Monitoring and identification of NSW Critical Habitat Sites for conservation of Grey Nurse Sharks

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EA Project No. 22499
June 2003

NSW Fisheries Final Report Series
No. 47
ISSN 1440-3544

Research and the collation of information presented in this report was undertaken with funding provided by NSW Fisheries and Environment Australia. The project – Critical Habitat sites for Protection of Grey Nurse Sharks - was undertaken for the Marine Species Protection Program.

The views and opinions expressed in this report are those of the authors and do not reflect those of the Commonwealth Government, the Minister for the Environment, or Environment Australia.

The report may be cited as 'Monitoring and identification of NSW Critical Habitat sites for conservation of Grey Nurse Sharks'.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

We thank Carolyn Bland and Kathy Bown of the NSW Fisheries library for their unrelenting efforts in accessing some very obscure literature on the Grey Nurse Shark. We are grateful to Sara Williams (Environment Australia) and Lachie Whetham (Coastcare) for their contributions to this study. We also thank David Harasti (Environment Australia, now NSW Fisheries) for his assistance and the cover photograph. We thank Geoff Gordon for his thought provoking discussions. Steve Kennelly and Bob Creese are thanked for their constructive reviews of this report.

The coastwide surveys would not have been possible without the assistance of Seaworld, Stradbroke Island Scuba Centre, Palm Beach Dive Centre, Stephanie Lemm of Queensland Parks Service, Byron Bay Dive Centre, Simon Hartley of Southern Cross University, Darrin White, Wooli Dive Centre, Dive Quest, Solitary Islands Marine Park (NSW MPA), Pacific Blue Dive Centre, the Pet Porpoise Pool, the Solitary Islands Underwater Research Group, Jetty Dive Centre, South West Rocks Dive Centre, Port Macquarie Dive Centre, Peter Huettner, Phil Bowman, Fishermans Wharf Dive Centre, Action Divers Tuncurry, Pro Dive Nelson Bay, Dive Nelson Bay, Dr Ken Zimmerman of Newcastle University, Pro Dive The Entrance, Terrigal Dive Centre, Southern Cross Divers, Sydney Aquarium, Michael McFadyen, David Pearson, Sydney Underwater Research Group, Max Western Dive Charters, Adam Smith, Leisure Coast Dive, Warren Jones, Jervis Bay Dive Club, Canberra University Dive Club, Malua Bay Dive, National Diving Academy, Ocean Hut Fishing and Dive Centre, and Merimbula Divers Lodge. To all involved, we are indebted for your efforts for without them we would not have gained a better understanding of the numbers of Grey Nurse Sharks along the NSW coast. Hopefully, the results of this study will provide a stepping-stone for the recovery and long-term conservation of the species.

EXECUTIVE SUMMARY

- The Grey Nurse Shark, *Carcharias taurus*, belongs to the Family Odontaspididae and occurs in coastal waters off NSW and southern Qld and south-west WA. The shark is also found off South Africa and North America where it is respectively known as the "spotted ragged-tooth shark" and the "sand tiger shark," respectively. The sharks are often found in, or near, gutters and caverns around inshore rocky reefs and islands.
- The Grey Nurse Shark is a large bodied, strong-swimming shark attaining a maximum length of 320 cm. Little is known about the biology and ecology of the species in Australian waters and what is known has been inferred from studies in South Africa and the USA.
- Male Grey Nurse Sharks mature at approximately 190 cm and females mature at approximately 220 cm. The Grey Nurse Shark exhibits an ovoviviparous reproductive strategy where there is no placental connection between the mother and the embryo. Instead, the two most developmentally-advanced embryos eat the remaining embryos and then unfertilized, ovulated, pea-sized eggs (phenomena known as intra-uterine cannibalism and oviphagy). The gestation period is approximately 9 to 12 months with two pups (occasionally one) born per litter. This is followed by a resting period of 1 year. The net result is a biennial reproductive cycle with only one pup born per female per year on average.
- Very little is known about the precise timing of mating and pupping of Grey Nurse Shark populations in Australian waters. However, scuba divers have observed recently-born pups in winter and early spring which is consistent with observations from the USA and South Africa.
- The Grey Nurse Shark was afforded protected status in New South Wales waters in 1984 as a result of: (1) reduced numbers observed by recreational scuba divers, (2) declining catches by spear fishers, (3) reduced catches in beach meshing programs, and (4) the realisation that the shark was not a "man-eater". Scuba diving and commercial/recreational fishing are the main human activities that occur in the habitats utilised by Grey Nurse Sharks. More recently, Grey Nurse Sharks have been inadvertently caught on demersal setlines and by recreational fishers.
- The Threatened Species status of the Grey Nurse Shark was upgraded from "Vulnerable" to "Endangered" in August 2000 under the Threatened Species provisions of the *NSW Fisheries Management Act 1994*.
- The current project was established: (1) to further quantify the distribution and abundance of Grey Nurse Sharks along the entire NSW coast; (2) to identify and map sites important to the shark in the Batemans Shelf and Twofold Shelf Bioregions; (3) to identify key aggregation sites (critical habitat); (4) to analyse statistically data from all surveys done to date; and (5) to identify the issues that need to be addressed in developing recovery plans for the species.
- The abundances of Grey Nurse Sharks were quantified in month-long surveys using underwater visual counts of sharks over a 15 minute period at sites along the NSW and southern Qld coastlines. Volunteer scuba divers along the NSW and southern Qld coast also participated in these surveys. At each site, divers recorded the number, sex and size of any Grey Nurse sharks present. They also recorded the presence of hooks, mating scars, etc.
- Sites used by Grey Nurse Sharks in the Batemans and Twofold Shelf bioregions were mapped.
- A voluntary code of conduct for scuba diving with Grey Nurse Sharks was developed with the co-operation and input of numerous recreational scuba divers from various urban centres in the state. The recommended code of conduct has the following guidelines:
    1. Do not block entrances to caves or gutters
    2. Do not interrupt the swimming pattern of the sharks
    3. Do not feed or touch the sharks

4. Do not chase or harass the sharks (i.e. no mechanical apparatus such as scooters, horns and anti-shark devices are to be used)
5. Dive groups must not have more than 10 divers
6. A dive brief is to be given by the dive leader before each dive
7. All commercial operators are to be signatories to the Code of Conduct
8. Code of Conduct is to be displayed in the shop and on the dive boat
9. Dive operators are to participate in scientific research

- Ten surveys were done from November/December 1998 to March/April 2001. An average of 57 sites were sampled in each of the 10 surveys. A maximum of 292 sharks was observed in the winter 2000 survey. The vast majority of Grey Nurse Sharks (almost 90% of the observed population) occupied 14 sites along the entire coast. No sharks were sighted at 63% of the sites, on average. Between 1 and 4 sharks were seen at the remaining 7 sites, on average.
- The 14 aggregation sites were utilised by Grey Nurse Sharks for substantial periods of time over the 2.5 years of observation. The occurrence of mating and pupping was also evident at these sites. Consideration should be given to declaring these sites as "critical habitat" to enhance the recovery and long-term conservation of the species. In December 2002, the NSW Government declared 10 of the aggregation sites as Critical Habitat.
- Analyses of the size-frequency distributions from the 10 surveys showed that the Grey Nurse Shark population exhibited segregation by size and sex. Proportionally more juvenile and adult male Grey Nurse Sharks occurred at Forster and sites to the north, and proportionally more juvenile and adult females occurred at Seal Rocks and sites to the south. The sex ratios of Grey Nurse Sharks were significantly biased towards females in all except the winter surveys (surveys 3 and 7) and this is most likely due to segregation of the sexes.
- On subdividing the coastline into a northern section (i.e. Forster and sites north) and a southern section (i.e. Seal Rocks and sites south), proportionally more males occurred in the northern section. In contrast proportionally more females were observed in the southern section, but in surveys 3 and 7 there were more females in the north than the south.
- The segregation of male and female Grey Nurse Sharks suggested a pattern of movement comprising: (1) movement of sexually mature males into shallower water in early autumn presumably to mate, (2) further movement northwards to sites in southern Queensland in July/August, (3) the movement of sexually mature females and immature sharks of both sexes to the south in spring and early summer, and (4) the return movement of the latter sharks to sites north of Forster in the autumn and winter months. These hypothesised movements are being tested in a tagging program.
- The recorded incidence of accidental hooking of Grey Nurse Sharks on all types of fishing gear has increased from approximately 2% to 12% over the past decade. The incidental capture of Grey Nurse Sharks was approximately seven times greater on hooks with nylon fishing line compared to hooks with wire trace.
- It is recommended that the survey results, research and management issues contained in this report are used in the preparation of the State and National Recovery Plans for the species.

1. INTRODUCTION AND PROJECT OBJECTIVES

1.1. Background

The Grey Nurse Shark, *Carcharias taurus* occurs in coastal waters off the NSW and southern Qld and south-west WA. A recent study (Otway & Parker 2000) examined the biology, ecology, distribution, and abundance of Grey Nurse Sharks in south eastern Australian waters. Numerous sites in the Tweed-Moreton Shelf, Manning Shelf and Hawkesbury Shelf bioregions were mapped and in doing so, it became apparent that caves, sandy-bottomed and boulder-filled gutters and large overhangs were crucial habitats utilised by Grey Nurse Sharks. This previous study involved volunteer recreational scuba divers along the NSW and southern Qld coast participating in three surveys, in November/December 1998, March/April and June/July 1999. On subdividing the coastline into northern (i.e. Forster - North Stradbroke Island) and southern (i.e. Seal Rocks - Eden) sections, proportionally more males occurred in the northern section in surveys 1-3. In contrast, proportionally more females were observed in the southern section in surveys 1 and 2, but in survey 3 there were more females in the north than the south. The size and sexual segregation of male and female Grey Nurse Sharks evident during the three surveys suggests a hypothesised pattern of movement comprising: (1) a movement of sexually mature males into shallower water in early autumn (April) - presumably to mate. They then move northwards and appear at the northerly most sites in southern Queensland in July/August; (2) the movement of sexually mature females and immature sharks of both sexes to the south in spring and early summer, followed by a return to sites north of Forster in the autumn and winter months.

The results of the surveys (Otway & Parker 2000) also showed that the total numbers of sharks were very low suggesting that the Grey Nurse Shark population in NSW waters has not recovered since it was made a protected species in 1984. These results supported the initial declaration of the shark as a threatened species.

This report builds upon and extends the work of Otway and Parker (2000). In so doing, this report uses Otway and Parker (2000) as a pilot study and tests some of the previously generated hypotheses through the collection of data over 2.5 years. This study also provides a more in-depth review of the ecological and management issues associated with Grey Nurse Sharks. Consequently, this report should become a key source document and provide a basis for the State and Commonwealth recovery planning processes to ensure the long-term conservation of the Grey Nurse Shark.

1.2. Project objectives

The project had 6 main objectives:

1. To conduct further surveys of numerous sites along the NSW and southern Queensland coasts, and to record the distribution and abundance of Grey Nurse Sharks and other data including site occupation (timing and duration), movements, population size structure and sex ratios;
2. To map sites utilised by Grey Nurse Sharks in the Batemans Shelf and Twofold Shelf bioregions;
3. To prepare a report on a voluntary code of conduct for scuba diving with Grey Nurse Sharks;
4. To prepare a report, which identifies key aggregation sites in the Tweed-Moreton, Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Bioregions;

5. To conduct statistical analyses of the data from all surveys by NSW Fisheries and provide a detailed interpretation of the distribution and abundance of Grey Nurse Sharks in coastal waters of NSW and southern Queensland; and
6. To consider other issues that need to be addressed in a future research program, and the recovery plans for the long-term conservation of the Grey Nurse Shark.

This report presents the findings associated with each of these objectives. Chapter two documents the biology and ecology of Grey Nurse Sharks. Chapter three presents maps of the sites utilised by Grey Nurse Sharks in the Batemans Shelf and Twofold Shelf bioregions. Chapter four presents the results and analyses of the data collected in 10 surveys from November/December 1998 to March/April 2001. Chapter five discusses the development of a Code of Conduct for scuba diving with Grey Nurse Sharks. Chapter six provides a summary and final conclusions.

2. THE BIOLOGY AND ECOLOGY OF GREY NURSE SHARKS

2.1. Names

Common: Grey Nurse Shark.
Other names: Ragged-tooth shark (South Africa),
Sand-tiger shark (USA).
Scientific: *Carcharias taurus* (Rafinesque, 1810)

2.2. Systematics

The nomenclature surrounding the Odontaspididae family can be quite confusing and several invalid scientific names for the Grey Nurse Shark have been used in the past, including: *Triglochis* (Muller & Henle, 1837), *Odontaspis* (Agassiz, 1838) and *Eugomphodus* (Gill, 1862). In 1965 the genera *Carcharias* and synonyms of *Carcharias* were placed on the Official Index of Rejected and Invalid Generic Names in Zoology by the International Commission of Zoological Nomenclature (Paxton *et al*. 1989). These genera were suppressed in favour of *Eugomphodus* as it was thought that *Carcharias* and *Odontaspis*, the other genera in the family Odontaspididae, were congeneric (Compagno, 1984). Later it was determined that the two type species were not congeneric so, in 1987, the commission reinstated the genus *Carcharias* (Paxton *et al*. 1989). Moreover, as the species was originally distributed widely across the Indian, Pacific and Atlantic oceans, this led to the use of several specific names including: *taurus* (Rafinesque 1810)*, americanus* (Mitchell 1815, Abbott 1861), *cinerea* (Macleay 1880) and *arenarias* (Ogilby 1911). It is now generally accepted that they all refer to the same species. The correct scientific name for the species is therefore *Carcharias taurus* (Rafinesque, 1810).

2.3. Description

The Grey Nurse Shark, *Carcharias taurus* (Rafinesque, 1810) is one of four species belonging to the family Odontaspididae (Compagno 1984). The shark has a large, stout, fusiform body with similarly-sized first and second dorsal fins and an asymmetrical caudal fin with a strong ventral lobe. The second dorsal fin is closer to the pelvic fins than it is to the pectoral fins. The head has a flattened-conical snout, small eyes without a nictitating membrane and a long mouth extending behind the eyes. Teeth on the upper and lower jaws are awl-like, having long, narrow cusps with single lateral cusplets. Individuals vary in colour from grey to grey-brown dorsally, with a paler off white under belly. Reddish or brownish spots may also occur on the caudal fin and posterior half of the body, particularly in (Compagno 1984, Last & Stevens 1994, Pollard *et al*. 1996, Otway & Parker 2000).

Grey Nurse Sharks grow to over 300 cm total length with the largest specimens reported from South Africa - 320 cm (Torres 1991), the east coast of the USA - 318 cm (Bigelow & Schroeder 1948, Compagno 1984) and Brazil - 282 cm (Sadowsky 1970). In SE Australia, Grey Nurse Sharks grow to at least 320 cm total length (Last and Stevens 1994, Otway unpubl. data).

2.4. Distribution

Grey Nurse Sharks initially had a broad inshore distribution, primarily in sub-tropical to cool temperate waters on continental shelves (Compagno 1984). Whilst the Grey Nurse Shark has been recorded from the Mediterranean Sea, Atlantic, Indian and Pacific oceans, it has only been sighted in recent times off the coasts of eastern USA (Springer 1948, Bigelow & Schroeder 1948), Brazil (Sadowski 1970, Sadowski *et al*. 1989, Amorim *et al*. 1998), Uruguay (Marin *et al*. 1998), Argentina (Chiaramonte 1998), South Africa (Bass *et al*. 1975, Compagno 1984) and Australia (Last & Stevens 1994).

In Australia, Grey Nurse Sharks have been recorded from Mooloolaba in Southern Queensland, around the greater part of the southern half of the continent and northwards to Shark Bay in Western Australia (Last and Stevens, 1994). The species does not occur in Tasmanian waters, but has been caught on one occasion in the Arafura sea (off the Northern Territory) by Taiwanese longliners (Read & Ward 1986). More recently, the distribution of the grey nurse has been confined to the coastal waters off southern Queensland and along the NSW coast, and to the coastal waters off West Australia.

2.5. Habitat

The Grey Nurse Shark is a coastal species found on the continental shelf from the surf zone down to 190 m (Compagno 1984, Klippel 1992, Last & Stevens 1994). The shark is a slow, strong-swimming species that is often seen hovering motionless near the bottom in or near deep sandy-bottomed gutters or in rocky caves around inshore rocky reefs and islands at depths between 15 and 40 meters (Goadby 1968, Grant 1982, Pollard *et al*. 1996, Cliff unpubl. ms., Otway & Parker 2000). These sites may play an important role in pupping and/or mating activities as Grey Nurse Sharks often form aggregations at these sites (Compagno 1984, Pollard *et al*. 1996, Cliff unpubl. ms., Smale pers. comm., and see Section 2.6). Occasionally, they are also found throughout the water column (Compagno 1984). The shark is thought to be more active at night (Compagno 1984, Pollard *et al*. 1996), but this needs to verified using acoustic telemetry (Otway & Parker 2000).

2.6. Abundance

Prior to 1998, the spatial and temporal patterns of abundance of the Grey Nurse Shark in South East Australia were poorly understood. In the past, what was known had been derived from: catch records from the NSW beach protective shark meshing programs (Reid & Krogh 1992, Krogh 1994); catch records from the log books of gamefishers (Pepperell 1992); and three limited surveys done on small spatial and temporal scales (Pollard *et al.* 1996, Parker & Bucher 2000, Pickering & Wilkinson unpubl. data).

The present study is a continuation of 3 underwater surveys done to quantify the abundances of Grey Nurse Sharks at quarterly intervals at approximately 60 sites along the entire NSW coast (Otway & Parker 2000). The 3 previous surveys showed that 88.2% of the Grey Nurse Sharks observed were found in aggregations of 5 or more sharks at 12 sites along the NSW coast. Moreover, two of these sites: Pimpernel Rock and the Cod Grounds occurred in Commonwealth waters (i.e. the sites are located more than 3 nautical miles from the NSW coast). The same Grey Nurse Sharks (as evidenced by the presence of hooks, wounds and/or the absence of fins) were often seen by scuba divers at these aggregating sites. These observations were consistent with those of researchers in South Africa (Smale pers. comm.) and suggested that the shark exhibits a high degree of site fidelity once a site (gutter or cave) is occupied. This tendency to aggregate at a few key sites is a biological characteristic that makes the species vulnerable to localised pressures (Environment Australia 1997).

2.7. Diet

In South Africa, Grey Nurse Sharks feed on a wide range of bony fish including: herrings (Family Clupeidae), croakers (Family Sciaenidae), bluefishes (Family Pomatomidae), mackerels (Family Scombridae), butterfishes (Family Odacidae), snappers (Family Lutjanidae), eels (Family Muraenidae), wrasses (Family Labridae), mullets (Family Mugilidae), sea basses (Family Serranidae), flatfishes (Families Platycephalidae & Bothidae), jacks (Family Carangidae), and likely many others, as well as small and juvenile sharks (especially those of the Families Carcharhinidae and Triakidae), eagle rays (Family Myliobatidae), squid and, on rare occasions, crabs and lobsters (Bigelow & Schroeder 1948, Bass *et al*. 1975, Compagno 1984, Schmid *et al.* 1990).

In NSW, it is reasonable to assume that the shark would consume fish from the same families (see above) given that the Australian and South African ichthyofauna exhibit many similarities. Hence, it is likely that the diet consists of pilchards, jewfish, tailor, bonito, morays, blue groper, sea mullet, flatheads, yellowtail kingfish, small and juvenile sharks, squid and possibly some crustaceans. However, this will need to be verified by gut content analysis of incidentally caught and killed Grey Nurse Sharks. It is important to note that many of the species that comprise the sharks' diet are also harvested by commercial (e.g. Gray & Otway 1994, Otway *et al*. 1996) and recreational (spear - Lincoln Smith *et al*. 1989 and line - Otway *et al*. 1996, Steffe *et al*. 1999) fishers.

2.8. Population demography

There is limited information available on the life-history of the Grey Nurse Shark in Australian waters. However, some life-history characteristics (detailed below) have been quantified for this species off South Africa (Bass *et al*. 1975, Govender *et al*. 1991, Cliff unpubl. ms.) and the east coast of the USA (Bigelow & Schroeder 1948, Springer 1948, Stead 1963, Gilmore *et al*. 1983, Schmid *et al*. 1990, Branstetter & Musick, 1994). The results of this research has led these, and other workers (e.g. Compagno 1984, 1990, Branstetter 1990, Hoenig & Gruber 1990, Chiaramonte 1998, Smith *et al*. 1998), to conclude that the life-history traits of Grey Nurse Sharks make them extremely vulnerable to over-exploitation.

2.8.1. Reproductive biology

Reproduction of the Grey Nurse Shark has been well documented for populations in the coastal waters off the USA (Springer 1948, Gilmore *et al*. 1983, Branstetter & Musick 1994) and South Africa (Bass *et al*. 1975, Cliff unpubl. ms.) and is regarded as one of the most unusual reproductive strategies used by sharks (Gilbert, 1981). They reach sexual maturity at total lengths of 190 - 195 cm and 220 - 230 cm for males and females, respectively (Gilmore *et al.* 1983). These lengths equate to ages of 4 - 6 years and 6 - 8 years for males and females, respectively (Gilmore *et al.* 1983, Branstetter & Musick 1994).

The reproductive studies (*op. cit*.) have shown that the Grey Nurse Shark is ovoviviparous with only two pups (occasionally one) born per litter. Female Grey Nurse Sharks have no placental connection with their young as do the carcharhinids (whalers). Instead, the two most advanced embryos (one in each uterus) eat the remaining developing embryos. Having consumed their siblings, the developing embryos then consume unfertilised eggs ovulated by the mother. These phenomena are known as intra-uterine cannibalism and oviphagy, respectively (Stead 1963, Bass *et al*. 1975, Gilmore *et al*. 1983, Compagno 1984). The gestation period of *C. taurus* is about 9 - 12 months, with pupping occurring in late winter to early spring when the pups are approximately 100 cm in length (Bass *et al*. 1975, Gilmore *et al*. 1983). Pregnant females avoid giving birth in embayments and areas of low salinity and prefer coastal, rocky reefs (Bass *et al*. 1975, Branstetter 1990). The females then enter a resting stage lasting about one year (Branstetter & Musick 1994,

Cliff unpubl. ms.) resulting in a biennial reproductive cycle. Consequently, Grey Nurse Sharks only produce one pup per annum, on average, which makes the species one of the least fecund of all sharks and extremely vulnerable to human-induced pressures.

The timing of mating and pupping of Grey Nurse Sharks in Australian waters is unknown. While some preliminary observations of pre-copulatory behaviour have been made in aquaria (Gordon 1992), very little has been documented with individuals in the wild. However, many Grey Nurse Sharks have been observed at Pimpernel Rock (SIMP - Commonwealth section) during the months of March and April with mating scars (i.e. bite marks around the head, pectoral and pelvic fins) (D. White pers. comm. in Otway & Parker 2000). Observations made during this study suggest that female grey nurses most likely give birth to their pups during winter at the sites where they aggregate. The timing of pupping, mating, and the duration of gestation will need to be verified by more intense diver surveys in winter and the examination of incidentally caught and killed Grey Nurse Sharks. Autopsies of such sharks will also enable the size/age of reproductive maturity to be documented for the Grey Nurse Shark in NSW waters.

2.8.2. Age, growth and longevity

Estimates of age and growth of Grey Nurse Shark along the east coast of the USA have been obtained from captive sharks held in aquaria in Florida (Schmid *et al*. 1990) and wild specimens captured from the NW Atlantic Ocean (Branstetter & Musick, 1994). Male and female Grey Nurse Sharks (n = 16) were measured and weighed over a period of 16 months (Schmid *et al*. 1990). In contrast, Branstetter and Musick (1994) counted the number of growth bands in sagittally-sectioned, vertebral centra to determine age, but this technique was not validated using oxy-tetracycline (or other) marking methods.

Table 2.1. Rates of growth of the Grey Nurse Shark from the east coast of the USA (After: Branstetter & Musick, 1994).

Life-history Stage	Rate of Growth (cm/year)	Age (years)
Pup	25-30	0 – 1
Juvenile	20-25	2 – 3
Juvenile/ Subadult	15-20	4 – 5
Subadult/Adult	10-15	6 - 7
Adult	5-10	> 8

In South Africa, estimates of the age and growth of Grey Nurse Shark have also been obtained using captive individuals. Govender *et al.* (1991) measured the lengths of captive sharks of known age from photographs taken in an aquarium at Durban. The age and growth data obtained in this study differed (only slightly) from those obtained in the USA. The differences were attributed to the slower growth of the males in the Durban aquarium (Branstetter & Musick 1994).

Despite the differential growth rates of males in the Durban aquarium, the studies in USA (Table 2.1) and South Africa have shown that juvenile Grey Nurse Sharks grow at an initial rate of 25 - 30 cm/year. However, once sexual maturity is attained, growth slows to less than 10 cm/year. The pattern of growth exhibited by the Grey Nurse Shark is considered to be slow relative to other sharks because the annual growth in the first year and thereafter represents an increase of less than 30% of the length at birth (Branstetter 1990).

The longevity of the species in the wild is unknown, but a Grey Nurse Shark lived for over 16 years in captivity in South Africa (Govender *et al.* 1991). In the absence of other information, Branstetter and Musick (1994) estimated the longevity of Grey Nurse Sharks to be 30 and 35 years for males and females, respectively. More recently, Cortes (2000) and Mollet (2001) suggested that longevities of 20 and 25 years for males and females, respectively may be more realistic.

There is no information on the age and growth of Grey Nurse Sharks in the coastal waters of NSW although there may be some limited data for the captive individuals held in aquaria. Clearly, the absence of age and growth data for Grey Nurse Sharks in NSW coastal waters needs to be addressed as a matter of urgency.

2.8.3. Rates of mortality

While rates of natural mortality of the Grey Nurse Sharks have been estimated by several authors (e.g. 12.9% p.a. - Smith *et al*. 1998, 15.43% p.a. - Mollet 2001) using the equations of Pauly (1980) or Hoenig (1983), there are no empirically-derived estimates of natural mortality. Furthermore, there are no published estimates of the instantaneous rates of fishing mortality for any Grey Nurse Shark populations. The need for age-structured estimates of the rates of mortality (natural and fishing-related) is important because these rates will identify which age class(es) have the greatest mortality. This information can, in turn, identify whether the observed mortality is causing the population to decline (Caughley 1977). This information can then focus management actions on the identified threats that have the greatest effect on populations.

2.9. Movements

Relatively little is known about the migratory habits of Grey Nurse Sharks in SE Australian waters. At certain times of the year, Grey Nurse Sharks aggregate according to sex. Males are predominant in southern Queensland during July to October, whereas females are more prevalent in central NSW (Otway & Parker 2000). These observations are also supported by data from the NSW Fisheries protective beach-meshing program (Reid & Krogh 1992, Krogh 1994). Otway and Parker (2000) suggested that female Grey Nurse Sharks migrate to the south coast of NSW in late spring and aggregate at two sites; the first at the Tollgate Islands off Batemans Bay and the second at Montague Island off Narooma. They also suggested that they occupy these sites until mid autumn, at which time they migrate northwards to sites off the mid-North coast of NSW (i.e. Forster to Coffs Harbour). More information is required to test hypotheses concerning the movements of Grey Nurse Sharks in NSW waters and this will require that a tagging program is initiated.

2.10. Natural predators

Past research in South Africa (e.g. Bass *et al.* 1973, Bass *et al.* 1975, Cliff *et al.* 1989 1990, Cliff & Dudley 1991) has shown that the great white shark (*Carcharodon carcharias*), short-finned mako (*Isurus oxyrinchus*), tiger shark (*Galeocerdo cuvier*) and bull shark (*Carcharhinus leucas*), consume a range of small sharks (< 1 m precaudal length) and the juveniles of larger sharks including the Grey Nurse Shark. Analyses of the gut contents of these 4 species caught in SE Australian waters (Stevens 1984, Last & Stevens 1994) has shown that small sharks and the juveniles of larger sharks are also prevalent in their diets. However, the degree of digestion prevented identification of the species consumed. Moreover, the distributions of great white, short-finned mako, tiger and bull shark (Stevens 1984, Pepperell 1992, Reid & Krogh 1992, Krogh 1994, Last & Stevens 1994, Otway unpubl. data) overlap the present distribution of the Grey Nurse in NSW waters (Last & Stevens 1994, Otway & Parker 2000). Consequently, it would be reasonable to hypothesise that these 4 species are the most likely natural predators of the Grey Nurse Shark. This prediction will need to be tested via the analyses of gut contents of the great white, short-

finned mako, tiger and bull shark. DNA "fingerprints" of Grey Nurse Sharks would clearly be advantageous in such work.

2.11. Conservation status

2.11.1. Worldwide

The Grey Nurse Shark is currently listed on the IUCN Red List of Threatened Animals as vulnerable worldwide and endangered on the east coast of Australia (Red List Number: VU A1ab+2d, Shark Specialist Group: World Conservation Monitoring Centre). Despite this, the degree of protection afforded the Grey Nurse Shark around the world is limited.

In South Africa, the species is currently being de-commercialised. It may be caught and kept, but may not be sold for financial gain (Cliff, pers. comm.), and the Natal Sharks Board hopes that fishers who catch these sharks will return them to the water.

In the USA, the Grey Nurse Shark is being managed under a shark management plan prepared by the National Marine Fisheries Service of NOAA. The plan was aimed at reducing catches of sharks by sport and commercial fishers. The Grey Nurse Shark or "sand tiger" as it is known in the USA, is one of five large coastal species that have been protected from directed fishing by a ruling in April 1997 (Smullen, 1997).

In Brazil, Uruguay and Argentina, the Grey Nurse Shark is harvested by commercial fishers as part of multi-species shark fisheries. However, it is only caught when the fishers work the inshore waters. Catches are generally very low despite an ever-increasing effort (Chiaramonte 1998). Recreational fishers also target the species and there is now concern over the viability of the population (Chiaramonte 1998).

In Japan, the shark was harvested extensively for its flesh which was utilised fresh, frozen, smoked, and dried (Compagno 1984). The population has now declined to a point where it is rarely caught by commercial fishers.

2.11.2. Australia

The Grey Nurse Shark was afforded protected status in New South Wales when legislation was gazetted in November 1984. Prior to protection, anecdotal accounts suggested that the abundance of the species had been severely reduced in SE Australian waters. Three main factors argued as evidence of the decline of the Grey Nurse Shark population in NSW waters were: (1) declining catches by spearfishers, (2) declining catches in beach meshing programs and (3) the realisation that the species was not responsible for attacks on humans (Pollard, 1990; Pollard *et al*., 1996). As a result, requests were made to NSW Fisheries to protect the species.

Protection of the species in State waters is managed under the Threatened Species provisions (Part 7A) of the *NSW Fisheries Management Act 1994* where it is listed as 'endangered'. The protection of the species in Commonwealth waters, including the Australian Fishing Zone and waters above the continental shelf, is carried out under the *Environment Protection and Biodiversity Conservation Act 1999* in which the species is listed as 'critically endangered' on the east coast and 'vulnerable' on the west coast of Australia.

3. GREY NURSE SHARK HABITAT MAPPING

3.1. Introduction

The aim of habitat mapping is to provide detailed information on the sites where Grey Nurse Sharks have been sighted. Anecdotal and quantitative information on the occupation of these sites by Grey Nurse Sharks can then be related to the key habitat features at each site. The sites utilised by Grey Nurse Sharks in the Batemans Shelf and Twofold Shelf Bioregions were mapped in this study. The habitat maps contain the location of the site in relation to the coast, the nature and characteristics of the habitat where the sharks are generally observed (usually a gutter or cave), the approximate distance of the site from the coast and any other unique features of each site.

The maps were generated from drawings and computer images provided by divers. Each map was scanned and enhanced using digital technology. Additional information such as depths and location of gutters and caves were then added to aid in interpretation. The information in the text accompanying each map provides details concerning: (1) the temporal occupancy of the site by Grey Nurse Sharks, (2) the approximate depths at which the sharks were observed, (3) the popularity of the site with recreational scuba divers, and (4) any other relevant information pertinent to each site, such as the extent and location of Marine Parks, fishing closures and Aquatic Reserves. Maps for all sites in the two bioregions are presented in latitudinal order from north to south.

The sites utilised by Grey Nurse Sharks in the Tweed Moreton Shelf, Manning Shelf and Hawkesbury Shelf Bioregions were previously mapped in Otway and Parker (2000). These are not presented in this report and in this respect, Otway and Parker (2000) must be viewed as a companion document.

3.1.1. Batemans Shelf and Twofold Shelf Bioregions

The Batemans Shelf Bioregion extends from Shellharbour (34^{o}35'S), southwards to Tathra (36^{o}48'S) on the south coast of NSW. The Twofold Shelf Bioregion extends from Tathra, southwards into Victoria. Thirteen sites in the Batemans Shelf and Twofold Shelf Bioregions were sampled as part of the distribution and abundance surveys (Table 3.1). Individual maps have been provided for all 13 sites.

Table 3.1. Location of sites where Grey Nurse Sharks have been observed in past decades in the Batemans and Twofold Shelf bioregions in NSW.

Bioregion	Location	Sites
Batemans Shelf	Shellharbour	Bass Point Gutters
		Bass Point Arch/Cave
	Jervis Bay	The Drum and Drumsticks
		The Docks
		Boat Harbour
		Weedy Valley
	Ulladulla	Brush Island Gutter
		Brush Island Pinnacle
	Batemans Bay	Tollgate Island Gutter
		Black Rock Arch
	Narooma	Montague Island Shark Gutter
		Montague Island The Gut
		Montague Island The Pinnacles
		Montague Island Bubble Cave
Twofold Shelf	Eden	Mewstone Rock
		South Head

3.1.1.1. Shellharbour

Grey Nurse Sharks have been observed at two sites at Shellharbour. Both sites: "The Gutter" and "The Arch/Cave" are located at Bass Point (Fig. 3.1). The Gutter is a reef system extending off the northern most tip of Bass Point near Lou's Reef with a deep sand-filled gutter that reaches a depth of 38 metres. The Arch/Cave is located on the southern side of Bass Point and is a reef system that reaches a depth of 30 metres. Grey Nurse Sharks are observed swimming or hovering inside or near the Cave or Arch. The sharks have been observed at these sites from December to June.

3.1.1.2. Jervis Bay

There are numerous dive sites within the Jervis Bay Marine Park. Grey Nurse Sharks are observed at four main sites, "The Drum and Drumsticks", "The Docks", "Boat Harbour" and "Weedy Valley" (Fig. 3.2). "The Drum and Drumsticks" are located outside of the Bay on the eastern side of Beecroft Peninsula. This site consists of a series of sand-filled gutters and a cave in waters reaching a maximum depth of 20 m. "The Docks" is located in a cove on the northern head of the entrance to the Bay. This site is also a series of gutters on rocky reef reaching a maximum depth of 20 m. "Boat Harbour" is next (west) to "The Docks" and is a rocky reef. Grey Nurse Sharks are usually observed along the wall and in a small shallow gutter. "Weedy Valley" is located on the northern tip of Bowen Island at the entrance to the Bay. This site is a rocky reef, and Grey Nurse Sharks are observed along a 7 m high wall that descends into 22 m of water. Grey Nurse Sharks are usually observed in the summer-autumn months.

3.1.1.3. Ulladulla

Grey Nurse Sharks are observed at two sites, "The Gutter" and "The Pinnacle", located at Brush Island (Fig. 3.3), which is just off the mainland at Bawley Point, south of Ulladulla. The Gutter reaches a maximum depth of 22 m and is located adjacent to a large bombora on the eastern side of Brush Island. During the 1950's and 1960's this gutter was a major aggregation site for Grey Nurse Sharks and large numbers could be regularly encountered during the summer months (Cropp

1964). The second site, "the Pinnacle" is located approximately 1.5 km east of Brush Island. The Pinnacle is a large, rocky structure rising from the bottom in 42 m of water to about 18 m from the sea surface. There is a small cave at the bottom of the Pinnacle in 40 m and Grey Nurse Sharks have been observed there in the past. To date, only one Grey Nurse Shark has been observed at Brush Island.

3.1.1.4. Batemans Bay

At Batemans Bay, Grey Nurse Sharks are found at two sites: "Tollgate Islands Shark Gutter" and "Black Rock Arch" during summer and autumn (Fig. 3.4). The Tollgate Islands are located at the mouth of Batemans Bay. "The Gutter" is on the south-eastern tip of the northern island and reaches a maximum depth of 15 metres. Black Rock is located east of Malua Bay on the southern edge of Batemans Bay. "The Arch" is a large overhang/cave in approximately 22 m of water and sharks are observed hovering or swimming in or near the cave.

3.1.1.5. Narooma

Grey Nurse Sharks are observed at four sites at Montague Island off Narooma (Fig. 3.5). The main site is called the "Shark Gutters" and is located on the northern tip of Montague Island and comprises a reef with a series of sand-filled gutters in approximately 18 m of water. The other three sites are the "Bubble Cave", the "Pinnacles" and "The Gut". These are located on the western side of the island on submerged reef extending from Montague Island. Grey Nurse Sharks usually occupy these sites during late summer and early autumn.

3.1.1.6. Eden

At Eden, Grey Nurse Sharks have been observed in the past at "Mewstone Rock" and "South Head" (Fig. 3.6). "Mewstone Rock" is located off Worang Point, the northern most headland of the bay at Eden. There is a small overhang on the western side of the rock and several sand-filled gutters running east to west through the rocky reef surrounding the eastern side of the rock. "South Head" is a site off Red Point, which is located on the southern most headland of Twofold Bay. The site consists of a series of gutters running in a roughly north-south direction through the rocky reef surrounding the rock formation referred to as "Seahorse Shoals". No Grey Nurse Sharks have been observed at these two sites over the period of the surveys (see Chapter 4).

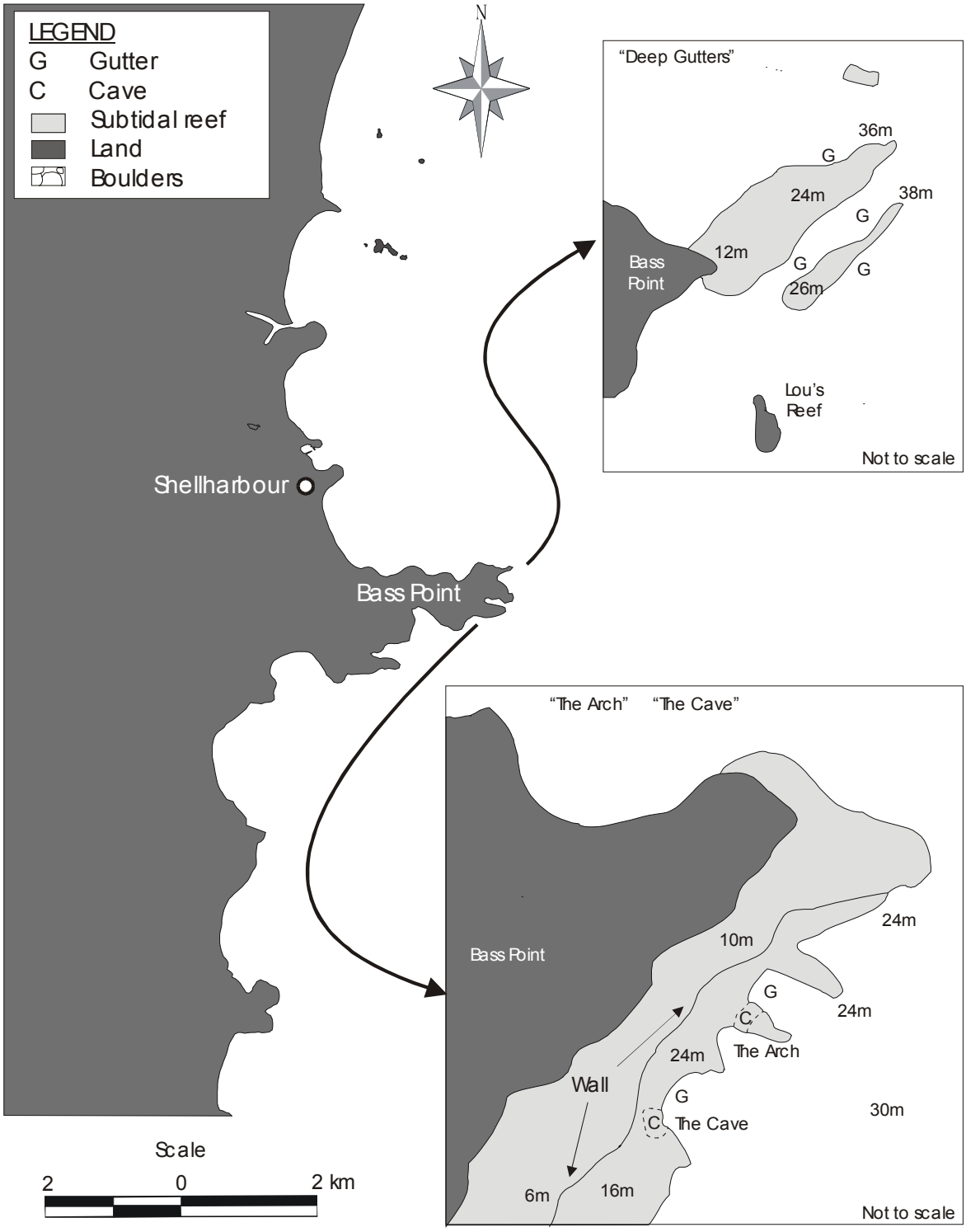

Figure 3.1. Sites at Shellharbour where Grey Nurse Sharks have been observed in past years.

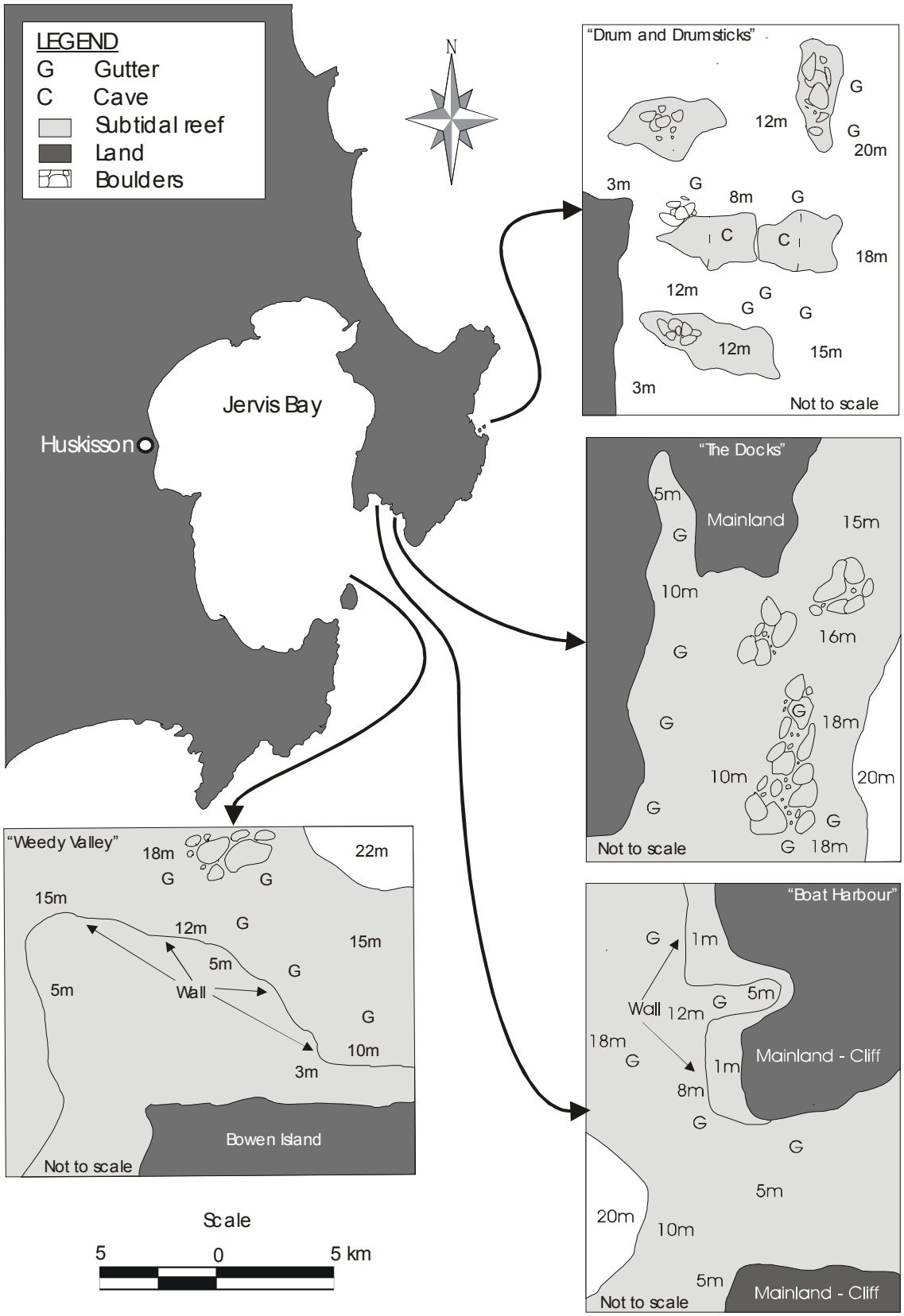

Figure 3.2. Sites at Jervis Bay where Grey Nurse Sharks have been observed in past years.

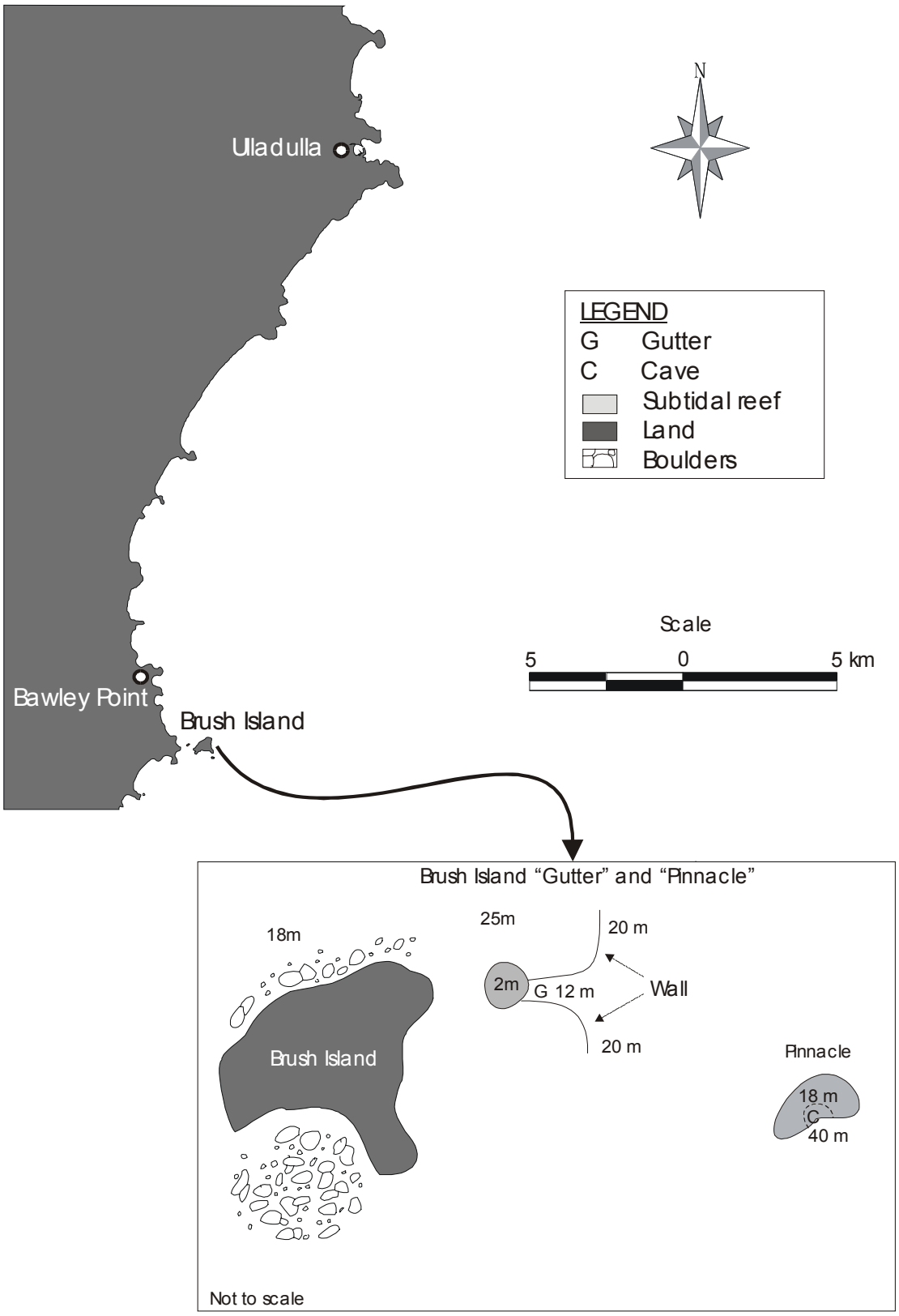

Figure 3.3. Sites at Ulladulla where Grey Nurse Sharks have been observed in past years.

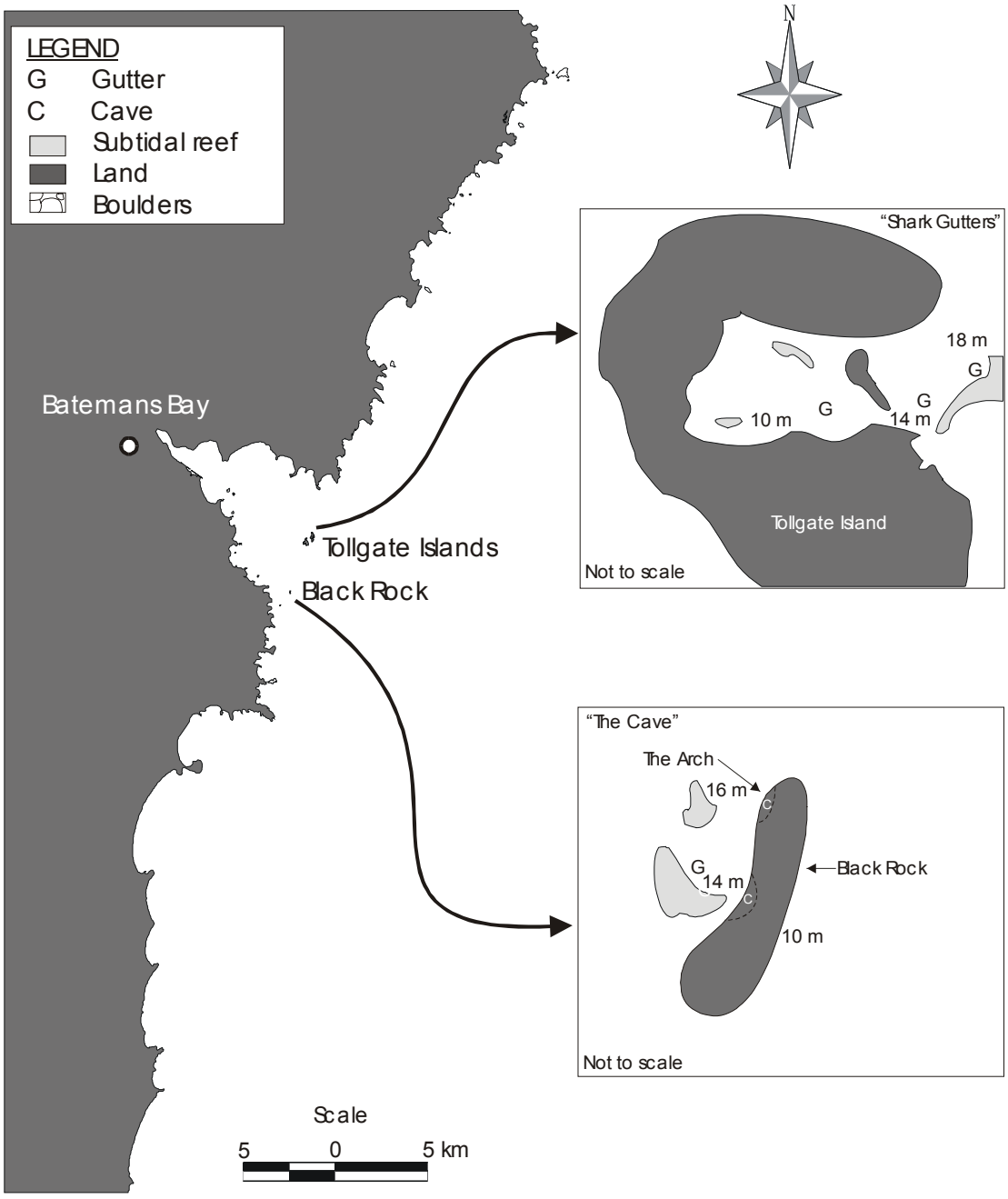

Figure 3.4. Sites at Batemans Bay where Grey Nurse Sharks have been observed in past years.

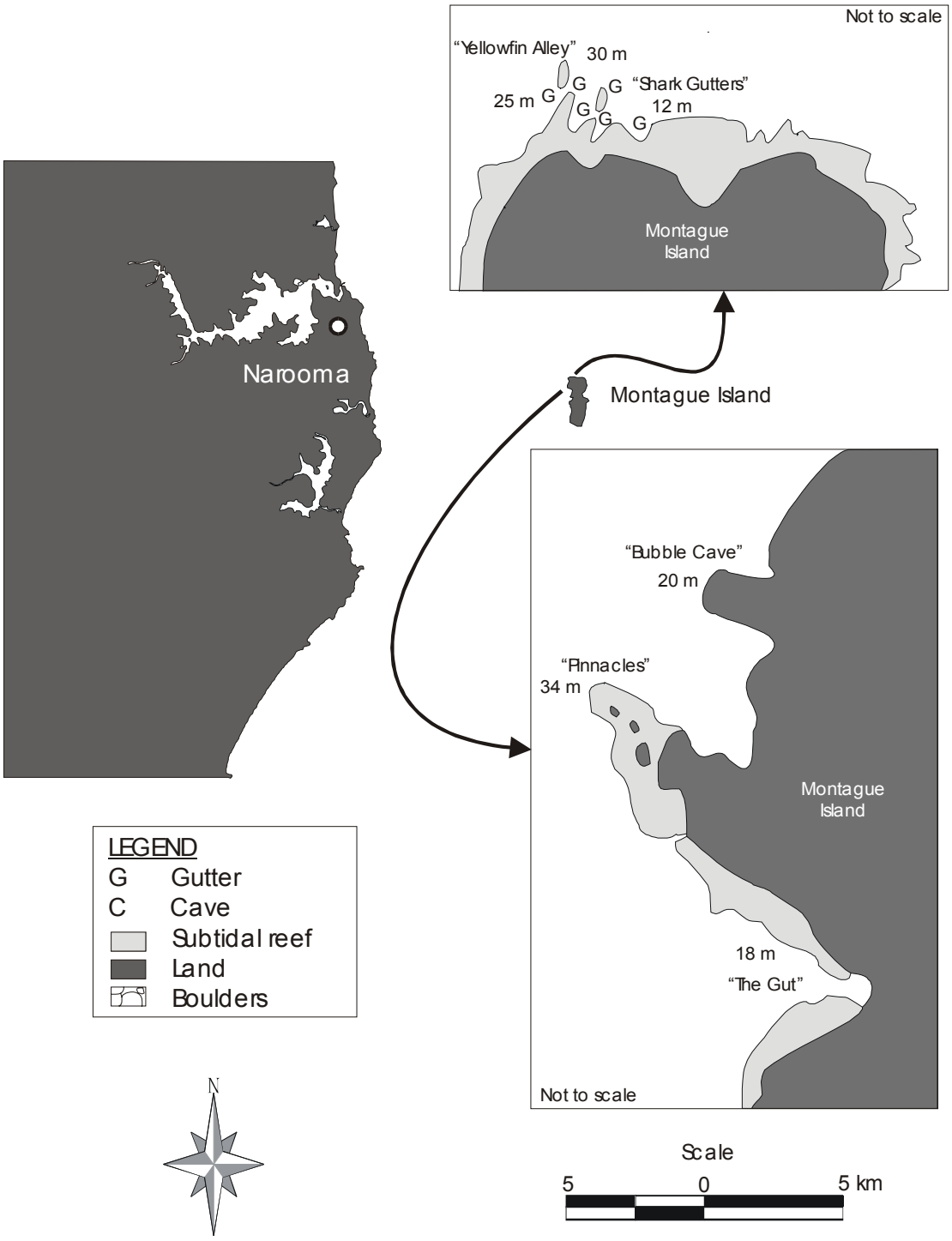

Figure 3.5. Sites at Narooma where Grey Nurse Sharks have been observed in past years.

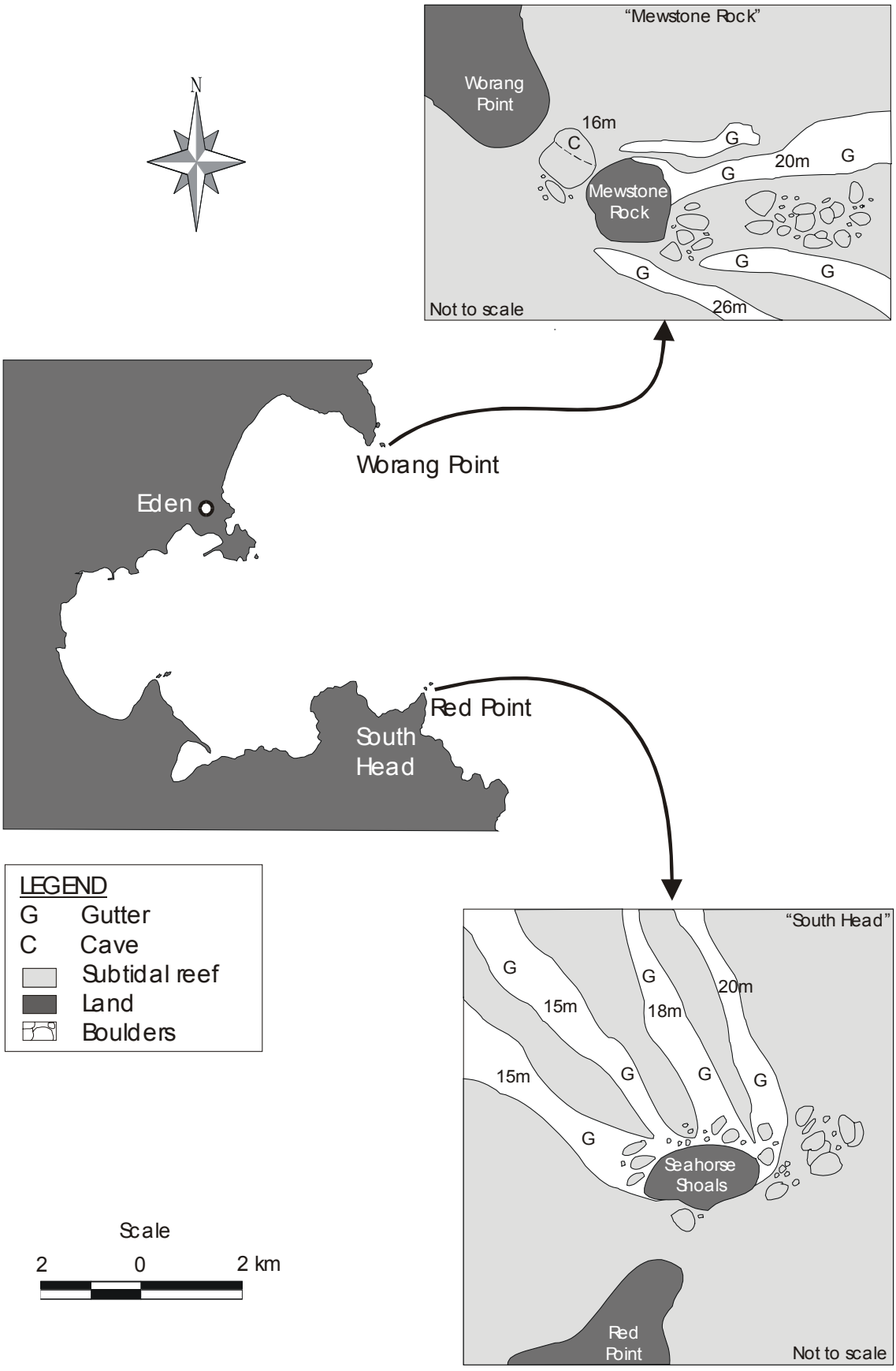

Figure 3.6. Sites at Eden where Grey Nurse Sharks have been observed in past years.

4. THE DISTRIBUTION AND ABUNDANCE OF GREY NURSE SHARKS

4.1. Introduction

Results of the previous coastwide surveys (Otway & Parker 2000) showed that the abundances of Grey Nurse Sharks along the NSW coast varied spatially and temporally with evidence of segregation by size and sex. However, it was not clear whether these preliminary patterns would be consistent over time. Consequently, there was a need to document the spatial and temporal patterns of abundances of Grey Nurse Sharks along the NSW coast over longer periods of time. Moreover, Otway & Parker (2000) recognised that further estimates of abundance would be needed to guard against errors in the interpretation of the data given the low numbers of sharks observed and the limited number of surveys.

4.2. Materials and methods

4.2.1. Sampling sites and protocol

The sites sampled in this study were the same as documented in Otway and Parker (2000) to ensure continuity of the data. They were originally chosen by Otway and Parker (2000) by reviewing the scientific and "grey" literature (i.e. popular books, diving magazines, newspaper articles, etc.) to document where Grey Nurse Sharks had been observed over the past 50 years. Approximately 75 sites (Fig. 4.1) were identified along the New South Wales and southern Queensland coasts: a distance of ≈ 2,000 km. These sites were grouped into clusters radiating from 21 coastal centres of urbanisation (hereafter called locations) along the coast. The number of sites within any given location varied from 1 – 8.

Scuba divers from universities, dive clubs, scuba diving schools, commercial aquaria were approached to continue their voluntary participation in the surveys. Together with scuba divers from NSW Fisheries, the distribution and abundance, size-structure and sex-ratios of Grey Nurse Sharks were quantified at intervals of 3 months. The visual surveys were done over a 4 week period to allow for inclement sea conditions (i.e. rough seas, moderate swell, strong currents, etc.) that occur at varying times along different stretches of the south-east Australian coast (Trenamen and Short 1987). At each site, scuba divers swam for a 15 minute period in or around habitats (e.g. gutters, caves and overhangs – Pollard *et al*. 1996; Otway and Parker 1999, 2000) known in the past to have been occupied by Grey Nurse Sharks. Within each 15 minute period, the divers recorded the total number of sharks present, estimated the total lengths (TL) of the sharks in 3 size-classes: 1 - 2 m, 2 - 3 m and > 3 m, and identified the sex of each individual. When sex could not be determined, the individual shark was simply recorded as "sex unknown". In addition, scuba divers noted the presence of mating scars, fishing gear (hooks, wire traces, line, etc.), and recorded the bottom water temperature to the nearest 1° C.

Some sites were relatively close to each other (i.e. < 2 km apart) and this raised the possibility that some movement between sites might have occurred during the survey period (i.e. 4 weeks). Unfortunately, as there is little information on the localised or coastwide patterns of movement of Grey Nurse Sharks along the east coast (Otway and Parker 1999, 2000), we assumed that there was no movement among sites within each 4-week survey. This means that some sharks may have been counted twice within any given survey. Consequently, the total number of Grey Nurse Sharks

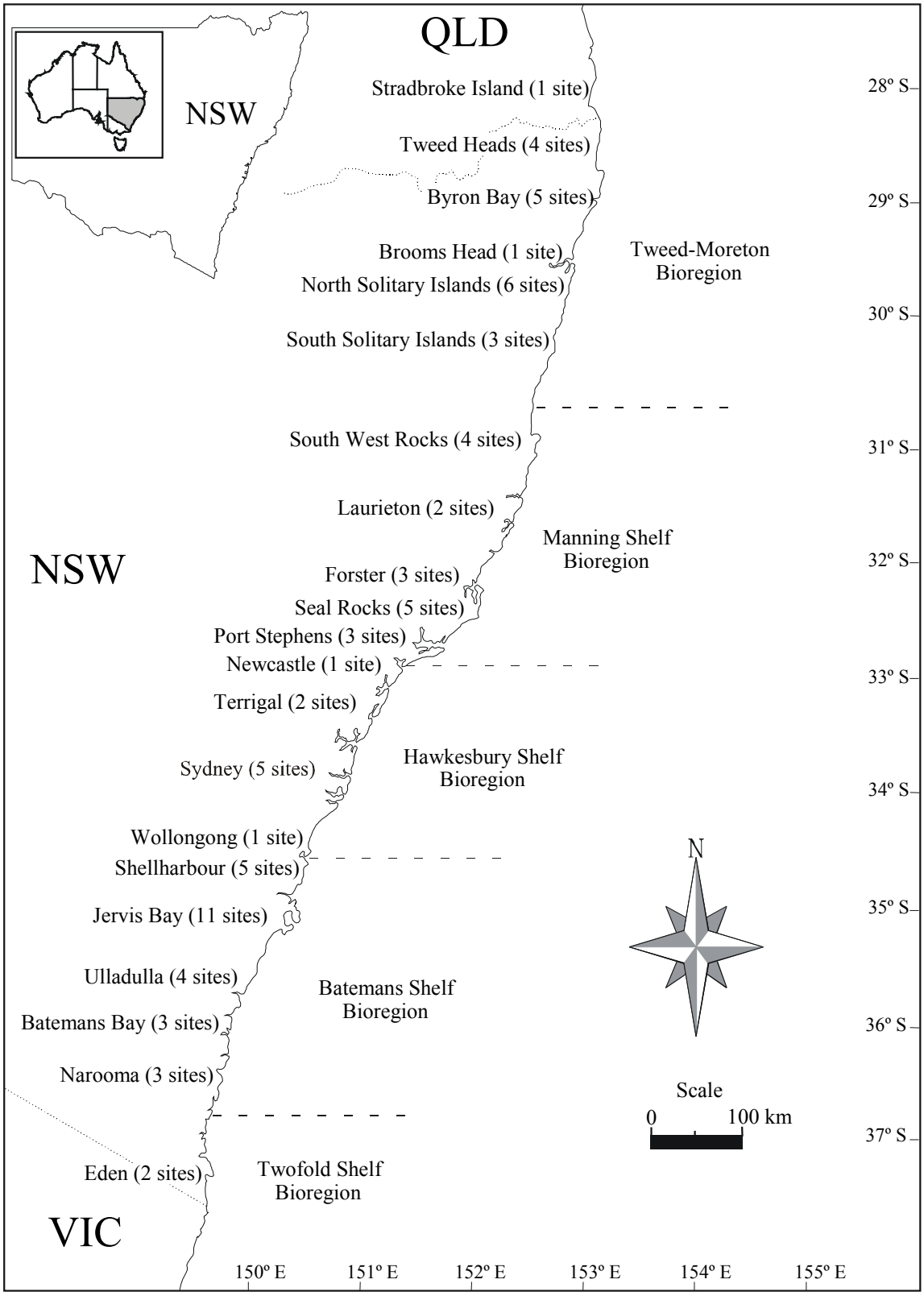

Figure 4.1. Map showing the locations sampled by the scuba diving community in cooperation with NSW Fisheries over four week periods from November/December 1998 to March/April 2001.

recorded in any given survey represents the maximum number seen, and this may be an overestimate.

NSW Fisheries and some dive groups did repetitive sampling through time at several of the sites. The data obtained enabled: (1) a comparison of the estimates of abundance and size-structure between dive-groups (i.e. a "quality control" check – estimates did not differ), and (2) an indication of short-term temporal changes in the populations of Grey Nurse Sharks at particular sites.

4.2.2. Statistical analyses

4.2.2.1. Spatial and temporal variation in abundance

The previous study by Otway & Parker (2000) analysed the abundances of sharks on 2 spatial scales: (1) along the entire coast, and (2) in northern and southern sections of the coast. Temporal changes in the abundances of male, female and the total number of Grey Nurse Sharks were also examined at these two spatial scales using t-tests and univariate analyses of variance with Type I error-rates of $\alpha = 0.05$. Comparisons of the annual mean number of all, male and female Grey Nurse Sharks in years 1 and 2 were done by using the pooled number of sharks in the relevant coastal region in each of the 4 surveys as replicate estimates of the sampled population in a year. Variation in the annual mean abundance of sharks along the entire coast was analysed using t-tests. Fluctuations in the annual mean abundances of sharks in the northern and southern sections of the coast were analysed using a 2-factor analysis of variance with "Years" and "Coastal Section" considered as fixed factors. Prior to analysis, individual cell variances were examined for heteroscedasticity using Cochran's test (Winer *et al*., 1991). When variances were heterogeneous, data were transformed using procedures specified by Scheffé (1959) and Underwood (1981, 1997).

4.2.2.2. Population size-structure and segregation by size and sex

The size-structure of the Grey Nurse Shark population along the entire coast and at the 21 locations were plotted for the 3 size-classes: 1 - 2 m, 2 - 3 m and > 3 m. Possible biases in sex-ratios and spatial and temporal differences in population size-structure were examined using χ^2 analyses with Type I error-rates of $\alpha = 0.05$. Prior to analysis, the length-frequency data for males and females were re-partitioned into 2 size-classes: (1) < 2 m TL and (2) ≥ 2 m TL because previous reproductive studies (e.g. Bass *et al*. 1975; Gilmore *et al*. 1983; Branstetter and Musick 1994) have shown that male and female Grey Nurse Sharks attain sexual maturity at 1.90 - 1.95 TL and 2.20 - 2.30 m TL, respectively. By so doing, the data were partitioned into approximate groupings of non-reproductive and reproductive individuals. However, it is important to note that some of the smallest females in the second size-class (i.e. sharks > 2 m TL) may not have been sexually mature.

Results of the first 3 surveys (Otway & Parker 2000) clearly showed that male and female Grey Nurse Sharks were segregated by size and sex along 2 sections of the coast from (1) Forster and sites to the north, and (2) Seal Rocks and sites to the south. Consequently, the length-frequency data were also re-partitioned in the same manner. Temporal changes in the proportions of male and female Grey Nurse Sharks, irrespective of size and in the < 2 m TL and ≥ 2 m TL size classes, were examined over the entire coast and at the smaller spatial scale (i.e. between the northern and southern sections of the coast).

4.2.2.3. Incidence of hooking

Grey Nurse Sharks with hooks embedded in their jaws and/or buccal cavity were observed along the entire coast from North Stradbroke Island (Qld) to Montague Island. These observations indicated that the hooking occurred with fishing gear comprising either: (1) a hook attached to

nylon line or (2) a hook attached to wire trace. Consequently, the data were first examined using the hooking incidence of both fishing gear combined. Then, the data were partitioned into these 2 types of gear. Prior to analysis, repetitive observations of the same shark at any given site were removed from the dataset. Estimates of the incidence of hooking were calculated as the number of sharks with hooks embedded in their jaws (and/or buccal cavity) divided by the total number of individuals per survey. This value was then expressed as a percentage. Data on hooking incidence were analysed in a number of ways. Firstly, the proportions of Grey Nurse Sharks with and without fishing gear were analysed using contingency tests. Secondly, the results from each of the 4 surveys in 1999 and 2000 were used as replicates to calculate an annual mean incidence of hooking and analysed using single and two-factor analyses of variance. Lastly, the data on hooking incidence from this study and that of Pollard *et al*. (1996) and Parker (unpubl.) were regressed on time to examine whether there was a significant trend (increasing or decreasing) in the incidence of hooking.

4.2.2.4. Identification of key sites (Critical Habitat)

The results of the first 3 surveys (Otway & Parker 2000) showed that the Grey Nurse Sharks were found in aggregations of 5 or more individuals at 14 sites along the entire coast. However, it was not clear whether the aggregation sites identified in the first 3 surveys would be used consistently by Grey Nurse Sharks over longer periods of time (i.e. over several years), especially given their likely migratory movements along the coast. To examine whether the aggregation sites were used over longer periods of time, the abundance data were analysed in several steps. Firstly, the numbers of Grey Nurse Sharks observed at each of these sites during the first survey were calculated as percentages of the total number of sharks observed in the first survey. Secondly, this process was repeated for the other 9 surveys. Thirdly, the percentages at each site were averaged over the 10 surveys providing mean values for each site. Finally, these means were summed to estimate the percentage of the total Grey Nurse Shark population observed at these aggregation sites averaged over the 10 surveys (i.e. 2.5 years).

It is important to note that the above analysis does not identify whether the aggregations occur consistently through time at the same sites. To estimate the degree of consistency through time, the number of times an aggregation of Grey Nurse Sharks (i.e. 5 or more individuals) was present at a given site was expressed as a percentage of the number times the site was sampled. This percentage was then calculated for each of the sites where Grey Nurse Sharks aggregated.

4.3. Results

4.3.1. Patterns of abundance

As a direct result of the scuba diving community's continued involvement, it was possible to sample the entire NSW coast from Eden to Tweed Heads and into southern Queensland (i.e. North Stradbroke Island) on a further 7 occasions (3 more than required under the study's objectives). The number of sites sampled in any single survey (Table 4.1) varied because of the prevailing sea-conditions (e.g. rough seas, moderate – heavy swell, currents and poor visibility due to floods in northern NSW) all of which varied greatly in space and time over the 2.5 year period. Despite this, an average of 57 sites were sampled along the entire coast from November/December 1998 to March/April 2001 (Table 4.1, surveys 1-10).

The total numbers of Grey Nurse Sharks observed also varied among surveys (Table 4.1) with a maximum of 292 individuals being seen in May/June 2000 (survey 7). Some sites were occupied by relatively large numbers of Grey Nurse Sharks, whereas others had none. Moreover, almost 64% of the sites sampled, averaged across the 10 surveys, had no Grey Nurse Sharks present.

Finally, the proportions of sites with and without Grey Nurse Sharks also varied significantly among surveys (Table 4.1, $\chi^2 = 20.10$, $P < 0.05$). A significantly greater proportion of sites were occupied by Grey Nurse Sharks in winter 1999 and 2000 (Table 4.1, surveys 3 & 7). Furthermore, there were proportionally fewer sites occupied in autumn 2000 (Table 4.1, survey 6).

Table 4.1. Summary of the abundances of Grey Nurse Sharks sampled over two years at sites along the entire NSW coast from 1998 to 2001. Data for surveys 1-3 are from Otway and Parker (2000).

Survey Number	Date	Total number of sharks seen	Number of sites sampled	Number (%) of sites with no sharks present	Sex Ratio (M : F)
1	Nov / Dec 1998	136	61	37 (61)	1 : 2.2
2	Mar / Apr 1999	129	51	35 (69)	1 : 3.6
3	Jun / Jul 1999	207	50	25 (50)	1 : 0.9
4	Aug / Sep 1999	187	44	24 (55)	1 : 4.1
5	Nov / Dec 1999	132	58	36 (62)	1 : 1.8
6	Mar / Apr 2000	149	64	49 (77)	1 : 1.9
7	May / Jun 2000	292	62	31 (50)	1 : 1.1
8	Aug / Sep 2000	146	57	39 (68)	1 : 2.5
9	Nov / Dec 2000	120	63	46 (73)	1 : 2.5
10	Mar / Apr 2001	166	48	34 (71)	1 : 2.1

The abundances of Grey Nurse Sharks along the entire coast (i.e. at a large spatial scale) varied over the 4 surveys within the first year with the largest numbers (i.e. 207 individuals) occurring in winter, 1999 (Table 4.1, survey 3). A similar pattern was repeated in the second year with a maximal number of 292 individuals observed in winter (Table 4.1, survey 7). As stated earlier, it is important to note that the number of sites sampled in any single survey varied because of sea conditions. Consequently, the total abundances of Grey Nurse Sharks were expressed as numbers/site. Irrespective of the adjustment for differential sampling effort across surveys, the total numbers of sharks was still at or near maximum over the winter period in both years (Fig. 4.2). The increases in Grey Nurse Shark numbers during winter periods was most likely caused by the influx of males (see below and Fig. 4.3). Moreover, using the numbers of sites sampled in each of the 4 surveys/year as replicates, the mean number of sites sampled per survey was greater in year 2 (60.25 sites/survey) compared to year 1 (50.50 sites/survey). However, the mean number of sites/survey did not differ significantly between years ($t = 2.25$, $P > 0.05$).

The annual mean abundance of all Grey Nurse Sharks (males, females, and those of unknown sex) along the entire coast did not differ significantly between years (Table 4.2, $P > 0.05$). Moreover, the annual mean abundances of all Grey Nurse Sharks did not differ significantly between coastal sections and years (Table 4.3a, $P > 0.05$), but there was a pronounced trend towards greater abundances of sharks in the northern section (Table 4.3b).

The annual mean abundance of male Grey Nurse Sharks along the entire coast did not differ significantly between years (Table 4.2, $P > 0.05$). However, the annual mean number of male Grey Nurse Sharks differed significantly between coastal sections, but not between years (Table 4.3a, $P < 0.05$ and $P > 0.05$, respectively). Significantly more male sharks were observed in the northern section (Table 4.3b).

The annual mean abundance of female Grey Nurse Sharks along the entire coast did not differ significantly between years (Table 4.2, $P > 0.05$). The annual mean abundances of female Grey Nurse Sharks did not differ significantly between coastal sections or years (Table 4.3, $P > 0.05$).

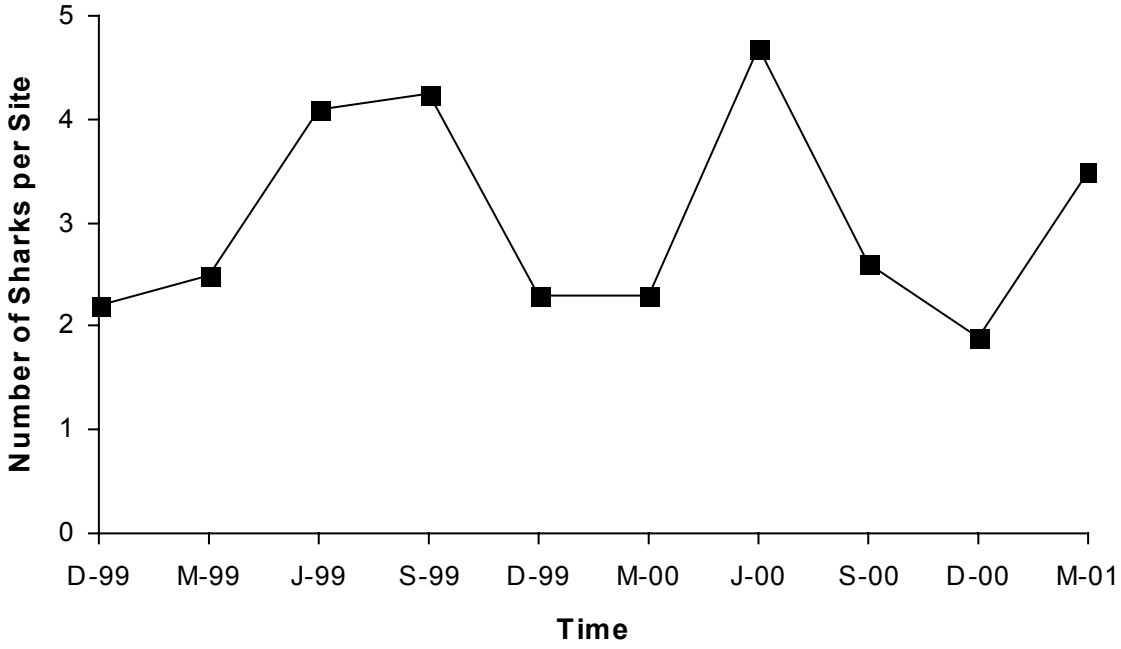

Figure 4.2. Number of Grey Nurse Sharks over 10 surveys from November/December 1998 to March/April 2001.

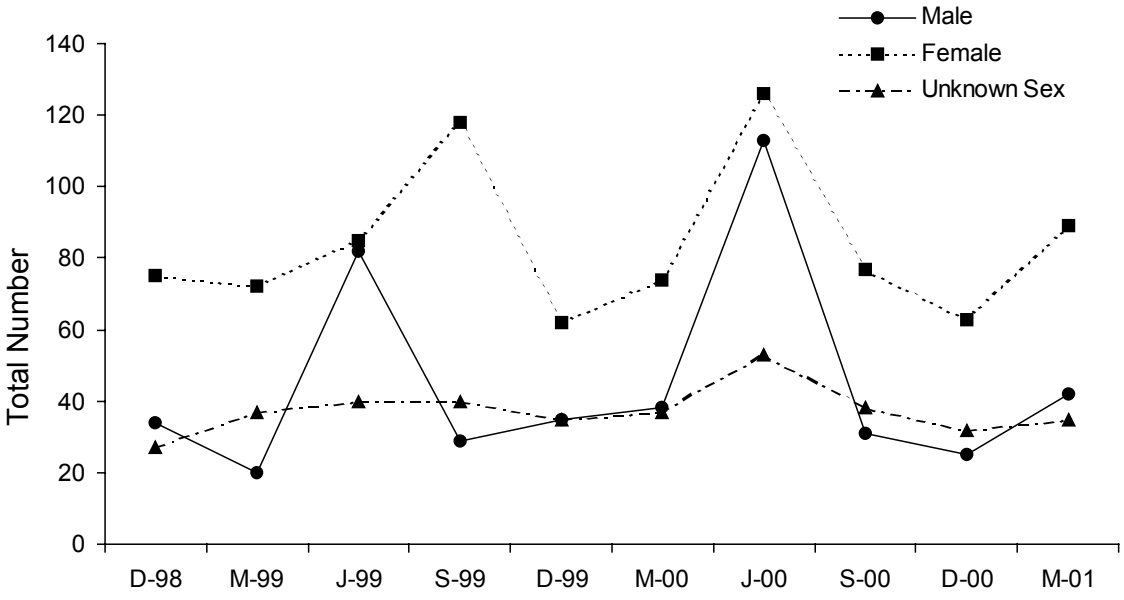

Figure 4.3. Long-term fluctuations in the total number of Grey Nurse Sharks categorised by sex, along the entire NSW and southern QLD coasts from November/December 1998 to March/April 2001.

Table 4.2. Comparison of the annual mean (SE) numbers of total, male and female Grey Nurse Sharks along the entire coast of NSW in 1999 and 2000 ($t_{0.05}$ with 6 df = 2.45, ns: not significant at $P > 0.05$).

Category	Mean (SE) Number 1999	2000	t	*P*
Total sharks	163.75 (19.64)	176.75 (39.96)	0.30	ns
Male sharks	41.25 (13.60)	51.75 (20.59)	0.43	ns
Female sharks	82.25 (12.41)	85.00 (13.99)	0.15	ns

Table 4.3. Analysis of the annual mean number of total, male and female Grey Nurse Sharks observed in the northern and southern sections of the coast in 1999 and 2000 (ns: not significant at $P > 0.05$; *: significant $P < 0.05$).

(a) Analysis of variance

Source of Variation	df	Total Sharks MS	F	Males MS	F	Females MS	F
Coastal Section	1	7353.06	3.65 ns	3782.25	6.49 *	56.25	0.08 ns
Year	1	217.56	0.11 ns	225.00	0.39 ns	25.0	0.04 ns
CS x Y	1	5.06	0.00 ns	16.00	0.03 ns	12.25	0.02 ns
Residual	12	2016.48		582.71		673.79	
Total	15						

(b) Annual mean (SE) numbers

Section of coast	Year	Total Sharks	Males	Females
Northern	1999	103.00 (19.68)	32.75 (14.35)	41.00 (14.53)
	2000	109.25 (31.64)	42.25 (18.75)	105.00 (14.40)
Southern	1999	59.00 (9.55)	4.00 (1.68)	39.00 (7.44)
	2000	67.50 (23.17)	9.50 (4.73)	39.75 (14.14)

The numbers of males, females and sharks of unknown sex throughout time exhibited similar patterns between years (Fig. 4.3). However, the total numbers of female Grey Nurse Sharks were substantially greater than the males in all surveys except for those in the winter period in both years (Fig. 4.3). In contrast, the total numbers of male Grey Nurse Sharks remained low males in all surveys except for those in the winter period (June) in both years (Fig. 4.3). Over winter, the numbers of male Grey Nurse Sharks increased markedly and were similar to the females. The numbers of Grey Nurse Sharks of unknown sex (Fig. 4.3) remained at low levels in all surveys in both years and did not differ proportionally through time ($\chi^2 = 10.90$, $P > 0.05$).

Grey Nurse Shark pups were observed in late winter/early spring (i.e. in surveys 4 – 5 and 7 – 8) at various sites along the coast (e.g. Julian Rocks, Fish Rock, and the Tollgate Islands). However, the numbers of recently born pups observed during the diver surveys were very low. For example, in spring 2000 (survey 8) only 14 pups were observed across all sites along the coast.

4.3.2. Population size-structure

4.3.2.1. General observations

The length-frequency distributions of Grey Nurse Sharks along the entire coast varied among the 10 surveys (Fig. 4.4) and were dominated by individuals (males and females) in the 1 - 2 m and 2 - 3 m TL size-classes. While the length-frequency distributions of Grey Nurse Sharks at individual locations along the NSW coast differed over time, there were also some more general patterns evident. These were generally related to the segregation by size and sex in the northern and southern regions of the coast.

4.3.2.2. Segregation by sex and size along the NSW and southern Queensland coasts

The length-frequency distributions of Grey Nurse Sharks along the entire coast varied among the 10 surveys (Figs. 4.4 - 4.6) and were dominated by individuals (males and females) in the 1 - 2 m and 2 - 3 m TL size-classes. While the length-frequency distributions of Grey Nurse Sharks at individual locations along the NSW coast differed over time, there were also some more general patterns that appeared to be related to the segregation of individuals by size and sex. To examine the statistical significance of possible size segregation, the data for male and females were partitioned into two size classes: (1) < 2 m TL, and (2) ≥ 2 m TL. The choice of size-classes also incorporates practical aspects of estimating sizes underwater (Otway & Parker 2000).

The length-frequency distributions for the entire coastline (Figs. 4.4 - 4.6) suggested that the sex ratios calculated for all individuals and those in the 2 size classes (see above) would differ along smaller sections of the coast. For example, it was apparent that there were more males than females at the northern locations, and fewer males than females across the southern locations. Consequently, the length-frequency data were re-examined using the arbitrary subdivision of Otway and Parker (2000). Briefly, the distribution of male Grey Nurse Sharks in November/December 1998 (Survey 1) was used to divide the coastline into two sections: (1) Forster and sites to the north, and (2) Seal Rocks and sites to the south.

4.3.2.3. Along the entire NSW and southern Queensland coasts

For those individuals of known sex (pooled across all sites), the proportions of male to female Grey Nurse Sharks observed along the entire coast differed significantly among surveys ($\chi^2 = 59.42$, $P < 0.001$). The ratio of males to females differed significantly from a 1:1 sex ratio on all occasions except in surveys 3 and 7 (Table 4.4) with a predominant bias towards females. In surveys 3 and 7, the number of males and females did not differ significantly from a 1:1 sex ratio (Table 4.4).

The proportions of male to female Grey Nurse Sharks < 2 m TL along the entire coast did not differ significantly among surveys ($\chi^2 = 10.11$, $P > 0.10$). Despite this, the ratio of males to females < 2 m TL differed significantly from a 1:1 sex ratio on all occasions except in survey 5 (Table 4.4). Sex ratios of 1:1.86 or greater were evident and consistently biased in favour of females. The proportions of male to female Grey Nurse Sharks ≥ 2 m TL along the entire coast differed significantly among surveys ($\chi^2 = 59.57$, $P < 0.001$). There were proportionally fewer males and more females ≥ 2 m TL on all occasions except in surveys 3 and 7 (Table 4.4). However, in surveys 3 and 7 there were proportionally more males and fewer females ≥ 2 m TL than expected by chance alone. Finally, the ratio of males to females ≥ 2 m TL differed significantly from a 1:1 sex ratio in surveys 1-6, 8 and 9 (Table 4.4). In survey 7, the numbers of male and female sharks did not differ from a 1:1 sex ratio (Table 4.4). In survey 3, the sex ratio was biased towards males, whereas in surveys 1, 2, 4-6, 8, and 9 the sex ratios were biased in favour of females.

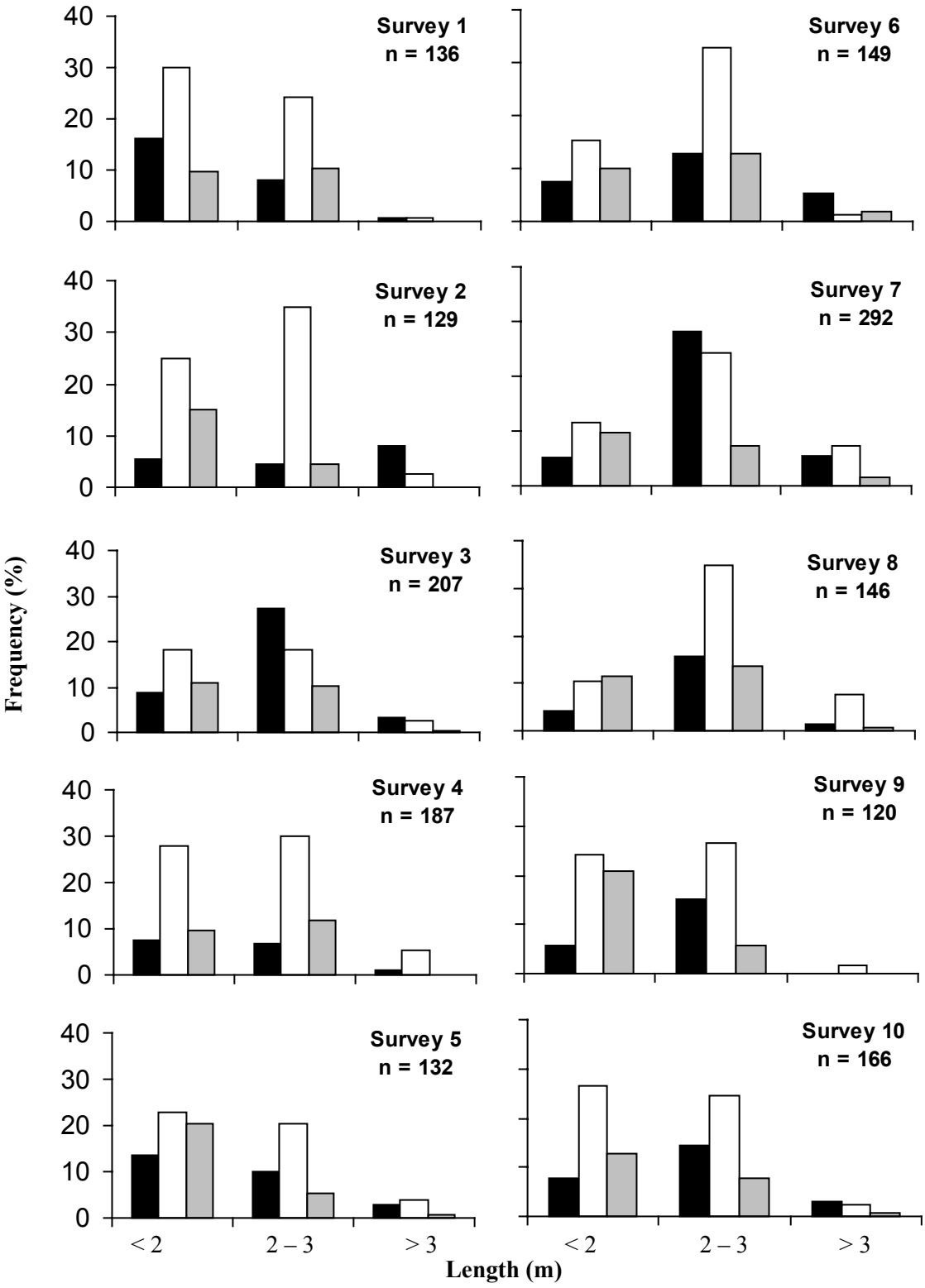

Figure 4.4. Percentage of male (■), female (□) and individuals of unknown sex (■) Grey Nurse Sharks, and individuals of unknown sex pooled across the entire coast from November/December 1998 to March/April 2001 (Surveys 1 - 10). Total lengths estimated visually and placed into 3 size-classes: < 2 m, 2-3 m and > 3 m.

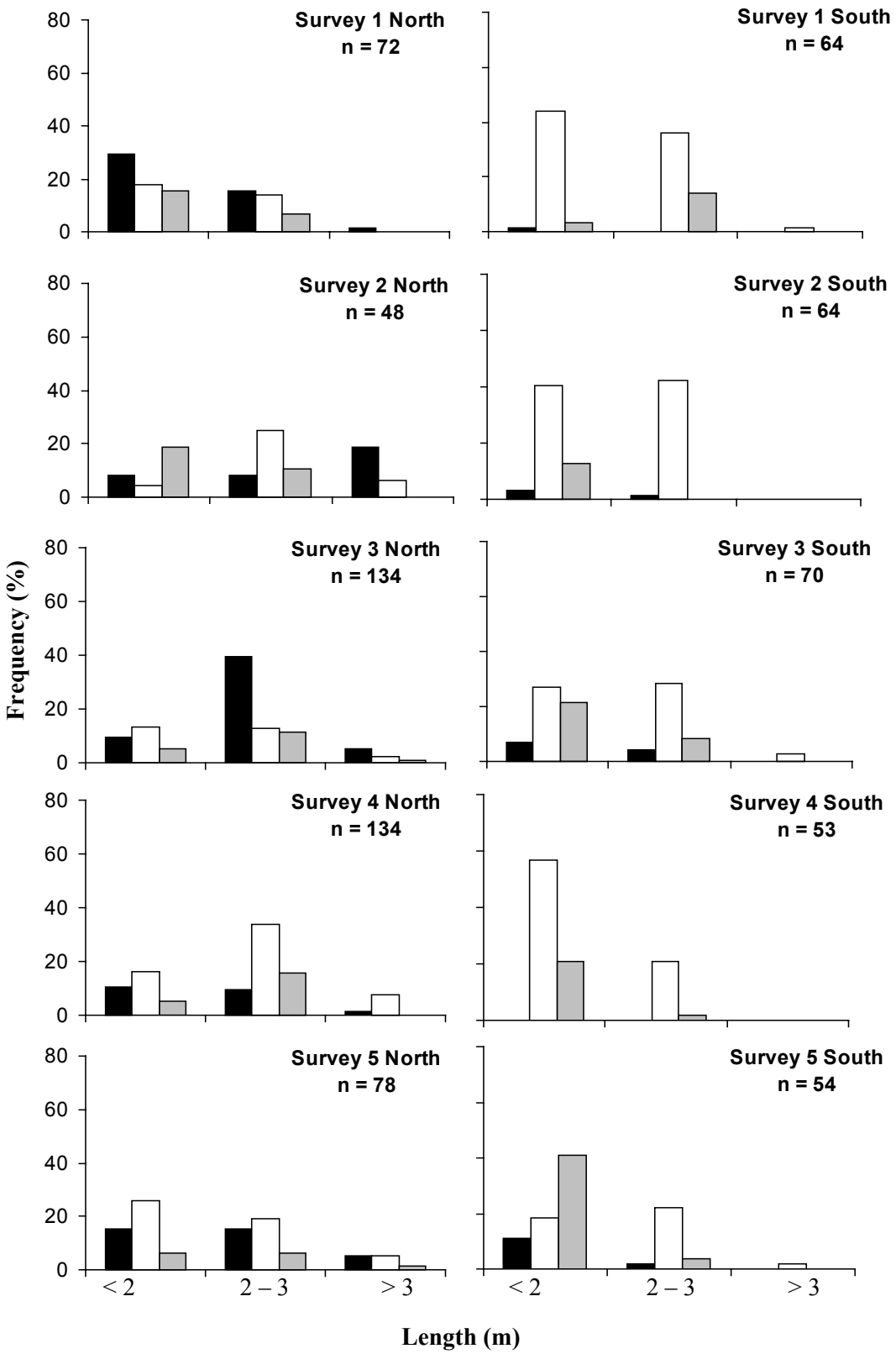

Figure 4.5. Percentage of male (■), female (□) and individuals of unknown sex (■) Grey Nurse Sharks observed along the 2 sections of the coast: (1) Forster and sites north, and (2) Seal Rocks and sites south from November/December 1998 to November/December 1999 (Surveys 1 - 5).

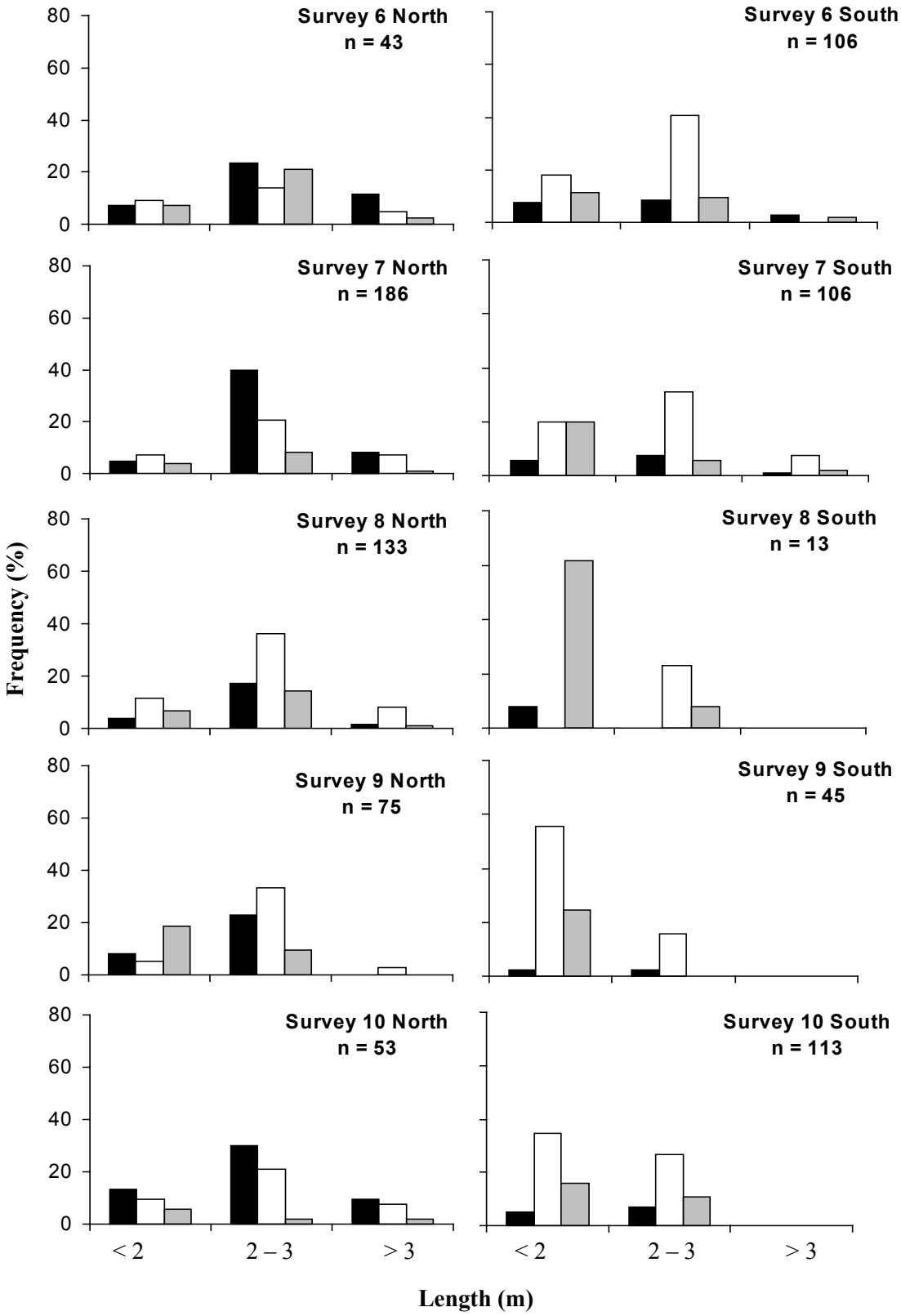

Figure 4.6. Percentage of male (■), female (□) and individuals of unknown sex (■) Grey Nurse Sharks observed along 2 sections of the coast: (1) Forster and sites north, and (2) Seal Rocks and sites south from March/April 2000 to March/April 2001 (Surveys 6 - 10).

Table 4.4. Numbers of male and female Grey Nurse Sharks in 2 size-classes (i.e. < 2 m TL and > 2 m TL) observed along the entire NSW coast in the surveys from November/December 1998 to March/April 2001. (In this and Tables 4.5 & 4.6, ns: not significant at $P > 0.05$; *: significant $P < 0.05$; **: significant $P < 0.01$; ***: $P < 0.005$).

Survey	Date	Size class	Male	Female	Ratio M:F	χ^2	P
1	Nov / Dec 1998	Total	**34**	**75**	1 : 2.21	15.42	***
		< 2 m	22	41	1 : 1.86	5.73	*
		≥ 2 m	12	34	1 : 2.83	10.52	***
2	Mar / April 1999	Total	**20**	**70**	1 : 3.50	27.78	***
		< 2 m	6	28	1 : 4.67	14.24	***
		≥ 2 m	14	42	1 : 3.00	14.00	***
3	June / July 1999	Total	**81**	**79**	1 : 0.98	0.03	ns
		< 2 m	18	37	1 : 2.06	6.56	*
		≥ 2 m	63	42	1 : 0.67	4.20	*
4	Aug / Sep 1999	Total	**29**	**118**	1 : 4.07	53.88	***
		< 2 m	14	52	1 : 3.71	21.88	***
		≥ 2 m	15	66	1 : 4.40	32.11	***
5	Nov / Dec 1999	Total	**35**	**62**	1 : 1.77	7.52	**
		< 2 m	18	30	1 : 1.67	3.00	ns
		≥ 2 m	17	32	1 : 1.88	4.60	*
6	Mar / April 2000	Total	**38**	**74**	1 : 1.95	11.57	***
		< 2 m	11	23	1 : 2.09	4.24	*
		≥ 2 m	27	51	1 : 1.89	7.39	**
7	May / June 2000	Total	**113**	**126**	1 : 1.12	0.40	ns
		< 2 m	15	34	1 : 2.27	7.37	**
		≥ 2 m	98	92	1 : 0.94	0.19	ns
8	Aug / Sep 2000	Total	**31**	**77**	1 : 2.48	19.59	***
		< 2 m	6	15	1 : 2.50	3.86	*
		≥ 2 m	25	62	1 : 2.48	15.74	***
9	Nov / Dec 2000	Total	**25**	**63**	1 : 2.52	16.41	***
		< 2 m	7	29	1 : 4.14	13.44	***
		≥ 2 m	18	34	1 : 1.89	4.92	*
10	Mar / April 2001	Total	**42**	**89**	1 : 2.12	16.86	***
		< 2 m	13	44	1 : 3.38	18.86	***
		≥ 2 m	29	45	1 : 1.55	3.46	ns

The proportions of < 2 m TL to ≥ 2 m TL male Grey Nurse Sharks along the entire coast differed significantly among surveys ($\chi^2 = 51.70$, $P < 0.001$). Proportionally fewer ≥ 2 m TL male Grey Nurse Sharks were observed in the spring and summer months (Table 4.4). Similarly, the proportions of < 2 m TL to ≥ 2 m TL female Grey Nurse Sharks differed significantly among surveys ($\chi^2 = 40.01$, $P < 0.001$). Proportionally more ≥ 2 m TL female Grey Nurse Sharks were observed during surveys 7 and 8 (Table 4.4).

4.3.2.4. Comparisons between sections of the coast

The proportions of all male Grey Nurse Sharks present at sites in the 2 coastal sections (i.e. at Forster and sites to the north versus Seal Rocks and sites to the south) differed significantly among surveys ($\chi^2 = 65.94$, $P < 0.001$). There were proportionally fewer males in the southern coastal section than would be expected by chance alone on all occasions except in surveys 2, 5 and 7 (Tables 4.5 & 4.6). The proportions of all female Grey Nurse Sharks in the 2 coastal sections also differed significantly among surveys (Tables 4.2 - 4.3 and $\chi^2 = 65.94$, $P < 0.001$). There were proportionally more females in the northern coastal section in the late winter and spring months (Table 4.5, surveys 4 & 8). In contrast, there were proportionally more females in the southern coastal section in the summer and autumn months (Table 4.6, surveys 1, 2, 5, 6 & 10).

The proportions of male Grey Nurse Sharks < 2 m TL in the 2 coastal sections differed significantly among surveys ($\chi^2 = 27.11$, $P < 0.001$). There were proportionally more < 2 m TL males in the northern coastal section than would be expected by chance alone in surveys 1 and 4 (Table 4.5). Similarly, the proportions of female Grey Nurse Sharks < 2 m TL present at Forster and sites to the north compared to Seal Rocks and sites to the south differed significantly among surveys ($\chi^2 = 75.07$, $P < 0.001$). There were proportionally more females in the southern coastal section than would be expected by chance alone in 7 of the 10 surveys (Table 4.6, surveys 2, 3, 5, 6 & 8 - 10).

The proportions of male Grey Nurse Sharks ≥ 2 m TL along the 2 sections of the coast differed significantly among surveys ($\chi^2 = 49.45$, $P < 0.001$). Proportionally fewer males ≥ 2 m TL occurred in the northern coastal section in surveys 6 and 10 (Table 4.5). In contrast, proportionally more males ≥ 2 m TL occurred in the southern coastal section in surveys 6 and 10 (Table 4.6). The proportions of female ≥ 2 m TL Grey Nurse Sharks present in the 2 coastal sections also differed significantly among surveys (Table 4.6 and $\chi^2 = 127.18$, $P < 0.001$). There were proportionally fewer females ≥ 2 m TL in the northern coastal section in the autumn months (Table 4.6, surveys 2, 6 & 10). In contrast, there were proportionally more females ≥ 2 m TL in the southern coastal section in the spring/summer months (Table 4.6, surveys 4, 8 & 9).

4.3.2.5. Comparisons within each coastal section

(1) Forster and sites to the north

The proportions of male to female Grey Nurse Sharks differed significantly among surveys ($\chi^2 = 65.45$, $P < 0.001$). There were proportionally more males in the winter periods (Table 4.5, surveys 3 & 7) and proportionally more females in the late winter/early spring months (Table 4.5, surveys 4 & 8). The ratio of males to females also differed significantly from a 1:1 sex ratio among surveys (Table 4.5). However, these differences were restricted to 4 of the 10 surveys. There was a significant bias towards males in the winter periods (Table 4.5, surveys 3 & 7) and a contrasting bias towards females in the late winter/spring months (Table 4.5, surveys 4 & 8).

The proportions of male to female Grey Nurse Sharks < 2 m TL did not differ significantly among surveys ($\chi^2 = 11.56$, $P > 0.10$). In contrast, the proportions of male to female Grey Nurse Sharks ≥ 2 m TL differed significantly among surveys ($\chi^2 = 72.89$, $P < 0.001$). There were proportionally more males ≥ 2 m TL observed in the winter periods (Table 4.5, surveys 3 & 7) and proportionally more females in the late winter/early spring months (Table 4.5, surveys 4 & 8). Moreover, these results were also reflected in sex ratios. However, the ratios of males to females < 2 m TL only differed significantly from a 1:1 sex ratio in survey 8 when there was there was a strong bias towards females (Table 4.5). The ratio of males to females ≥ 2 m TL also differed significantly from a 1:1 sex ratio among surveys (Table 4.5). There was a significant bias towards males in the late autumn/ early winter months (Table 4.5, surveys 3 & 7) and a contrasting bias towards females in the late winter/early spring months (Table 4.5, surveys 4 & 8).

The proportions of male Grey Nurse Sharks < 2 m TL to ≥ 2 m TL differed significantly among the 10 surveys ($\chi^2 = 56.41$, $P < 0.001$). There were proportionally more < 2 m TL and fewer ≥ 2 m TL males over the spring/summer months in 1998 and 1999 (Table 4.5). There were also proportionally fewer < 2 m TL and more ≥ 2 m TL males in the winter months in 1999 and 2000 (Table 4.5). The proportions of female Grey Nurse Sharks < 2 m TL to ≥ 2 m TL also differed significantly among the 10 surveys ($\chi^2 = 35.51$, $P < 0.001$). There were proportionally more < 2 m TL and fewer ≥ 2 m TL females in surveys 1, 3 and 5 (Table 4.5). In contrast, there were proportionally fewer < 2 m TL and more ≥ 2 m TL females in surveys 7 - 9 (Table 4.5).

(2) Seal Rocks and sites to the south

The proportions of male to female Grey Nurse Sharks differed significantly among surveys ($\chi^2 = 31.20$, $P < 0.001$). There were no males observed in survey 4 and proportionally fewer males and more females in surveys 1, 2 and 9 (Table 4.3). Furthermore, there were proportionally more males and fewer females in surveys 5 – 7 (Table 4.6). The ratio of males to females also differed significantly from a 1:1 sex ratio on all occasions except survey 8 (Table 4.6). Sex ratios of 1:3.00 or greater were evident and consistently biased in favour of females.

The proportions of male to female Grey Nurse Sharks < 2 m TL differed significantly among surveys ($\chi^2 = 31.86$, $P < 0.001$). There were proportionally fewer males and more females < 2 m TL in surveys 1, 4 and 9 (Table 4.6). Furthermore, there were proportionally more males and fewer females < 2 m TL in surveys 5 – 7 (Table 4.6). In contrast, the proportions of males to females ≥ 2 m TL did not differ significantly among the 10 surveys ($\chi^2 = 14.65$, $P > 0.10$). The sex ratios of Grey Nurse Sharks also exhibited marked differences from a 1:1 sex ratio. The ratio of males to females < 2 m TL was significantly biased in favour of females on all occasions except surveys 5 and 8 (Table 4.6). This bias was even more pronounced for the female sharks ≥ 2 m TL. Their sex ratios were significantly biased in favour of females in all 10 surveys (Table 4.3).

The proportions of male Grey Nurse Sharks < 2 m TL to > 2 m TL did not differ significantly among the 10 surveys ($\chi^2 = 8.08$, $P > 0.10$). However, the proportions of female Grey Nurse Sharks < 2 m TL to > 2 m TL differed significantly among the 10 surveys ($\chi^2 = 39.75$, $P < 0.001$). There were proportionally more < 2 m TL and fewer ≥ 2 m TL females in surveys 4 and 9 (Table 4.6). Moreover, there were proportionally fewer < 2 m TL and more ≥ 2 m TL females in surveys 6 - 8 (Table 4.6).

Table 4.5. Numbers of male and female Grey Nurse Sharks in 2 size-classes (i.e. < 2 m TL and > 2 m TL) observed in the northern section (i.e. Forster and sites north) from November/December 1998 to March/April 2001. Note the subdivision of coastline was based on the distribution of male Grey Nurse Sharks in the first survey.

Survey	Date	Size class	Male	Female	Ratio M:F	χ^2	P
1	Nov / Dec 1998	Total	**33**	**23**	1 : 0.70	1.79	ns
		< 2 m	21	13	1 : 0.62	1.88	ns
		≥ 2 m	12	10	1 : 0.83	0.18	ns
2	Mar / April 1999	Total	**17**	**17**	1 : 1.00	0.00	ns
		< 2 m	4	2	1 : 0.50	0.67	ns
		≥ 2 m	13	15	1 : 1.15	0.14	ns
3	Jun / Jul 1999	Total	**73**	**38**	1 : 0.52	11.04	*
		< 2 m	13	18	1 : 1.38	0.81	ns
		≥ 2 m	60	20	1 : 0.33	20.00	*
4	Aug / Sep 1999	Total	**29**	**77**	1 : 2.66	21.74	*
		< 2 m	14	22	1 : 1.57	1.78	ns
		≥ 2 m	15	55	1 : 3.67	22.86	*
5	Nov / Dec1999	Total	**28**	**39**	1 : 1.39	1.81	ns
		< 2 m	12	20	1 : 1.67	2.00	ns
		≥ 2 m	16	19	1 : 1.18	0.26	ns
6	Mar / April 2000	Total	**18**	**12**	1 : 0.67	1.20	ns
		< 2 m	3	4	1 : 1.33	0.14	ns
		≥ 2 m	15	8	1 : 0.53	2.13	*
7	May / June 2000	Total	**98**	**64**	1 : 0.65	7.14	*
		< 2 m	9	13	1 : 1.45	0.73	ns
		≥ 2 m	89	51	1 : 0.57	10.31	*
8	Aug / Sep 2000	Total	**30**	**74**	1 : 2.47	18.62	*
		< 2 m	5	15	1 : 3.00	5.00	*
		≥ 2 m	25	59	1 : 2.36	1.50	ns
9	Nov / Dec 2000	Total	**23**	**31**	1 : 1.34	1.19	ns
		< 2 m	6	4	1 : 0.67	0.40	ns
		≥ 2 m	17	27	1 : 1.59	2.27	ns
10	Mar / April 2001	Total	**28**	**20**	1 : 0.71	1.33	ns
		< 2 m	7	5	1 : 0.71	0.33	ns
		≥ 2 m	21	15	1 : 0.71	1.00	ns

Table 4.6. Numbers of male and female Grey Nurse Sharks in 2 size-classes (i.e. < 2 m TL and > 2 m TL) observed in the southern section (i.e. Seal Rocks and sites south) from November/December 1998 to March/April 2001. Note the subdivision of coastline was based on the distribution of male Grey Nurse Sharks in the first survey.

Survey	Date	size class	Male	Female	Ratio M:F	χ^2	P
1	Nov / Dec 1998	Total	**1**	**52**	1 : 52.00	49.08	*
		< 2 m	1	28	1 : 28.00	25.14	*
		≥ 2 m	0	24	-	24.00	*
2	Mar / April 1999	Total	**3**	**53**	1 : 17.67	44.64	*
		< 2 m	2	26	1 : 13.00	20.57	*
		≥ 2 m	1	27	1 : 27.00	24.14	*
3	Jun / Jul 1999	Total	**8**	**41**	1 : 5.13	22.22	*
		< 2 m	5	19	1 : 3.80	8.17	*
		≥ 2 m	3	22	1 : 7.33	14.44	*
4	Aug / Sep 1999	Total	**0**	**41**	-	41.00	*
		< 2 m	0	30	-	30.00	*
		≥ 2 m	0	11	-	11.00	*
5	Nov / Dec1999	Total	**7**	**23**	1 : 3.29	8.53	*
		< 2 m	6	10	1 : 1.67	1.00	ns
		≥ 2 m	1	13	1 : 13.00	10.29	*
6	Mar / April 2000	Total	**20**	**62**	1 : 3.10	21.51	*
		< 2 m	8	19	1 : 2.38	4.48	*
		≥ 2 m	12	43	1 : 3.58	17.47	*
7	May / June 2000	Total	**15**	**62**	1 : 4.13	28.69	*
		< 2 m	6	21	1 : 3.50	8.33	*
		≥ 2 m	9	41	1 : 4.56	20.48	*
8	Aug / Sep 2000	Total	**1**	**3**	1 : 3.00	1.00	ns
		< 2 m	1	0	1 : 0.00	1.00	ns
		≥ 2 m	0	3	-	3.00	*
9	Nov / Dec 2000	Total	**2**	**32**	1 : 16.00	26.47	*
		< 2 m	1	25	1 : 25.00	22.15	*
		≥ 2 m	1	7	1 : 7.00	4.50	*
10	Mar / April 2001	Total	**14**	**69**	1 : 4.93	36.45	*
		< 2 m	6	39	1 : 6.50	24.20	*
		≥ 2 m	8	30	1 : 3.75	12.74	*

4.3.3. Identification of key sites (Critical Habitat)

Grey Nurse Sharks were observed in aggregations of 5 or more individuals at 14 of the sites sampled over the 10 surveys. These aggregations accounted for 89.8% of the sharks observed averaged over the 10 surveys (Table 4.7). Of the 14 sites, only 5 sites occurred in marine protected areas (i.e. Julian Rocks Aquatic Reserve - 1 site, Solitary Islands Marine Park - 3 sites, Jervis Bay Marine Park - 1 site) and have been afforded some form of protection. These marine protected areas accounted for 14.2% of the sharks observed along the entire coast over the 10 surveys (Table 4.7). Two of the 14 sites: "Pimpernel Rock and the "Cod Grounds", occur in Commonwealth waters. Furthermore, with the exception of "the Drum and Drumsticks", there is currently no protection for any of the aggregation sites south of Coffs Harbour. Five of these key sites spanning South West Rocks to Nelson Bay (see Table 4.7) account for 60.6% of the sharks observed along the entire coast averaged over the 10 surveys.

The degree of consistency of usage of these sites varied between 10 and 100% of time (i.e. between 1 & 10 surveys - Table 4.7). Grey Nurse Shark aggregations were present at 7 key sites for at least 8 of the 10 surveys (i.e. an aggregation consistency ≥ 80% - Table 4.7). Moreover, the percentage usage was positively correlated with the mean percentage of the observed population at a given aggregation site ($r_s = 0.855$, $P < 0.01$).

Table 4.7. Mean percentage of Grey Nurse Sharks observed in aggregations and consistency of aggregation site usage along the NSW coast (listed from North to South) for the population sampled over 10 surveys from November/December 1998 to March/April 2001. See text for details of calculations. AR: Aquatic Reserve; MP: Marine Park; NP: Not Protected; *: site is located in commonwealth waters.

Site	Nearest coastal town	Mean (SE) percentage of sampled population	Aggregation consistency (% usage)	Protected status of site
Julian Rocks	Byron Bay	2.7 (2.39)	30.0	AR
Pimpernel Rock *	Brooms Head	4.6 (2.45)	75.0	MP
Nth Solitary Is.	Wooli	2.5 (1.37)	40.0	MP
Sth Solitary Is.	Coffs Harbour	4.4 (1.63)	80.0	MP
Fish Rock & Green Is.	SW Rocks	12.7 (6.27)	80.0	NP
Cod Grounds *	Laurieton	11.8 (10.00)	100.0	NP
Pinnacle	Forster	12.7 (2.75)	100.0	NP
Big & Little Seal Rks.	Seal Rocks	14.0 (5.18)	80.0	NP
Little Broughton Is.	Nelson Bay	9.4 (3.03)	90.0	NP
Magic Point	Maroubra	3.5 (1.68)	55.6	NP
Bass Point	Shellharbour	1.0 (0.58)	10.0	NP
Drum & Drumsticks	Jervis Bay	0.3 (1.25)	25.0	MP
Tollgate Is.	Batemans Bay	8.9 (3.09)	90.0	NP
Montague Is.	Narooma	1.3 (1.02)	20.0	NP

4.3.4. Incidence of hooking

Grey Nurse Sharks with hooks embedded in their jaws were seen at all the aggregations sites in NSW waters. There was no significant difference between years in the annual mean incidence of hooking (Table 4.8a and c, $P > 0.05$). However, the proportions of Grey Nurse Sharks with and without hooks embedded in their jaw and/or buccal cavity differed significantly among replicate surveys (Table 4.9, $\chi^2 = 24.35$, $P < 0.01$). Greater incidences of hooking than would be expected by chance alone ($P < 0.05$) were evident in surveys 2, 5, 7 and 10 (Table 4.9). There were also occasions (Table 4.9 - surveys 6, 8 and 9) where fewer hooking incidences were evident.

Table 4.8. Analysis of variance of the mean number of Grey Nurse Sharks with nylon or wire trace embedded in their jaws and/or buccal cavity in 1999 and 2000. (a) Analysis of variance of the two fishing gears combined, (b) analysis of variance of the two fishing gears between years, and (c) mean numbers (SE) and percentage (SE) of sharks with nylon or wire trace fishing gear.

(a) Analysis of variance of the two fishing gears combined

Source of Variation	df	SS	MS	F	P
Year	1	60.50	60.5	0.568	0.480
Residual	6	639.00	106.5		
Total	7	699.50			

(b) Analysis of variance of the two fishing gears between years

Source of Variation	df	SS	MS	F	P
Year	1	34.93	34.93	100.34	0.063
Nylon vs wire	1	697.49	697.49	13.63	0.003
Y x N vs W	1	0.35	0.35	0.01	0.936
Residual	12	614.21	51.18		
Total	15	1346.98			

(c) Mean numbers (SE) and percentage (SE) of sharks with nylon or wire trace fishing gear

Year	Fishing Gear				Total	
	Nylon		Wire			
	No (SE)	% (SE)	No (SE)	% (SE)	No (SE)	% (SE)
1999	16.50 (2.40)	10.40 (1.89)	3.00 (1.08)	1.99 (0.90)	19.50 (1.76)	12.38 (1.71)
2000	13.25 (6.65)	6.37 (1.72)	0.75 (0.48)	0.34 (0.20)	14.00 (7.08)	6.71 (1.86)
Pooled Mean	14.88 (3.33)	8.38 (1.41)	1.88 (0.69)	1.16 (0.53)	16.75 (3.53)	9.55 (1.59)

Table 4.9. Comparison of the numbers of Grey Nurse Sharks with and without hooks and/or trace present in surveys 1-10.

	Survey									
Category	1	2	3	4	5	6	7	8	9	10
Hooks Present	10	17	23	16	22	8	35	9	4	21
No Hooks	126	112	184	171	110	141	257	137	116	145

The annual mean incidences of hooking with nylon or wire trace fishing gear did not differ significantly between years, but the annual mean number of sharks hooked with nylon line was significantly greater than those hooked with wire trace (Table 4.8b, $P > 0.05$ & $P < 0.01$, respectively). Approximately, seven times more sharks were observed with hooks and nylon line compared to hooks and wire trace (Table 4.8c).

Moreover, the proportions of Grey Nurse Sharks bearing hooks with nylon line compared to hooks with wire trace did not differ significantly among surveys (Table 4.10 - $\chi^2 = 14.83$, $P > 0.05$). Finally, the regression of hooking incidence on time was significant (Fig. 4.7 - $R^2 = 0.8568$, $P < 0.05$) and showed that hooking by both fishing gears combined (i.e. nylon line and wire trace) had increased six-fold. In 1991, approximately 2% of the sharks surveyed had hooks embedded in their jaws compared to about 12% in 2001.

Finally, there were numerous sightings over the 10 surveys of a female Grey Nurse Shark that had been finned (i.e. the dorsals, pectorals and lower caudal fin had been removed). The shark was first observed at Fish Rocks (South West Rocks) in May 1999 and was subsequently observed at Manta Arch (South Solitary Is.), the Cod Grounds (off Laurieton) and off Montague Island (Narooma).

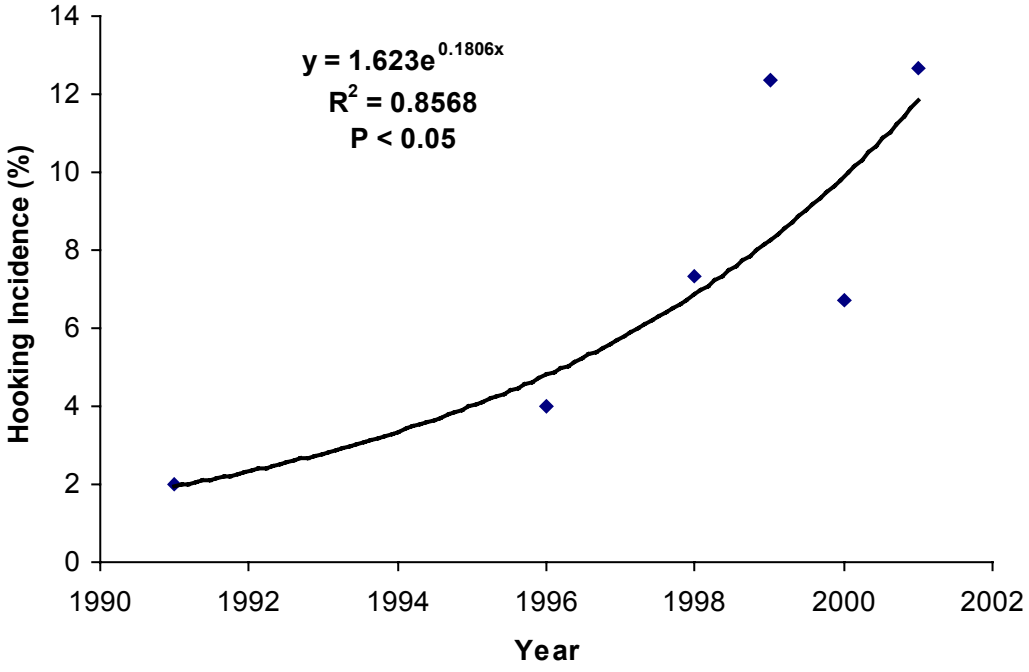

Figure 4.7. Regression of hooking incidence of Grey Nurse Sharks on time. Data for 1991 and 1996 are from Pollard *et al*. 1996.

Table 4.10. Comparison of hooking incidences with wire trace and nylon line for surveys 1-10.

Survey	Date	Fishing Gear								% of sharks with hooks in survey
		Hook and Nylon Monofilament line				Hook and Wire Trace				
		M	F	U	Total	M	F	U	Total	
1	Nov/Dec 98	1	8	0	9	1	0	0	1	7.35
2	Mar/Apr 99	0	3	8	11	2	3	1	6	13.18
3	May/Jun 99	2	7	11	20	1	1	1	3	11.11
4	Sep/Oct 99	0	8	6	14	1	1	0	2	8.56
5	Nov/Dec 99	8	8	5	21	0	1	0	1	16.67
6	Mar/Apr 00	2	2	4	8	0	0	0	0	5.37
7	May/Jun 00	11	10	12	33	0	1	1	2	11.99
8	Aug/Sep 00	3	3	2	8	0	1	0	1	6.16
9	Nov/Dec 00	3	1	0	4	0	0	0	0	3.33
10	Mar/Apr 01	4	10	2	16	1	4	0	5	12.65

4.4. Discussion

4.4.1. Spatial and temporal variation in abundance

The abundances of Grey Nurse Sharks exhibited substantial spatial and temporal variation along the entire NSW coast. Despite this, there were obvious patterns that were consistent between years. Fourteen sites had fairly consistent aggregations of 5 or more Grey Nurse Sharks present over the 10 surveys. Observations of new-born pups at these sites indicate that these sites play an important role in reproduction. Why these particular sites are chosen over others is unclear at this stage, especially given that the physical habitats were very similar at all the sites sampled. However, it is likely that there are, as yet unknown, physical and/or biological attributes which attract the sharks to these particular sites.

The maximum number of sharks observed (i.e. 292 individuals over 57 sites, on average) along the entire coast was very low given that Grey Nurse Sharks have been protected since 1984. It is possible that large numbers of sharks were not sighted because they were moving between sites at the time of the survey. However, the likelihood of such a scenario is probably small because of: (1) the large number of sites sampled, (2) the absence of widely disparate results over the 10 surveys, and (3) the distribution of sites along the entire coast. The absence of Grey Nurse Sharks at 63% of the sites sampled is a statistic that is cause for concern, especially given that the sites were chosen because of their previous occupation by Grey Nurse Sharks (i.e. in the 1960's). Given the extremely low numbers, it is important that these surveys are repeated on a regular basis over several years to provide estimates of the inter-annual variation in abundance. Moreover, the documentation of the mean annual abundances would enable trends in population abundance (i.e. towards recovery or extinction) to be examined over longer time periods.

The need for a tagging program to document: (1) the total number of Grey Nurse Sharks in the NSW population, (2) localised and migrational movements, (3) estimates of the timing and duration of occupancy of a site, and (4) estimates of the rates of inadvertent capture (i.e. as by-catch) by commercial fishers (i.e. on setlines) or recreational fishers (i.e. on various gear) has been recommended previously (see Otway & Parker, 2000). To this end, a tagging program using "cattle ear tags" has commenced. This work should provide preliminary information addressing all four questions raised above.

The coastwide surveys of Grey Nurse Sharks have also been limited by the maximum depth to which recreational scuba divers can dive (i.e. ≈ 40 metres). However, it is likely that the sharks, and especially the males, could utilise appropriate habitats (i.e. gutters, overhangs and caves) in waters 10 – 20 m deeper than the diving surveys permit (i.e. to an overall depth of 60 m). If deeper sites are utilised, it is likely that some or many of these sites would be located in commonwealth waters. The absence of surveys in deeper waters has been a point of contention at meetings with fishing groups including commercial fishers, gamefishers, charterboat fishers, spearfishers and recreational line fishers. It is desirable, therefore, to ascertain whether Grey Nurse Sharks utilise sites in waters deeper than 40 metres. If present in deeper waters, it will be necessary to quantify the spatial and temporal patterns of abundance at intervals of time similar to the diver surveys to enable more robust interpretations of the resulting data.

Documenting whether Grey Nurse Sharks do actually utilise sites in deeper water will require four, contemporaneous, lines of investigation. First, it will be necessary to review the data concerning the capture of Grey Nurse Sharks by gamefishers. These data would identify whether Grey Nurse Sharks were caught at sites in deeper water and these could be highlighted for further investigation. Second, consultation with representatives from the commercial and recreational (e.g. linefishers, gamefishers & charterboat fishers) fishing sectors would also be used to identify other potential sites in deeper waters. Third, it may be necessary to use underwater video census techniques to sample sites in deeper water. Last, it would also be important to use archival, acoustic ("smart") tags fitted with depth sensors to record the depth of water in which individual Grey Nurse Sharks swim.

The first two lines of investigation provide preliminary information on possible sites in deeper water. The subsequent two lines of investigation would provide rigorous, quantitative data. All four lines of investigation have an associated cost, and while the use of acoustic tags is initially high, they maximise the amount of information gained and simultaneously minimise the effort required within a restricted time-period. Moreover, it is unlikely that the necessary information could be obtained by any other means or for an equivalent cost because the sea-time required for video census work would require even greater funds for the chartering of vessels and the submersible video equipment.

Ideally, a combination of all 4 lines of investigation will be needed to overcome the shortfall in the diver surveys because, singularly, they would not provide a complete picture.

4.4.2. Population size-structure, reproduction and recruitment

The results from the 10 surveys along the entire coast showed that the Grey Nurse Shark population exhibited a sex-ratio biased in favour of females except in winter when there was a 1: 1 sex ratio. A previous survey at Seal Rocks in spring 1991 showed that 86% of the Grey Nurse Sharks observed were female (Ecology Lab, 1991; Pollard *et al*., 1996). This bias towards females is also consistent with the predominance of females in the overall catch of Grey Nurse Sharks (i.e. 77.4% - Reid and Krogh, 1992 and 77.8% - Krogh, 1994) in the protective beach nets in NSW (i.e. off Newcastle, Sydney and Wollongong). A similar pattern has been reported off Natal (South Africa), where sex-ratios have reached 2.3: 1 biased in favour of females (Bass *et al*., 1975; Cliff, unpub.), and off the east coast of the USA (Springer, 1963; Clark and Von Schmidt, 1965; Gilmore *et al*., 1983). These same authors concluded that sexual segregation of male and female Grey Nurse Sharks was responsible for the biased sex-ratios. Consequently, the biased sex-ratios in: (1) this study, (2) the 1991 survey, and (3) the protective beach nets were most likely due to segregation of the sexes rather than an actual difference in the abundances of males and females.

On subdividing the coastline into northern (i.e. Forster - N. Stradbroke Is) and southern (i.e. Seal Rocks - Eden) sections based on the distribution of the male Grey Nurse Sharks, the biases in the sex-ratios changed markedly. The differences in the sex-ratios in northern and southern sections are most likely due to a combination of sexual segregation, reproductive activities (pupping and mating), and sex-related differences in migratory movements. Previous research in South Africa (e.g. Bass *et al*., 1975; Cliff unpub.) and on the east coast of the USA (e.g. Bigelow and Schroeder, 1953; Gilmore *et al*., 1983) has shown that female Grey Nurse Sharks undergo regular migratory movements for mating, gestation and parturition. Unfortunately, less is known about the migratory movements of males in these regions. Nevertheless, research in South Africa (Cliff unpub.) has shown that male Grey Nurse Sharks tend to commence their migratory movements several weeks after the females. If we assume that the Grey Nurse Sharks on the east coast of Australia also undergo migratory movements similar to that documented on the east coast of the USA, it is likely that the greater number of males in the northern section of the coast and their near absence from Seal Rocks to Eden is the result of differential migratory movements. While these observations provide support for a "migration hypothesis" (see Otway & Parker, 2000) they could also be the result of localised (small-scale) movements. It will be important to gain further information concerning localised and migrational movements. Fluctuations in abundance at any particular site will likely be the result of short-term, localised movements. The range over which these movements occur is, as yet, unknown and needs to be quantified.

Documenting the short-term, localised movements would be best achieved by using acoustic ("smart") tags as they maximise the amount of information gained whilst simultaneously minimising the effort required within a restricted time period. The only drawback is their initial cost. However, it is unlikely that the necessary information could be obtained by any other means or for an equivalent level of funding. In spite of this, some preliminary information concerning short-term, localised movements should be forthcoming via the tagging program discussed earlier.

The results of the 10 surveys also have substantial implications for the fecundity, reproduction and recruitment of Grey Nurse Sharks along the east coast of Australia (NSW and southern Queensland). Previous research in South Africa and along the east coast of the USA (e.g. Bass *et al*., 1975; Gilmore *et al*., 1983; Branstetter, 1990; Branstetter and Musick, 1994) has shown that female Grey Nurse Sharks attain sexual maturity on reaching 2.20 - 2.30 m TL and give birth to 2 pups (0.90 - 1.20 m TL) every 2 years. This gives a mean fecundity of 1 pup per annum. Furthermore, as pupping in South Africa and on the east coast of the USA occurs in Winter (Gilmore *et al*., 1983; Branstetter and Musick, 1994; Cliff, Unpub. MS) it is likely to occur at a similar time off the east coast of Australia. Moreover, female Grey Nurse Sharks in the Underwater World aquarium (Mooloolaba, Qld.) have given birth to 2 healthy pups on several occasions in August/September (A. Scrivyer, pers. comm.). These observations suggest that the fecundity and timing of parturition in Australia should be similar to that in South Africa and along the east coast of the USA. Observations of near-term pregnant females followed by new-born pups during the winter surveys at several of the aggregation sites supports the interpretation that pupping does indeed occur during winter and possibly into early spring.

With this in mind, it is likely that pups born in 1999 and 2000 would have been readily observed in the winter or spring surveys (i.e. surveys 3-4 and 7-8, respectively). Any pups observed would have been approximately 1.00 - 1.20 m TL and easily discernible from other individuals in the population. However, very few pups were observed over these periods or indeed the entire 10 surveys. This is cause for concern for at least 3 reasons related to: (1) sampling error, (2) reproductive failure, and (3) mortality.

First, it may be that the pups were not observed using the existing sampling techniques possibly because they moved away from the pupping sites and were therefore not seen. However, given that Grey Nurse Shark pups (male and female) remain with the reproductively mature females for many

months after birth (Branstetter and Musick, 1994; Cliff, Unpub. MS) and the fact that divers observed a few pups swimming with aggregations of reproductively mature sharks (i.e. > 2 m TL), it is unlikely that large numbers of pups would have moved away. This suggests that the sampling techniques used were appropriate and detected any pups that were present. It is also possible that several important pupping sites may not have been identified and sampled despite the intense sampling effort over the 10 surveys (i.e. 57 sites on average).

Second, if there were indeed fewer pups than expected, then a reproductive failure may have occurred. This may have been triggered by continuously declining numbers of Grey Nurse Sharks. Consider the following example based on the direct relationship between the numbers of reproductively mature females and pups. If we assume that all the female Grey Nurse Sharks > 2 m TL were reproductively mature in winter 2000 (i.e. 92 females in survey 7 given a 50:50 sex ratio – see Table 4.4), then there should have been 92 pups evident in winter 2000. Given that pups would have been recorded in the 1 - 2 m TL size-class which comprised 49 individuals, there were fewer pups than the expected. However, as previous research has shown that female Grey Nurse Sharks do not attain reproductive maturity until at least 6 years of age (e.g. Gilmore *et al*., 1983; Branstetter and Musick, 1994), the 1 - 2 m TL size-class will contain a mix of individuals aged 0+ to 5+ years (i.e. 6 age-classes). If individuals in the 1 - 2 m TL size-class divided into 6 numerically equal size-classes, each size-class would only comprise approximately 8 individuals, on average. Clearly, 8 pups is well below the expected number of 92. If a reproductive failure has occurred, it is likely that it occurred over several years, given the numbers of individuals in the projected 6 age-classes contained within the 1 - 2 m TL size-class (see discussion above). More importantly, if a reproductive failure has occurred, the average fecundity of the shark falls to below 1 pup per annum: a rate that is clearly insufficient to sustain a population yet alone enable it to recover.

Third, the large difference between the numbers of pups observed and expected may be due to an extremely high rate of mortality of pups. If we assume that the 14 pups observed in spring 2000 (see section 4.3.1) were the only survivors of the recruitment pulse for that year, this would give a mortality rate of about 85% based on the expected 92 pups. This is a dramatic contrast to estimates of natural mortality over the life-span of Grey Nurse Sharks which range from 12.90% (Smith *et al.* 1998), 15.43% (Mollet 2001) to 18.42% (Mollet & Cailliet, 2002). While the evolutionary role of reduced fecundity and live birth at a relatively large size is to reduce the rate of mortality to a level that will ensure long-term survival of the species, the natural rate of mortality of shark pups (i.e. 0+ years) may be higher than the older individuals (e.g. Holden 1977, Cailliet 1992). However, the above calculated rate of mortality is clearly extreme to say the least. This rate, even if overestimated by a factor of 4, clearly suggests that sources other than those associated with natural mortality are occurring. Given the significantly increased incidence of hooks embedded in the jaws of Grey Nurse Sharks (see Section 4.3.4), it is likely that pups and/or juvenile sharks have been exposed to fishing-related mortality. Numerous authors (e.g. Olsen 1954, Cailliet 1992, Smith *et al.* 1998) have indicated that high rates of fishing mortality on juvenile sharks can result in serious decreases in the overall population size. More recently, Mollet and Cailliet (2002) have shown that fishing the juvenile age classes has the same effect on the growth of the entire population as fishing all adult age classes. Moreover, a 10% increase in the fishing mortality of juveniles or adults would require an approximate 50% increase in the sharks fecundity to return the population to its original growth rate (Mollet & Cailliet, 2002). This is clearly not possible for Grey Nurse Sharks because of their inter-uterine cannibalistic phase that prevents an increase in fecundity beyond the 2 pups every 2 years.

Clearly, the rates of fishing mortality will need to be quantified in the future (see comments in Chapter 6). Preliminary estimates could arise through the tagging study discussed earlier. The ability to estimate rates of mortality from a range of sources will depend greatly on the degree of reporting of tagged individuals.

4.4.3. Identification of key sites (Critical Habitat)

Twelve sites accounted for 88.5% of the Grey Nurse Sharks observed over the 10 surveys. Of these, only Julian Rocks Aquatic Reserve (i.e. 1 site) and Solitary Islands Marine Park (3 sites including "Pimpernel Rock" in Commonwealth waters had been afforded some form of protection at the completion of the surveys (i.e. in autumn 2001). The aggregation site within the Julian Rocks Aquatic Reserve (i.e. an area of radius 500 m from the rocks) accounted for 2.7% of the Grey Nurse Shark population (Table 4.7). Commercial fishing has been banned in the aquatic reserve, but recreational fishing is still allowed. Whilst the aquatic reserve protects the shark from commercial fishing, it is likely that accidental hooking via recreational fishing will continue (see Table 4.7). The area around Pimpernel Rock (i.e. a 500 m radius from the rock) was declared a sanctuary zone by the Commonwealth government (see Commonwealth of Australia 2001) and all forms of fishing (i.e. spearfishing, recreational, charterboat and commercial fishing) are banned. Other non-destructive activities are still allowed, but require permits. It is likely that the 4.6% of the Grey Nurse Shark population observed over the surveys (Table 4.7) will receive greater protection at this site. The key aggregation sites and North and South Solitary Islands accounted for 2.5% and 4.4% of the Grey Nurse Shark population, respectively (Table 4.7). Unfortunately, these key aggregation sites are not located in the sanctuary zones around both islands. However, the use of wire traces for bottom fishing has been banned within 500 m of both islands (Marine Parks Authority, 2002). Given the incidence of hooking of Grey Nurse Sharks by hooks attached to nylon line (see Table 4.10), it is likely that the sharks will still be vulnerable to hooking by recreational fishers at these sites. With this in mind, it is recommended that critical habitats be declared at the aggregation sites at North and South Solitary Islands.

The four marine protected areas discussed above all occur in the northern NSW coastal waters and combined, account for 14.2% of the sharks observed along the entire coast. Given that the Grey Nurse Shark population is segregated by sex with more males occurring in the northern NSW waters, these four sites will protect proportionally more males than females. The remaining 8 sites, including the "Cod Grounds" in Commonwealth waters, had no management arrangements in place at the end of the surveys (i.e. in autumn 2001). These sites were occupied by 74.3%, on average, of the observed Grey Nurse Shark population documented during the surveys. From a biological perspective, observations of pups and females with mating scars at these key (aggregation) sites indicate that these places play an important role in reproduction (see Section 4.3.1). Why these particular sites have fairly consistent aggregations is unclear at present given that the physical habitats (i.e. gutters, caverns and/or caves) were very similar at all the sites sampled. However, it is likely that there are, as yet unknown, biological attributes that attract the sharks to these particular sites. However, given that the degree of consistency of usage of these sites was also positively correlated with the percentage of the population present, it is clear that these sites are important for various stages of the life-cycle of Grey Nurse Sharks.

In December 2002, NSW Fisheries declared Critical Habitats at Julian Rocks (Byron Bay), Fish Rock and Green Island (South West Rocks), The Pinnacle (Forster), Big and Little Seal Rocks (Seal Rocks), Little Broughton Island (Port Stephens), Magic Point (Sydney), Bass Point (Shellharbour), the Tollgate Islands (Batemans Bay), and Montague Island (Narooma) under Section 220Q of the *Fisheries Management Act 1994 (and Amendments)*. Moreover, Environment Australia is currently engaged in a consultation process aimed at providing protection for the "Cod Grounds." Consideration should also be given to declaring "Pimpernel Rock" and the "Cod Grounds" as critical habitat under the *EPBC Act (1999)*.

4.4.4. Incidence of hooking

The coastwide surveys showed that there has been a significant increase in the incidence of hooking over the past decade. The tagging program now underway will also enable independent estimates of the incidence of hooking. These estimates should be substantially more accurate as they will be based on individually identifiable sharks. This will enable the apparent levels of accidental hooking evident in 2001 to be verified. The incidental capture on hooks with nylon fishing line was greater than that on hooks with wire trace. Accidental capture (and subsequent release) can cause a number of pathological and physiological changes in sharks (see section 6.1.1 for a summary) and these may have long-lasting effects. Consequently, these effects will need to be assessed rigorously in the near future as a matter of priority. In the meantime, the accidental hooking of Grey Nurse Sharks is potentially an important process that may threaten the recovery of the species. With this in mind, a precautionary approach should be adopted. The need for a precautionary approach is also heightened by the limited scientific evidence on the effects of accidental hooking of Grey Nurse Sharks in the waters off the east coast of Australia. However, the effects of hooking on other species of shark have been documented (see De Roos & De Roos 1978, Holeton & Heisler 1978, Gruber & Keyes 1981, Cliff & Thurman 1984, Moss 1984, Dingerkus 1989, Smith 1992). Consequently, appropriate mitigative measures should be taken, where possible, to reduce the incidence of accidental hooking. Furthermore, the incidence of hooking could also be quantified during tagging operations. This could be achieved by using a metal detector to document whether the particular Grey Nurse Shark has any hooks embedded in its buccal cavity or digestive tract. Thus, the use and application of a metal detector should be further investigated.

5. DEVELOPMENT OF A VOLUNTARY CODE OF CONDUCT FOR SCUBA DIVING WITH GREY NURSE SHARKS

5.1. Introduction

The Grey Nurse Shark is a unique predator because scuba divers can approach the species without fear of an attack, due to the shark's placid nature. Diving with Grey Nurse Sharks in NSW is a popular recreational activity amongst scuba divers. Some of the key sites where Grey Nurse Sharks aggregate have become popular dive sites. It has been suggested that these " shark dives" may have an impact on the shark and its behaviour. However, Otway and Parker (2000) considered that the effects of the actions of scuba divers on the sharks were likely to be negligible compared to other activities such as commercial and recreational fishing.

In spite of this, there is little scientific evidence documenting whether a diver's behaviour whilst observing Grey Nurse Sharks has an impact on the species (i.e. its biology and/or behaviour). The Scuba Divers Association of NSW felt that any impact that scuba divers may have on the shark would be mitigated by divers adopting a responsible attitude and ensuring appropriate behaviour. With this in mind, the Scuba Divers Association of NSW suggested that a voluntary code of conduct be developed for scuba diving with Grey Nurse Sharks and provided NSW Fisheries with a range of suggestions for inclusion in a draft code.

5.2. Materials and methods

NSW Fisheries facilitated a united effort with the recreational scuba diving industry to develop a practical, voluntary code of conduct for diving with Grey Nurse Sharks. The steps involved in the development of the code are outlined in a flow-chart (Fig. 5.1). A 4-page document was prepared and included: (1) background information about Grey Nurse Sharks, (2) an outline of the consultation process, and (3) the suggestions provided by the Scuba Divers Association of NSW (Table 5.1). This document was sent to numerous scuba diving groups along the entire NSW coast. These scuba diving groups were asked to indicate their agreement or disagreement with the suggestions. They were also invited to make further suggestions for inclusion in the draft code of conduct. The various scuba diving groups were also asked to provide relevant contact details so that the statewide results could be forwarded to them. This was done to enable them to compare their own views with those of other divers from around the state.

The information provided by the scuba diving groups was entered into a computer database. The number (and percentage) of responses that agreed or disagreed with each of the suggestions provided by the Scuba Divers Association of NSW was quantified. These data were then summarised and tabulated.

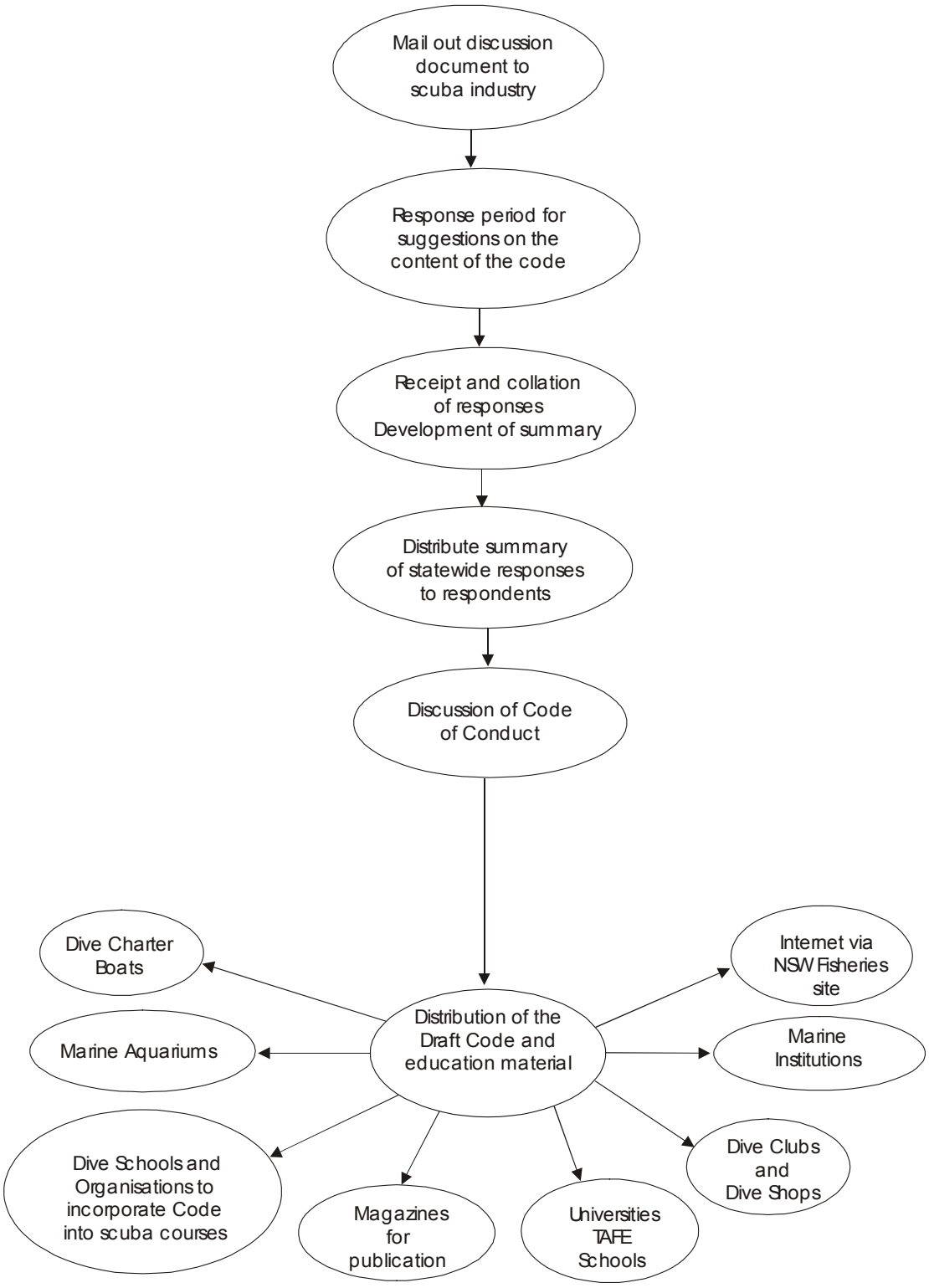

Figure 5.1. Flow chart for the development of a voluntary code of conduct for scuba diving with Grey Nurse Sharks

Table 5.1. Suggestions for the voluntary code of conduct provided by the Scuba Divers Association of NSW.

Suggestions
- Each dive site should have at least one Grey Nurse Shark sanctuary area (gutter) where human interaction (i.e. from scuba divers) should be kept to a minimum - Observe shark from above on top of ridges - Keep out of gutters - Do not block entrances to cave or gutter - Do not interrupt the swimming pattern of the sharks - Do not feed or touch sharks - Do not chase or harass sharks – no mechanical apparatus i.e. scooters, horns - Divers must stay together as a group - All dive guides to have logged at least 20 dives with Grey Nurse Sharks - Group must be no more than ten divers - A comprehensive and specific dive brief will be given by the dive leader before each dive - All commercial operators must be signatories to the Code of Conduct - All dive guides must attend a workshop on Grey Nurse Sharks and have a comprehensive knowledge of the dive site - Recognised Grey Nurse Shark dives must be led by a qualified dive guide - Code of Conduct to be displayed in a prominent position with in the boat or shop - All divers must comply with the Code of Conduct (commercial, clubs, private dive groups) - Dive operators must participate in scientific research

5.3. Results

Of the 181 documents sent out, 86 documents (47.5%) were returned completed. This was greater than anticipated, and reflects the commitment of NSW scuba divers to the conservation of the shark. It is important to note that the responses were from individuals and clubs with memberships in excess of 30 divers. Consequently, the total number of divers in NSW contributing to the development of the code of conduct was far greater than indicated by the 86 responses received.

Each respondent was sent copies of the statewide summary of responses together with a copy of their original response. This enabled each respondent to examine where their responses lay in comparison to the statewide summary. Feedback from the divers involved in the survey indicated that the overall process was informative and that there was general support for a code of conduct.

The responses exhibited varying degrees of support for the 17 proposals (Table 5.2). Despite this, the proposals could be placed into 3 groups based on the level of agreement/disagreement. The first group comprised 9 of the 17 proposals (Table 5.2, Proposals 4 – 7 and 13 – 17 inclusive) and had very high levels of acceptance of 90 – 99%. The second group comprised 2 of the 17 proposals (Table 5.2, Proposals 1 and 9) and had high levels of acceptance of 83% and 84%, respectively. The third group comprised 6 of the 17 proposals (Table 5.2, Proposals 2 – 3, 8 and 10 – 12 inclusive) and had low to medium levels of acceptance varying between 45% and 67%.

The respondents were also given an opportunity to provide additional comments and these are summarised in Table 5.3.

Table 5.2. The statewide responses by the scuba diving industry.

Question	Agree		Disagree		No comment	
	No.	%	No.	%	No.	%
1. Each location to have at least one Grey Nurse Shark sanctuary area	71	83	12	14	3	3
2. Observe shark from tops of ridges	47	55	36	42	3	3
3. Keep out of gutters	39	45	43	50	4	5
4. Do not block entrances to cave or gutter	84	98	2	2	0	0
5. Do not interrupt the swimming pattern of the sharks	85	99	1	1	0	0
6. Do not feed or touch sharks	79	92	6	7	1	1
7. Do not chase or harass sharks - no mechanical apparatus i.e. scooters, horns	85	99	1	1	0	0
8. Divers must stay together as a group	58	67	25	29	3	4
9. Group must be no more than ten divers	72	84	10	12	4	4
10. Recognised Grey Nurse Shark dives must be led by a qualified dive guide	57	66	28	33	1	1
11. All dive guides to attend a workshop on Grey Nurse Sharks	56	65	25	29	5	6
12. All dive guides to have logged at least 20 dives with Grey Nurse Sharks	47	55	33	38	6	7
13. A dive brief to be given by the dive leader before each dive	81	94	3	4	2	2
14. All commercial operators to be signatories to the Code of Conduct	82	95	1	1	3	4
15. Code of Conduct to be displayed in the boat or shop	78	91	4	5	4	4
16. All divers to comply with the Code of Conduct (clubs, private dive groups)	84	98	1	1	1	1
17. Dive operators to participate in scientific research	77	90	8	9	1	1

Table 5.3. List of additional comments provided by the recreational scuba diving industry for further consideration.

Additional Comments

- the possibility of limiting some diving & boating activities at Grey Nurse Shark sites,
- the development of an education program,
- the promotion of passive observations,
- an “exclusion” zone at some sites,
- limit or ban flash photography and bright lights,
- limit anchoring,
- banning extractive activities,
- diver experience,
- limit approach to sharks according to a distance in meters,
- guided shark dives,
- promotion of the Code of Conduct,
- public moorings to be provided on shark sites,
- a "Shark Tax" for commercial divers towards management,
- access be limited to charter boats in areas where it is felt more control is required,
- all shark dives to be conducted by registered (permitted) operators or clubs,

- code should be designed to cater for each area or site,
- commercial operators receive official "caretakers" status,
- details of every GNS dive to be supplied to NSW Fisheries,
- develop dive plan for each major GNS dive site,
- email or call 1800 number to give details after diving with GNS,
- keep out of narrow gutters <3 m,
- licensed dive operators who profit from GNS dive give proceeds to research,
- limit access to some sites to researchers only (e.g. scientific research zone),
- non compliance with code results in operator/diver being banned from site,
- refrain from giving information on GNS location to fishing parties, etc.,
- review date and performance monitoring of code, and
- vessels should not be left unattended at GNS dive sites.

5.4. Discussion

The varying degrees of support for the 17 proposals and the subsequent placement into groups based on the levels of agreement/disagreement reflected the types of issues being addressed. The first group of 9 proposals had very high levels of acceptance and comprised 2 sets of proposals. The first set of proposals (Table 5.2, Proposals 4 – 7) dealt with issues relating to the interaction of scuba divers and the sharks directly. The second set (Table 5.2, Proposals 13 – 17) were concerned more with advertising and compliance with the proposed code of conduct. The second group comprised 2 proposals and had high levels of acceptance. The slightly lower levels of support may be due to a misunderstanding of the word “sanctuary” in Proposal 1 and, in part, to an unintentional suggestion, in Proposal 2, that would restrict current diving practices. On talking to some of the divers, it became apparent that their understanding of the word “sanctuary” was a site protected from all human activities including scuba diving. The more accepted meaning and that used in this study, was a site that is protected from all threatening human activities as is the case with sanctuary zones in NSW marine parks.

The third group of proposals, also comprised 2 sets of outcomes, the first of which (Table 5.2, Proposals 2 & 3) clearly dealt with where divers could observe the sharks. Obvious differences in the site topography and diving conditions (e.g. surge, currents and or visibility) among the various dive sites would have contributed greatly to the differing responses and lower levels of acceptance. The second set of outcomes (Table 5.2, Proposals 10 – 12 inclusive) clearly focussed on the experience of dive guides responsible for overseeing the “shark dive.” It is possible that these proposals may have highlighted inappropriate levels of experience and/or restricted the current diving practices among some of the respondents. This was clearly reflected in the lower levels of acceptance of these proposals (Table 5.2, Proposals 2 – 3, 8 and 10 – 12 inclusive).

In developing the recommended “voluntary code of conduct for scuba diving with Grey Nurse Sharks” an 80% level of acceptance was used because this would result in a large majority of recreational scuba divers supporting the proposal. However, it was also important to note that Proposal 1 (Table 5.2) as proposed may have been interpreted in different ways by the respondents. This potential misunderstanding is likely to have arisen via differential interpretations of what was meant by the word “sanctuary.” Consequently, and in spite of the 83% support for Proposal 1 (Table 5.2), this proposal was removed from the recommended code of conduct for scuba diving with Grey Nurse Sharks (Table 5.4).

Table 5.4. Recommended voluntary code of conduct for scuba diving with Grey Nurse Sharks.

Code of conduct
1. Do not block entrances to caves or gutters
2. Do not interrupt the swimming pattern of the sharks
3. Do not feed or touch the sharks
4. Do not chase or harass the sharks (i.e. no mechanical apparatus such as scooters, horns and anti-shark devices are to be used)
5. Dive groups must not have more than 10 divers
6. A dive brief is to be given by the dive leader before each dive
7. All commercial operators are to be signatories to the Code of Conduct
8. Code of Conduct is to be displayed in the shop and on the dive boat
9. Dive operators are to participate in scientific research

There is an obvious need to engage in further discussion with the recreational diving industry over other proposals not currently part of the recommended code. Furthermore, it will be necessary to examine ways of distributing this recommended code of conduct for scuba diving with Grey Nurse Sharks to a wider audience within the commercial and recreation diving community. This will necessitate the publication of the code of conduct in popular dive magazines, and its incorporation within lectures as part of basic and higher scuba diving courses. Finally, consideration should be given to incorporating the recommended code of conduct into the State and National recovery plans for the Grey Nurse Shark.

6. SUMMARY AND CONCLUSIONS

The current project further quantified the distribution and abundance of Grey Nurse Sharks along the entire NSW coast. The maximum of 292 sharks, observed in the winter 2000 survey, supports the declaration of the Grey Nurse Shark as an endangered species under *NSW Fisheries Management Act 1994 & Amendments*. Similarly, the data also support the declaration of the species as critically endangered under Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.

The numbers of Grey Nurse Sharks exhibited substantial spatial and temporal variation along the entire NSW coast. Despite this, there were obvious patterns that were consistent between years and this included the segregation by size and sex. However, it is important to note that the patterns observed over these surveys may simply reflect the behaviour of a population in serious decline. Whether these or different patterns would have been evident 50 years ago is difficult to address given the lack of biological information from that period of history.

The current project also identified and mapped sites important to the shark in the Batemans Shelf and Twofold Shelf Bioregions. Several of these sites proved to be key aggregation sites. Over the 10 surveys, 12 aggregation sites accounted for 88.5% of the Grey Nurse Sharks observed. Newborn pups were also observed at these sites and this indicates that they also play an important role in reproduction.

This project developed a voluntary code of conduct for scuba diving with Grey Nurse Sharks with the co-operation and input of numerous recreational scuba divers from various urban centres along the NSW coast. This Code of Conduct should be distributed widely and all scuba divers and the scuba diving industry should be encouraged to adopt it.

Information on reproduction, age, growth and mortality is generally regarded as a minimum requirement for the ecologically sustainable management of a marine animal. The absence of this information for the Grey Nurse Shark will make prioritising actions to recover the species extremely difficult. Consequently, it would be prudent to ensure that the actions needed to secure this information are given particular emphasis. To this end, this report has provided a detailed account of the information required and the many interlocking components of research and management that will need to be done to ensure the recovery of the species.

Recovery plans (State and/or Commonwealth) for the Grey Nurse shark will need to redress this fundamental lack of information. Moreover, it will be necessary for the recovery plans to develop a range of criteria to measure the success (or otherwise) of the species. This report provides the results of ongoing research together with the most recent synthesis of information concerning the Grey Nurse Shark. Consequently, it is recommended that information contained in this report be incorporated in the New South Wales, Queensland and National Recovery Plans for the Grey Nurse Shark.

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