified dolphin)	-	0	1	0.1(0)	0.07

4.3.2.2 Mzamba

Since the Mzamba experiment was ongoing at 30 September 1995, the results presented here are preliminary only. The most striking contrast with the La Mercy experiment was the lower rate of scavenging. At Mzamba, only 11% of baits were completely scavenged one day after baiting and a further 14% were partially scavenged. The comparative La Mercy figures were 60% and 23%. After three days, the respective percentages at Mzamba were 58% and 25% (La Mercy 91% and 2%). Possible reasons for the differences between the two experiments included a) the likelihood that all the Mzamba lines were anchored on sand and b) the fact that mean sea surface temperatures at Mzamba are lower than at La Mercy (Fig. 4.8).

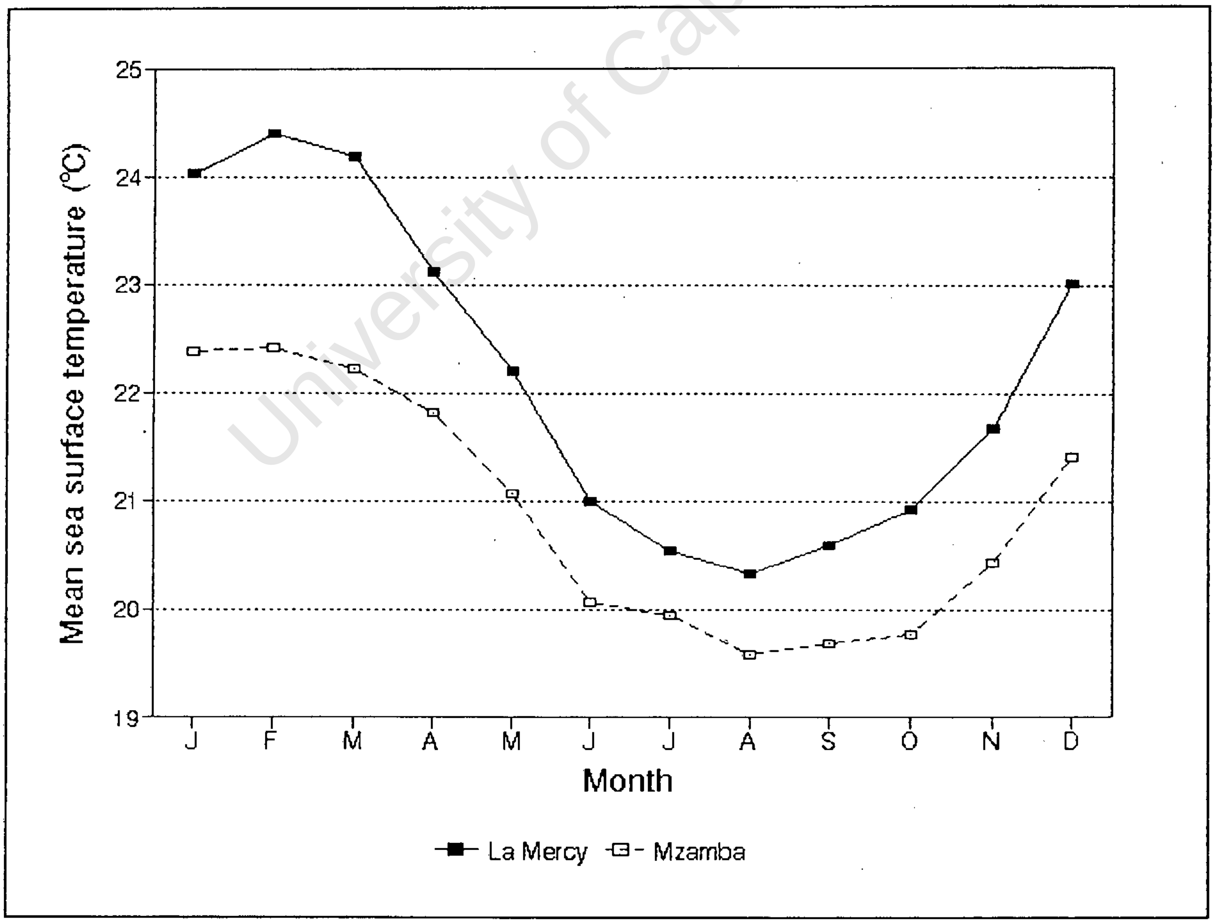


Figure 4.8: Mean monthly sea surface temperature at La Mercy and Mzamba, 1981-1992

The catch rate of sharks at Mzamba was greater when two or three days had elapsed between baiting and inspection of hooks, than after one day (Table 4.IX). This contrasted with the result obtained at La Mercy, where catch rate declined with time elapsed. The difference is probably explained by the lower rate of scavenging of the baits at Mzamba. As at La Mercy, however, no sharks were caught after four or more days.

Table 4.IX: The relationship at Mzamba between time elapsed from baiting to inspection of hooks, and shark catch

Time elapsed (days)	Total shark catch (number)	Total number of hooks	CPUE (sharks.hook^{-1})
1	8	308	0.026
2	1	21	0.048
3	2	48	0.042
4	0	23	0
10	0	5	0
15	0	6	0

Eleven sharks were captured and six of these released (Table 4.X). Three species, the copper shark *Carcharhinus brachyurus*, the scalloped hammerhead shark *Sphyrna lewini* and the great white shark *Carcharodon carcharias*, had not previously been captured on drumlines. The white shark was a female of 230 cm (*ca* 190 kg). It, together with the four *G. cuvier*, was injected with oxytetracycline as part of an age-validation study, tagged and released. The palatability of *E. nitidus* to *C. carcharias* was confirmed in that the shark was captured feeding on this bait rather than by scavenging on a juvenile *C. obscurus*.

4.4 Discussion and conclusions

The drumline experiments were successful in demonstrating the ability of drumlines to catch the three most dangerous species taken by the shark control program, *Carcharodon carcharias*, *Galeocerdo cuvier* and *Carcharhinus leucas*. The catch of the

Table 4.X: Total captures in the Mzamba drumline experiment. (Number found alive in parentheses)

Species	Catch (number)	Size range (*PCL*, cm)
Carcharhinus obscurus Dusky	2(1)	73-99
C. brachyurus Copper	3(0)	138-142
Galeocerdo cuvier Tiger	4(4)	107-145
Sphyrna lewini Scalloped hammerhead	1(0)	*ca.* 115
Carcharodon carcharias Great white	1(1)	230

latter two species at La Mercy was, in fact, higher on the drumlines than in the nets, and several *G. cuvier* have been taken on the Mzamba lines over a short period. Heinsohn (no date given), in Paterson (1986), Paterson (1990) and Simpfendorfer (1992) all stated that drumlines were more species selective than nets, and that they tended to target *G. cuvier* and "whalers" (*Carcharhinus* spp.) but not species such as the hammerheads, *Sphyrna* spp.

A true comparison of catch rates between nets and drumlines is not yet possible, given the small sample sizes. With the accumulation of additional data the use of some method of standardising effort across different gear types may be appropriate. Hilborn & Walters (1992), for example, suggest the use of the generalised linear model of Nelder & Mead (1975) to standardise effort. The fishing power of any fishing gear varies with species and hence effort standardisation between nets and drumlines will also vary with species. In addition, length selectivity of the nets would have to be a factor in the analysis. In Queensland, the assumption is made that one 180 m net equates to six drumlines (Anon 1992), but this was not based upon a quantitative assessment (N. Gribble, pers. comm.).

Determination of the number of lines to be deployed at KwaZulu-Natal beaches would entail not only effort standardisation but also consideration of the possibility that these beaches probably have a greater level of protection than is necessary (Chapter 2). The Natal Sharks Board has contracted the same firm of consultants referred to in Section 2.8 to conduct effort standardisation analyses, and hence to compare catch rates, using catch and effort data from the nets and drumlines deployed at both La Mercy and Mzamba.

The drumlines have been shown to be capable of catching large sharks; (*G. cuvier* of 233 cm & 190 kg; *C. leucas* of 221 cm & 238 kg; *C. obscurus* of 210 cm & *ca* 135 kg, *I. oxyrinchus* of 210 cm & *ca* 122 kg and *C. carcharias* of 230 cm & *ca* 190 kg). Sharks of these sizes constitute the bulk of the intended catch of the shark control program, although an upper limit of 238 kg would exclude a small proportion of the larger *G. cuvier* (NSB unpubl. data) and *C. carcharias* (Cliff *et al.* 1989) taken in the nets. There were indications that some sharks, presumably larger than those listed above, had broken free from the drumlines. On two occasions, for example, the splicing of the anchor rope to the drum was pulled out. In addition, two hooks were straightened, and it may prove necessary to experiment with larger hooks. Although hook straightening has also been recorded in Queensland (Paterson 1986), 14/0 hooks continue to be used (Anon 1992). A possible solution to the problem of capturing large sharks is to utilise a combination of nets and drumlines, as is the practice at many Queensland beaches (B.H. Lane pers comm.). The 50.8 cm mesh nets have a high selectivity for sharks measuring 260-270 cm (Chapter 3). It should be possible to formulate specific recommendations concerning net/drumline combinations once the consultants mentioned above have completed their analyses.

Scavenging of the bait was a major factor, particularly on drumlines anchored on high-profile reef. For this reason, drumline placement should preferably be on sand. This should also reduce gear loss though chaffing. The high catch of juvenile *C. obscurus* at La Mercy was unexpected, but the capture of several large sharks scavenging on the *C. obscurus* was a positive consequence. Scavenging is also a factor in the Queensland program (Paterson 1986), but has not prevented the apparently successful use of drumlines. The rapid decline in the fishing power of the drumlines with time elapsed after the hooks were baited indicates that rebaiting should occur daily at a site such as La Mercy and every second day at a site such as Mzamba. The general introduction of drumlines would be dependent upon the availability of suitable bait. Attempts to establish from the suppliers whether sufficient *E. nitidus* would be available year-round for a large-scale drumline operation have so far been unsuccessful.

Concern has been expressed about the possible attractant effect of the baits (Anon 1935). This concern has also been a factor militating against the complete conversion of the Queensland program to drumlines (Anon 1992). Strong shore-parallel currents occur frequently in the vicinity of the nets, and these will enhance distribution of the olfactory stimulus. The distance over which sharks are sensitive to olfactory stimuli is thought to be of the order of hundreds of metres, however, as opposed to kilometres (Springer & Gold 1989). (Little is known of interspecific variability in sensitivity, particularly with regard to bull, tiger and white sharks.) Thus the baits on the drumlines are likely only to attract sharks which are already in the vicinity of a bathing beach. Animals captured in nets also act as an attractant to sharks. Paterson (1986) details several incidents in which "whaler", white or tiger sharks were caught in the same net installations as other sharks or marine mammals upon which they had been scavenging. Cliff *et al.* (1989) report the capture of a white shark adjacent to a dolphin upon which it had been scavenging and Cliff & Dudley (1991a) report scavenging by copper sharks on netted cetaceans. Attraction of sharks to baited drumlines will exceed that to netted animals, however, in that the netting of animals is intermittent whereas the baiting of drumlines is routine.

As anticipated, the by-catch of harmless animals on the drumlines was negligible. This finding lends strong support to continued experimentation with drumlines.

The high rate of gear loss is a negative factor. Not only does gear loss increase financial costs, but drumlines which have broken loose may themselves constitute a hazard. One drowning as a result of entanglement in a dislodged drumline has been reported in Queensland (Anon 1992). As a result of the subsequent enquiry (Anon 1992), contingency plans were formulated for the location and retrieval of any lost equipment (B.H. Lane pers. comm.).

Factors contributing to gear loss include equipment failure and theft. Equipment failure can be reduced by means of regular inspection and replacement of worn components. A service schedule similar to that employed for the nets, in which each net is removed from the water for cleaning and inspection at intervals of about two weeks, should be considered. Inspection of anchor ropes on drumlines anchored on high-profile reef is particularly important. Theft may best be countered through public education and through clear marking of equipment.

Appendix 4.I: Results of binary response model of the effect of various factor variables on each possible event recorded for the La Mercy drumlines (Days=days since last baited, SST=water temperature, Clarity=water clarity, Current=current direction, Bait=bait type, Line=line number, Topography=bottom topography)

Event (*n*)	Significant factor variables (***x***)	Parameter estimate	S.E.	χ^2 prob.
Bait completely scavenged (*n*=1)	Clarity Days Topography	-0.0880 0.4040 0.1606	0.0327 0.0425 0.0514	0.0071 0.0001 0.0018
Bait partially scavenged (*n*=2)	Clarity Days Topography	0.1707 -1.3630 -0.8297	0.0510 0.1530 0.0879	0.0008 0.0001 0.0001
Bait intact (*n*=3)	Intercept SST Current Days Bait Topography	9.2932 -0.3935 -0.7736 -0.9033 0.5071 -0.8932	1.1641 0.0515 0.1838 0.1363 0.1199 0.1154	0.0001 0.0001 0.0001 0.0001 0.0001 0.0001
Hook missing (*n*=4)	Intercept	-4.1026	0.1729	0.0001
Line missing (*n*=5)	Intercept Clarity Days Topography	-12.1179 0.5041 0.3465 1.3933	2.1840 0.2066 0.1719 0.6130	0.0001 0.0147 0.0434 0.0230
Shark capture (*n*=6)	Intercept Days Topography	-1.8826 -0.4397 -0.3291	0.3208 0.1301 0.1313	0.0001 0.0007 0.0122

SYNTHESIS

Synthesis

This study aimed to determine the environmental impact of the KwaZulu-Natal shark control program and, in order to reduce both that impact and the financial cost of the operation, to consider modifications of and alternatives to the existing *modus operandi*.

Potential environmental impact takes the form of a) direct effects of fishing mortality on stocks of individual species, and b) indirect effects on the inshore ecosystem as a result of a reduction in numbers of apex predators. Direct effects were assessed in terms of trends in catch per unit effort of individual species. Although catches of shark species similar in appearance were combined in the early years of netting, rendering the analysis crude, it appears that, after initial local depletions in numbers of most species or species groups, catch rates are now sustained by the steady harvesting of immigrants. Depletions are sometimes localised, not only for species thought to be resident but also for highly migratory species, suggesting that sub-groups within populations may follow separate migratory routes. Turtle and teleost stocks do not appear to be threatened by net mortalities but marine mammalogists question whether catches of *Sousa plumbea*, in particular, are sustainable. The impact of netting on stocks of batoid species is unknown, but release rates are very high.

With regard to indirect effects, the reduction in predation on juvenile *C. obscurus* has probably contributed to an increase in numbers of this species, but it is difficult to separate this cause from a possible angling-induced reduction in competition. A reduction in predation on turtles and dolphins may partially offset the effect of captures of these animals.

Comparison of the shark control programs of New South Wales, Queensland and KwaZulu-Natal reveals very different levels of fishing effort. These differences appear to have arisen largely from *ad hoc* decision-making processes, rather than from an analysis of differences in the physical or biological environments of the three regions. There is therefore a case for reducing the number of nets in KZN, although no basis exists for deciding on the appropriate extent of that reduction. This question forms the basis for a new project being undertaken by a firm of population dynamicists, in consultation with the NSB.

An understanding is required of the relative extents to which shark nets act as physical barriers, or as fishing devices. The nets are not impenetrable; 35% of all sharks caught are moving offshore from within the netted area. The presence of nets does, however, impede the progress of sharks attempting to move in an onshore direction. If this barrier effect predominates, emphasis should be placed on beach "coverage", i.e. the physical spanning of the beach by nets. The successful New South Wales (NSW) practice of moving nets from beach to beach runs counter to this concept, however.

The basis of the fishing effect is that the nets reduce shark numbers, resulting in a reduction in the probability of an encounter between a bather and a shark. If the fishing effect predominates, the importance of beach "coverage" is less critical. Rather managers should ensure that the same, or similar, numbers of potentially dangerous sharks continue to be caught using fewer nets, perhaps differently positioned, or by means of an alternative fishing device, such as baited lines. The use of only one or two nets per beach in the NSW program, and the use of drumlines in Queensland, is consistent with this concept.

Because the presence or absence of the barrier effect is particularly difficult to demonstrate, and because it is known that shark catch rates have declined substantially since the introduction of nets, it was assumed in this study that the fishing effect is predominant.

Two methods of reducing by-catch were therefore examined. The first of these entailed an assessment of the selectivity of a larger (70 cm) mesh for large (*PCL*>1.6 m), potentially dangerous sharks. It was concluded that, although the introduction of this mesh would probably lead to a reduction in by-catch of dolphins, an unacceptable reduction in bather safety levels would result from reduced selectivity for the large sharks. The work is continuing in order to reduce variances on selectivity estimates.

The second method of reducing by-catch was the use of baited lines, or drumlines, as alternative shark catching devices. The results of this were far more encouraging, with the drumlines proving to be more species selective than nets in terms of shark catch, and taking a negligible by-catch of non-shark species. This work, too, is continuing, but indications are that a combination of nets and drumlines may be a viable alternative to the present all-net system.

The NSB is making progress with the development of an electromagnetic repellent as a non-destructive alternative to shark nets. If this device fulfils its potential and is put into service, it should meet both of the above criteria i.e. reduced cost and reduced environmental impact. It remains to be seen, however, whether it will be possible to deploy the device in conditions of heavy surf such as are found on the KwaZulu-Natal coast. The NSB has been awarded a contract to provide bather protection at a number of Hong Kong beaches in early 1996. The method to be used entails surrounding the bathing areas with small-mesh barrier nets, and is suitable for sheltered environments only. For the foreseeable future, therefore, attempts to refine the more conventional techniques of bather protection should continue.

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