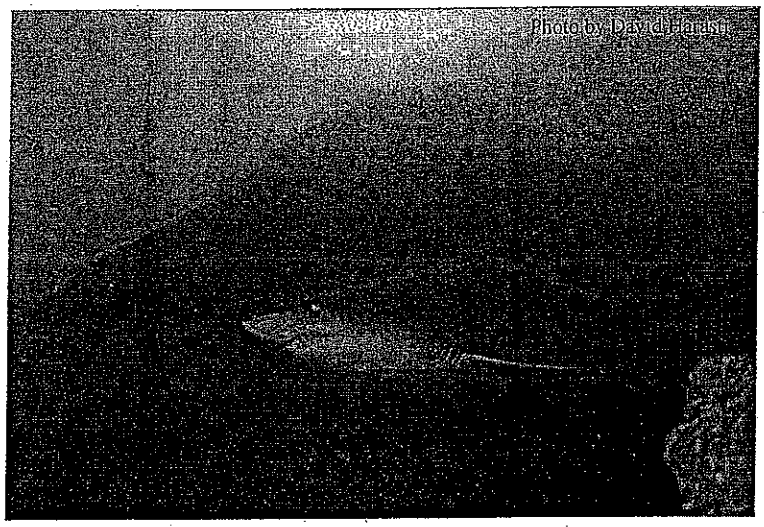
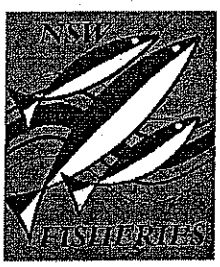
The biology, ecology, distribution, abundance and identification of marine protected areas for the conservation of threatened Grey Nurse Sharks in south east Australian waters

N. M. Otway and P. C. Parker

NSW Fisheries Office of Conservation
Port Stephens Fisheries Centre
Private Bag 1, Nelson Bay, NSW 2315
Australia





February 2000

NSW Fisheries Final Report Series
No. 19
ISSN 1440-3544

Research and the collation of information presented in this report was undertaken with funding provided by Environment Australia. The project - Marine Protected Areas for Protection of Threatened Grey Nurse Sharks - was undertaken for the Marine Protected Areas 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 'The biology, ecology, distribution, abundance and identification of Marine Protected Areas for the conservation of threatened Grey Nurse Sharks in south east Australian waters'.

Copies of the report may be borrowed from the library:

Environment Australia
GPO Box 787
Parkes ACT 2601 AUSTRALIA

TABLE OF CONTENTS

ACKNOWLEDGMENTS VII

EXECUTIVE SUMMARY VIII

1. INTRODUCTION AND PROJECT OBJECTIVES 1

1.1 BACKGROUND 1
1.2 PROJECT OBJECTIVES 1

2. LITERATURE REVIEW 3

2.1 INTRODUCTION 3
2.2 TAXONOMY 3
2.3 BIOLOGY 3
2.3.1 DESCRIPTION 3
2.3.2 SIZE 4
2.3.3 AGE & GROWTH 4
2.3.4 REPRODUCTION 5
2.3.4.1 In Australia 6
2.4 DIET AND FEEDING 7
2.5 BEHAVIOUR 7
2.6 MIGRATORY MOVEMENTS 7
2.6.1 WORLD 7
2.6.2 SE AUSTRALIA 8
2.7 DISTRIBUTION 8
2.7.1 WORLD 8
2.7.2 AUSTRALIA 8
2.8 ABUNDANCE IN SE AUSTRALIA 9
2.8.1 BEACH MESHING PROGRAMS AND GAMEFISH ANGLER RECORDS 9
2.8.2 SURVEY AT SOLITARY ISLANDS AQUATIC RESERVE (NOW MARINE PARK) 10
2.8.3 SURVEYING AT SEAL ROCKS 11
2.8.4 STUDY IN NORTHERN NSW 11
2.8.5 DIVER SIGHTINGS OF GREY NURSE SHARKS 13
2.9 HABITATS UTILISED BY GREY NURSE SHARKS 16
2.10 HUMAN USAGE OF GREY NURSE SHARK HABITATS 16
2.10.1 SCUBA DIVING 16
2.10.2 COMMERCIAL/RECREATIONAL FISHING 17
2.10.3 PROTECTIVE BEACH MESHING 17
2.11 CONSERVATION 17
2.11.1 WORLD 17
2.11.2 AUSTRALIA 18
2.11.2.1 Current situation in NSW 18
2.12 CONCLUSIONS AND RECOMMENDATIONS 19
2.12.1 ABUNDANCE 19
2.12.2 REPRODUCTION, MIGRATION AND CONSERVATION 19
2.12.3 HUMAN USAGE OF GREY NURSE SHARK HABITAT 19

3. GREY NURSE SHARK HABITAT MAPPING 21

3.1 INTRODUCTION 21
3.1.1 TWEED-MORETON BIOREGION 21
3.1.1.1 Stradbroke Island 23
3.1.1.2 Tweed Heads 23

3.1.1.3 Byron Bay 23
3.1.1.4 Brooms Head 27
3.1.1.5 The North Solitary Islands 27
3.1.1.6 The South Solitary Islands 27
3.1.2 MANNING BIOREGION *31*
3.1.2.1 South West Rocks 33
3.1.2.2 Laurieton 33
3.1.2.3 Forster 33
3.1.2.4 Seal Rocks 37
3.1.2.5 Port Stephens 37
3.1.3 HAWKESBURY BIOREGION *40*
3.1.3.1 The Central Coast 40
3.1.3.2 Sydney 40

4. DISTRIBUTION AND ABUNDANCE 45

4.1 INTRODUCTION 45
4.2 MATERIALS AND METHODS 46
4.2.1 SAMPLING LOCATIONS *46*
4.2.1.1 General 46
4.2.1.2 South West Rocks and Seal Rocks 46
4.2.1.3 Remaining Locations 48
4.2.2 SAMPLING PROTOCOL *51*
4.2.2.1 General 51
4.2.2.2 At South West Rocks and Seal Rocks 51
4.2.2.3 At Other Locations 51
4.2.3 STATISTICAL ANALYSES *51*
4.2.3.1 General 51
4.2.3.2 Temporal Variation at Seal Rocks 51
4.2.3.3 Spatial Variation between South West Rocks and Seal Rocks 52
4.2.3.4 Spatial Variation across All Locations 52
4.2.3.5 Short-Term Temporal Variation at Particular Sites 52
4.2.3.6 Population Size-Structure and Segregation by Sex and Size of Grey Nurse Sharks along the NSW Coast 52
4.3 RESULTS 53
4.3.1 SOUTH WEST ROCKS AND SEAL ROCKS *53*
4.3.1.1 General Observations 53
4.3.1.2 Temporal Variation at Seal Rocks 53
4.3.1.3 Spatial Variation between South West Rocks and Seal Rocks 53
4.3.1.4 Population Size-Structure at South West Rocks and Seal Rocks 56
4.3.2 ALL LOCATIONS *57*
4.3.2.1 General Observations 57
4.3.2.2 Spatial and Temporal Variation in Abundance along the NSW Coast 62
4.3.2.2.1 Spatial Variation 62
4.3.2.2.2 Short-Term Temporal Variation 62
4.3.2.2.3 Long-term Temporal Variation 62
4.3.2.3 Population Size-Structure along the NSW and southern Queensland Coasts 69
4.3.2.4 Segregation by Sex along the NSW and southern Queensland Coasts 69
4.3.2.4.1 Along the Entire NSW and Southern Queensland Coasts 74
4.3.2.4.2 Comparisons Between Sections of the Coast 74
4.3.2.4.3 Comparisons within each section of the coast 75
4.3.2.4.3.1 (1) Forster and sites to the north 75
4.3.2.4.3.2 (2) Seal Rocks and sites to the south 75
4.3.2.5 Segregation by Size Along the NSW Coast and Southern Queensland 75

4.3.2.5.1 Along the Entire NSW Coast and Southern Queensland 75
4.3.2.5.2 Comparisons between sections of the coast 77
4.3.2.5.3 Comparisons within each section of the coast 78
4.3.2.5.3.1 (1) Forster and sites to the north 78
4.3.2.5.3.2 (2) Seal Rocks and sites to the south 78
4.3.2.6 Incidence of Hooking on Bottom Setlines 78
4.4 DISCUSSION 79
4.4.1 SPATIAL AND TEMPORAL VARIATION IN ABUNDANCE *79*
4.4.2 POPULATION SIZE-STRUCTURE *80*
4.4.3 IMPLICATIONS FOR MIGRATORY MOVEMENTS *81*
4.4.4 IMPLICATIONS FOR FECUNDITY, REPRODUCTION AND RECRUITMENT *83*
4.4.5 INCIDENTAL CAPTURE ON BOTTOM SETLINES *84*

5. IDENTIFICATION OF MARINE PROTECTED AREAS IN THE MANNING SHELF BIOREGION **85**

5.1 INTRODUCTION 85
5.2 THE ROLE OF MARINE PROTECTED AREAS 85
5.3 TYPE OF PROTECTION 85
5.3.1 FISHERIES CLOSURES *86*
5.3.1.1 Advantages: 86
5.3.1.2 Disadvantages: 86
5.3.2 AQUATIC RESERVES *86*
5.3.2.1 Advantages: 86
5.3.2.2 Disadvantages: 86
5.4 RECOMMENDED SITES FOR CONSIDERATION AS AQUATIC RESERVES 86

6. CONCLUSIONS AND RECOMMENDATIONS **89**

6.1 NEED FOR FUTURE SURVEYS 89
6.2 CONSERVATION STATUS 89
6.3 RECOMMENDATIONS 90

REFERENCE LIST **91**

GLOSSARY **97**

LIST OF FIGURES

Figure 2.1. Grey nurse shark, *Carcharias taurus* 4
Figure 2.2. Worldwide distribution of *Carcharias taurus* 8
Figure 2.3. Decline in the numbers of Grey Nurse Sharks caught in shark meshing nets in the Newcastle/Sydney/Wollongong regions from 1950-1990 10
Figure 2.4. Seasonal abundance of Grey Nurse Sharks in the Solitary Islands Aquatic Reserve from Winter 1992 to Spring 1993 10
Figure 2.5. Mean number of Grey Nurse Sharks observed during morning and afternoon surveys at four sites at Seal Rocks in November 1991 11
Figure 2.6. The frequency of Grey Nurse Sharks sighted in the major diving regions in northern NSW waters over a 15 month period 12
Figure 2.7. Abundance of Grey Nurse Sharks sighted in relation to water temperature 13
Figure 2.8. Locations along NSW coast where Grey Nurse Sharks have previously been sighted. 15
Figure 2.9. Percentage frequency of Grey Nurse Sharks sighted in four different environments 16
Figure 3.1. Locations of Grey Nurse Shark survey sites in the Tweed-Moreton Bioregion. 22
Figure 3.2. Grey Nurse Shark survey site at Stradbroke Island. 24
Figure 3.3. Grey Nurse Shark survey sites at Tweed Heads. 25
Figure 3.4. Grey Nurse Shark survey sites at Byron Bay. 26
Figure 3.5. Grey Nurse Shark survey site at Brooms Head. 28
Figure 3.6. Grey Nurse Shark survey sites in the Northern Solitary Islands 29
Figure 3.7. Grey Nurse Shark survey sites in the Southern Solitary Islands 30
Figure 3.8. Locations of Grey Nurse Shark survey sites in the Manning Shelf Bioregion. 32
Figure 3.9. Grey Nurse Shark survey sites at South West Rocks 34
Figure 3.10. Grey Nurse Shark survey sites at Laurieton 35
Figure 3.11. Grey Nurse Shark survey sites at Forster. 36
Figure 3.12. Grey Nurse Shark survey sites at Seal Rocks. 38
Figure 3.13. Grey Nurse Shark survey sites at Port Stephens. 39
Figure 3.14. Locations of Grey Nurse Shark survey sites in the Hawkesbury Shelf Bioregion 41
Figure 3.15. Grey Nurse Shark survey sites on the Central Coast. 42
Figure 3.16. Grey Nurse Shark survey sites in and around Sydney. 43
Figure 4.1. Map showing the sites sampled at South West Rocks and Seal Rocks over consecutive days from 30 November to 4 December, 1998. 47
Figure 4.2. Map showing the locations sampled by the scuba diving community in cooperation with NSW Fisheries over four week periods in November/December 1998, March/April 1999 and May/June 1999. 50
Figure 4.3 The mean number of Grey Nurse Sharks at (A) Seal Rocks in 1991, 1995 and 1998, and (B) at South West Rocks and Seal Rocks over the period 30 November to 4 December, 1998 54
Figure 4.4 Total number of Grey Nurse Sharks observed at the 21 locations along the NSW coast sampled in November/December 1998, March/April 1999 and May/June 1999. 58
Figure 4.5 Total number of Grey Nurse Sharks observed at sites where aggregations of five or more individuals occurred in the surveys in November/December 1998, March/April 1999 and May/June 1999 60
Figure 4.6 Mean (+ SE) number of Grey Nurse Sharks observed at the 21 locations along the NSW coast during the period November - December 1998, March/April, 1999 and May/June, 1999 64
Figure 4.7 Short-term fluctuations in the total number of Grey Nurse Sharks observed at Manta Arch (South Solitary Islands) during the November to December, 1998 survey. 66
Figure 4.8 Short-term fluctuations in the total number of Grey Nurse Sharks categorised by sex at (A) Tollgate Islands (Batemans Bay), (B) The Pinnacles (Forster), and (C) Fish Rock (South West Rocks) during the November to December, 1998 survey 67
Figure 4.9 Long-term fluctuations in the total number of Grey Nurse Sharks along the entire NSW and southern Queensland coasts during the November/December 1998, March/April 1999 and

May/June 1999 surveys. (A) Total numbers categorised by sex and (B) Total numbers adjusted by effort 68
Figure 4.10 The length-frequency distributions of male and female Grey Nurse Sharks, and individuals of unknown sex pooled across the entire coast in November/December, 1998 (Survey 1), March/April, 1999 (Survey 2) and May/June, 1999 (Survey 3) 70
Figure 4.11 The length-frequency distributions of male and female Grey Nurse Sharks, and individuals of unknown sex at various locations along the NSW in November/December 1998 (Survey 1). 71
Figure 4.12 The length-frequency distributions of male and female Grey Nurse Sharks, and individuals of unknown sex pooled across the entire coast in the surveys in March/April (Survey 2) 72
Figure 4.13 The length-frequency distributions of male and female Grey Nurse Sharks, and individuals of unknown sex pooled across the entire coast in the surveys May/June 1999 (Survey 3). 73
Figure 4.14. Regression of hooking rate on time. Hooking rate is expressed as a percentage and calculated as the number of sharks with hooks embedded in their jaws divided by the total number of individuals per survey. 79
Figure 4.15 Hypothesised migratory movements of male and female Grey Nurse Sharks off the NSW and southern Queensland coasts. 82

LIST OF TABLES

Table 2.1. Growth rates of the Grey Nurse Shark 5
Table 2.2. Age at sexual maturity of Grey Nurse Sharks 5
Table 2.3. Timing of Embryonic Development of the Grey Nurse Shark 6
Table 2.4. Number (percentage) of Grey Nurse Sharks caught in the beach meshing nets for the Newcastle, Sydney and Wollongong regions for the periods 1950-72 and 1972-90 9
Table 2.5. Locations of Grey Nurse Sharks sightings in previous years in NSW. 13
Table 3.1. The sites (and locations) surveyed in the Tweed-Moreton Bioregion 21
Table 3.2. The sites (and locations) surveyed in the Manning Shelf Bioregion 31
Table 3.3. The sites (and locations) surveyed in the Hawkesbury Shelf Bioregion 40
Table 4.1. Additional sites sampled by the scuba diving community in cooperation with NSW Fisheries over four week periods in November/December 1998, March/April 1999 and May/June1999. 48
Table 4.2. Analysis of variance of the numbers of Grey Nurse Sharks seen at Seal Rocks in 1991, 1995 and 1998. 53
Table 4.3 Analysis of variance of the numbers of Grey Nurse Sharks at South West Rocks and Seal ocks over the period 30 November, 1998 to 4 December, 1998. 55
Table 4.4 Population size-structure of Grey Nurse Sharks at South West Rocks and Seal Rocks over the period 30/11/98 to 4/12/98. 56
Table 4.5 Numbers of sites with and without Grey Nurse Sharks along the entire NSW coast and in southern Queensland sampled in November/December 1998, March/April 1999 and May/June 1999. 57
Table 4.6 Analysis of the parameter estimates from a general linear model based on a Poisson regression for the number of Grey Nurse Sharks observed at 13 locations along the NSW coast over a 4 week period from mid-November to mid-December, 1998. 63
Table 4.7 Numbers of male and female Grey Nurse Sharks observed along the entire NSW coast and in the 2 sections of coast (1. Forster and sites north, and 2. Seal Rocks and sites south) in the surveys in November/December 1998, March/April 1999 and May/June 1999. 74
Table 4.8 Numbers of male and female Grey Nurse Sharks in 2 size-classes (i.e. 1 - 2 m TL and > 2 m TL) observed along the entire NSW coast and in the 2 sections of coast (1. Forster and sites north, and 2. Seal Rocks and sites south) in the surveys in November/December 1998, March/April 1999 and May/June 1999. 76
Table 4.9. Numbers of Grey Nurse Sharks with and without bottom setline hooks embedded in their jaws observed along the entire NSW coast recorded in the surveys in November/December 1998, March/April 1999 and May/June 1999. 79
Table 5.1. The location of sites with aggregations of Grey Nurse Sharks that would contribute to the conservation of the species if declared as Aquatic Reserves. 87

ACKNOWLEDEMENTS

We are grateful to Carloyn 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 thank Geoff Gordon for his thought provoking discussions and help with the poisson regression analysis. We are grateful to Edward Kleverlaan, Nathan Harris and David Harasti of Environment Australia and Phil Gibbs of NSW Fisheries for their ongoing help and review of the report. We also thank The Ecology Lab and Lachie Whetham of Coastcare for their contributions to this study. We are grateful to Drs Pollard, Lincoln-Smith and Smith for the use of their data (see Section 4.3.1). Finally, a special thanks to David Harasti for the use of his photograph on the cover of this report.

The coastwide survey would not have been possible without the assistance of Seaworld, Stradbroke Island Scuba Centre, Palm Beach Dive Centre, the Blue Juice Dive Co., Sundive, Bayside Scuba, Simon Hartley of Southern Cross University, Darrin White, Wooli Dive Centre, Dive Quest, Marine Parks Authority (SIMP), 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, Phil Bowman, Fishermans Wharf Dive Centre, Action Divers Tuncurry, Pro Dive Nelson Bay, Dive Nelson Bay, Dr Ken Zimmerman and Karla Casey of Newcastle University, Pro Dive The Entrance, Terrigal Dive Centre, Aqua Zero, Southern Cross Divers, Sydney Aquarium, 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, 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 the stepping-stone for the recovery and long-term conservation of the species.

This study was funded by the Natural Heritage Trust via Environment Australia's Marine Protected Areas Program.

EXECUTIVE SUMMARY

- The Grey Nurse Shark, *Carcharias taurus* belongs to the Family Odontaspididae and occurs in coastal waters off the 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". The sharks are often found in or near gutters and caverns around inshore rocky reefs and islands.

- The Grey Nurse Shark is a slow, strong swimming shark with a large body and attains a maximum length of 320 cm. Little is known about the biology and ecology of the species in Australian waters and what is understood has been inferred from studies in South Africa and North America.

- 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 advanced developmentally embryos eat the remaining embryos and then ovulated eggs (a phenomena known as intra-uterine cannibalism and oviphagy). The gestation period is approximately 9 to 12 months with two pups, occasionally one and rarely four born per litter. Females reproduce biennially and thus only one pup is born per female per year on average. Very little is known about the precise timing of mating and pupping activities and the migratory habits of the Grey Nurse Shark populations in Australian waters.

- The Grey Nurse Shark was afforded protected status in New South Wales waters in 1984 as a result of: (1) a reduction in numbers observed by recreational scuba divers, (2) declining catches by spear fishermen, (3) declining catches in the 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.

- The current project was set up to: (1) quantify the distribution and abundance of Grey Nurse Sharks along the entire NSW coast, (2) identify and map sites important to the shark in the Manning Bioregion, and (3) investigate the potential for declaring the important sites as Marine Protected Areas to facilitate the recovery and long-term conservation of the species.

- At the same time as the project commenced, the Grey Nurse Shark was declared a Threatened Species with "Vulnerable" status by the NSW Fisheries Scientific Committee under the Threatened Species provisions of the *Fisheries Management Act 1994*.

- The abundances of Grey Nurse Sharks in the survey were quantified using underwater visual counts of sharks over a 15 minute period at a range of sites along the NSW and southern Qld coastlines. The surveys were carried out for a period of approximately 4 weeks and 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. Volunteer recreational scuba divers along the NSW and southern Qld coast also participated in these surveys.

- Numerous sites in the Tweed-Moreton Shelf, Manning Shelf and Hawkesbury Shelf bioregions were mapped. 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.

- The 3 coastwide surveys were done in November/December 1998, March/April and June\July 1999. In survey one, 136 Grey Nurse Sharks were observed across 61 sites along the coast. A total of 106

(78% of all sightings) sharks was observed at 9 of the 61 sites (15 % of all sites), and no sharks were sighted at 37 of the 61 sites (61% of all sites). Between 1 and 4 sharks were seen at the remaining 15 of the 61 sites (24% of all sites). Sixty of the 136 (44%) Grey Nurse Sharks observed in survey one were of a reproductively mature size. For individuals of known sex, only 12 males were of a reproductively mature size, and 34 females were of a reproductively mature size.

- In Survey two, 129 Grey Nurse Sharks were observed across 51 sites along the coast. A total of 114 (88% of all sightings) sharks was observed at 6 of the 51 sites (12 % of all sites), and no sharks were sighted at 35 of the 51 sites (69 % of all sites). Between 1 and 4 sharks were seen at the remaining 10 of the 51 sites (20% of all sites). Sixty-one of the 112 (54%) Grey Nurse Sharks observed in survey two were of a reproductively mature size. For individuals of known sex, only 14 males were of a reproductively mature size, and 42 females were of a reproductively mature size.

- In survey three, 207 Grey Nurse Sharks were observed across 50 sites along the coast. A total of 180 (67% of all sightings) sharks was observed at 13 of the 50 sites (26 % of all sites), and no sharks were sighted at 25 of the 50 sites (50% of all sites). Between 1 and 4 sharks were seen at the remaining 12 of the 50 sites (24% of all sites). One hundred and twenty-seven out of the 204 (62.3%) Grey Nurse Sharks observed in survey 3 were of a reproductively mature size. For individuals of known sex, 63 (30.9%) males were of a reproductively mature size, and 42 (20.6%) females were of a reproductively mature size.

- The results of the surveys 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 also support the initial declaration of the shark as a threatened species.

- Analysis of the size frequency distributions from surveys 1-3 showed that the Grey Nurse Shark population exhibited segregation by size and sex. Proportionally more male 1 - 2 m and > 2 m TL Grey Nurse Sharks occurred at Foster and sites to the north and proportionally more females 1 - 2 m and > 2 m TL occurred at Seal Rocks and sites to the south. The sex ratios of Grey Nurse Sharks were significantly biased towards females in surveys 1 and 2. In contrast the sexes were not biased in survey 3. The biased sex ratios in surveys 1 and 2 is most likely due to segregation of the sexes rather than an actual difference in the abundance's of males and females.

- On subdividing the coastline into northern (i.e. Forster - N. Stradbroke Is.) 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 number of pups observed (i.e. 6 - 14) was less than expected (i.e. 34 - 42) based on the numbers of reproductively mature females. This is cause for concern because: (1) it suggests that the pups were not observed using the existing sampling techniques, or (2) it is possible that a reproductive failure may have occurred giving an average fecundity of less than 1 pup per annum: a rate that is clearly insufficient to sustain a population yet alone enable it to recover.

- Information from surveys in 1991, 1995 and this study has shown that there has been a significant increase in the rate of incidental capture of Grey Nurse Sharks on bottom setlines.

- As a result of the entire study nine recommendations were made and are listed below.
    1. That the status of the Grey Nurse Shark be reviewed with a view to upgrading the status from VULNERABLE to ENDANGERED.
    2. That Green Island, Fish Rock, Cod Grounds, The Pinnacles, Big Seal Rock, Little Seal Rock and Broughton Island be considered for declaration as aquatic reserves to assist in the long-term conservation of the Grey Nurse Shark.
    3. That further surveys at the various sites along the coast be done to document the short-term spatial and temporal fluctuations and inter-annual variability in abundance.
    4. That the location, timing and number of pups born be quantified to estimate the average rate of recruitment.
    5. That estimates of the number of sexually mature females be further quantified and the location of mating sites be identified.
    6. That the timing and direction of migratory movements of Grey Nurse Sharks be quantified using tagging techniques.
    7. That the proportions of Grey Nurse Sharks repeatedly observed in the surveys be quantified using tagging techniques as this will provide an independent assessment of the population status and an estimate of the total population.
    8. That estimates of the rates of inadvertent capture on bottom setlines be further quantified.
    9. That acoustic tagging techniques be used to document the localised, short-term movements as these will determine the efficable size of Marine Protected Areas.

1. INTRODUCTION AND PROJECT OBJECTIVES

1.1 BACKGROUND

A review of the biology of the Grey Nurse Shark (Otway & Parker, 1999) has shown much of the information concerning the species has been derived from studies in the USA and South Africa. Furthermore, little is known about the Grey Nurse Shark off New South Wales and southern Queensland and this is directly attributable to the absence of any extensive studies on the species. What is known has been gleaned from a few published studies (Pepperell, 1992; Reid & Krogh, 1992; Gordon, 1993; Krogh, 1994; Pollard *et al.*, 1996), unpublished reports (e.g. Ecology Lab, 1991; Parker, Unpub.) and anecdotal accounts (e.g. Garbutt, 1995: Marsh, 1995), the results of which are summarised in Otway and Parker (1999). There is also little, if any, local information on the distribution and abundance of the species that could assist with its conservation along the NSW coast. However, to assist the sharks' long-term conservation, the NSW government declared the Grey Nurse Shark a protected species in 1984 and, in doing so, the shark became the first protected shark in the world.

By the early 1990's, two primary sources of information suggested that the Grey Nurse Shark population in NSW coastal waters had not recovered from the indiscriminant spearing that occurred in the 1950's and 60's. First, the catches of Grey Nurse Shark in the protective mesh nets off beaches in Newcastle, Sydney and Wollongong had declined to zero by 1980 (Fig. 2.3) and remained at or near this level thereafter (Reid & Krogh, 1992; Krogh, 1994 for details). Second, surveys at Seal Rocks in 1991 and 1995 (see later) indicated that the abundances of Grey Nurse Sharks were well below those documented in the anecdotal reports of the 1960's (e.g. Cropp, 1964).

In addition to this, more recent anedotal information (e.g. Garbutt, 1995) has shown that Grey Nurse Sharks have been inadvertently caught on bottom setlines targeting wobbegongs (*Orectolobus ornatus* and *O. maculatus*). This has also led to sightings of Grey Nurse Sharks with hooks (and associated wire traces) embedded in their jaws. The rate of inadvertent capture and its consequences (i.e. rates of survival/mortality) have not been assessed in detail to date.

Understandably, the continued decline in catches of Grey Nurse Shark in the protective mesh nets, the reduced abundances compared to the anecdotal reports of the 1960's combined with the inadvertent hookings prompted further concern within NSW Fisheries. Consequently, a conservation-related research project was set up by NSW Fisheries with funding from the Natural Heritage Trust under Environment Australia's Marine Protected Areas Program. This report details the findings of that research project.

1.2 PROJECT OBJECTIVES

The project has 6 main objectives and these are listed below.

1) To review all available information on the biology and ecology of the Grey Nurse Shark, the habitats utilised by the shark, the human uses of the main habitats and to highlight those uses that are contrary to the long-term conservation of the species,

2) To repeat the distribution and abundance survey of Grey Nurse Sharks at Seal Rocks and extend it to South West Rocks. To analyse statistically the results of this and previous surveys and evaluate the design and efficacy of the survey.

3) To assess the feasibility of using Marine Protected Areas to assist in conserving "migratory" species such as the Grey Nurse Shark, and

4) To map the habitats utilised by the Grey Nurse Shark in the region surrounding Seal Rocks and South West Rocks, and identify sites suitable for declaration as Marine Protected Areas.

The scope of the project was expanded after additional funds were provided by Environment Australia to allow sampling of the entire NSW coast. The objectives of the expanded project are listed below.

5) To provide more detailed information about the distribution and abundance of the Grey Nurse Shark on the east coast of Australia by surveying recreational dive sites where Grey Nurse Sharks had previously been sighted, from Stradbroke Island in southern Qld to Eden in southern NSW, and

6) To undertake additional mapping of the habitats utilised by Grey Nurse Sharks to encompass the sites sampled in the Tweed Moreton Shelf and Hawkesbury Shelf Bioregions.

This report presents the findings associated with each of the main objectives. Chapter Two documents a review of the available literature on the biology and ecology of the Grey Nurse Shark, including the habitats utilised by the shark and the main human uses of those habitats; Chapter Three presents maps of the sites surveyed displaying the habitats utilised in the Tweed Moreton Shelf, Manning Shelf and Hawkesbury Shelf Bioregions; Chapter Four presents the results and analysis of the data collected from the distribution and abundance surveys conducted at Seal Rocks in 1991, 1995 and 1998 as well as the data collected for the statewide surveys conducted in November/December 1998, March/April 1999, and May/June 1999; Chapter Five discusses the feasibility of using Marine Protected Areas to assist in the conservation of the Grey Nurse Shark; and Chapter Six presents the recommendations and final conclusions of the project.

2. LITERATURE REVIEW

2.1 INTRODUCTION

The aim of this review is to outline available information on the biology and ecology of the Grey Nurse Shark, including habitats utilised by the shark. Also, this review will describe the human uses of the main habitats utilised by the Grey Nurse Shark and highlight those uses that are contrary to the long-term conservation of the species.

The Grey Nurse Shark (*Carcharias taurus*), belongs to the family Odontaspididae which has two genera and four species world wide. Of these, two species are found within Australian waters (Last and Stevens, 1994). These are the Grey Nurse Shark and Herbst's Nurse shark (*Odontaspis ferox*), both of which are protected species within New South Wales waters since legislation was gazetted in November 1984 (Pollard *et al.*, 1996).

2.2 TAXONOMY

The nomenclature surrounding the Odontaspididae family can be quite confusing and several invalid scientific names for the Grey Nurse Shark are in common usage, including: *Triglochis* (Muller and Henle, 1837), *Odontaspis* (Agassiz, 1838) and *Eugomophodus* (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 as it was thought that the genera *Carcharias* and *Odontaspis*, the other genus in the family Odontaspididae, were congeneric (Compagno, 1984). Later it was determined that the two type species identified were not congeneric so in 1987 the commission reinstated the genus *Carcharias* (Paxton *et al.*, 1989).

The wide distribution of the species in the Indian, Pacific and Atlantic oceans has led to the use of several specific names including: *taurus, americanus, tricuspidatus* (Bass *et al.*, 1975), *cinerea* (Last and Stevens, 1994) or *arenarias* (Britannica On-line). It is now generally accepted that they all refer to the same species. The correct scientific name for the species is *Carcharias taurus*.

2.3 BIOLOGY

To date most of the information on the species has been obtained from studies undertaken in the USA and South Africa, and the biology of the Grey Nurse Shark in Australian waters is not well known. The limited information on the population along the east coast of Australia is restricted to catch records from beach meshing programs (Reid and Krogh, 1994; Krogh, 1992), popular accounts in diving and fishing magazines (e.g. Ireland, 1984; Harding, 1990; Aitken, 1991) and some small localised surveys (Pollard *et al.*, 1996).

2.3.1 DESCRIPTION

Grey Nurse Sharks (Fig. 2.1) have large fusiform bodies (i.e. tapered at both ends), with a conical snout and small eyes. The nictitating membrane of the eye, common in many other sharks, is not present in Odontaspid sharks (Last and Stevens, 1994). The shark has two large spineless dorsal fins of similar size. The mouth extends beyond the front of the eyes and contains long slender lanceolate (spear-shaped) teeth with single cusplets (lateral projections). The caudal (tail) fin is strongly heterocercal with the top lobe being larger than the bottom. The dorsal surface of the shark is bronze coloured and the underside is paler. Juveniles have dark spots on the posterior half of the body and on the caudal fin. These spots fade as the shark becomes larger, but they are sometimes still evident on adults (Last and Stevens, 1994; Pollard *et al.*, 1996) (Fig. 2.1).

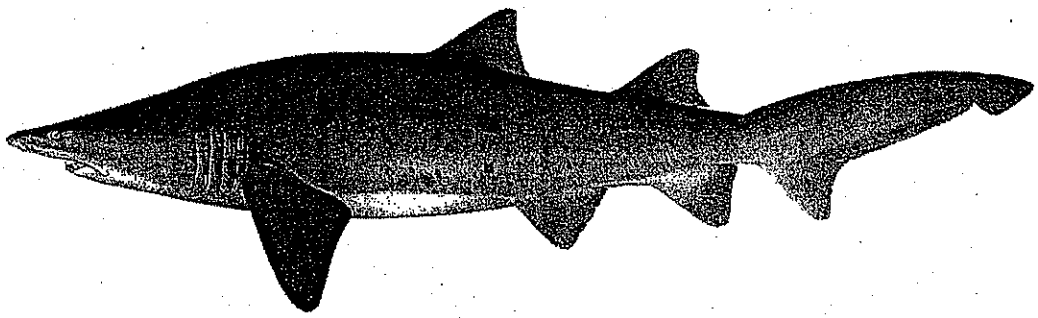


Figure 2.1. Grey Nurse Shark, *Carcharias taurus* (From: Last and Stevens, 1994).

The Grey Nurse is a slow, strong swimming shark that is often seen hovering motionless near the bottom (Bass *et al.*, 1975; Compagno, 1984; Last and Stevens, 1994; Pollard *et al.*, 1996; Cliff, unpub.). Feldmeth and Wagoner (1972) have observed *C. taurus* hovering motionless in an aquarium in South Africa. They attribute the species unique buoyancy control to air being held in the stomach, which is thought to be swallowed at the surface, allowing the shark to achieve almost neutral buoyancy. It is unclear whether this method of buoyancy control is utilised by non-captive individuals.

2.3.2 SIZE

The maximum length of the Grey Nurse Shark differs between the sexes with females attaining a greater length than males. The maximum lengths recorded are 318 cm and 257 cm for females and males, respectively (Bigelow and Schroeder, 1953; Bass *et al.*, 1975; Gilmore *et al.*, 1983; Compagno, 1984; Branstetter and Musick, 1994). It has been suggested (Smith, 1949) that the maximum length for the species could be up to 457 cm. This suggestion was rightly questioned by Bass *et al.* (1975) who concluded that a shark of this length would have been a sighting of the Herbst Nurse Shark (*Odontaspis ferox*) which is very similar in morphology and colouration, but attains a greater length.

2.3.3 AGE & GROWTH

Estimates of age and growth for the Grey Nurse Shark have been obtained from captive sharks held in aquaria in Florida, USA (Schmid *et al.*, 1990) and Durban, South Africa (Govender *et al.*, 1991), and wild specimens captured from the NW Atlantic Ocean (Branstetter and Musick, 1994). Schmid *et al.*, (1990) measured and weighed male and female Grey Nurse Sharks (n = 16) over a period of 16 months. They found that juvenile and adult Grey Nurse Sharks in captivity grew rapidly at a rate of 23-25 cm/year, but once sexually mature growth slowed to less than 10 cm/year.

Govender *et al.* (1991) measured the lengths of captive sharks of known age from photographs. 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 tetracycline marking methods. The age and growth data obtained in the two studies differed and was attributed to the slower growth of the males in the Durban aquarium (Branstetter and Musick, 1994 and Table 2.1 for details).

In the NW Atlantic, Grey Nurse Sharks exhibited two distinctive periods of growth within in the same year as evidenced by single growth bands in Winter and Summer (Branstetter and Musick, 1994). Despite the slightly greater summer growth, the similarity in growth may be due to the north-south migratory patterns in combination with differential availability of food. Growth of wild Grey Nurse Sharks is relatively rapid and growth rates determined by Branstetter and Musick (1994) are provided in Table 2.1. The longevity of Grey Nurse Sharks was estimated at 30 and 35 years for males and females, respectively.

Table 2.1. Growth rates of the Grey Nurse Shark (After: Branstetter and Musick, 1994).

Life History Stage	Age (yr)	Growth Rate (cm/yr)
Juvenile	0-1	25-30
Juvenile	2-3	20-25
Sub adult/Adult	4-5	15-20
Sub adult/Adult	6-7	10-15
Adult	>8	5-10

To date no age and growth studies have been published on wild or captive Grey Nurse Sharks in Australia.

2.3.4 REPRODUCTION

The reproductive biology of the Grey Nurse Shark has been well documented (e.g. Springer, 1948; Bass *et al.*, 1975; Gilmore *et al.*, 1983; Branstetter and Musick, 1994) and is regarded as one of the most unusual reproductive strategies used by sharks (Gilbert, 1981). The first account was based on the dissection of a recently captured female with two advanced embryos still alive inside (Springer, 1948). Subsequently, Gilmore *et al.* (1983) described the early reproductive activity and embryonic development more extensively. These reproductive studies have shown that the Grey Nurse Shark is ovoviviparous with only one or two pups (rarely four) born per litter. The female has no placental connection (as with the carcharhinids), instead the two most advanced embryos eat the remaining embryos and developing eggs (a phenomena known as intra-uterine cannibalism and oviphagy - Stead, 1963; Bass *et al.*, 1975; Gilmore *et al.*, 1983; Compagno, 1984). The gestation period of *C. taurus* can last from 9 to 12 months with parturition occurring when the pups are approximately 100 cm in length (Bass *et al.*, 1975; Gilmore *et al.*, 1983). Cliff (unpub.) described a unique hydroid growth (*Amphisbetia aperculata* and *Plumularia sp.*) on the teeth of females during the gestation period in South Africa. He suggested that the female sharks may go for long periods without feeding.

Estimates of the age at sexual maturity (Table 2.2) were obtained with length at age data from Von Bertanlanffy growth curves (Branstetter and Musick, 1994) using lengths of 190-195 cm and 220-230 cm for males and females, respectively as these were considered to be the lengths at which the species reached maturity (Gilmore *et al.*, 1983).

Table 2.2. Age at sexual maturity of Grey Nurse Sharks (After: Gilmore *et al.*, 1983 and Branstetter and Musick, 1994).

Sex	Length (cm)	Age (yr)
Male	190-195	4
Female	220-230	6

The embryonic development of Grey Nurse Sharks has been described by Gilmore *et al.* (1983) after examination of 26 captured pregnant females. They were able to classify the intrauterine developmental stages and assign a time period to each developmental stage according to the date of capture of the female (Table 2.3).

Table 2.3. Timing of Embryonic Development of the Grey Nurse Shark (After: Gilmore *et al.*, 1983)

Development Stage	Embryo Length (mm TL)	Time of Year
Early Gonadal and Embryonic	0 - 60	January to September
Post Hatch and Intrauterine Cannibalism	60 - 334	June to September
Late Gestation, Post-cannibalistic, Oophagous, Pre-parturition	334 - 1000	September to March
Parturition	1000 - 1200	December to March

Gilmore (1993) suggested that reproduction of the Grey Nurse Shark occurs annually with no resting stage. However, Branstetter and Musick (1994) have shown that Grey Nurse Sharks in the NW Atlantic ocean (i.e. off the USA) reproduce biennially and have a resting stage. Their work was based on the analysis of uteri from 56 captured females. Twenty nine of these were mature and did not contain any eggs or embryos at the time of capture (May to October), only egg follicles were present, indicating that these females were captured during a reproductive resting phase. Cliff (unpub.) also concluded that females along the east coast of South Africa reproduce biennially after examining sexually inactive females that had been tagged and recaptured. Given that the Grey Nurse Shark only produces two pups per litter every two years, the species is highly vulnerable to human induced pressures.

Mating of the Grey Nurse Shark in South African waters has been described by Cliff (unpub.) as occurring between late October and the end of November with the females giving birth during the winter months. The timing of mating and pupping of the Grey Nurse Shark off the Florida coast, USA was described by Gilmore *et al.* (1993). They established that winter/spring was the breeding period and parturition was occurring between December and March. While some preliminary observations of pre-copulatory behaviour have been made nothing substantial has been documented with individuals in the wild.

2.3.4.1 In Australia

Very little is known about the precise timing of mating and pupping of *C. taurus* populations in Australian waters. However, pre-copulatory behaviour of captive *C. taurus* has been observed by workers at Oceanworld Manly, Sydney, Australia (Gordon, 1993). Divers in the Solitary Islands Marine Park have observed a single display of pre-copulatory behaviour of the species in the wild (Pickering and Wilkinson, pers. comm.). On both occasions the male was observed biting and gripping the female around the pectoral fin. The ferocity of copulation was not recorded for the sharks held in captivity, but wild sharks have been observed violently thrashing around on the sea bed. Many sharks have been observed at Brooms Head during the months of March and April with mating scars, bite marks around the pectoral fins and head area (D. White, pers. comm.).

2.4 DIET AND FEEDING

Grey Nurse Sharks feed on a variety of teleost fishes (e.g. kingfish, bream, morwong), smaller sharks, rays, squid, and crustaceans (Last and Stevens, 1994; Pollard *et al.*, 1996). A study on the feeding habits of captive Grey Nurse Sharks at Sea World Florida revealed that they consumed an average of 1.9% of their own body weight per week (Schmid *et al.*, 1990). Observations also suggest that schools of Grey Nurse Sharks feed cooperatively by bunching up schooling prey before feeding on them (Compagno, 1984; Ireland, 1984). Ireland (1984) also suggested that Grey Nurse Sharks have a definite feeding order, with the most dominant shark feeding first, but these observations have not been substantiated by other observers.

2.5 BEHAVIOUR

Over the years, scuba divers have spent hours observing the behaviour of Grey Nurse Sharks in the wild and in captivity. The shark is timid, usually difficult to approach, and will often leave the area when disturbed (Ireland, 1984; Bicskos, 1985; G. Pickering, pers. comm.). However, a survey undertaken in northern New South Wales found that if the species is not disturbed they are curious animals and are not upset by scuba divers (Parker, unpub.). Other behavioural observations have been made on individuals inhabiting a rocky reef off Sydney by professional divers (see Ireland, 1984 for further details).

2.6 MIGRATORY MOVEMENTS

2.6.1 WORLD

Several studies have been undertaken around the world on the migratory habits of the Grey Nurse Shark. Most authors have inferred linkages between migratory movements and breeding activities. The migratory movements of the species may also be a function of the species moving to be within a preferred water temperature range (Branstetter and Musick, 1994; Parker, unpub.), or following migrating food sources (T. Byron, pers. comm.). The migration of Grey Nurse Shark populations around the world has been generalised by Compagno (1984). He considered that pronounced poleward migrations occur in summer and equatorial movements occur in autumn and winter.

Studies undertaken in the USA (e.g. Gilmore *et al.*, 1983; Schmid *et al.*, 1990; Branstetter and Musick, 1994) have documented the migratory habits of the Grey Nurse Shark and shown that northward movements occur along the east coast each spring with females occupying summer gestation grounds as far north as the Gulf of Maine. This is followed by a return journey in Autumn to winter pupping grounds located in the south (Bigelow and Schroeder, 1953). Gilmore *et al.* (1983) suggested that groups of female Grey Nurse Sharks undertake migratory movements for breeding, gestation and parturition. They also suggested that coordinated breeding activities and post-breeding migrations occurred. These conclusions were drawn from the examination of females carrying embryos in the same state of development and captured contemporaneously at the same location. The migratory movements of Grey Nurse Sharks along the US east coast can be generalised as northward (poleward) movements occurring in the summer and southward (equatorial) movements occurring in the winter.

Studies of the Grey Nurse Shark on the eastern coast of South Africa. (Cliff, unpub.) have described the migratory habits of females and to a lesser extent of males throughout the breeding season. Most of the information was derived from beach meshing programs and observations of tagged sharks.

The females moved northward in spring to the mating grounds around Durban, with copulation occurring from October to November. They continued northwards to "gestation grounds" where they spent the summer. It is here that sharks have been seen with hydroid growths on their teeth. In late autumn, pregnant females move southward towards the winter pupping grounds, but the movements of male Grey Nurse Sharks are poorly understood. In South African waters the species generally move northward (equatorial) in summer and southward (poleward) in winter.

The movements of Grey Nurse Sharks off the east coast of the USA concur with Compagno (1984). However, South African populations exhibit contrary movements. The contradictory movements may indicate that the migration of the Grey Nurse Shark is influenced by more than one factor. As a result more widespread research needs to be undertaken into the migratory movements of the Grey Nurse Shark, taking into account all environmental influences that may affect the species.

2.6.2 SE AUSTRALIA

Relatively little is known about the migratory habits of Grey Nurse Sharks in SE Australian waters. A study undertaken on the abundance of the species on the northern New South Wales coastline (Parker, unpub.) found a pattern that suggested migratory movements. The pattern appeared to agree with the generalised world migrational movements suggested by Compagno (1984). It has been hypothesised that these movements are in response to water temperatures (Reid and Krogh, 1992; Hoppen, 1997a). Data from the beach meshing programs (Krogh, 1994; Reid and Krogh, 1992) and movements of tagged sharks from records of gamefish anglers in NSW (Pepperell, 1992) provide further evidence in support of possible migratory habits. Clearly, more information is required to test hypotheses concerning the movements of the Grey Nurse Shark in SE Australian waters.

2.7 DISTRIBUTION

2.7.1 WORLD

The distribution of *C. taurus* seems to be fairly well understood and extensively documented (e.g. Compango, 1984; Last and Stevens, 1994). The Grey Nurse Shark is found primarily in sub-tropical to cool temperate inshore waters around the main continental landmasses, except in the eastern Pacific Ocean off North and South America (Fig. 2.2).

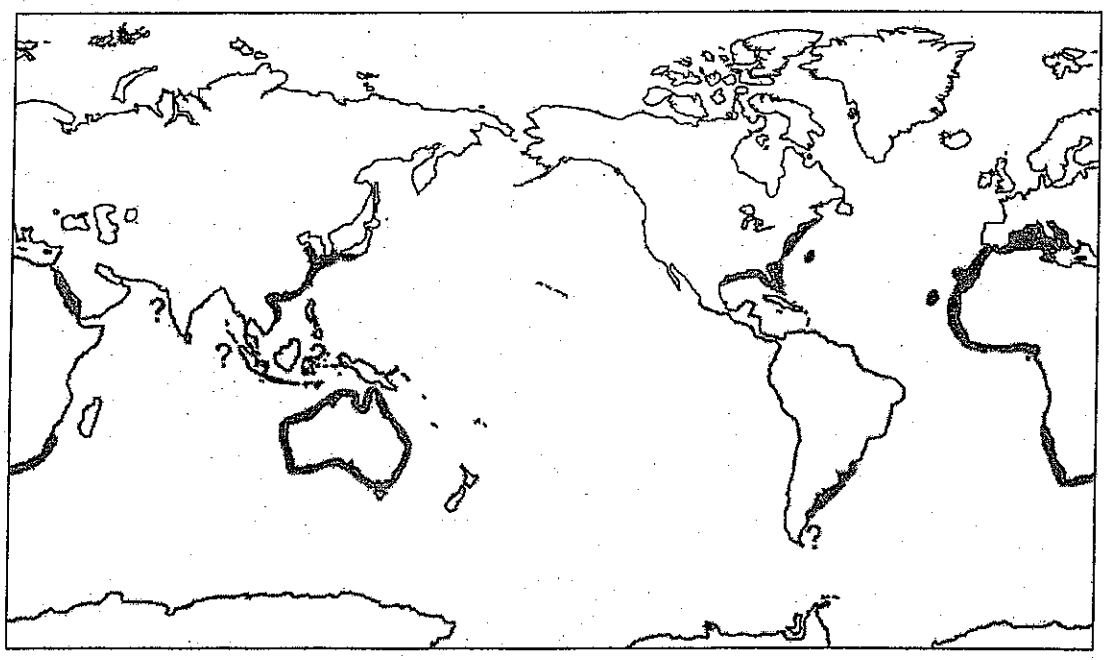


Figure 2.2. Worldwide distribution of *Carcharias taurus* (From: Last and Stevens, 1994).

2.7.2 AUSTRALIA

The Grey Nurse Shark has 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 is rare in Tasmanian waters, but Grey Nurse Sharks have been caught in the Arafura sea off the Northern Territory by Taiwanese longliners (Read and Ward, 1986).

2.8 ABUNDANCE IN SE AUSTRALIA

The spatial and temporal patterns of abundance of the Grey Nurse Shark in SE Australia is poorly understood. However, some data do exist for the abundance of this species in New South Wales waters. These are:

1. the NSW beach meshing programs (Reid and Krogh, 1992; Krogh, 1994),
2. log books of gamefish anglers (Pepperell, 1992),
3. a small survey in the Solitary Islands Aquatic Reserve (now a Marine Park) and adjacent areas in 1992-1993 (Pickering and Wilkinson, unpub.),
4. a survey at Seal Rocks in 1991 (Pollard *et al.*, 1996),
5. a study in northern NSW waters in 1996-1997 (Parker, unpub.), and
6. diver sightings of Grey Nurse Sharks in NSW.

Most of these surveys have been undertaken on a small spatial scale over a relatively short period of time and are on a localised scale. Thus, there is very little information concerning the actual abundance of Grey Nurse Sharks along the SE Australian coast. The details from each source will be discussed in more detail below.

2.8.1 BEACH MESHING PROGRAMS AND GAMEFISH ANGLER RECORDS

The NSW beach meshing program was initiated in the 1930s to protect bathers from shark attack at beaches in the Wollongong, Sydney and Newcastle areas (Reid and Krogh, 1992). Grey Nurse Sharks comprised 3.7% of the total catch of the NSW beach meshing program between 1950 and 1990 (Reid and Krogh, 1992). Moreover, the number of Grey Nurse Sharks declined over the period 1950-1990 (Table 2.4). While other species of sharks have also declined in the NSW beach meshing program, the decline in numbers of Grey Nurse Sharks would appear to be far greater than all other species. Finally, the effort (i.e. number of beaches meshed) has increased sporadically since meshing began in the 1930's.

Table 2.4. Number (percentage) of Grey Nurse Sharks caught in the beach meshing nets for the Newcastle, Sydney and Wollongong regions for the periods 1950-72 and 1972-90 (After: Reid and Krogh, 1992).

LOCATION	1950-1972	1972-1990
Newcastle	202 (7.7%)	52 (2.4%)
Sydney	46 (2.8%)	33 (1.4%)
Wollongong	36 (8.4%)	0 (0.0%)

The total numbers of Grey Nurse Sharks caught in the nets of the protective beach meshing program (Fig. 2.3) was greatest during the 1950s when up to 36 Grey Nurse Sharks were meshed per year. This declined to a maximum of 3 Grey Nurse Sharks meshed per year in the 1980s.

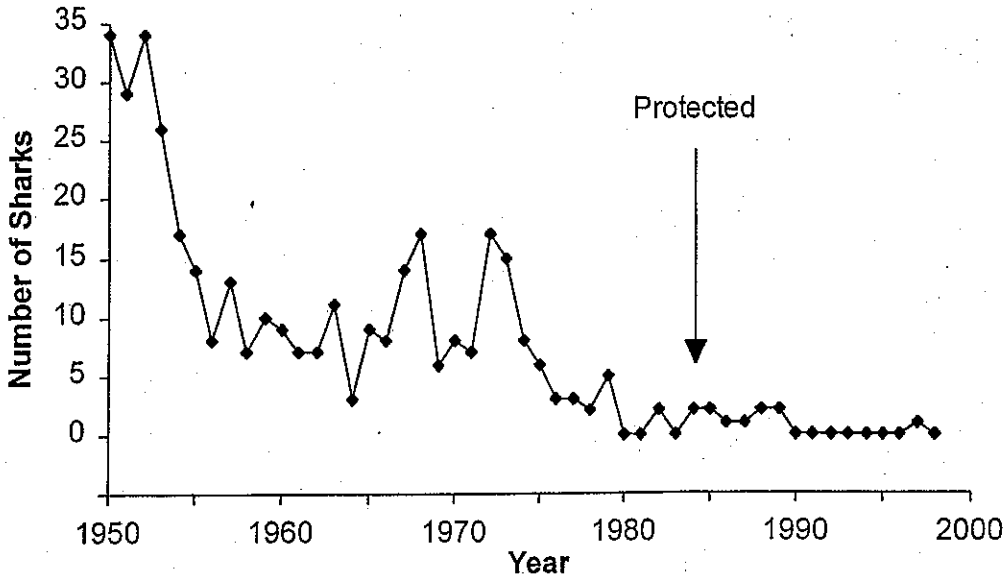


Figure 2.3. Decline in the numbers of Grey Nurse Sharks caught in shark meshing nets in the Newcastle/Sydney/Wollongong regions from 1950-1990 (From: Pollard *et al.*, 1996).

Over a similar period (i.e. 1961-1990), larger numbers of Grey Nurse Sharks were taken by gamefish anglers, than the beach meshing programs, with the 406 Grey Nurse Sharks representing 5% of the total recorded catch of sharks (Pepperell, 1992).

2.8.2 SURVEY AT SOLITARY ISLANDS AQUATIC RESERVE (NOW MARINE PARK)

The abundance of Grey Nurse Sharks was quantified by the Solitary Islands Underwater Research Group over a period of 16 months from June 1992 through to October 1993. In total 144 Grey Nurse Shark were recorded from 33 sightings at scuba diving sites within the Solitary Islands Aquatic Reserve. The sharks were sighted in water temperatures ranging from 16 to 23°C and their abundance's exhibited seasonal patterns, with greatest numbers occurring in Winter/Spring (Fig. 2.4).

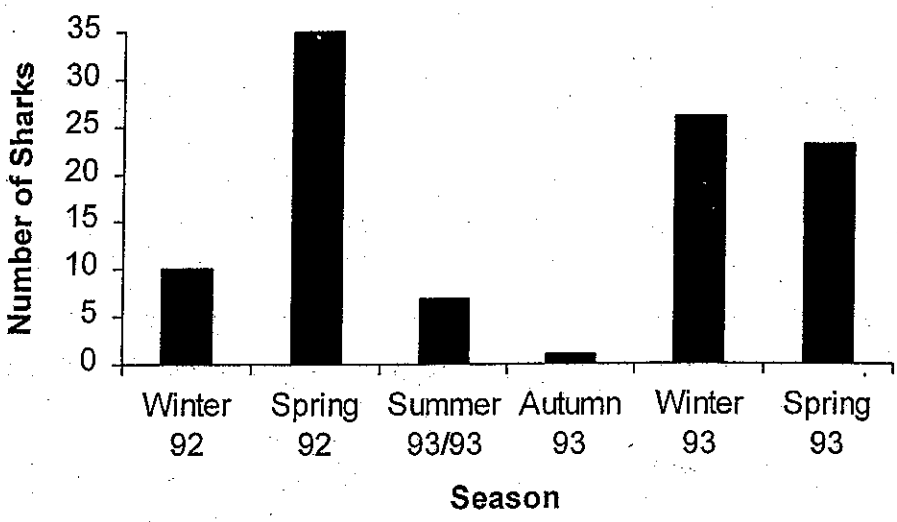


Figure 2.4. Seasonal abundance of Grey Nurse Sharks in the Solitary Islands Aquatic Reserve from Winter 1992 to Spring 1993 (From: Pickering and Wilkinson, unpub.).

2.8.3 SURVEYING AT SEAL ROCKS

The abundance's of Grey Nurse Sharks were quantified at Seal Rocks in November 1991. Four scuba diving sites were surveyed, and these included: Skeleton Rocks, Big Seal Rock, Little Seal Rock and Edith Breaker. Replicate timed counts (15 minutes each) were carried out in the morning and in the afternoon at each site. Counts were made of the total number of Grey Nurse Sharks observed. The survey (Fig. 2.5) showed that the majority of the sharks were seen during the morning at Little Seal Rock, but the sharks were sighted in other areas.

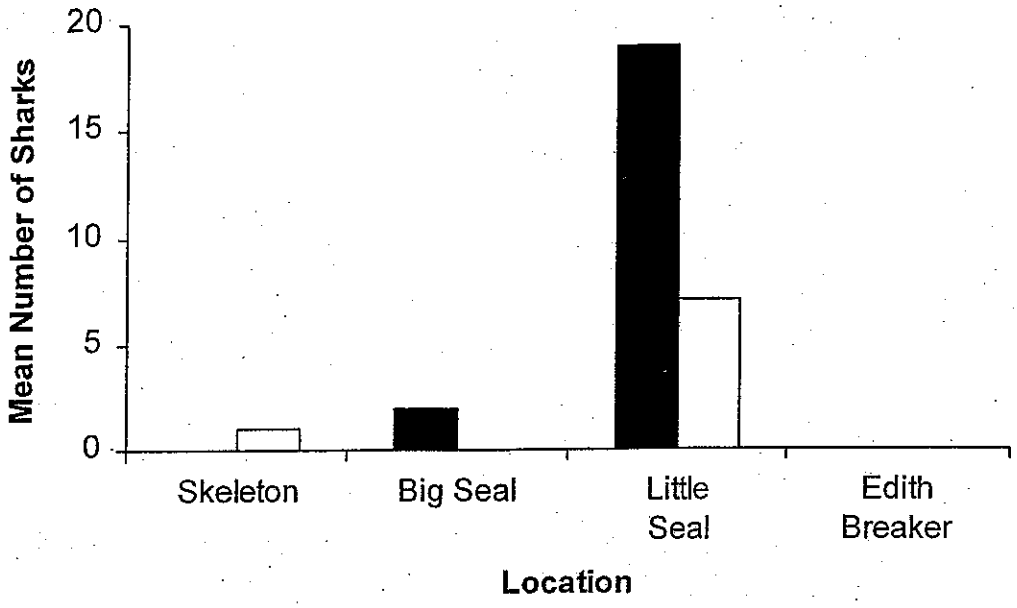


Figure 2.5. Mean number of Grey Nurse Sharks observed during morning (shaded) and afternoon (unshaded) surveys at four sites at Seal Rocks in November 1991 (From: Pollard *et al.*, 1996).

2.8.4 STUDY IN NORTHERN NSW

The abundance's of Grey Nurse Sharks were quantified over 15 months (August 1996 to October 1997) in northern NSW (Byron Bay to South West Rocks). The information obtained in the survey provided an insight into the frequency and seasonality of shark sightings at popular dive sites in northern NSW (Fig. 2.6).

Fig. 2.6 infers movements of the species in the northern waters of their range along the NSW coast. The presence of the species in the north during the winter and the absence of the species in the area studied (northern NSW) during the summer may indicate a coastwide migration of the species is occurring. The pattern suggests that the sharks spend summer in the south and winter in the north. This is further supported by anecdotal information from sightings of Grey Nurse Sharks in southern waters over late Spring to Summer with a subsequent disappearance in Autumn (see Table 2.5).

Parker (unpub. data) also suggested that temperature played an important role in possible migratory movements. The Grey Nurse Shark appears to have a strong preference for water temperatures between 17 to 26^{o}C (Fig. 2.7).

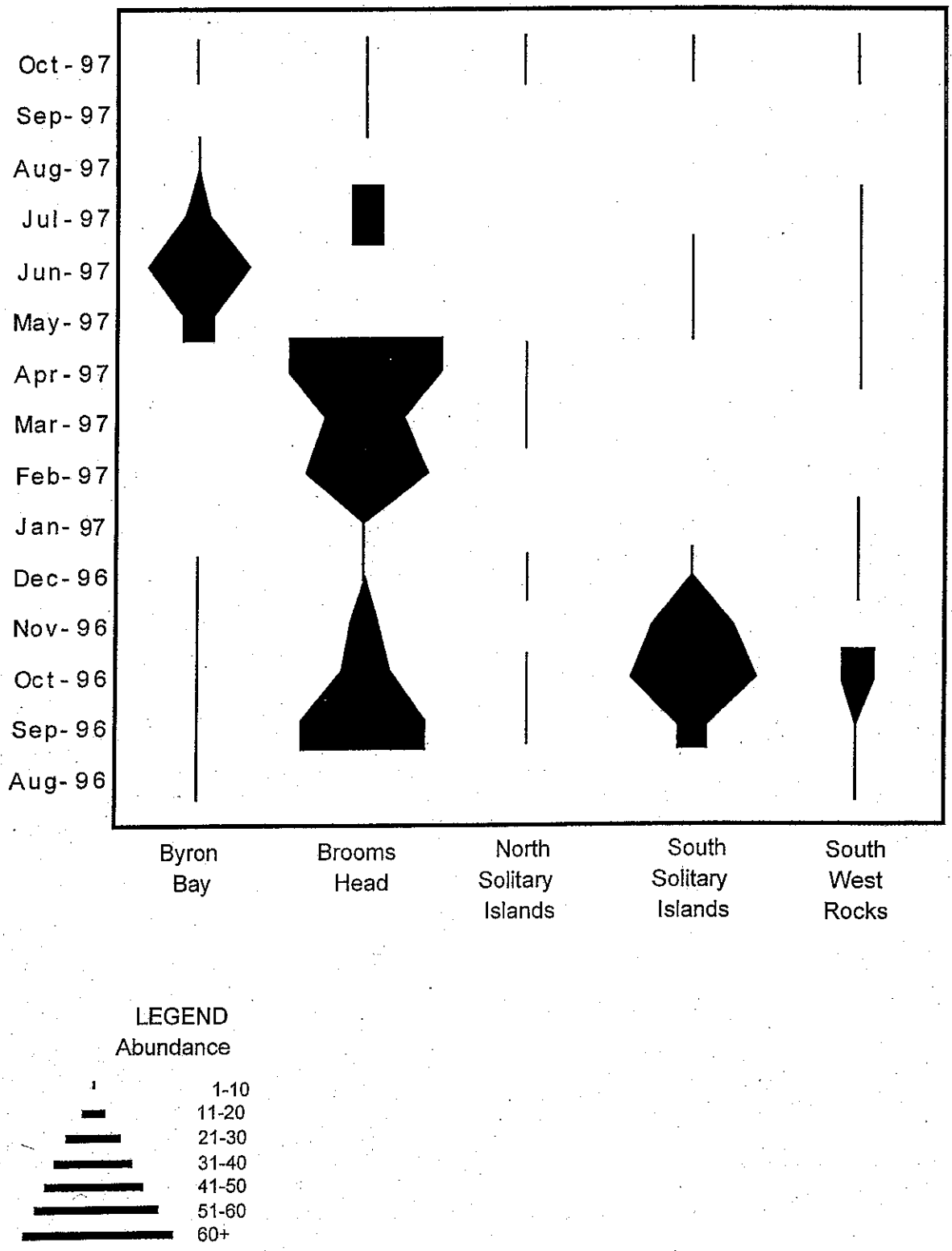


Figure 2.6. The frequency of Grey Nurse Sharks sighted in the major diving regions in northern NSW waters over a 15 month period (From: Parker, unpub. data).

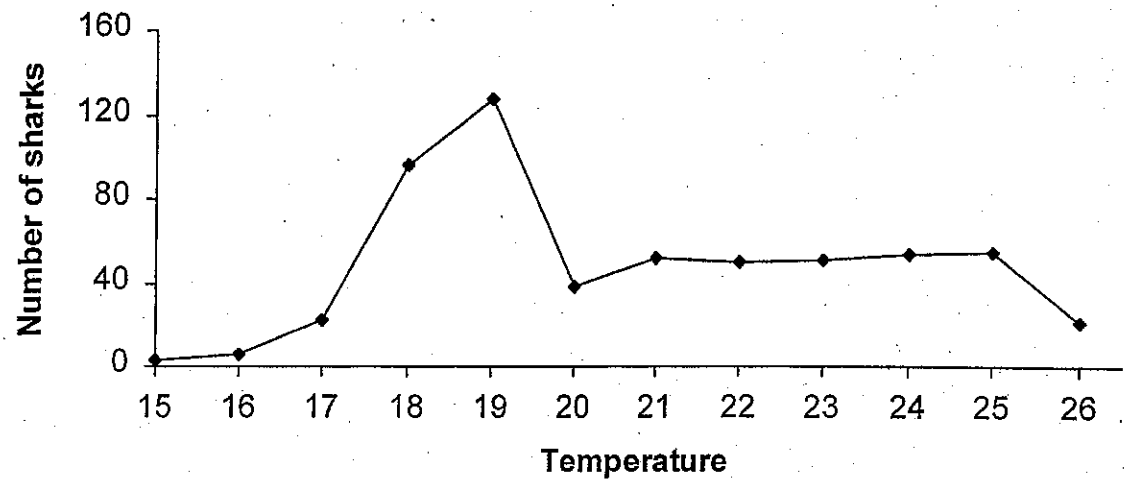


Figure 2.7. Abundance of Grey Nurse Sharks sighted in relation to water temperature (From: Parker, unpub. data).

2.8.5 DIVER SIGHTINGS OF GREY NURSE SHARKS

For the purpose of this review, preliminary anecdotal information has been gathered to determine the locations where sharks have been sighted in previous years. These locations are displayed in Table 2.5 and Fig. 2.8.

Table 2.5. Locations of Grey Nurse Sharks sightings in previous years in NSW.

BIOREGION (IMCRA, 1998)	LOCATION	SITE NAME	TYPICAL HABITAT	TIME OF YR SIGHTED
Tweed-Moreton	Brisbane	North Stradbroke Is.	Gutters	Jul-Oct (J)
	Tweed Heads	Nine Mile Reef	Gutters	Jun-Aug(B)
		Cook Island	Gutters	Jun-Aug(B)
	Byron Bay	Julian Rocks	Gutters	Jun-Jul (A)
		Spot X	Pinnacles/Gutters	Jun-Jul (A)
	Evans Head	Riordan Shoals	Gutter	-
	Brooms Head	Freeburn Rock	Gutter	-
		Pimpernel Rock	Cavern and Gutters	Nov-Apr (C)
	N W Solitary Is.	"E Gutters"	Gutters	Periodic (C)
	N Solitary Is.	Anemone Bay	Gutters	Periodic (C)
	S Solitary Is.	Manta Arch	Gutters/Overhangs	Jun-Dec (F)
		The Big Arch	Overhang	Jun-Dec(F)
	Split Solitary Is.	Coral Cove	Gutters	Jun-Dec(F)
Manning Shelf	S W Rocks	Fish Rock	Cave and Gutters	-
	Port Macquarie	The Cod Grounds	Gutters	Sep (I)
		Mermaid Reef	Gutters	-
	Forster/Tuncurry	The Pinnacles	Boulders/Gutters	All Year (D)
	Seal Rocks	Big Seal Rock	Gutter/Cave	All Year (D)
		Little Seal Rock	Gutters/Ledge	All Year (D)
		Edith Breaker	Gutters/ Ledge	All Year (D)
		Skeleton Rocks	Caves	Periodic (A)
	Nelson Bay	Broughton Island	Caves/Gutters	Apr

Table 2.5 Cont. Locations of Grey Nurse Sharks sightings in previous years in NSW.

BIOREGION (IMCRA, 1998)	LOCATION	SITE NAME	TYPICAL HABITAT	TIME OF YR SIGHTED
Hawkesbury Shelf	Newcastle	Samurai Beach	-	-
		Boat Harbour	-	-
	Swansea	Caves Beach Reef	Reef	-
	Norah Head	Hargraves Reef	-	-
		Three Mile Reef	-	-
	Terrigal	Foggy Cave	Cave	Feb-Apr (A)
		East Reef Bombora	-	Feb-Apr (A)
	Sydney	Hole in the Wall	Gutters	All Year (G)
		The Wall (Longreef)	Gutters and Caves	Dec-Jan (A)
		Maroubra	Boulders/Gutters	Dec-Jan (A)
		Sth Palm Beach Reef	Caves/Gutters	Dec-Jan (A)
		One Mile Reef	Gutters	Dec-Jan (A)
		Jibbon Bombora	Cave and Gutters	Dec-Jan (A)
Batemans Shelf	Wollongong	Toothbrush Is.	Gutter	-
	Shell Harbour	Bass Point	Gutters	-
		Windang Island	Gutters	-
	Kiama	Gerroa Bommie	-	-
	Jervis Bay	The Docks	Gutters	Dec-May (L)
		Boat Harbour	Caves	Dec-May (L)
		Bowen Island	Wall	Dec-May (L)
		Stoney Creek	Gutter	Dec-May (L)
		Drum and Drumsticks	Caves	Dec-May (L)
	Batemans Bay	Tollgate Islands	Gutters	Dec-Apr (E)
		Black Rock	Gutters	Dec-Apr (E)
		Brush Island	Gutters/Pinnacles	Dec-Apr (E)
	Narooma	Montague Is. Gutters	Gutters	Jan-Apr (H)
		Montague Is. Cave	Gutters and caves	Jan-Apr (H)
Twofold Shelf	Merimbula	Tura Head	Gutter	Jan-Feb (K)
	Eden	North Head	Mewstone Rock	Jan-Feb (K)

(A): Byron, (1985); **(B)**: A. Bennett, pers. comm.; **(C)**: Parker (unpub. data); **(D)**: D. Kemp, pers. comm.; **(E)**: D. Harasti, pers. comm.; **(F)**: Pickering and Wilkinson, pers. comm.; **(G)**: Ireland (1994); **(H)**: D Bond, pers. comm.; **(I)**: S. Ward, pers. comm.; **(J)**: Horton (1997) **(K)**: R. McDougall, pers. comm; **(L)**: W. Jones, pers. comm.

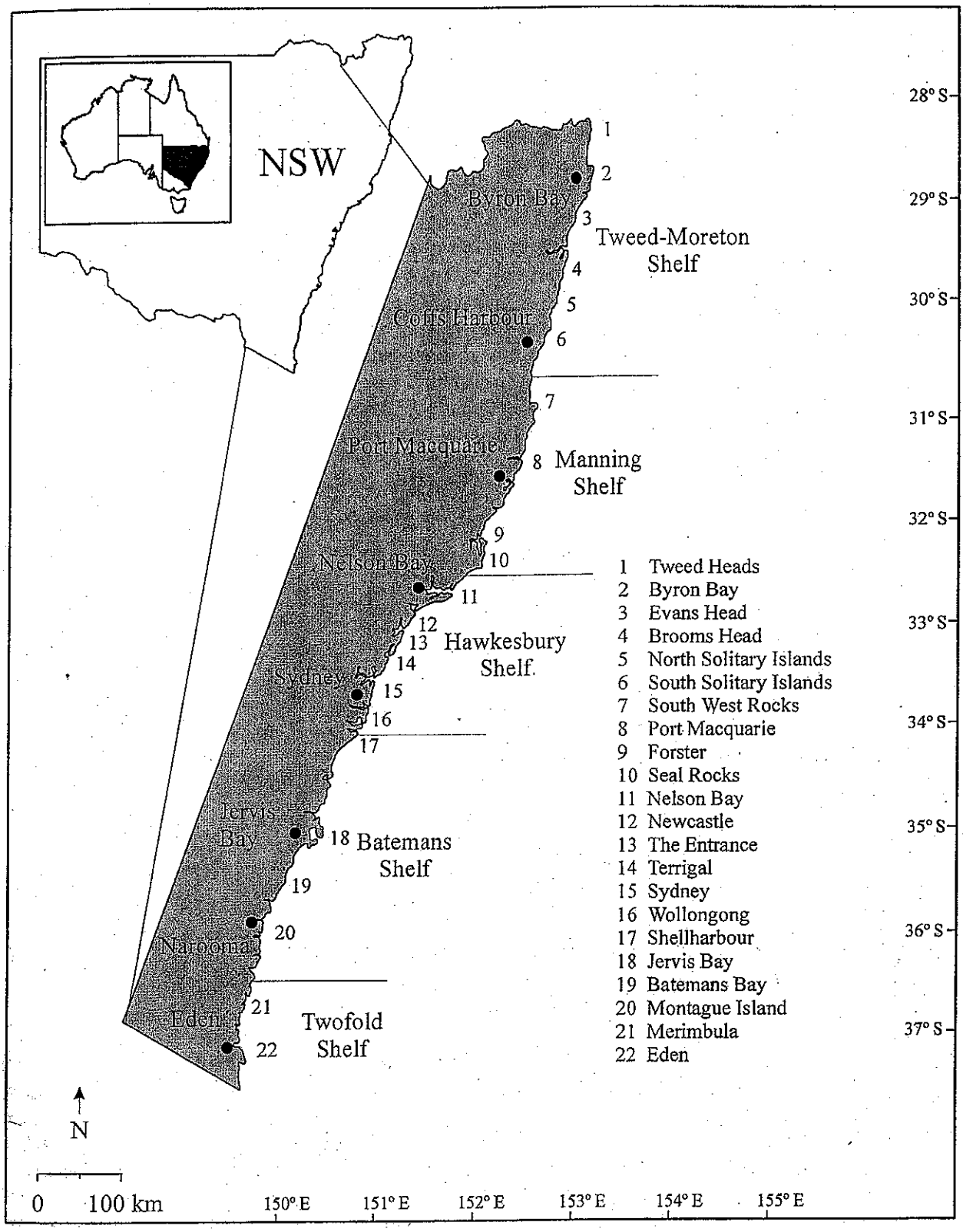


Figure 2.8. Locations along NSW coast where Grey Nurse Sharks have previously been sighted.

2.9 HABITATS UTILISED BY GREY NURSE SHARKS

The Grey Nurse Shark is a coastal species found on the continental shelf from the surf zone down to at least 190 m (Compagno, 1984; Klippel, 1992; Last and Stevens, 1994; Pollard *et al.*, 1996). They are often found in or near deep sandy-bottomed gutters (Goadby, 1968; Grant, 1982; Bicskos, 1985) or in rocky caves around inshore rocky reefs and islands at depths between 15 and 25 meters (Pollard *et al.*, 1996). They are also, on occasion, found throughout the water column (Compagno, 1984).

A recent survey in Northern New South Wales (Parker, unpub.) found that Grey Nurse Sharks were most commonly sighted in sandy gutters (42% of sightings) and in large caves or caverns (24% of sightings) (Fig. 2.9.). Further research on the Grey Nurse Shark should take into consideration habitat preferences and the apparent importance of a preferred water temperature range.

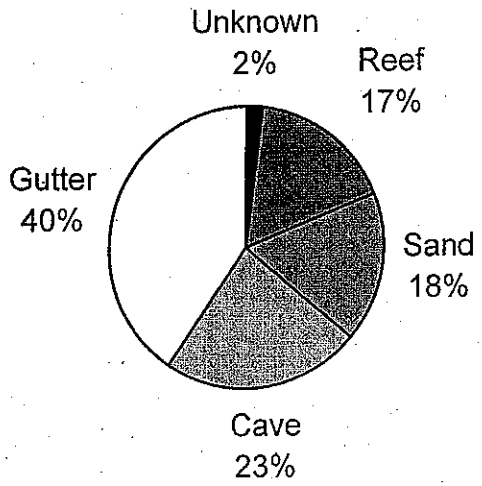


Figure 2.9. Percentage frequency of Grey Nurse Sharks sighted in four different environments (From: Parker, unpub. data).

2.10 HUMAN USAGE OF GREY NURSE SHARK HABITATS

Scuba diving and commercial/recreational fishing are the main human activities that occur in the habitats utilised by Grey Nurse Sharks. Protective meshing of beaches in Newcastle, Sydney and Wollongong has, in the past, caught transitory individuals and thus this activity has the potential to affect the abundances of Grey Nurse Sharks.

2.10.1 SCUBA DIVING

In recent years "shark diving" has become increasingly popular with scuba divers all over Australia, with many divers recounting their experiences in diving magazines (e.g. Harding, 1990; Aitken, 1991; Cairn-Duff, 1994; Garbutt, 1995; Marsh, 1995; Scott, 1995; Hoppen, 1997a; Baumann, 1997). The emergence of shark diving ecotourism as a recreational activity occurred following the realisation that the shark was not a "man-eater".

The Grey Nurse Shark has become a big attraction to scuba divers and increasing pressure has been placed on operators to take divers to places where they can encounter the shark. This new wave of interest may be affecting the shark in unforseen ways and this needs to be assessed. However, if divers continue to keep their distance whilst diving with the shark, experience would suggest that it is unlikely that scuba diving *per se* will have any detrimental effects on the sharks' survival.

2.10.2 COMMERCIAL/RECREATIONAL FISHING

The Grey Nurse Shark has not been fished legally as a commercially or recreationally important species in NSW since it was afforded protected status in 1984. Moreover, published (e.g. Pepperell, 1992) and anecdotal accounts indicate that recreational game-fishing for Grey Nurse Sharks ceased before 1984 (i.e. in the late 70's) because of concerns over their numbers and the fact that they were considered to be "most uninteresting and inactive" as a game species (Goadby, 1987).

Pollard *et al.* (1996) quoting Cropp (1964) indicated that spearfishing for the species was a popular sport during the 1950's and 1960's. This sport weakened as declining numbers of the species were observed, coupled with the growing realisation that the species was not a man-eater (Stevens, 1993; Pollard *et al.*, 1996).

Whilst the species is protected from all fishing activities, accidental hooking is still occurring. Scientists (e.g. Pollard *et al.*, 1996; Parker, unpub. data) and recreational scuba divers have observed fish hooks and wire traces embedded in the jaws of Grey Nurse Sharks. Photographic evidence has also been published in several scuba diving magazines (e.g. Garbutt, 1995; Marsh, 1995; Scott, 1995). Most recently, staff at Seaworld (Gold Coast, Qld.) observed numerous hooks in the stomach wall of a Grey Nurse Shark during an autopsy (T. Long, pers. comm.). Despite these observations, two independent studies have shown that the rates of hooking appear to be relatively low. First, a survey at Seal Rocks in 1991 (Pollard *et al.*, 1996) showed that only 2% of the sharks observed had fishing gear (e.g. hooks, wire traces, etc.) in their mouths. Second, a 15 month study (Parker, unpub. data) covering sites from Byron Bay (Julian Rocks) to SW Rocks noted that only 4% (i.e. n = 23) of all the Grey Nurse sightings were of individuals with fishing gear attached to their jaws.

At present, it is unclear whether accidental hooking is having any detrimental effects on Grey Nurse Sharks. Further research is needed to determine the extent of accidental hooking and the effect that this is having on individual sharks and the population overall.

2.10.3 PROTECTIVE BEACH MESHING

As stated earlier, protective meshing commenced in the 1930's to reduce the chances of a shark attack at beaches in Newcastle, Sydney and Wollongong. Given that the nets are set off beaches, they clearly do not target the 'preferred' habitats (e.g. gutters and caves) of the Grey Nurse Shark. Moreover, the Grey Nurse Sharks that have been caught were most likely transitory individuals.

While the protective beach meshing program has obviously been responsible for the capture of numerous Grey Nurse Sharks in the past, the extremely low capture rates in recent years will likely continue until the population increases substantially in the coastal waters of NSW. The continued use of the protective nets in the long-term will probably have negligible effects. Furthermore, it is NSW Fisheries' policy that, where possible, all Grey Nurse Sharks caught in protective nets be transported away from the beaches and released alive. In addition, all released individuals will be tagged to assist with scientific studies quantifying population size, growth rates and migratory movements. In the unlikely event that individuals are caught and die in the protective nets, the subsequent autopsies will provide very necessary biological information that will greatly assist in the long-term conservation of the Grey Nurse Shark.

2.11 CONSERVATION

2.11.1 WORLD

The Grey Nurse Shark is currently listed on the IUCN Red List of Threatened Animals as vulnerable world wide 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 decommercialised: it may be caught and kept, but may not be sold for financial gain (G. Cliff, pers. comm.). Moreover, researchers from the Natal Sharks Board hope that fishers who catch these sharks will return them to the water.

In the Atlantic the Grey Nurse Shark is being managed under a shark management plan drawn up by the National Marine Fisheries service (NMF's). The plan was aimed at reducing catches of sharks by sport and commercial fisherman. The Grey Nurse Shark (sand tiger as it is known in the USA) is one of five 'large coastal species' sharks that have been protected from directed fishing by a ruling in April 1997 (Smullen, 1997).

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. Pollard (1990) attributed the decline to spearfishing and capture by the protective beach meshing program. Pollard *et al.* (1996) argue that there were three main factors leading to the protection of the Grey Nurse Shark in NSW waters. These were: (1) declining catches by spearfishermen, (2) declining catches in beach meshing programs and (3) the realisation that the species was not responsible for attacks on humans. As a result, requests were made to NSW Fisheries to protect the species.

Protection of the species in State waters is managed under the regulations of the *NSW Fisheries Management Act 1994* . The protection of the species in Commonwealth waters, including the Australian Fishing Zone and waters above the continental shelf, is carried out under the *Endangered Species Protection Act 1992* in which the species is listed as 'vulnerable'.

The Herbst's Nurse Shark (*Odontaspis ferox*), a close relative of the Grey Nurse Shark, is also protected under both acts because distinguishing this species from the Grey Nurse Shark is difficult (Pollard *et al.*, 1996).

2.11.2.1 Current situation in NSW

The low fecundity of the species coupled with pressures on the species from use of their habitats by divers and fishers, indicates that continued existence of the species will be ensured when further strategies other than legislative protection can be provided for the shark.

Many articles have been written arguing that legislative protection is not enough and that habitat protection is the next step forward (Scott, 1995; Hoppen, 1997b; Marsh, 1995; Garbutt, 1995). Ideally, particular areas where the sharks tend to congregate or particular habitats that are essential to the species life history should be provided with some form of protection. For example, scuba divers at South West Rocks (a well known shark refuge) noticed continued declines in the abundance of the species in the area and voiced their concern at a public meeting. As a result a fisheries closure over an area covering a 500 metre radius around Fish Rock was proposed (Alcock, 1996), and declared by NSW Fisheries in July 1995 (Smith, 1995). This closure has been extended until July 2003 (Government Gazette number 115).

Other areas along the NSW coast may be important to the species, even on a short-term basis (i.e. certain months of the year). If these sites can be identified then the Grey Nurse Shark may be provided with extra protection than is currently granted by the legislation.

2.12 CONCLUSIONS AND RECOMMENDATIONS

2.12.1 ABUNDANCE

To date very few quantitative surveys have been done to document the long-term and inter-annual variation in the abundance of Grey Nurse Sharks. Those surveys that have been done were confined to small sections of the NSW coast and generally of short duration.

Clearly, the future conservation and management of the Grey Nurse Shark in NSW waters will depend on the provision of reliable estimates of abundance. To this end, it will be necessary to ensure that the spatial and temporal variation in abundance of Grey Nurse Sharks is documented on a regular basis. This monitoring, if carried out at an appropriate frequency, will also provide information on particular life-history events such as mating and pupping.

2.12.2 REPRODUCTION, MIGRATION AND CONSERVATION

The Grey Nurse Shark species is highly vulnerable to human induced pressures because it has a two year reproductive cycle and generally only produces two young per litter (Branstetter and Musick, 1994). Moreover, very little is known about the precise timing of mating and pupping of *C. taurus* populations in Australian waters. Any information concerning the reproduction of Australian populations of Grey Nurse Sharks will make major contributions to the management of the shark, particularly in relation to protecting sites that are important in the reproductive cycle of the Grey Nurse Shark.

Future findings on migratory habits may help determine nursery areas and mating grounds of the species which will enable more informed decisions for effective management of the Grey Nurse Shark in NSW waters.

2.12.3 HUMAN USAGE OF GREY NURSE SHARK HABITAT

There is very little quantitative information about the interactions between Grey Nurse Sharks and scuba divers. Future research should document the timing and nature of these shark/diver interactions as this information will assist in assessing the possible impacts of recreational scuba divers on shark populations.

Future research will need to determine primary pressures upon the Grey Nurse Shark and how they can be dealt with most effectively, as well as establishing the residency status of the species' in an area. The importance of particular sites to the population as a whole will also need to be quantified. Once these have been determined, actions can be recommended to further protect the species. For example, it may be possible to: (1) incorporate some of the important sites into a system of marine protected areas, and/or (2) use fishing closures at sites where Grey Nurse Sharks are present over restricted period of time. Both approaches are advantageous in that they meet the conservation needs whilst maintaining ecologically sustainable multiple use.

3. GREY NURSE SHARK HABITAT MAPPING

3.1 INTRODUCTION

The aim of the mapping component is to provide detailed information on locations and sites where Grey Nurse Sharks have been sighted and to provide anecdotal and quantitative information on the occupation of these sites by Grey Nurse Sharks. The sites surveyed in three Bioregions, Tweed-Moreton Shelf Bioregion, Manning Shelf Bioregion and the Hawkesbury Shelf Bioregion have been mapped. The maps show the location of the site in relation to the coast, the nature and characteristics of the habitat (usually gutter or cave) where the sharks are generally sighted, approximate distance of the site from the coast and any other unique features of each particular site.

The maps were generated from drawings and computer images submitted by the surveyors of the sites. 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 are generally sighted, (3) the popularity of the site with recreational scuba divers, and (4) any other relevant information that is unique to each site, such as, the extent and location of Marine Protected Areas, fishing closures and Aquatic Reserves around the sites sampled. Maps for the three bioregions are presented in latitudinal order from north to south.

3.1.1 TWEED-MORETON BIOREGION

The Tweed-Moreton Bioregion extends from just north of Nambucca Heads (30°39'S), northwards into Queensland. Fifteen sites in the Tweed-Moreton Bioregion were sampled as part of the distribution and abundance surveys (Table 3.1). Individual maps have been provided for all 15 sites (Fig. 3.1).

Table 3.1. The sites (and locations) surveyed in the Tweed-Moreton Bioregion. (*: the site falls outside the 3 n m state limit. **: the site is near State/C'wlth boundary).

Location	Sites
Stradbroke Island	Flat Rock
Tweed Heads	Cook Island Nine Mile Reef * Alberta Wreck
Byron Bay	Julian Rocks - Cod Hole Julian Rocks - Cleaner Cave Julian Rocks - Hugoes Trench Mackerel Bowl
Brooms Head	Pimpernel Rock *
North Solitary Islands	Bay of Anemones Wrights Reef ** "E" Gutters
South Solitary Islands	Manta Arch Shark Gutters Buchannans Wall

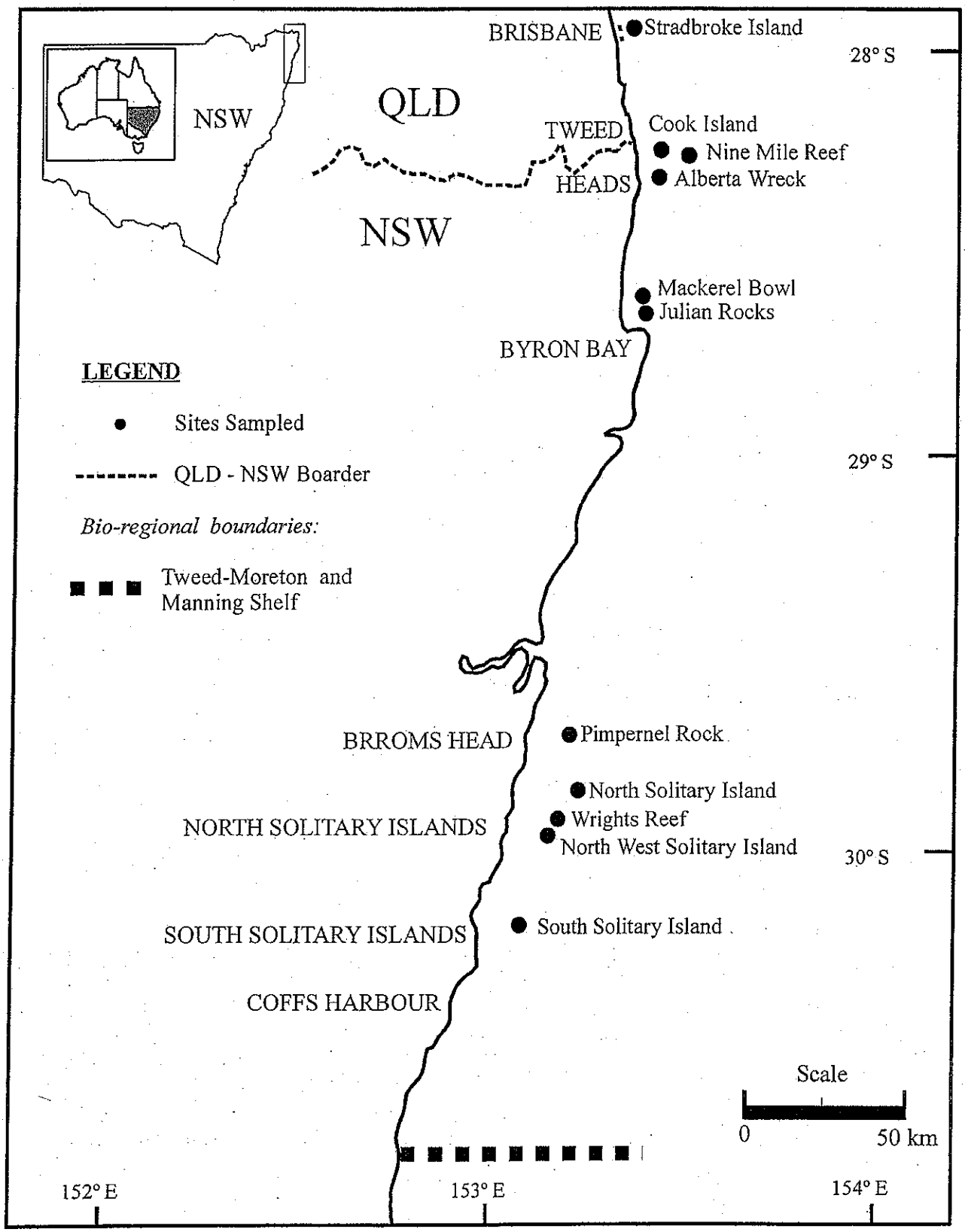


Figure 3.1. Locations of Grey Nurse Shark survey sites in the Tweed-Moreton Bioregion.

3.1.1.1 Stradbroke Island

The site where Grey Nurse Sharks are most commonly encountered at Stradbroke Island is known as 'Flat Rock'. It is located off the northern tip of North Stradbroke Island (Fig. 3.2) and comprises an exposed rock with fringing reef and a series of gutters reaching a depth of 25 metres. It is in these gutters that Grey Nurse Sharks have been sighted. The sharks are mostly sighted in the winter months with the first sharks generally arriving at Stradbroke Island in July and leaving around late August - early September. However, in rough weather the sharks disappear and it is assumed that they move to deeper waters. Recreational scuba divers explore this site on a regular basis throughout the year mostly from a boat which anchors to the reef.

3.1.1.2 Tweed Heads

At Tweed Heads there are three main sites where Grey Nurse Sharks are encountered: Cook Island, Nine Mile Reef and the Alberta Wreck (Fig. 3.3). The Grey Nurse Sharks are most commonly encountered at Nine Mile Reef. This reef is located 9 nm directly east of Fingal Head in northern NSW. The sharks are observed swimming along an 8-12 m sheer wall. Cook Island Nature Reserve is exposed rock with fringing reef located 700 m off the shore at Fingal Head. The north eastern end of the fringing reef is composed of bommies and gutters reaching depths of 25 metres. Grey nurse sharks are seen in these gutters in winter months.

Alberta wreck is located offshore from Kingscliff in northern NSW. Few sharks have been encountered at this site but a 19 m deep gutter directly east of the wreck is an area where Grey Nurse Sharks have been sighted on previous occasions. Grey nurse sharks occupy this site at similar times to Stradbroke Island with sightings mainly occurring in the winter months.

3.1.1.3 Byron Bay

There are four sites at Byron Bay where divers have encountered Grey Nurse Sharks (Table 3.1). However, Grey Nurse Sharks tend to be most commonly sighted at the 'Cod Hole' at Julian Rocks. Julian Rocks is a Nature Reserve approximately 2 km offshore from Byron Bay. The waters surrounding Julian Rocks in a 500 metre radius from the rock's trigonometric station were declared an Aquatic Reserve in March 1982. Recreational scuba diving is undertaken by divers from boats which moor at one of several moorings provided within the aquatic reserve. The 'Cod Hole' is located on the northern tip of the island and is characterised by a series of gutters and a small cavern where sightings of the species are common in the winter months. Also, there is a series of gutters extending from the Cod Hole in an eastwards direction to the Cleaner Cave where Grey Nurse Sharks are also commonly sighted (Fig. 3.4). These gutters have an average depth of 18 m. The Mackerel Bowl is another site where Grey Nurse Sharks have been encountered, however this site is not dived as regularly as the sites at Julian Rocks. The Mackerel Bowl is a submerged reef reaching depths of 26 m, approximately 750m north of Julian Rocks and is characterised by a series of gutters where Grey Nurse Sharks have been sighted during the winter months.

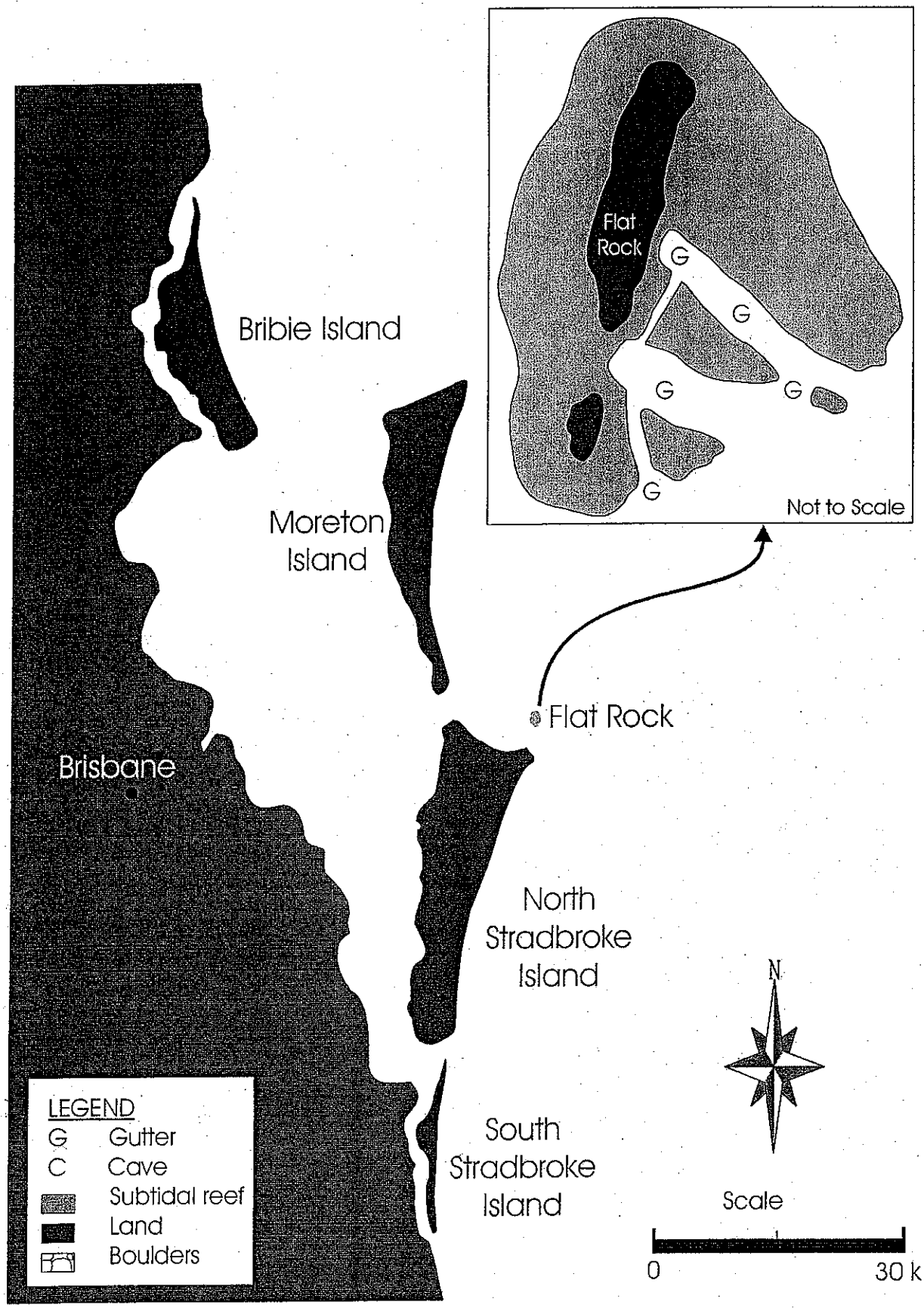


Figure 3.2. Grey Nurse Shark survey site at Stradbroke Island.

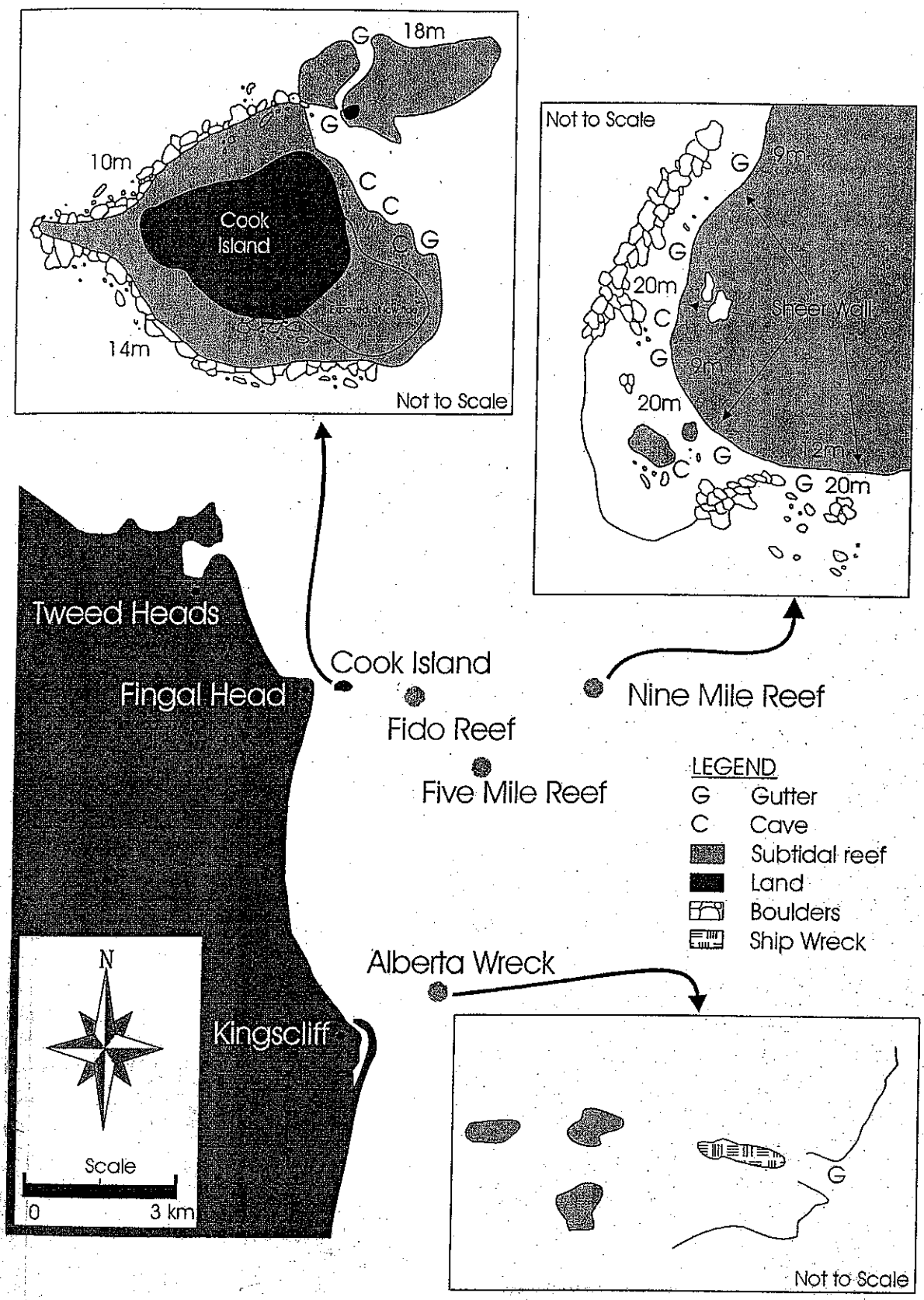


Figure 3.3. Grey Nurse Shark survey sites at Tweed Heads.

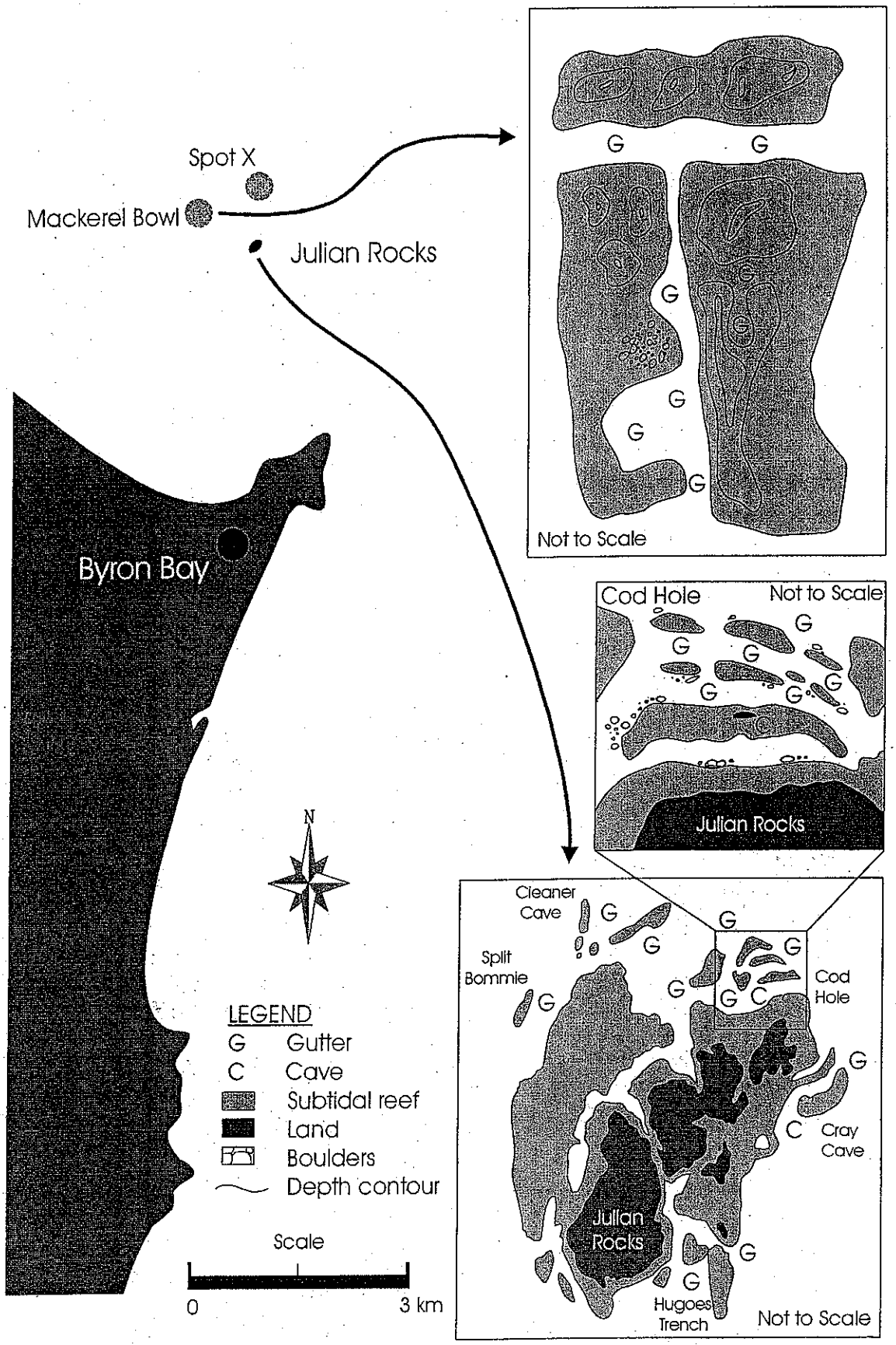


Figure 3.4. Grey Nurse Shark survey sites at Byron Bay.

3.1.1.4 Brooms Head

Aggregations of Grey Nurse Sharks have been encountered by scuba divers off Brooms Head at a site called Pimpernel Rock. Pimpernel Rock is a submerged reef over 3 nautical miles offshore from Sandon Bluff in the northern section of the Solitary Islands Marine Park (Fig. 3.5). The site is a large pinnacle of rock that sites in 50 m of water and rises to within 12 m of the sea surface. The site is characterised by a large cavern approximately 10 to 15 m deep and 20- to 25 m long with gutters extending out from both entrances of the cavern. Grey nurse sharks are generally seen inside the cavern and in the gutters fringing the cavern. The species is mainly encountered during autumn, winter and spring with occasional sightings in summer. Some mating activity has been observed in the months of autumn. The waters surrounding Pimpernel Rock is currently zoned as a refuge zone within the Solitary Islands Marine Park. The zoning plan is currently being reviewed and it is likely that the area will be zoned as a sanctuary in the future.

3.1.1.5 The North Solitary Islands

The Northern Solitary Islands are located in the northern section of the Solitary Islands Marine Park and provide popular scuba diving sites at North Solitary Island and North West Solitary Island (Fig. 3.6). The Solitary Islands Marine Park stretches along 75km of coastline from Coffs Harbour to the Sandon River. The area was declared an Aquatic Reserve in 1991 and then a Marine Park in 1997. Grey nurse sharks can be encountered at several sites in this section of the Park. The Bay of Anemones is located on the north eastern tip of North Solitary Island and relatively large numbers of the sharks can be observed during winter and spring. The site is characterised by a 30 m deep gutter where the sharks are most frequently sighted. Further south is a submerged reef known as 'Wrights Reef'. The reef ascends out of 30 m to 18 m and Grey Nurse Sharks can be seen in gutters and near a small cavern. This site is not regularly dived by recreational scuba divers so the frequency of occurrence of Grey Nurse Sharks at this site is relatively unknown. Further south at North West Solitary Island a popular site aptly named the 'E gutters'. The site comprises a series of gutters shaped like a large E on the south eastern tip of the Island. Grey nurse sharks have been encountered cruising through these gutters during the latter half of the year.

3.1.1.6 The South Solitary Islands

The Southern Solitary Islands are located in the southern section of the Solitary Islands Marine Park and encompasses scuba sites at South Solitary Island. Grey nurse sharks have been seen at South Solitary Island at three main sites: the 'Manta Arch,' the 'Shark Gutters' and 'Buchannans Wall' (Fig. 3.7). The Manta Arch and the Shark Gutters are located on the northern tip of the Island. These sites provide a series of 18 - 25 m deep gutters and a range of overhangs where sharks can be commonly encountered throughout the winter, spring and early summer months. Buchannans Wall is located around the southern end of the island and is characterised by a series of 25 m deep gutters running east-west. Grey nurse sharks have sometimes been seen in these gutters.

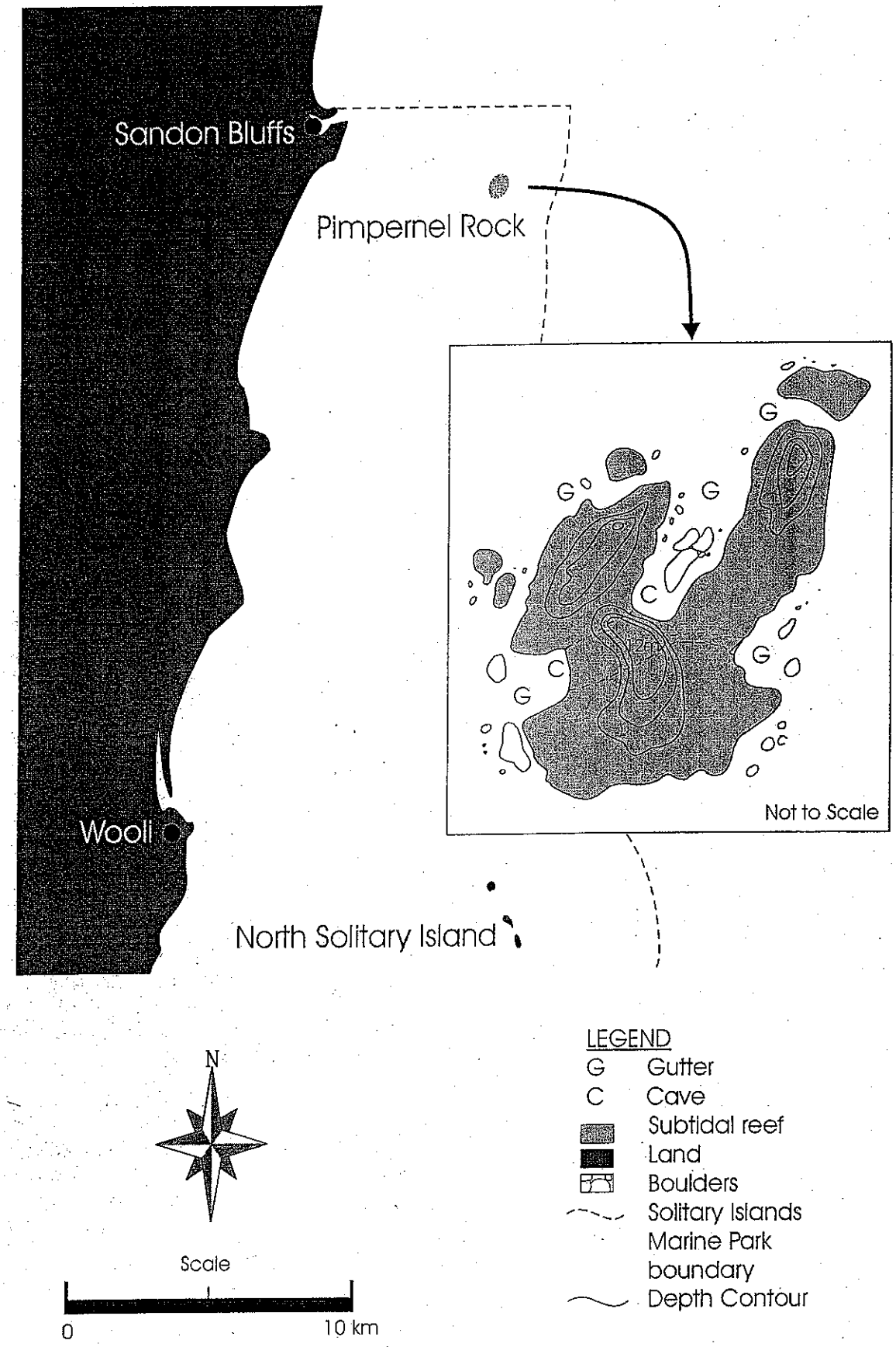


Figure 3.5. Grey Nurse Shark survey site at Brooms Head.

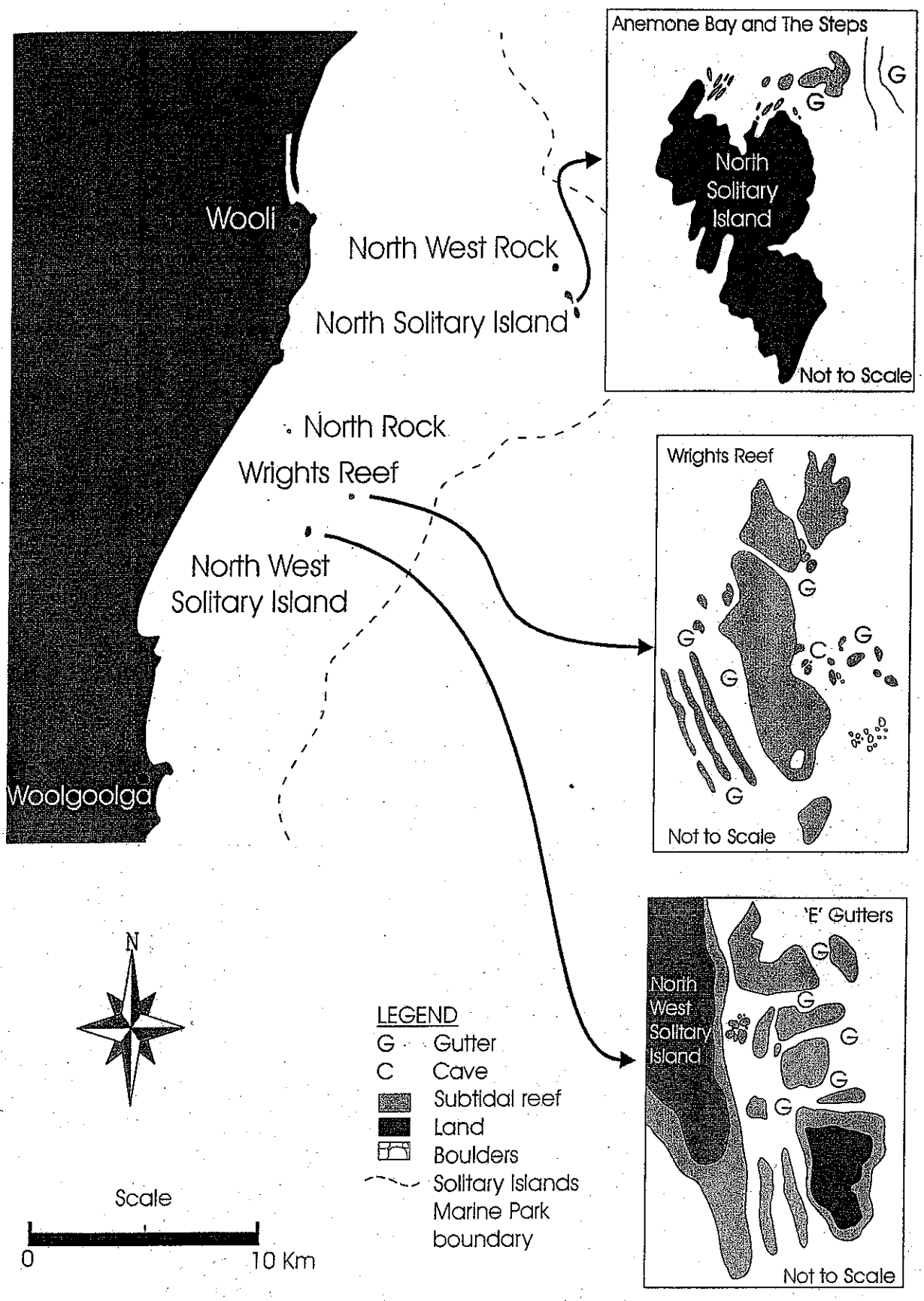


Figure 3.6. Grey Nurse Shark survey sites in the Northern Solitary Islands.

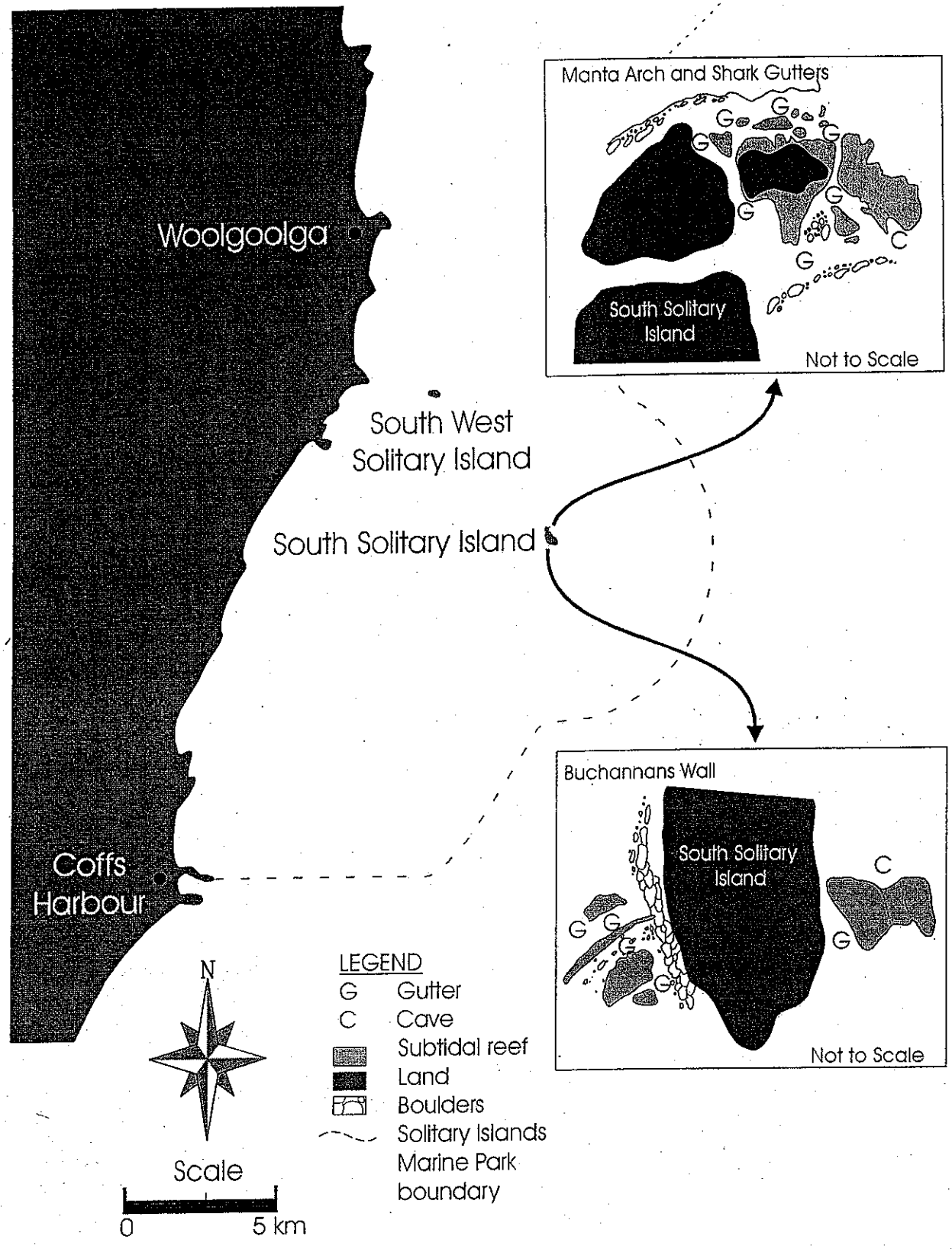


Figure 3.7. Grey Nurse Shark survey sites in the Southern Solitary Islands.

3.1.2 MANNING BIOREGION

The Manning Shelf Bioregion extends from just north of Nambucca Heads (30°39'S) southwards to Stockton (32°54'S) near Newcastle. There are 16 sites across 5 locations (Fig. 3.8) within the Manning Shelf Bioregion and these were sampled as part of the distribution and abundance surveys (Table 3.2). These sites have been mapped and details of Grey Nurse Shark occupancy are provided.

Table 3.2. The sites (and locations) surveyed in the Manning Shelf Bioregion

Location	Sites
South West Rocks	Green Island
	Fish Rock Pinnacle
	Fish Rock Gutters
	Black Rock
Laurieton	Cod Grounds **
	Mermaid Reef (inner and outer)
Forster	Latitude Rock
	Latitude Reef
	The Pinnacle
Seal Rocks	Skeleton Rocks
	Big Seal
	little Seal
	Edith Breaker (inner and outer) **
Port Stephens	Broughton Island
	North Rock
	Boondelbah Island

** indicates the site is located on the boundary between State and Commonwealth waters.

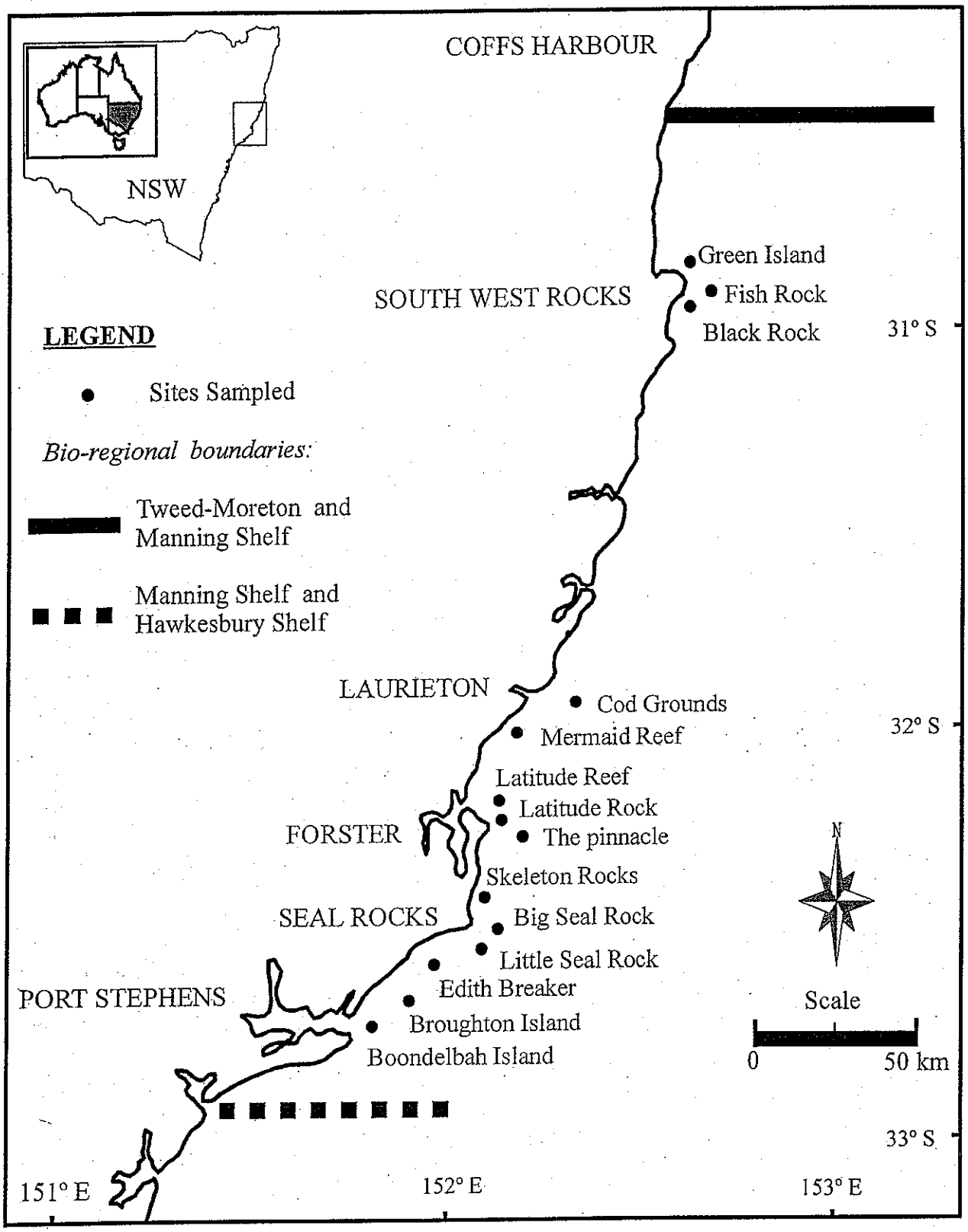


Figure 3.8. Locations of Grey Nurse Shark survey sites in the Manning Shelf Bioregion.

3.1.2.1 South West Rocks

South West Rocks is a well known area for diving with Grey Nurse Sharks during winter and spring. Grey nurse sharks frequent two sites around Fish Rock: the 'Gutters' and the 'Pinnacle' (Fig. 3.9). These sites provide a good vantage point for observing the sharks in their natural environment. The 'Pinnacle' is located on the north eastern side of the island and is comprised of a pinnacle of rock and a series of gutters with sandy bottoms. The sharks are frequently sighted swimming though the 25 m deep gutters around the pinnacle. The other site, the 'gutters' is located on the southern end of the island. It comprises a series of gutters running east-west in 18 m of water. The sharks are frequently sighted swimming through the gutters or hovering near gutter walls. The waters in a 500 m radius around Fish rock are closed to fishing and have been since July 1995.

Grey nurse sharks have also been sighted at two other sites at South West Rocks at: Green Island and Black Rock. Green Island is a relatively shallow site in 15m of water that has a gutter on the eastern side. Large numbers of Grey Nurse Sharks have been sighted in this gutter in previous years. Black Rock is further south and is a small exposed rocky outcrop with a fringing reef in around 12 m of water. The fringing reef comprises boulder zones, kelp beds and some smaller gutters where the Grey Nurse Sharks have been sighted.

3.1.2.2 Laurieton

Laurieton is located south of Port Macquarie on the New South Wales mid north coast. Large aggregations of Grey Nurse Sharks have been sighted at two sites: the 'Cod Grounds' and 'Mermaid Reef' (Fig. 3.10). The Cod Grounds is directly east of Perpendicular Point and comprises a series of three pinnacles rising to approximately 18 m from the sea bed in 40 m of water. The Grey Nurse Sharks have been seen in relatively large numbers swimming between the three pinnacles and hovering among the pinnacles and boulders during the winter and spring months. Mermaid reef is a large area of reef closer to shore and south of the Cod Grounds. The two main sites where Grey Nurse Sharks have been seen comprise a series of gutters with sandy bottoms and boulder areas in 8 - 12 m of water. Large aggregations of Grey Nurse Sharks have been seen at Mermaid Reef in spring, particularly around September. However, the reef is not a site that is regularly dived by recreational scuba divers, so little is known about their occupancy and activity at this site.

3.1.2.3 Forster

Forster is located on the mid north coast east of Taree. Grey nurse sharks have previously been seen at three sites: The Pinnacle, Latitude Rock and Latitude Reef offshore from Forster (Fig. 3.11). The Pinnacle is a pinnacle of rock that rises to approximately 24m from the sea bed in 46m of water. The pinnacle covers a large area and the sharks are sighted in all different areas. The site has a few large gutters where Grey Nurse Sharks (in large groups or individuals) are frequently seen hovering and swimming among the boulders. Latitude Rock is a small shallow (12 m) rocky outcrop close to the shore where Grey Nurse Sharks have been sighted swimming and hovering among shallow gutters and overhangs. Latitude Reef is a seaward extension of reef from Latitude Rock that comprises of a few shallow (14 m) sandy bottomed gutters where small numbers of the shark have been sighted. The sharks frequent these sites in most months of the year with large aggregations occurring at the 'Pinnacle' in autumn.

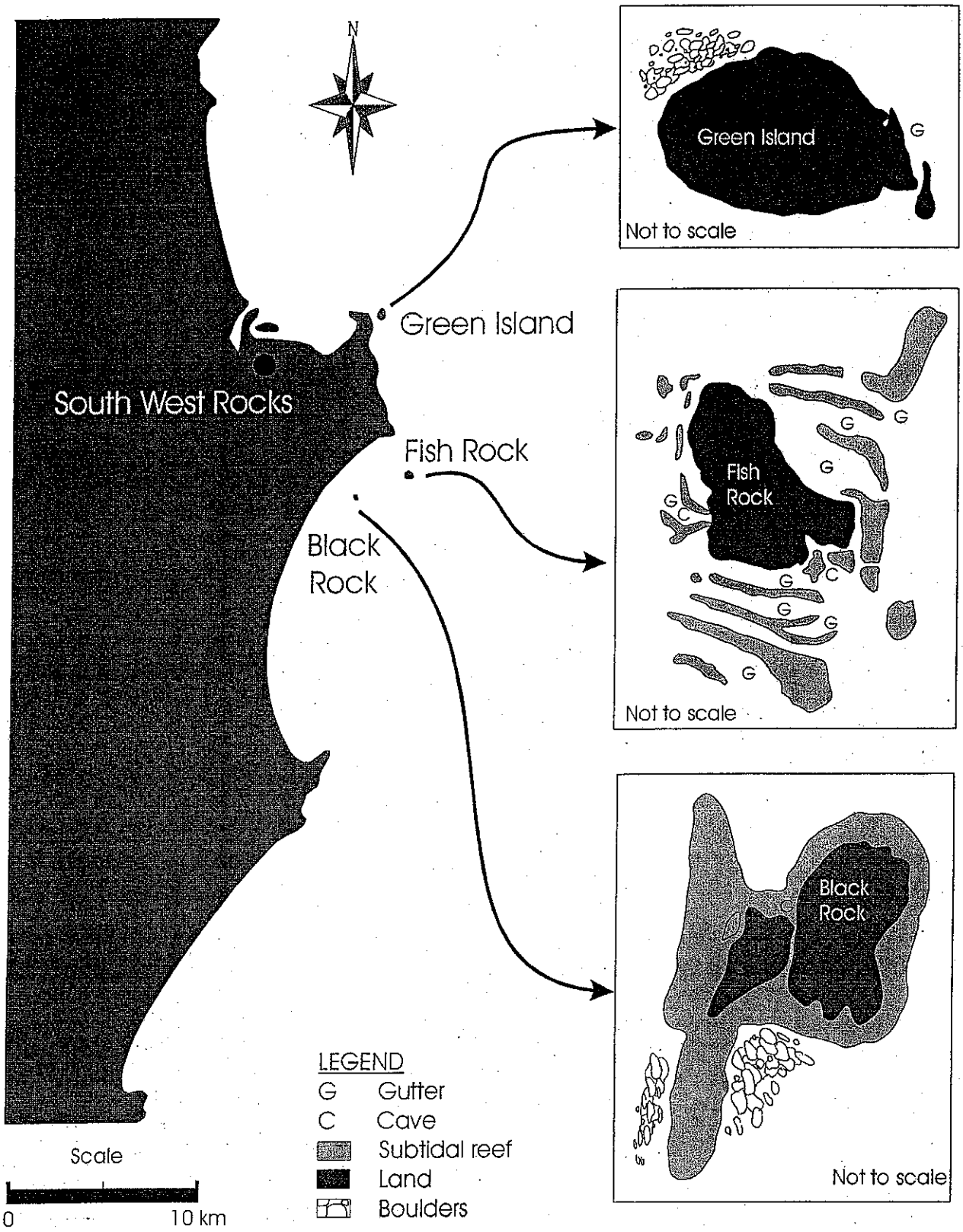


Figure 3.9. Grey Nurse Shark survey sites at South West Rocks.

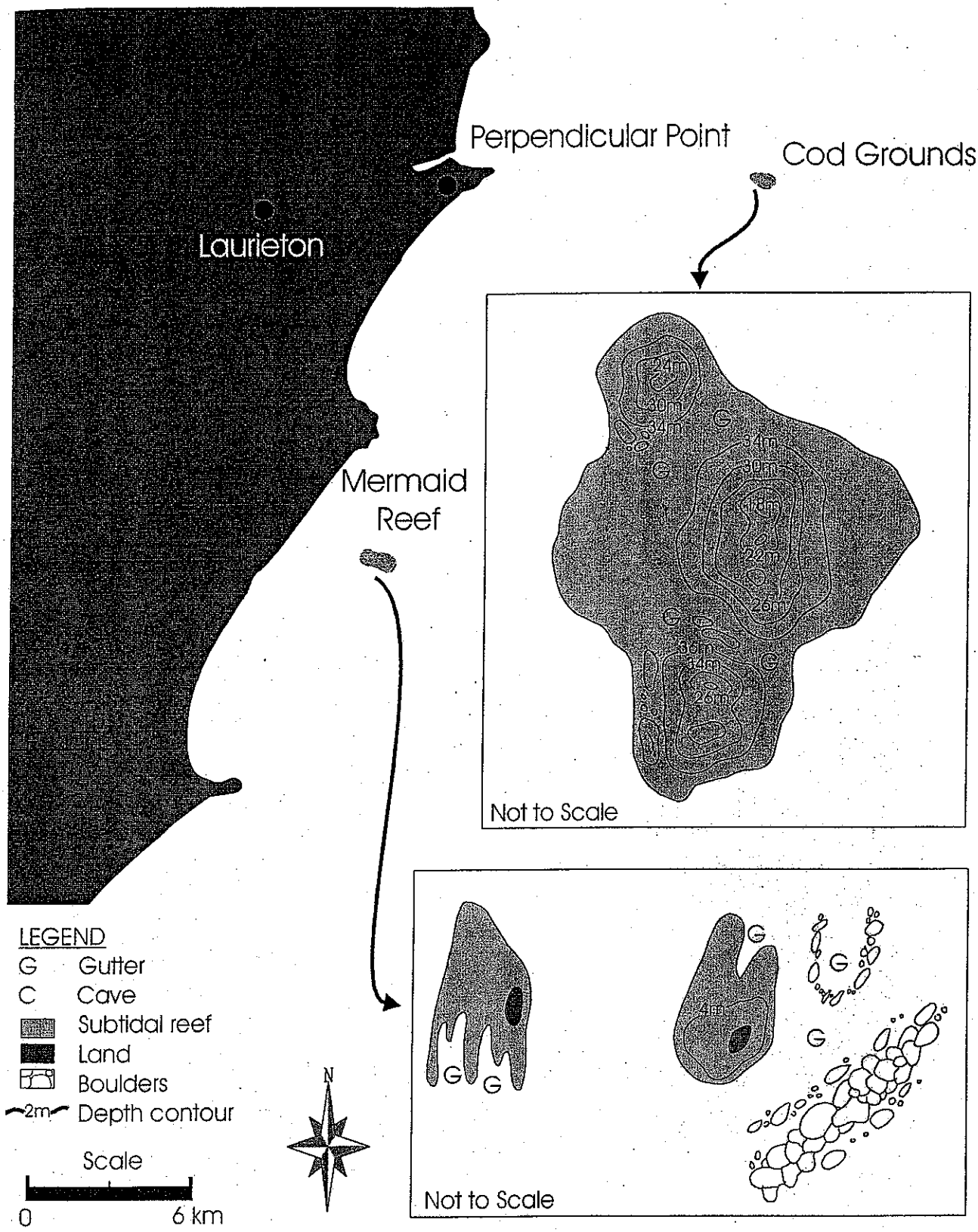


Figure 3.10. Grey Nurse Shark survey sites at Laurieton.

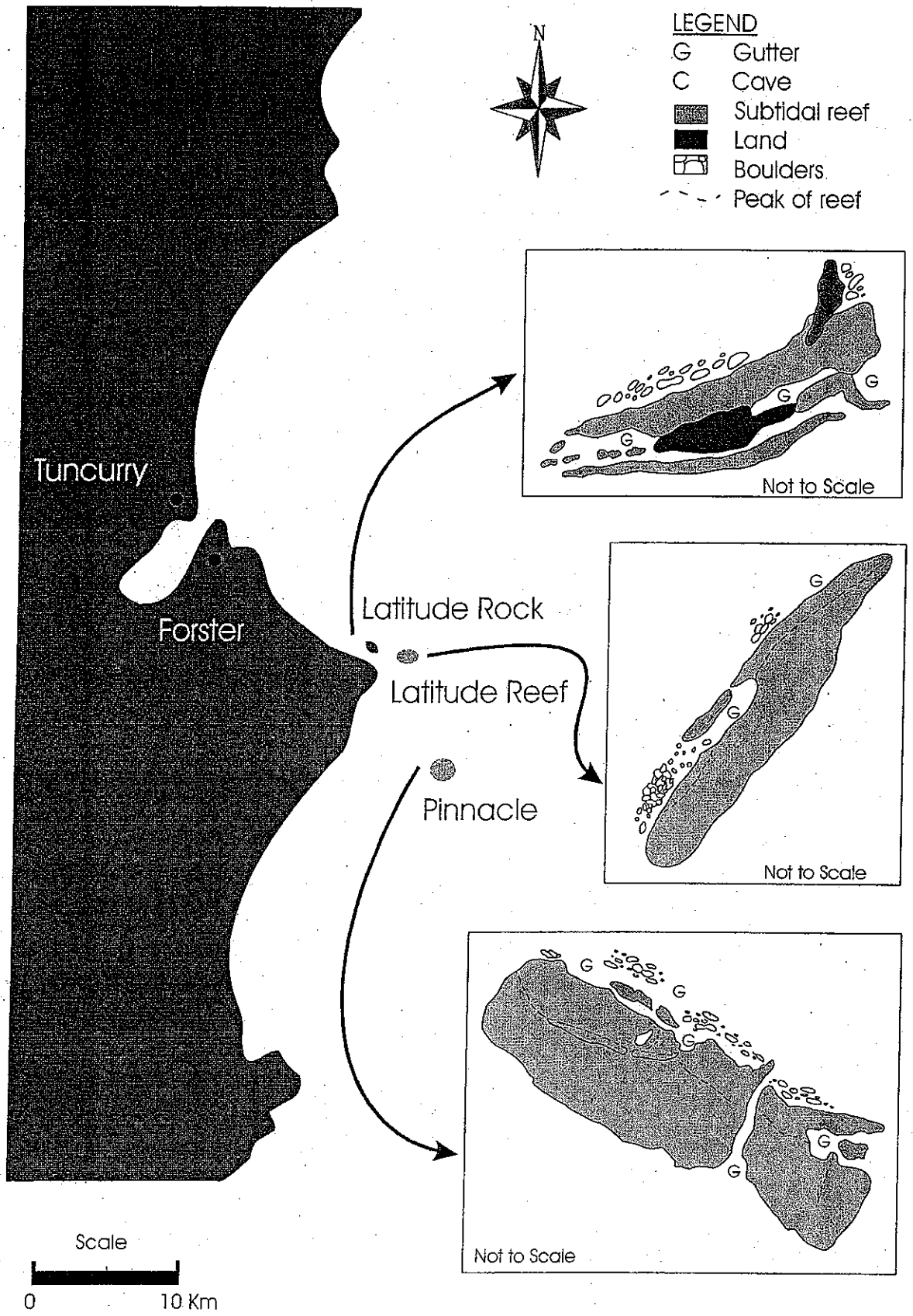


Figure 3.11. Grey Nurse Shark survey sites at Forster.

3.1.2.4 Seal Rocks

Seal Rocks is located on the mid north coast south of Forster. The small fishing village is the gateway to popular Grey Nurse Shark dive sites in New South Wales. There are four main areas where Grey Nurse Sharks have been seen in the Seal Rocks Region. They include, Skeleton Rock, Big Seal, Little Seal and Edith Breaker (Fig. 3.12). Skeleton Rock is a reef comprising of two pinnacles of rock rising to approximately 10 meters below the surface from the sea bed in 40 metres of water. Grey nurse sharks have been seen at the southern pinnacle previously, but very few aggregations of sharks have been sighted in recent years. A gutter on the eastern side in deeper water and a shallower overhang and gutter on the western side are areas where sharks have also been sighted.

Big Seal and Little Seal are two islands offshore from Sugarloaf Point. They are both barren rock outcrops that have extensive surrounding reefs. Big Seal is the most renown area for diving with Grey Nurse Sharks. Several decades ago, the species occupied this site in large aggregations and sharks were observed throughout the year. In recent years, only small aggregations of sharks are seen sporadically. The main site is a large overhang where a number of the sharks can be seen milling around or hovering under the overhang or swimming along the gutter near the overhang in approximately 20 m of water. Little Seal is also a well known site for seeing large aggregations of Grey Nurse Sharks. There are a series of gutters and large boulders extending from east to west on the northern side of the island in about 18 m of water. Edith Breaker is a large reef system south of the two islands extending in an east-west direction. There are a few gutters in this reef system where Grey Nurse Sharks have been sighted in large numbers. The site in Figure 3.12 shows a gutter running in a north-south direction breaking a ridge that runs east-west. The gutter is approximately 15 metres deep and almost 10 metres wide, making it a very large gutter. The gutter reaches a depth of 25 metres and also has a small overhang and swim-through at one end. In previous years, large aggregations of Grey Nurse Sharks have been seen in this sandy-bottomed, boulder-filled gutter.

3.1.2.5 Port Stephens

Port Stephens is the gateway to Broughton Island. There are several sites at Broughton Island that have gutters and overhangs where Grey Nurse Sharks have been seen (Fig. 3.13). The sharks are usually seen from late summer to winter with large aggregations occurring on occasions. Grey nurse sharks have been seen at two other sites: North Broughton Island and Boondelbah Island. North Broughton is a small island linked into the reef system of Broughton Island and the sharks are usually seen in a gutter on the eastern side of the island. Boondelbah Island is just off the north head of Port Stephens. It is a relatively small island that has a large cove called Safety Bay where Grey Nurse Sharks are sometimes seen.

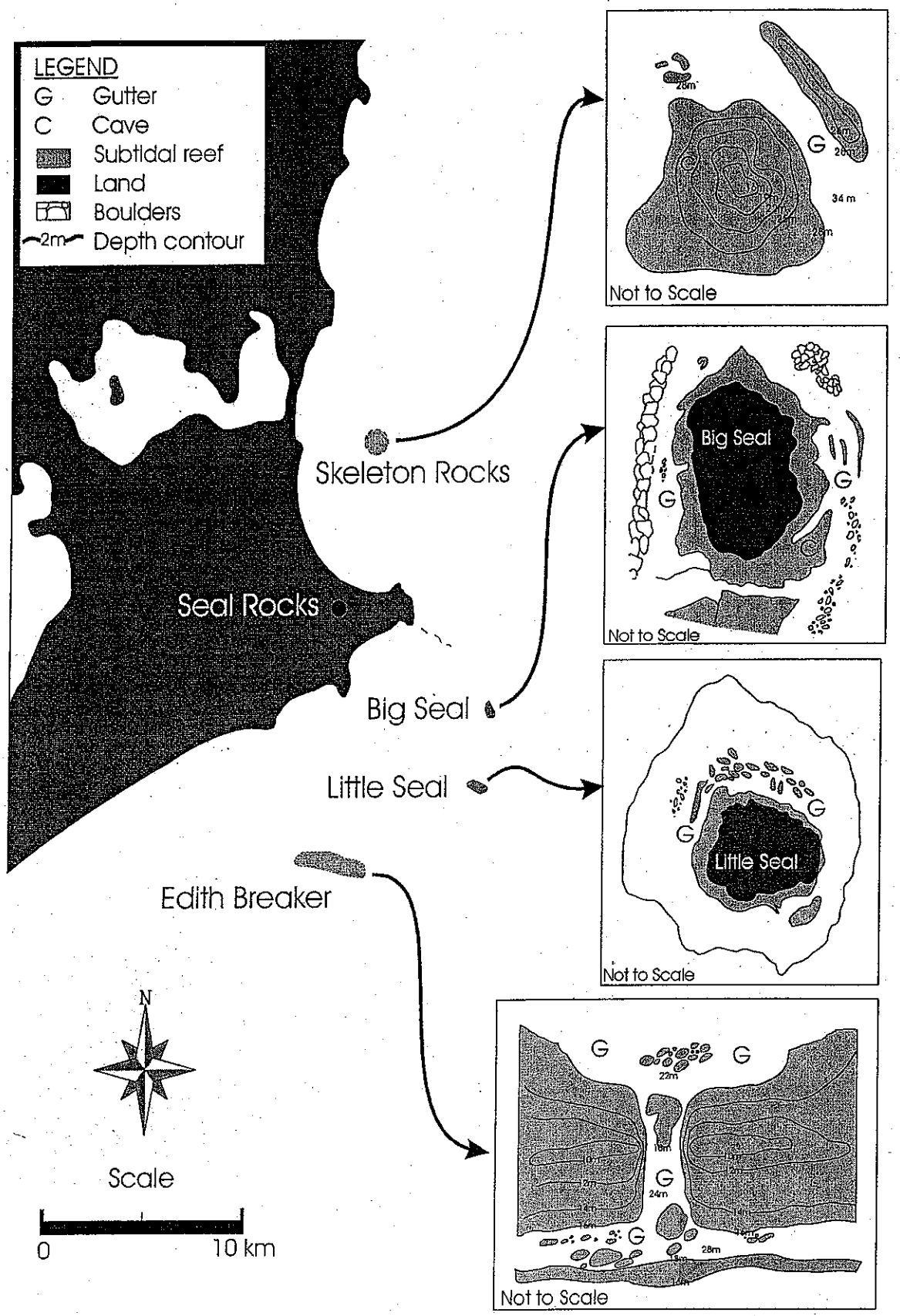


Figure 3.12. Grey Nurse Shark survey sites at Seal Rocks.

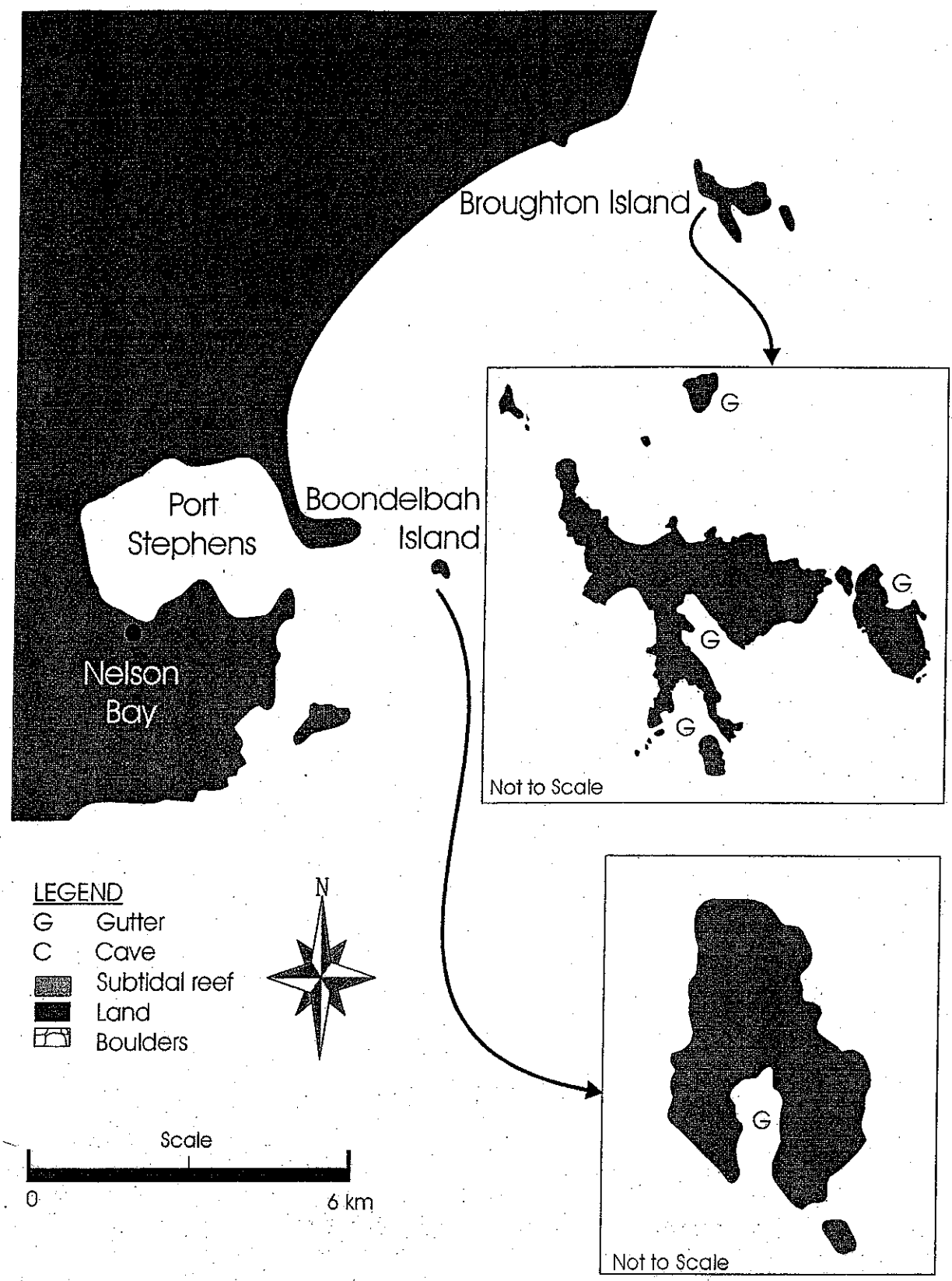


Figure 3.13. Grey Nurse Shark survey sites at Port Stephens.

3.1.3 HAWKESBURY BIOREGION

The Hawkesbury Shelf Bioregion extends from Stockton (32°54'S) near Newcastle southwards to Shellharbour (34°35'S) near Wollongong. There are seven sites (Fig. 3.14) that were sampled as part of the distribution and abundance surveys (Table 3.3). The six sites have been mapped and details of Grey Nurse Shark occupancy is discussed.

Table 3.3. The sites (and locations) surveyed in the Hawkesbury Shelf Bioregion

Location	Sites
The Central Coast	Wybung Reef Twin Bommies Foggy's Cave
Sydney	Long Reef Maroubra South Marley

3.1.3.1 The Central Coast

The Central Coast is located north of Sydney. There are three sites: 'Wybung Reef', 'Twin Bommies' and 'Foggy's Cave' on the central coast and these have been sampled as part of the distribution and abundance surveys (Fig. 3.15). Wybung Reef is located off Wybung Head in between Swansea and Norah Head. The reef is not a regular recreational dive site, and very little is known about the occupancy of the sharks at this site. The site is characterised by an 8 m sheer wall in about 40 m of water. There are large boulders at the base of the wall and the sharks have been sighted swimming along the base of the wall and around the boulders.

The Twin Bommies are located off The Entrance and comprise a series of small rocky reefs. Grey nurse sharks are seen in the sandy bottomed gutters in-between the reefs in approximately 14 m of water. Foggy's Cave is another dive site off Terrigal where Grey Nurse Sharks are often sighted in autumn and winter. In previous years, large aggregations were observed at this site, however in recent years, only one or two sharks are sighted infrequently. The site is characterised by a wall with a series of overhangs and a large cave jutting into the wall. The cave entrance is 6 m deep starting at 31 m and extends into the rock for 12 m. The sharks are usually seen just outside or inside the cave.

3.1.3.2 Sydney

Grey nurse sharks have been seen at three sites around Sydney and these are Long Reef, Maroubra and South Marley (Fig. 3.16). Long Reef is a well known site for sighting Grey Nurse Sharks. The sharks are seen is a gutter on the eastern wall on the northern tip of the reef in about 16 m of water. The sharks have been seen during winter and occasionally in the autumn and spring months. Grey nurse sharks are also seen off Maroubra. The site comprises an overhang that is part of the reef system extending from the headland. The overhang and gutter like formations near the overhang occur in approximately 14 m of water and provide habitat for the shark. The site is not a regular recreational scuba diving site and therefore little is known about the occupancy of the sharks at this site. Small numbers have been seen during winter. Grey nurse sharks have also been seen off South Marley close inshore off the Royal National Park. The site is characterised by a large gutter running almost parallel to the shore along a steep wall in about 16 m of water. The Grey Nurse Sharks have generally been sighted on the western side of the gutter under an overhang jutting into the wall. This site is not regularly dived by scuba divers so little is known about the occupancy of the species at the site.

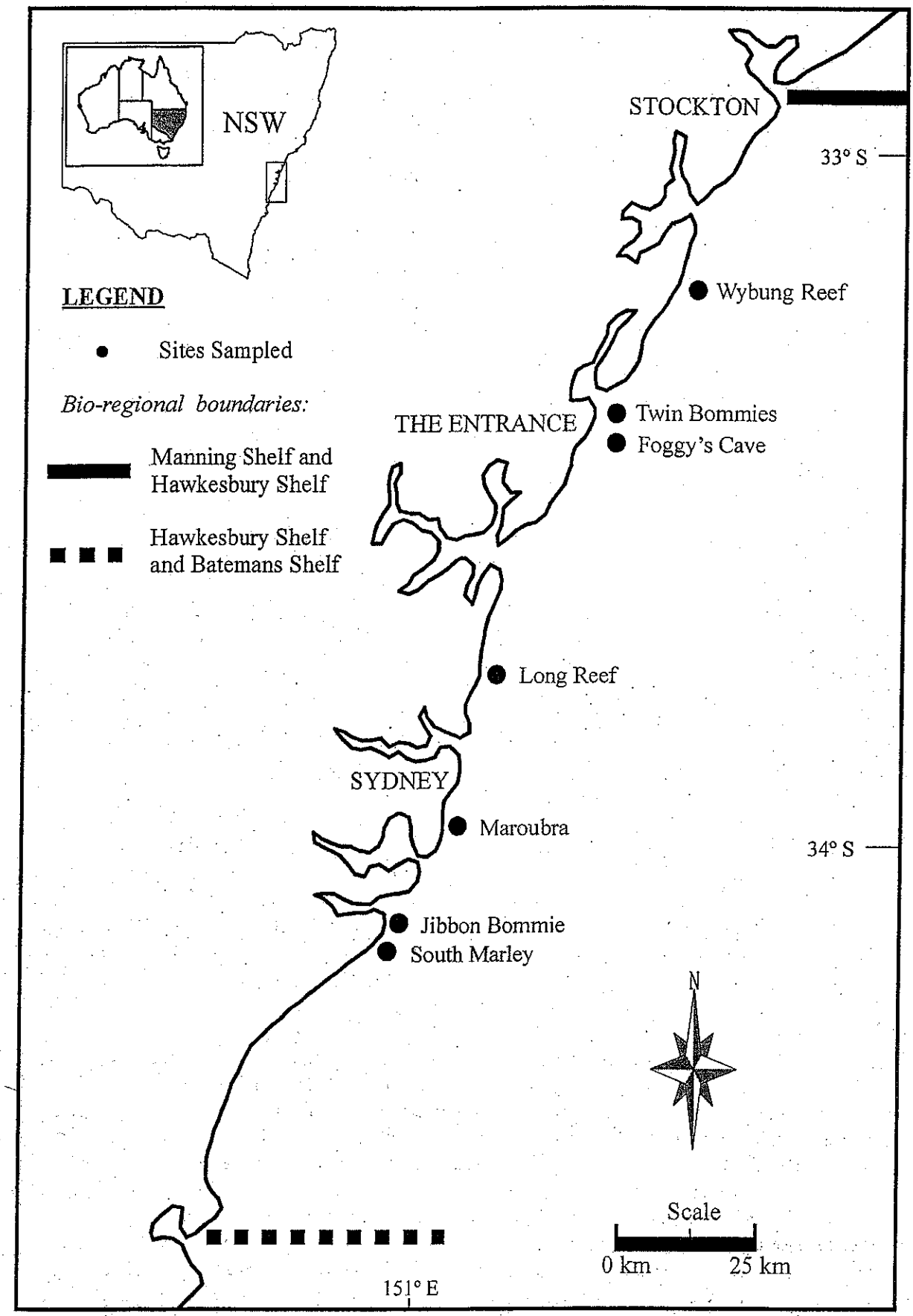


Figure 3.14. Locations of Grey Nurse Shark survey sites in the Hawkesbury Shelf Bioregion

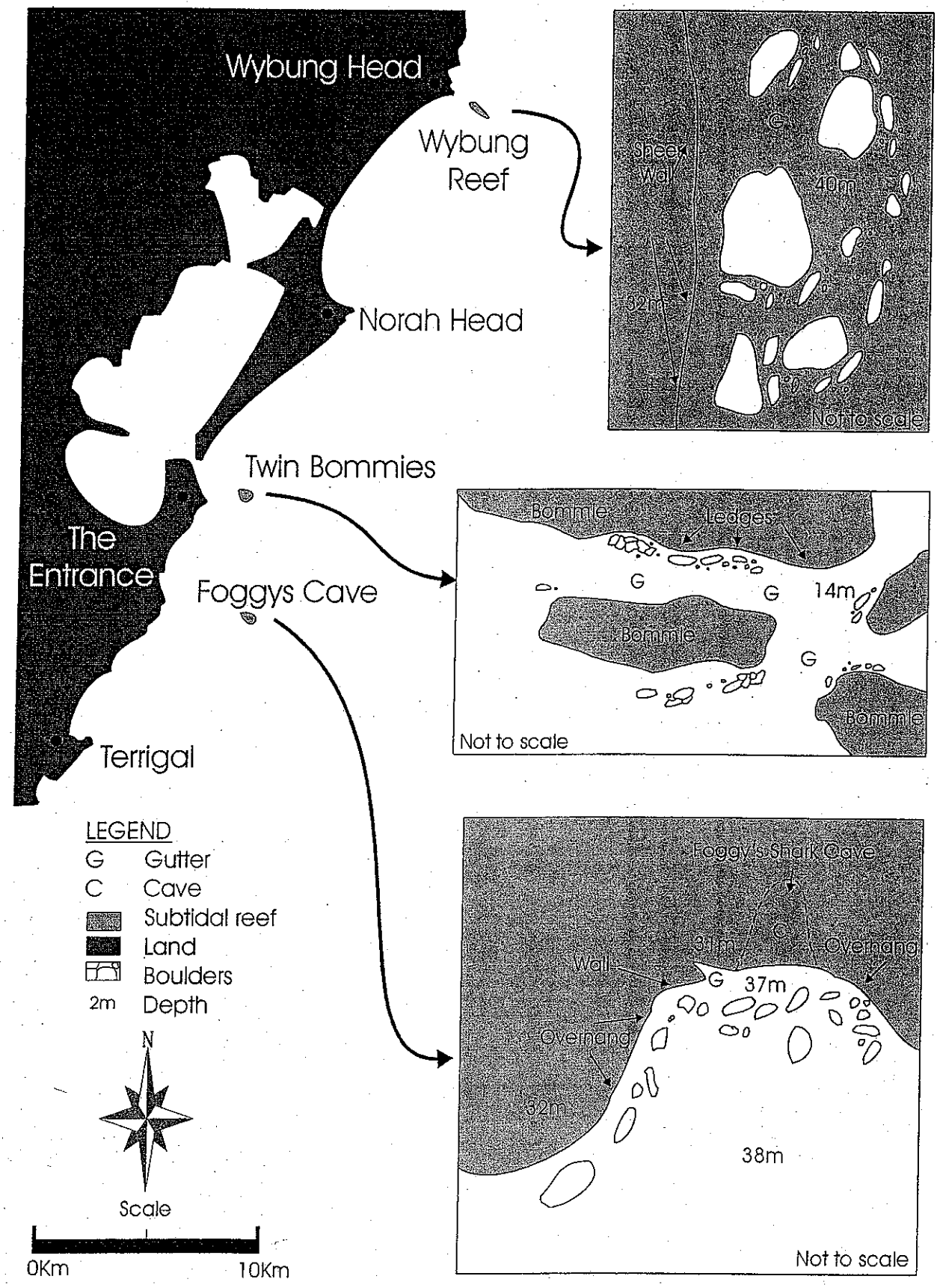


Figure 3.15. Grey Nurse Shark survey sites on the Central Coast.

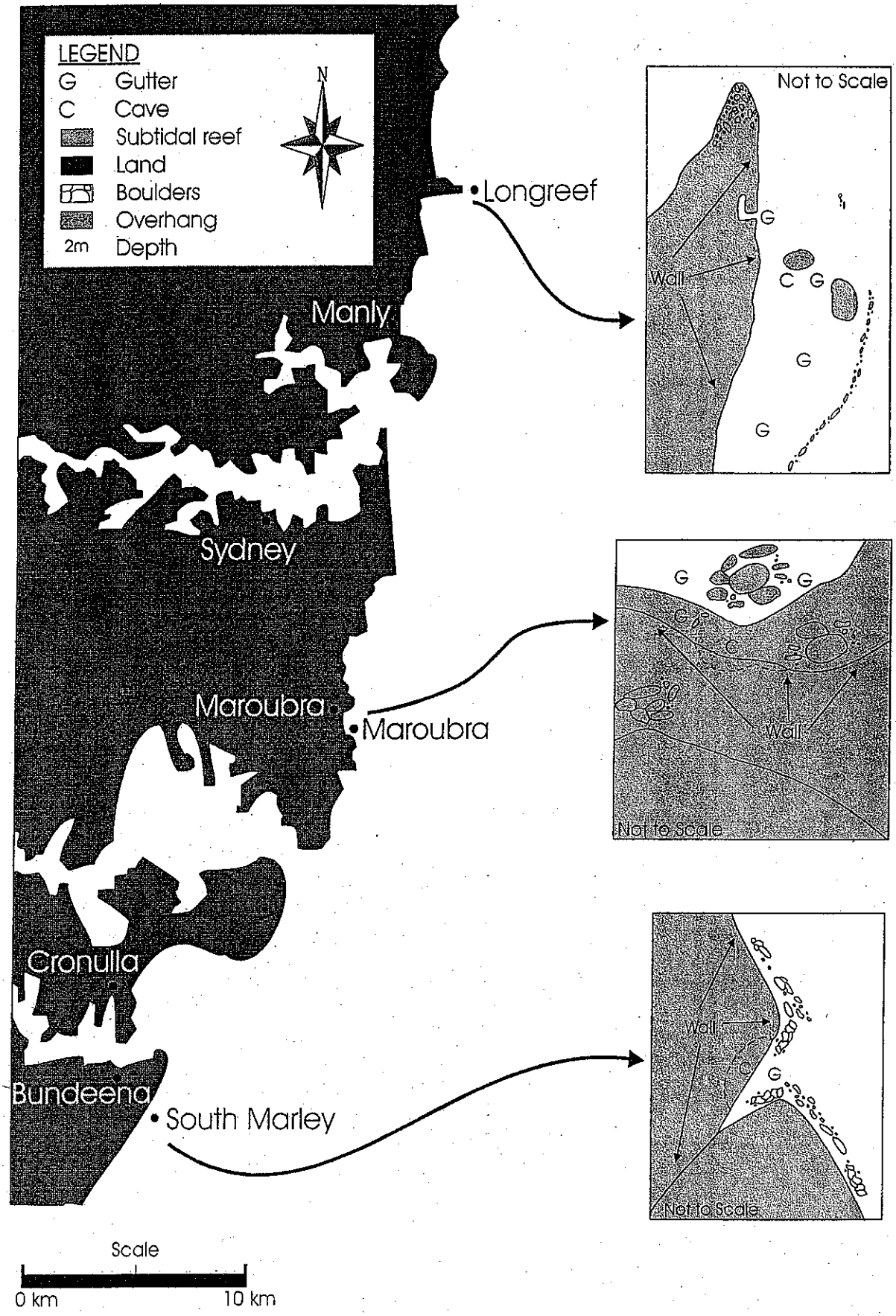


Figure 3.16. Grey Nurse Shark survey sites in and around Sydney.

4. DISTRIBUTION AND ABUNDANCE

4.1 INTRODUCTION

Sharks are found in all the world's oceans, from great depths to the shallow continental margins and into coastal rivers and lakes, and from tropical to the coldest arctic and antarctic waters (Compagno, 1984; Moss 1984; Otway, 1986; Dingerkus, 1987). On closer examination, their global patterns of distribution can be explained by water temperature and, in part, by water depth (see Otway, 1986; Dingerkus, 1987 for details). The abundances of sharks have usually be quantified by using data from protective mesh nets (e.g. Cliff & Dudley, 1991, 1992; Simpfendorfer, 1992), game fishing tournaments (e.g. Stevens, 1984; Pepperell, 1992), the by-catch of trawlers or longliners targeting fish (e.g. Moreno & Moron, 1992; Stevens, 1992), shark fisheries (e.g. Anderson, 1985; Stevens & Wiley, 1986), scientific studies of shark fisheries using handlines, gillnets and longlines (e.g. Lyle, 1987; Stevens & McLoughlin, 1991; Branstetter & Musick, 1994), and occasionally visual surveys (e.g. McLaughlin & O'Gower, 1971).

Recent studies (e.g. Compagno, 1990; Daves & Nammack, 1998) have focused attention on the overfishing of sharks and highlighted the need for addressing all aspects of their conservation. About 20 species of shark are now listed on the IUCN Red List of Threatened Animals (IUCN, 1996) and among these is the Grey Nurse Shark (*Carcharias taurus*). Whilst the Grey Nurse Shark has been recorded from the Indian, Atlantic and Pacific Oceans and the Mediterranean Sea (Compagno, 1984; Last & Stevens, 1994), it has only been sighted in recent times off South Africa (e.g. Cliff & Dudley, 1992; Cliff, Unpub.), the east coast of the USA (e.g. Branstetter, 1990; Branstetter & Musick, 1994), in south-western and south-eastern waters of Australia (e.g. Krogh, 1994, Pollard *et al.*, 1996).

A review of the biology of the Grey Nurse Shark (see Chapter 2; Otway & Parker, 1999) has shown much of the information concerning the species has been derived from studies in the USA and South Africa. Furthermore, little is known about the Grey Nurse Shark off New South Wales and southern Queensland and this is directly attributable to the absence of any extensive studies on the species. What is known has been gleaned from a few published studies (Pepperell, 1992; Reid & Krogh, 1992; Gordon, 1993; Krogh, 1994; Pollard *et al.*, 1996), unpublished reports (e.g. Ecology Lab, 1991; Parker, Unpub.) and anecdotal accounts (e.g. Garbutt, 1995: Marsh, 1995), the results of which are summarised in Otway and Parker (1999). There is also little, if any, local information on the distribution and abundance of the species that could assist with its conservation along the NSW coast. However, to assist the sharks' long-term conservation, the NSW government declared the Grey Nurse Shark a protected species in 1984 and, in doing so, the shark became the first protected shark in the world.

By the early 1990's, two primary sources of information suggested that the Grey Nurse Shark population in NSW coastal waters had not recovered from the indiscriminate spearing that occurred in the 1950's and 60's. First, the catches of Grey Nurse Shark in the protective mesh nets off beaches in Newcastle, Sydney and Wollongong had declined to zero by 1980 (Fig. 2.3) and remained at or near this level thereafter (Reid & Krogh, 1992; Krogh, 1994 for details). Second, surveys at Seal Rocks in 1991 and 1995 (see later) indicated that the abundances of Grey Nurse Shark were well below those documented in anecdotal reports of the 1960's (e.g. Cropp, 1964). Consequently, a distribution and abundance survey was designed to assess the population status of the Grey Nurse Shark off the NSW and southern Queensland coasts.

4.2 MATERIALS AND METHODS

4.2.1 SAMPLING LOCATIONS

4.2.1.1 General

While the requested funding was sufficient to repeat the sampling at Seal Rocks and extend it to another location (see Section 4.2.2), it was obvious that such a survey would not provide a truly representative estimate of the distribution and abundance of Grey Nurse Sharks along the entire NSW coast (≈ 2,000 km) because of the restricted number of locations (i.e. n = 2). However, to sample the entire NSW coast would have required funds in the order of $250,000 which clearly exceeded those available at the time. Notwithstanding this, we felt that it was absolutely essential to increase the spatial coverage (i.e. the number of locations) as this would be the only way of obtaining a much-needed representative estimate of the abundance, size-structure and sex-ratio of Grey Nurse Sharks in NSW coastal waters. Consequently, to carry out the survey along the entire NSW coast we enlisted the help of scuba divers from universities, dive clubs, scuba diving schools and commercial aquaria. As a direct result of the scuba diving community's involvement it was possible to cover the entire NSW coast from Eden to Tweed Heads and into southern Queensland (i.e. North Stradbroke Island). Additional funds provided by Environment Australia enabled a further two coastwide surveys to be carried out (see Section 4.2.1.3). In doing so, between 50 and 61 sites across 21 locations were sampled (see Section 4.3) on three separate occasions.

4.2.1.2 South West Rocks and Seal Rocks

The two previous surveys at Seal Rocks in 1991 and 1995 were carried out on behalf of NSW Fisheries by the Ecology Lab Pty. Ltd. To ensure continuity in personnel and consistency in sampling methodology, the Ecology Lab Pty. Ltd. was again contracted to assist NSW Fisheries personnel with the survey at Seal Rocks and also South West Rocks. Four sites: Little Seal Rock, Big Seal Rock, Edith Breaker and Skeleton Rocks at Seal Rocks and 4 sites at South West Rocks: Fish Rock Cave, Fish Rocks Aquarium, Black Rock and Green Island (Fig. 4.1) were sampled over consecutive days from 30 November to 4 December, 1998 to ensure similar timing with previous surveys.

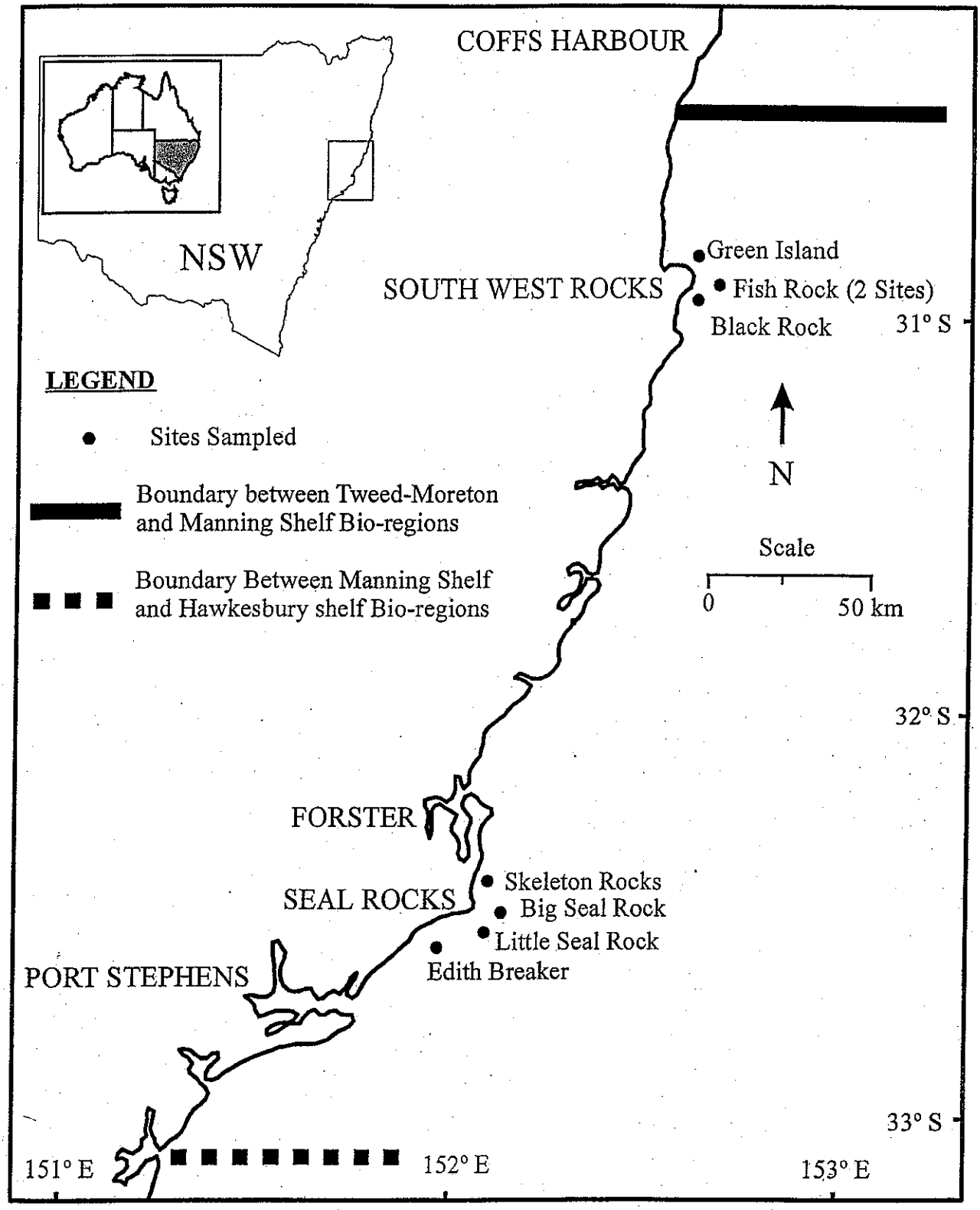


Figure 4.1. Map showing the sites sampled at South West Rocks and Seal Rocks over consecutive days from 30 November to 4 December, 1998.

4.2.1.3 Remaining Locations

An additional 66 sites across 19 locations (Table 4.1 and Fig. 4.2) were sampled by staff from NSW Fisheries and the scuba diving community. Three surveys, each of 4 weeks duration, were carried out in November/December, 1998 (survey 1), in March/April, 1999 (survey 2) and May/June, 1999 (survey 3). It was necessary to allow a 4 week period because of inclement sea conditions (i.e. rough seas, moderate swell, etc.) that occurs at different times along various stretches of the NSW coast.

Table 4.1. Additional sites sampled by the scuba diving community in cooperation with NSW Fisheries over four week periods in November/December 1998, March/April 1999 and May/June1999.

Location	Site	Location	Site
Stradbroke Island (A)	Flat Rock Boat Rock	**South Solitary's (F)**	Manta Arch Shark Gutters Buchannans Wall
Tweed Heads (B)	Nine Mile Reef Cook Island Fido Reef Alberta Wreck	**South West Rocks (G)**	Fish Rock - Gutters Fish Rock - Pinnacle Black Rock Green Island
Byron Bay (C)	Mackeral Boulders Julian Rocks - Cod Hole Julian Rocks - Hugoes Trench Julian Rocks - Cleaner Cave Julian Rocks - Split Bommie	**Laurieton (H)**	Cod Grounds Mermaid Reef
Brooms Head (D)	Pimpernel Rock	**Forster (I)**	Pinnacle Latitude Reef Latitude Rock
North Solitary's (E)	Bay of Anemones North West Rock Elbow Cave Wrights Reef E Gutters Tall Timbers	**Seal Rocks (J)**	Edith Breaker Little Seal Rock Big Real Rock Skeleton Rock Sawtooth Rocks

Table 4.1. Cont Additional sites sampled by the scuba diving community in cooperation with NSW Fisheries over four week periods in November/December 1998, March/April 1999 and May/June1999.

Location	Site	Location	Site
Port Stephens	Broughton Is. - Shark Gutters	**Jervis Bay**	Shark Rock
(K)	Boondelbah Is. - Safety Bay	**(Q)**	Pinnacle Cave
	North Broughton Island		The Docks
			The Nursery
Newcastle	Wybung Head Reef		Govenor Head Wall
(L)			Pyramid Rock
Terrigal	East Bombora		Weedy Valley
(M)	Foggy's Cave		Cathedral Cave
Sydney	Jibbon Bombora	**Ulladulla**	Brush Island - Pinnacle
(N)	South Maroubra	**(R)**	Brush Island - Gutters
	Long reef - The Wall		Belowla Island West
	South Palm Beach Reef		Pebbly Beach
	Marley Point		
		Batemans Bay	Tollgate Island
Wollongong	Toothbrush Island	**(S)**	Black Rock
(O)			Broulee
Shellharbour	Bass Point - Arch		
(P)	Bass Point - Deep Gutters	**Narooma**	Montague Is. - Shark Gutter
	Bass Point - South Cave	**(T)**	Montague Is. - The Gut
	Stack Island		Montague Is. - Yellowfin Alley
	Windang Island		
		Eden	Mewstone Rock
Jervis Bay	Boat Harbour	**(U)**	South Head
(Q)	Drum and Drumsticks		
	Ray Bay		

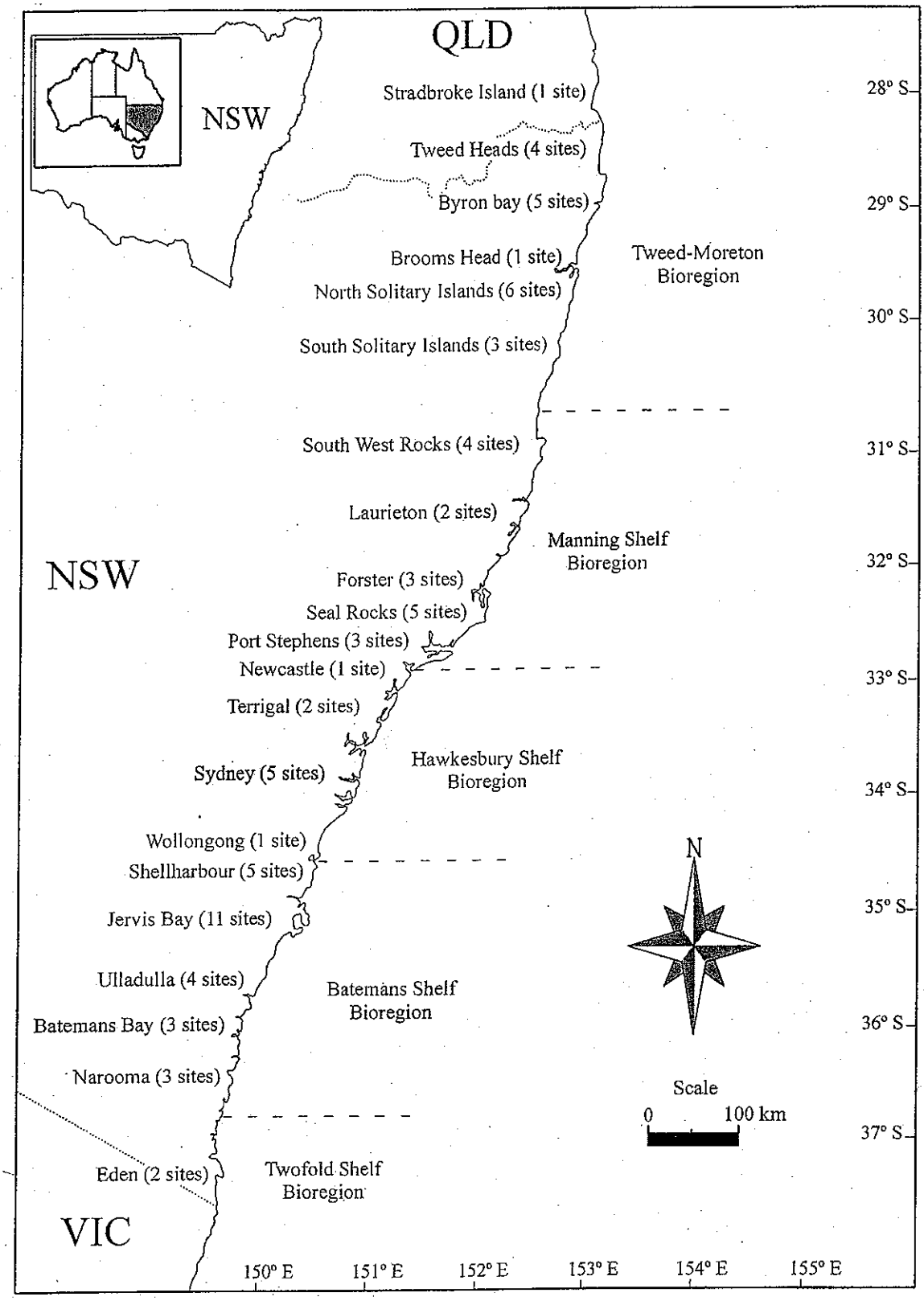


Figure 4.2. Map showing the locations sampled by the scuba diving community in cooperation with NSW Fisheries over four week periods in November/December 1998, March/April 1999 and May/June 1999.

4.2.2 SAMPLING PROTOCOL

4.2.2.1 General

Visual surveys were used to estimate the distribution and abundance of Grey Nurse Sharks. At each replicate site, scuba divers swam for a 15 minute period in or around habitats (e.g. gutters, caves and overhangs - Otway & Parker, 1999) known to have been occupied by Grey Nurse Sharks in previous years. Within each 15 minute period, the divers recorded the total number of sharks present, and when present, the total length (TL) and sex (where possible) of each individual. Total lengths were recorded in 3 size-classes: 1 - 2 m, 2 - 3 m and > 3 m. In addition, the presence of mating scars, tags and fishing gear (hooks, wire traces, line, etc.) was also noted. The data were recorded on underwater slates and transferred to data sheets on completion of the dive.

4.2.2.2 At South West Rocks and Seal Rocks

The previous surveys at Seal Rocks in 1991 and 1995, adopted a sampling protocol in which replicate counts were obtained by diving the same site over 3 consecutive days. This method has problems (see Section 4.2.3 - Statistical Analysis) and was not used in this survey. Instead, two separate areas within each site (e.g. Big Seal Rock) at each location (e.g. Seal Rocks) were each surveyed for a 15 minute period on the same day to provide two replicate counts of Grey Nurse Sharks. In the absence of detailed information on local movements, these counts were assumed independent on the day of sampling. However, it is likely that Grey Nurse Sharks do, over time, swim between these areas and recognition of this will need to be incorporated in the statistical analyses (see below).

4.2.2.3 At Other Locations

The additional sites across 19 locations (Table 4.1) were sampled using a minimum of one 15 minute period at each site as outlined in Section 4.2.2.1. Repetitive sampling was undertaken by several dive groups at a few locations. These data enabled: (1) a comparison of the estimates of abundance, size-structure, etc. between dive-groups (i.e. a "quality control" check), and (2) short-term temporal changes in the populations of Grey Nurse Sharks at particular sites.

4.2.3 STATISTICAL ANALYSES

4.2.3.1 General

Prior to analysis, individual cell variances were examined for heteroscedasticity using Cochran's test (Winer, 1971; Winer *et al.*, 1991). When variances were heterogeneous data were transformed using procedures outlined by Scheffe (1959), Winer (1971), Snedecor & Cochran (1980) and Underwood (1981b). Data were then examined using univariate analyses of variance with a Type I error-rate of $\alpha = 0.05$. In each analysis of variance, *post hoc* removal of terms in the original model was done, where possible, to provide more powerful tests of the remaining sources of variation. These pooling procedures follow the recommendations of Winer (1971) and are in line with arguments by Bozivich *et al.* (1956), and Green and Tukey (1960).

Following analysis of variance, any significant differences among means were identified using the Student-Newman-Keuls (SNK) multiple comparison test (Winer, 1971; Snedecor & Cochran, 1980; Winer *et al.*, 1991) with a Type I error-rate of $\alpha = 0.05$.

4.2.3.2 Temporal Variation at Seal Rocks

In the previous surveys at Seal Rocks in 1991 and 1995 (The Ecology Lab 1991, 1995; Pollard *et al.*, 1996), replicate counts were obtained by diving the same site/area over 3 consecutive days. It is highly likely that the sharks observed on all three days would have been the same individuals. Data obtained in

this manner should not be subjected to statistical analysis because they violate the assumption of independence of replicate samples which underlies parametric and non-parametric statistical tests (Hollander & Wolfe, 1973; Underwood, 1981, 1997).

Analysis of the abundances of Grey Nurse Sharks among years (i.e. 1991, 1995 and 1998) at Seal Rocks was based on a 1-factor analysis of variance using the counts of sharks at each of the 4 sites (i.e. Little Seal Rock, Big Seal Rock, Edith Breaker and Skeleton Rocks) for a particular year as replicates. Because the sampling protocols of the 3 surveys differed slightly (see Section 2.2.2), the data were separated into subsets then aggregated, where necessary, to permit an unbiased analysis across years. For the 1991 and 1995 surveys, only data recorded during the morning dives on the first day of sampling at each site were used in the analysis. In the current survey, the abundances of Grey Nurse Shark in each replicate area within each site were summed to give the total number of sharks per site. These values were then used as replicate samples.

4.2.3.3 Spatial Variation between South West Rocks and Seal Rocks

Analysis of the abundance of Grey Nurse Sharks between replicate areas within each site (e.g. Fish Rock) and between locations (i.e. South West Rocks & Seal Rocks) was based on a 2-factor, nested analysis of variance with both factors considered random.

4.2.3.4 Spatial Variation across All Locations

Analysis of the abundance of Grey Nurse Sharks across all locations was based on a 1-factor analysis of variance with unequal replication across Locations. To enhance the efficacy of the analysis, only locations where at least 2 replicate sites were sampled were included. Furthermore, all locations where no Grey Nurse Sharks were seen (i.e. all replicates were zero) were also omitted from the analysis. Despite this, the analysis still suffered because of excessive variation among replicates counts (see results - Section 4.3.2.2). Consequently, a general linear model based on a Poisson regression (SAS, 1997), was also used to examine the data. In a Poisson distribution the mean and variance are equal to 1.0 (Johnson and Kotz, 1969), but the model fitted allowed the variances to be altered ("relaxed") to allow for overdispersion. In so doing, the model enabled the identification of the factors (in this case "locations") that contributed significantly more variance than would be expected by chance alone. The scaling factor to allow for overdispersion was estimated by (Pearson's χ^2 /degrees of freedom)$^{0.5}$.

4.2.3.5 Short-Term Temporal Variation at Particular Sites

Repetitive sampling was carried out at several sites over the 4-week sampling period. However, in the absence of replicates it was not possible to analyse the data (e.g. using analysis of variance) without making several assumptions. Moreover, past experience indicates that these assumptions are generally valid with biological data exhibiting spatial and temporal variation. Consequently, the data were graphed and examined for trends.

4.2.3.6 Population Size-Structure and Segregation by Sex and Size of Grey Nurse Sharks along the NSW Coast

The size-structure of the Grey Nurse Shark population along the entire coast and at the individual locations where the sharks were observed were plotted for the size categories detailed earlier (see Section 4.2.2.1). As other shark species are known to segregate by size and sex, possible biases in sex-ratios and population size-structure were examined using χ^2 analyses.

4.3 RESULTS

4.3.1 SOUTH WEST ROCKS AND SEAL ROCKS

4.3.1.1 General Observations

Thirty-two Grey Nurse Sharks were observed at Seal Rocks and South West Rocks with the vast majority occurring at Seal Rocks. The sharks were only observed at 2 sites at each location: Big Seal and Little Seal Rocks (Seal Rocks, n = 17 and 11, respectively), and Fish Rock Aquarium and Fish Rock Cave (South West Rocks, n = 3 and 1, respectively).

4.3.1.2 Temporal Variation at Seal Rocks

The mean numbers of Grey Nurse Sharks (Fig. 4.3a) did not differ significantly over time (Table 4.2, analysis of variance, $P > 0.05$). It is important to note, that this analysis would not have been able to detect a doubling of the population (i.e. an average increase of 100%) with Type I and Type II error-rates of a = 0.05 and b = 0.20, respectively. That is power of 0.80, which is a reasonable level for ecological systems (Cohen, 1988; Fairweather, 1991), was not realised in the analysis of Grey Nurse abundances at Seal Rocks over the 3 sampling occasions.

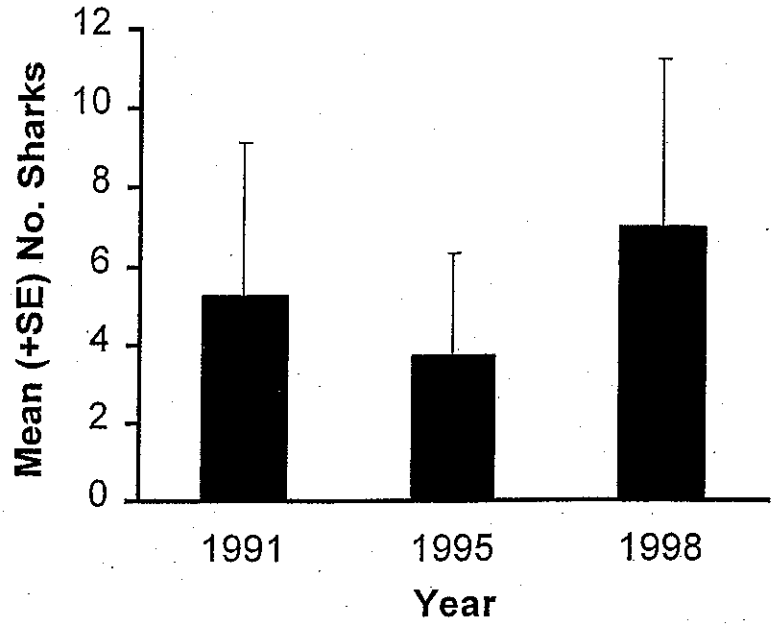
Table 4.2. Analysis of variance of the numbers of Grey Nurse Sharks seen at Seal Rocks in 1991, 1995 and 1998. Raw data - variances homogeneous, Cochran's test, ns: C = 0.45, $P > 0.05$ (in this and all subsequent tables: ns, not significant, $P > 0.05$; *, significant, $P < 0.05$).

Source of variation	SS	df	MS	F	*P*
Years	21.16	2	10.58	0.20	> 0.80, ns
Residual	477.00	9	53.00		
Total	498.16	11			

4.3.1.3 Spatial Variation between South West Rocks and Seal Rocks

The mean number of Grey Nurse Sharks (Fig. 4.3b) did not differ significantly between sites at each location nor between locations (Table 4.3, analysis of variance, $P > 0.25$ and $P > 0.05$, respectively). There was, however, a clear trend towards more Grey Nurse Sharks at Seal Rocks (mean = 7.00) compared to South West Rocks (mean = 1.00).

A.



B.

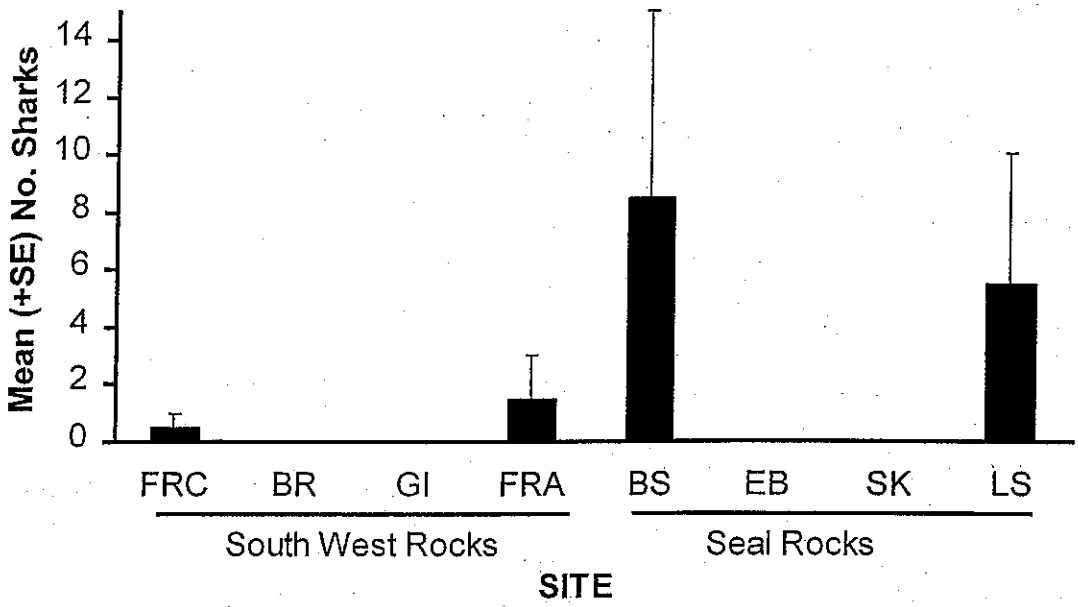


Figure 4.3 The mean number of Grey Nurse Sharks at (A) Seal Rocks in 1991, 1995 and 1998, and (B) at South West Rocks and Seal Rocks over the period 30 November to 4 December, 1998 (n = 4 sites at each location).

FRC	Fish Rock Cave	BS	Big Seal
BR	Black Rock	EB	Edith Breaker
GI	Green Island	SK	Skeleton Rocks
FRA	Fish Rock Aquarium	LS	Little Seal

Table 4.3 Analysis of variance of the numbers of Grey Nurse Sharks at South West Rocks and Seal Rocks over the period 30 November, 1998 to 4 December, 1998. Raw data - variances homogeneous, Cochran's test, ns: C = 0.65, $P > 0.05$.

A. Without *post-hoc* pooling

Source of variation	SS	df	MS	F	*P*
Locations	36.00	1	36.00	1.96	> 0.20, ns
Sites(Locations)	109.98	6	18.33	1.13	> 0.25, ns
Residual	130.00	8	16.25		
Total	275.98	15			

Note: Residual = Areas (Sites(Locations)) - see Section 2.2.2.

B. With *post-hoc* pooling

Source of variation	SS	df	MS	F	*P*
Locations	36.00	1	36.00	2.10	> 0.10, ns
Residual	239.98	14	17.14		
Total	275.98	15			

4.3.1.4 Population Size-Structure at South West Rocks and Seal Rocks

Grey nurse sharks with total lengths greater than 2 m comprised 78.5% and 75% of all individuals at Seal Rocks and South West Rocks, respectively (Table 4.4). Of the 27 individuals of known sex (pooled across both locations), 23 were female and 4 were male giving a sex-ratio of 5.75 to 1 which was significantly biased in favour of females (Table 4.4, $\chi^2 = 13.38$, $P < 0.01$).

Table 4.4 Population size-structure of Grey Nurse Sharks at South West Rocks and Seal Rocks over the period 30/11/98 to 4/12/98.

LOCATION	LENGTH CATEGORY		
	Pup	1 - 2 m	> 2m
South West Rocks			
Male	0	1	2
Female	0	0	1
Unidentified	0	0	0
TOTAL	0	1	3
Seal Rocks			
Male	0	0	1
Female	0	5	17
Unidentified	0	1	4
TOTAL	0	6	22

4.3.2 ALL LOCATIONS

4.3.2.1 General Observations

Totals of 136, 129 and 207 Grey Nurse Sharks were observed at the 50 - 61 sites across 21 locations from Eden to North Stradbroke Island over the 3 surveys in November/December 1998, March/April 1999 and May/June 1999 (Fig. 4.4). Some sites were occupied by relatively large numbers of Grey Nurse Sharks, whereas others had none. In survey 1, 106 Grey Nurse Sharks (i.e. 78% of all sightings) were observed in aggregations of 5 or more individuals at 9 of the 61 sites (Fig. 4.5), whereas no Grey Nurse Sharks were seen at 37 sites. The other 30 sharks were observed in small groups (up to 4) or as isolated individuals across the remaining 15 sites. In survey 2, 114 of the sharks (i.e. 88%) occurred in aggregations of 5 or more individuals at 6 of the 51 sites (Fig. 4.5) with the remaining individuals distributed across 10 sites. In survey 3, 180 Grey Nurse Sharks (i.e. 67% of all individuals) were observed in aggregations at 13 of the 50 sites (Fig. 4.5). The remaining 27 Grey Nurse Sharks were observed across 12 sites. No sharks were seen at 37 (61%), 35 (69%) and 25 (50%) of the sites in surveys 1, 2 and 3, respectively. Finally, the proportions of sites with and without Grey Nurse Sharks present did not differ significantly among surveys (Table 4.5, $\chi^2 = 3.66$, $P > 0.10$).

Table 4.5 Numbers of sites with and without Grey Nurse Sharks along the entire NSW coast and in southern Queensland sampled in November/December 1998, March/April 1999 and May/June 1999.

Sites	Survey 1	2	3	Total
With Sharks	24	16	25	65
Without Sharks	37	35	25	97
Total	61	51	50	162

Figure 4.4 Total number of Grey Nurse Sharks observed at the 21 locations along the NSW coast (listed below) sampled in November/December 1998, March/April 1999 and May/June 1999.

A - Stradbroke Island
B - Tweed Heads
C - Byron Bay
D - Brooms Head
E - North Solitary Islands
F - South Solitary Islands
G - South West Rocks
H - Laurieton
I - Forster
J - Seal Rocks
K - Port Stephens
L - Newcastle
M - Terrigal
N - Sydney
O- Wollongong
P - Shellharbour
Q - Jervis Bay
R - Ulladulla
S - Batemans Bay
T - Narooma
U - Eden.

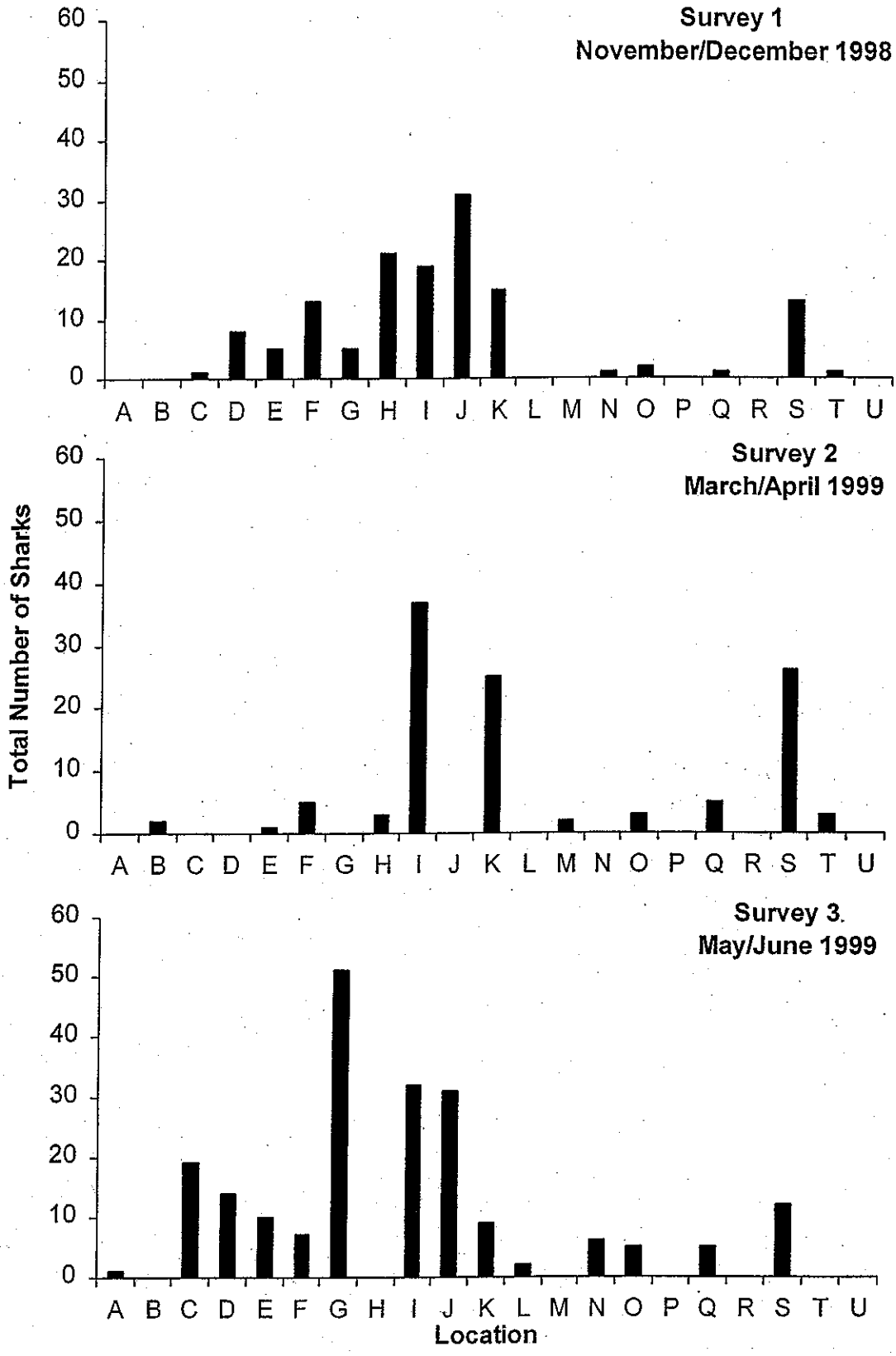
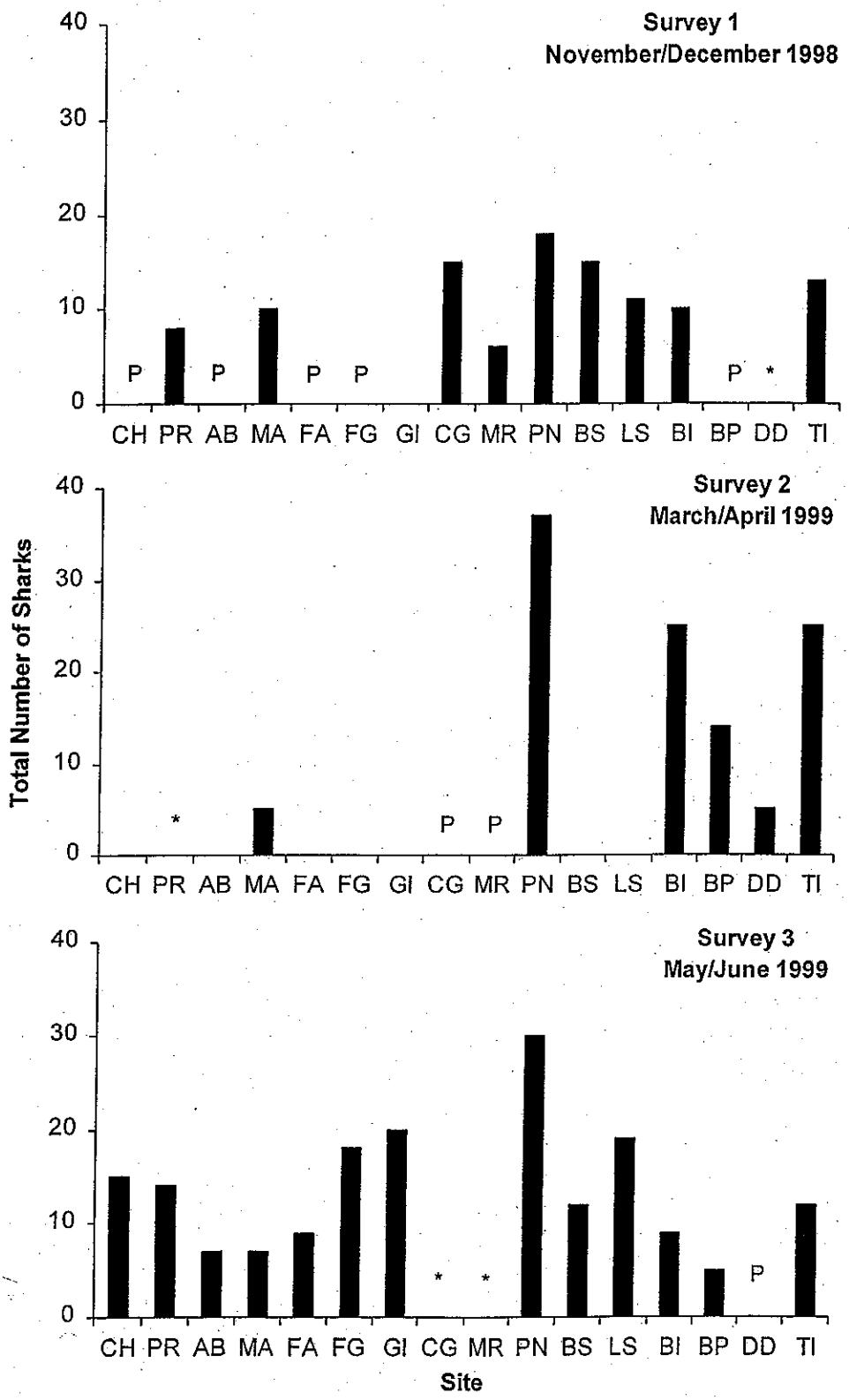

Survey 1
November/December 1998
Survey 2
March/April 1999
Survey 3.
May/June 1999
Total Number of Sharks
0
10
20
30
40
50
60
A B C D E F G H I J K L M N O P Q R S T U
Location

Figure 4.5 Total number of Grey Nurse Sharks observed at sites (listed below) where aggregations of five or more individuals occurred in the surveys in November/December 1998, March/April 1999 and May/June 1999 (P: less than 5 sharks present; * : site not sampled).

CH - Cod Hole
AB - Bay of Anemones
FA - Fish Rock Pinnacle
GI - Green Island
MR - Mermaid Reef
BS - Big Seal Rock
BI - Broughton Island
DD - Drum and Drumsticks
PR - Pimpernel Rock
MA - Manta Arch
FG - Fish Rock Gutter
CG - God Grounds
PN - Pinnacles, Forster
LS - Little Seal Rock
BP - Bass Point
TI - Tollgate Islands


Survey 1
November/December 1998
Survey 2
March/April 1999
Survey 3
May/June 1999
Total Number of Sharks
0
10
20
30
40
CH PR AB MA FA FG GI CG MR PN BS LS BI BP DD TI
Site
P
*

4.3.2.2 Spatial and Temporal Variation in Abundance along the NSW Coast

4.3.2.2.1 Spatial Variation

There was substantial spatial variation present among the sites sampled in each of the 3 surveys (Fig. 4.6). A more detailed analysis of the data from survey 1 is detailed below to exemplify the patterns of variation present.

On omitting all locations where no Grey Nurse Sharks were seen (i.e. all replicates were zero) and locations with only 1 sampling site, data for 13 locations (Table 4.6) were analysed. The mean number of Grey Nurse Sharks (Fig. 4.6) varied along the coast and there was an obvious trend towards greater mean abundances at the South Solitary Islands, Laurieton, Forster, Seal Rocks, Port Stephens and Batemans Bay. However, analysis of the data did not identify any significant differences in the mean numbers of Grey Nurse Sharks at the 13 locations (Table 4.6 - analysis of variance, $P > 0.05$). It is likely that the large within location variation (i.e. among replicate sites) reduced the power of the test to detect differences among locations. The trend for greater means at 6 of the 13 locations was most probably driven by the occurrence of aggregations at one or more of the replicate sites at these locations (Fig. 4.6 and Table 4.6).

In contrast, the analysis of the parameter estimates for the general linear model based on a Poisson regression showed that the local Grey Nurse Shark populations off the South Solitary Islands, Laurieton, Forster, Seal Rocks, Port Stephens and Batemans Bay contributed significantly more variance than would be expected by chance alone (Table 4.6 - χ^2 tests, $P < 0.05$). Moreover, it is likely that aggregations of sharks at particular replicate sites combined with low numbers at the remaining replicate sites at these 6 locations (Fig. 4.4) was responsible for the significant results obtained.

4.3.2.2.2 Short-Term Temporal Variation

Repetive sampling was carried out Manta Arch (South Solitary Islands), Fish Rock (South West Rocks), Pinnacles (Forster) and the Tollgate Islands (Batemans Bay) by NSW Fisheries and voluntary scuba divers. The number of Grey Nurse Sharks at Manta Arch (Fig. 4.7a) gradually increased from 4 to 10 individuals over the 22 days (22/11 - 13/12). Initially males were more abundant, but by the end of the survey period both sexes were equally represented with 5 males and 5 females present over 12 - 13/12/98 (Fig. 4.7b).

The total number of sharks at the Tollgate Islands (Batemans Bay) also exhibited a similar pattern (Fig. 4.8a). There were no Grey Nurse Sharks present prior to the survey period (Poidevin, pers. comm. Smith, pers. comm.). Eight females were then seen on 4/12/98 and this increased to 13 and fluctuated thereafter. In contrast, the total number of Grey Nurse Sharks declined at the Pinnacles (Forster) over the 3 days of sampling (Fig. 4.8b). The decrease in abundance was, however, clearly due to the disappearance of the 11 males.

Finally, observations over 3 days at Fish Rock (South West Rocks) showed that 2 Grey Nurse Sharks (1 male and 1 female) occupied the shark gutter (Fig. 4.8c). Initially, both sharks were seen together, but on the second and third occasions (i.e. 29/11/98 and 1/12/98) only one or the other was observed.

4.3.2.2.3 Long-term Temporal Variation

There was substantial long-term (among survey) variation present across the 50 - 61 sites sampled in the 3 surveys (Fig. 4.6). It was clear that the timing of occupation and duration of occupation of particular sites varied over longer time intervals and was most likely related to the sharks movements. Detailed analysis of possible patterns was not carried out because these were obtained from the analysis of the length-frequency data (see later). Despite this there was a general trend for the total number of female Grey Nurse Sharks to remain unchanged over time (Fig. 4.9a). In contrast, the total number of males

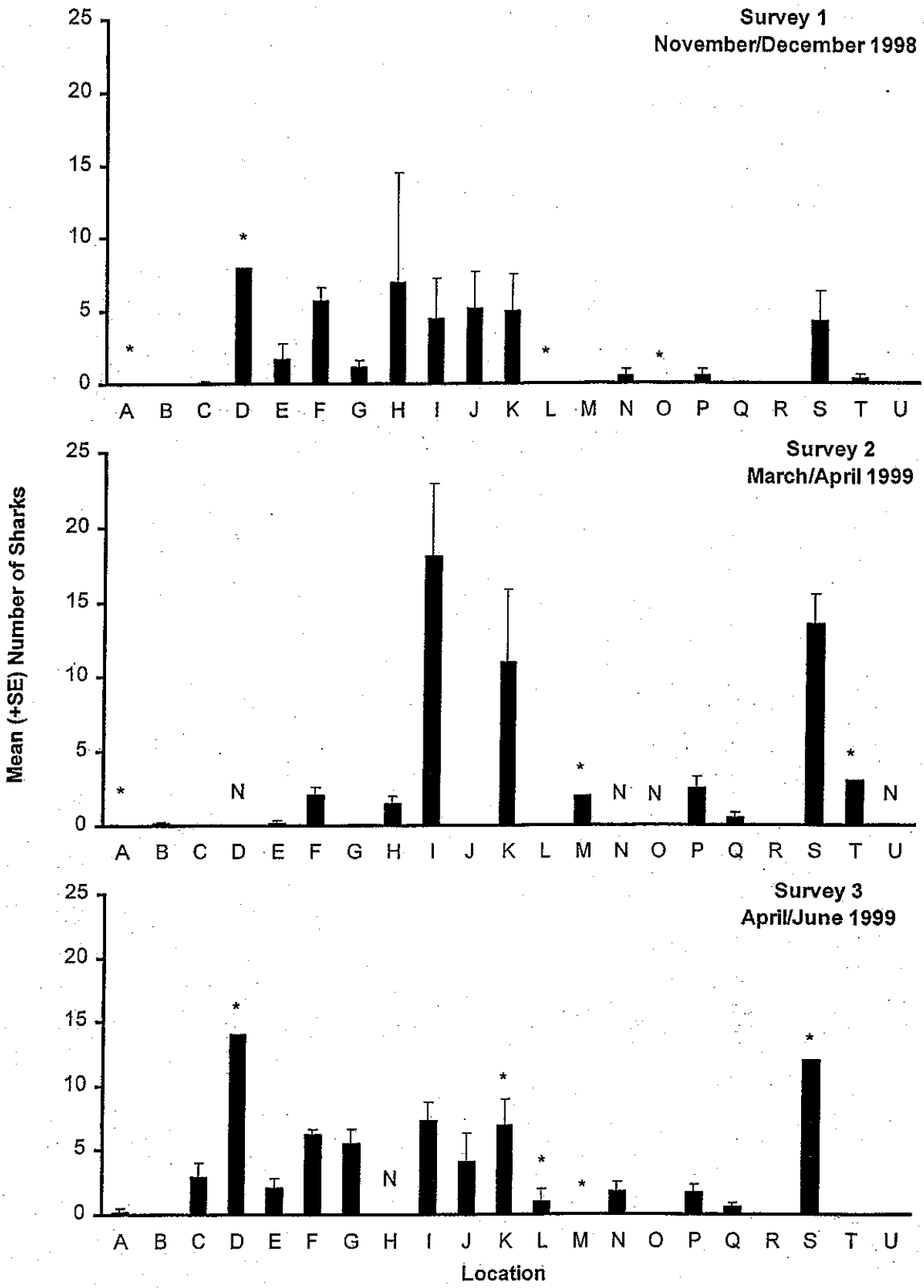
observed increased markedly in the third survey (Fig. 4.9a). The significance of this latter observation will be discussed with the analysis of the length frequency data. Finally, incorporating sampling effort (i.e. the number of sites sampled) showed that the mean number of sharks per site was relatively unchanged in surveys 1 and 2 but increased in survey 3 (Fig. 4.9b). The increase in survey 3 was most likely caused by the influx of males evident in figure 4.9a.

Table 4.6 Analysis of the parameter estimates from a general linear model based on a Poisson regression for the number of Grey Nurse Sharks observed at 13 locations along the NSW coast over a 4 week period from mid-November to mid-December, 1998.

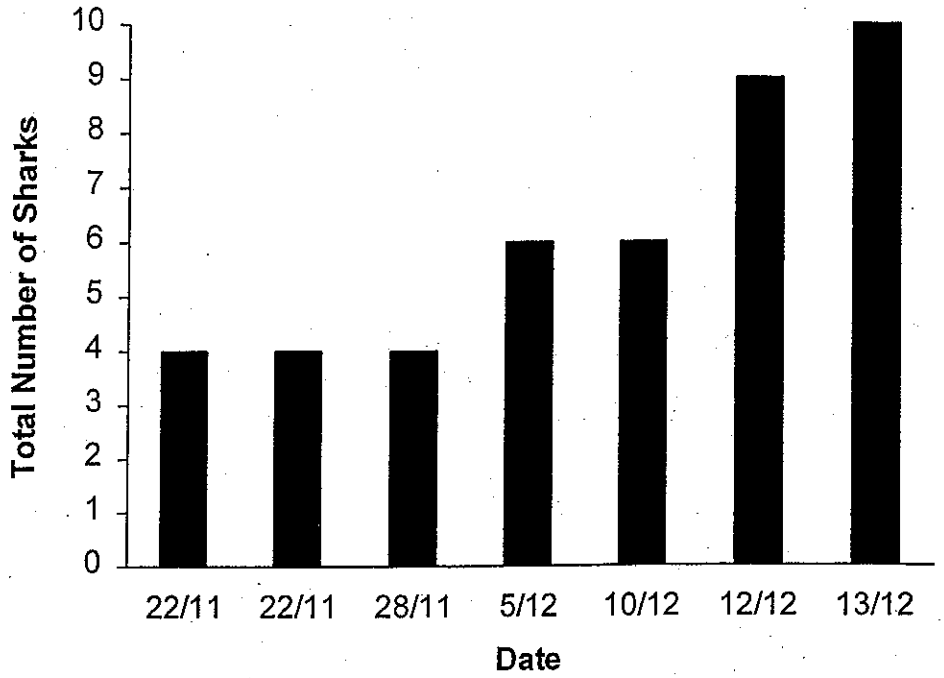
Parameter	df	Estimate	SE	χ^2	*P*
Byron Bay	1	- 1.3863	2.0896	0.4401	0.5071, ns
North Solitary Is.	1	0.5108	0.9345	0.2988	0.5846, ns
South Solitary Is.	1	1.8718	0.5795	10.4315	0.0012, *
South West Rocks	1	0.2231	0.9345	0.0570	0.8113, ns
Laurieton	1	1.9459	0.4560	18.2117	0.0001, *
Forster	1	1.8458	0.4794	14.8259	0.0001, *
Seal Rocks	1	1.6422	0.3753	19.1476	0.0001, *
Port Stephens	1	1.6094	0.5395	8.8987	0.0029, *
Sydney	1	- 0.6931	2.0896	0.1100	0.7401, ns
Shellharbour	1	- 0.4055	1.4776	0.0753	0.7838, ns
Jervis Bay	1	- 2.0794	2.0896	0.9903	0.3197, ns
Batemans Bay	1	1.4663	0.5795	6.4017	0.0114, *
Narooma	1	- 1.0986	2.0896	0.2764	0.5991, ns

Figure 4.6 Mean (+ SE) number of Grey Nurse Sharks observed at the 21 locations (listed below) along the NSW coast during the period November - December 1998, March/April, 1999 and May/June, 1999 (*: total number of sharks rather than the mean because only 1 site could be sampled at the location; N: not sampled).

A - Stradbroke Island
B - Tweed Heads
C - Byron Bay
D - Brooms Head
E - North Solitary Islands
F - South Solitary Islands
G - South West Rocks
H - Laurieton
I - Forster
J - Seal Rocks
K - Port Stephens
L - Newcastle
M - Terrigal
N - Sydney
O- Wollongong
P - Shellharbour
Q - Jervis Bay
R - Ulladulla
S - Batemans Bay
T - Narooma
U - Eden.


Survey 1
November/December 1998
Survey 2
March/April 1999
Survey 3
April/June 1999
Mean (+SE) Number of Sharks
Location
A B C D E F G H I J K L M N O P Q R S T U
0 5 10 15 20 25
N

A.



B.

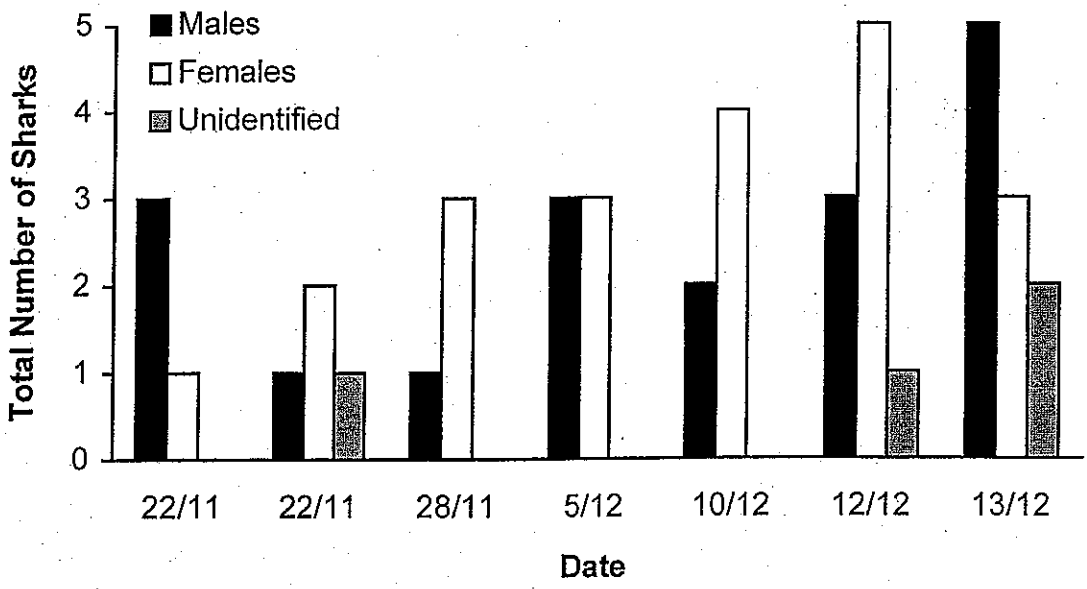


Figure 4.7 Short-term fluctuations in the total number of Grey Nurse Sharks observed at Manta Arch (South Solitary Islands) during the November to December, 1998 survey. (A) Uncategorised, (B) Categorised by sex.

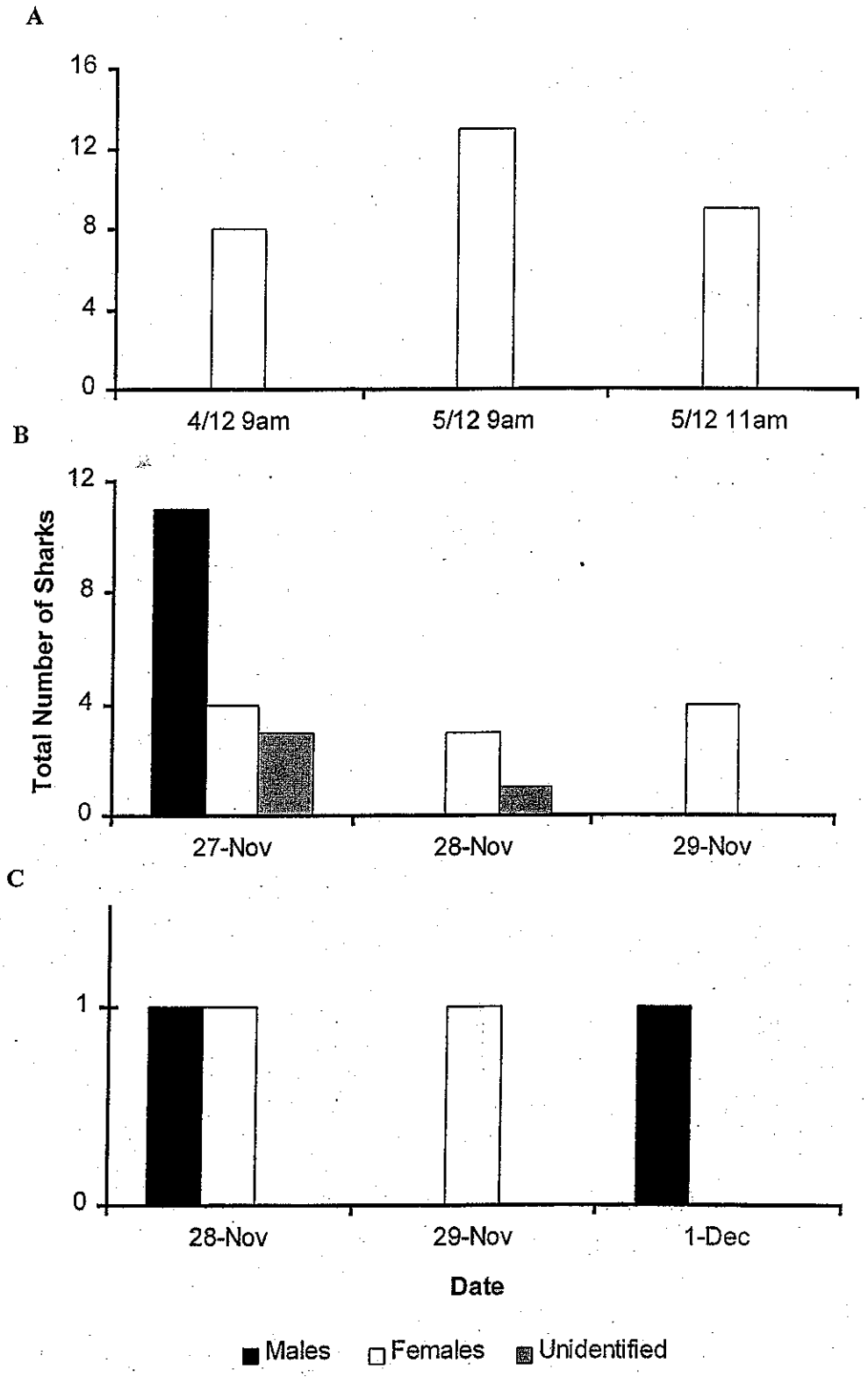


Figure 4.8 Short-term fluctuations in the total number of Grey Nurse Sharks categorised by sex at (A) Tollgate Islands (Batemans Bay), (B) The Pinnacles (Forster), and (C) Fish Rock (South West Rocks) during the November to December, 1998 survey.

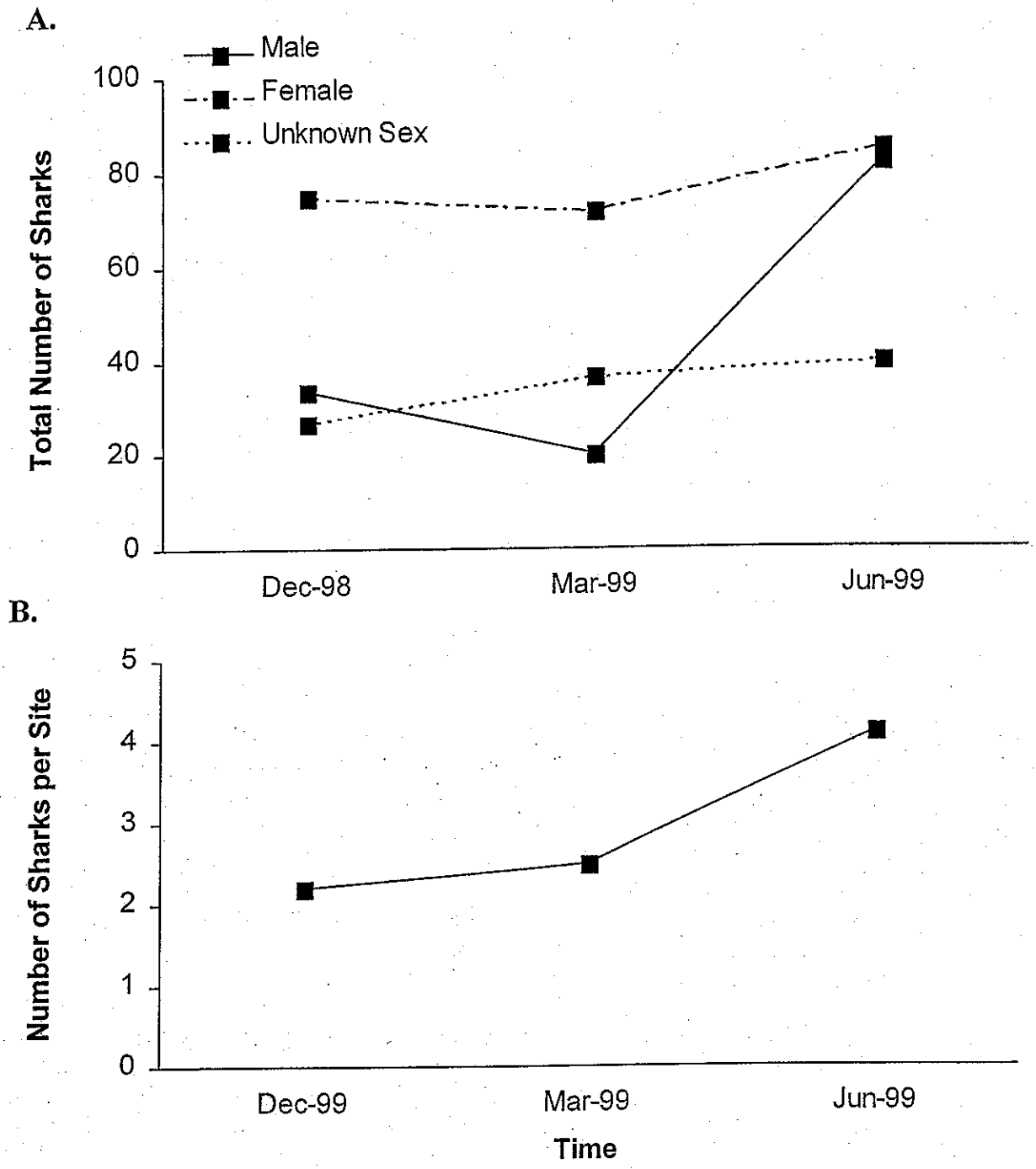


Figure 4.9 Long-term fluctuations in the total number of Grey Nurse Sharks along the entire NSW and southern Queensland coasts during the November/December 1998, March/April 1999 and May/June 1999 surveys. (A) Total numbers categorised by sex and (B) Total numbers adjusted by effort (number of sites sampled).

4.3.2.3 Population Size-Structure along the NSW and southern Queensland Coasts

In November/December 1998, the Grey Nurse Shark population along the entire NSW coast was dominated by individuals 1 - 2 m and 2 - 3 m TL. Of the 136 sharks sighted, 76 individuals (i.e. 56% of the total population) were 1 to 2 m TL and 58 individuals (i.e. 42% of the total population) were 2 - 3 m TL. Furthermore, only 2 individuals: 1 male and 1 female (i.e. 2% of the total population) exceeded 3 m TL. In March/April 1999, the Grey Nurse Shark population was also dominated by individuals 1 - 2 m and 2 - 3 m TL. However, of the 129 sharks sighted, it was only possible to determine sex and length for 112 individuals. Of these, 51 individuals (i.e. 46% of n = 112) were 1 to 2 m TL and 49 individuals (i.e. 43% of n = 112) were 2 - 3 m TL. A further 12 individuals (i.e. 11% of n = 112) exceeded 3 m TL. In May/June 1999, the Grey Nurse Shark was again dominated by individuals 1 - 2 m and 2 - 3 m TL. However, of the 207 sharks sighted, it was only possible to determine sex and length for 204 individuals. Of these, 77 individuals (i.e. 38% of n = 204) were 1 to 2 m TL and 114 individuals (i.e. 56% of n = 204) were 2 - 3 m TL. A further 13 individuals (i.e. 6% of n = 204) exceeded 3 m TL.

The length-frequency distributions of Grey Nurse Sharks at the individual locations varied markedly along the coast and among the 3 surveys (Figs. 4.11 - 4.13) and this was primarily due to the aggregations of sharks at particular sites within a number of locations along the NSW coast. For example, at Seal Rocks no male sharks were seen and 23 (74%) of the remaining individuals were female. Of these, 18 females (i.e. 78% of all females) were greater than 2 m TL (Fig. 4.8b). This contrasts with the patterns observed off Port Stephens (Broughton Is., etc. - see Table 1) and at the Tollgate Islands off Batemans Bay which were similar. All 15 Grey Nurse Sharks observed off Port Stephens were female and only 5 (27%) had total lengths exceeding 2 m. At the Tollgate Islands, the 13 Grey Nurse Sharks present were also all female, but only 2 (15%) were greater than 2 m TL.

While the length-frequency distributions of Grey Nurse Sharks at individual locations along the NSW coast differed, there were also some more general patterns evident. Thirty-three of the male Grey Nurse Sharks (97% of the male population) were observed at the 6 locations from Forster and north to Broom's Head (Fig. 4.8b). The length-frequency distribution of male Grey Nurse Sharks at each of these locations was characterised by the presence of individuals with total lengths of 1 - 2 m (Fig. 4.8b). However, this similarity did not extend to male Grey Nurse Sharks greater than 2 m TL as these 12 individuals were only seen at Pimpernel Rock (Brooms Head), Mermaid Reef (Laurieton) and the Pinnacles (Forster). The remaining male, a 1 - 2 m TL individual, was observed at Montague Is. (Narooma) on 6/12/98 (Fig. 4.8b).

Female Grey Nurse Sharks were observed from Byron Bay to Batemans Bay with 22 individuals (29% of the total female population) occurring off Forster and 6 locations to the north (Fig. 4.8b). Of these, 12 sharks were 1 - 2 m TL and 10 individuals were greater than 2 m TL. The remaining 53 females (71% of the female population) were observed from Seal Rocks to Batemans Bay (Fig. 4.8b). Of these, 29 had total lengths of 1 - 2 m, whereas the remaining 24 individuals were greater than 2 m TL.

4.3.2.4 Segregation by Sex along the NSW and southern Queensland Coasts

While the overall size-structure of the the Grey Nurse Shark population along the entire NSW coast appeared consistent through time, plots of size-frequency distributions for males and females along the entire coast for each of the 3 surveys (Figs. 4.11 - 4.13) suggested that this was not the case. For example, the size-frequency distributions of male and female Grey Nurse Sharks suggested a dominance of females in surveys 1 and 2. However, this dominance of females was not apparent in survey 3 and was most likely due to the increase in the abundance of males discussed earlier.

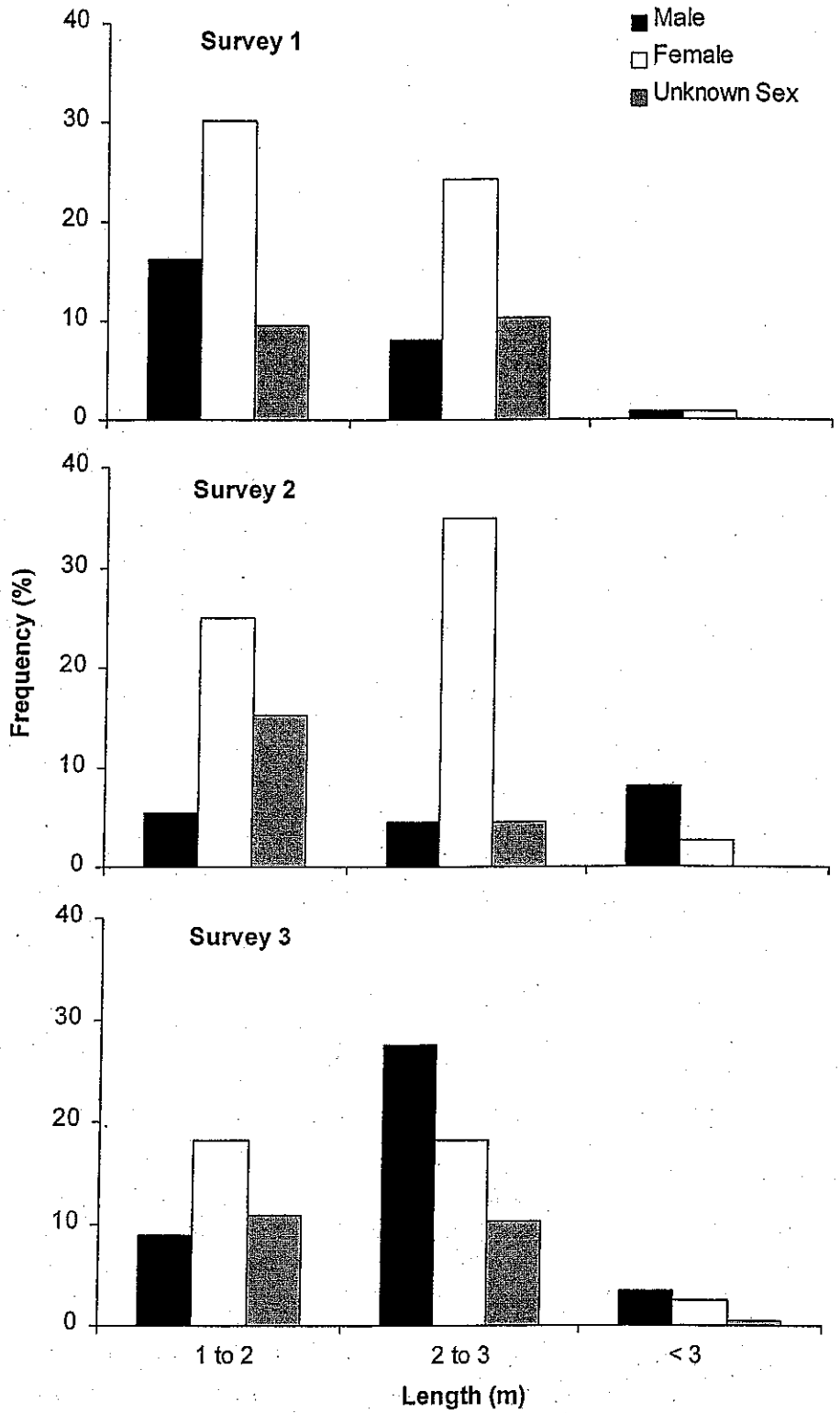


Figure 4.10 The length-frequency distributions of male and female Grey Nurse Sharks, and individuals of unknown sex pooled across the entire coast in November/December, 1998 (Survey 1), March/April, 1999 (Survey 2) and May/June, 1999 (Survey 3). Total lengths estimated visually and placed into 3 size-classes: 1 - 2 m, 2 - 3 m and > 3 m.

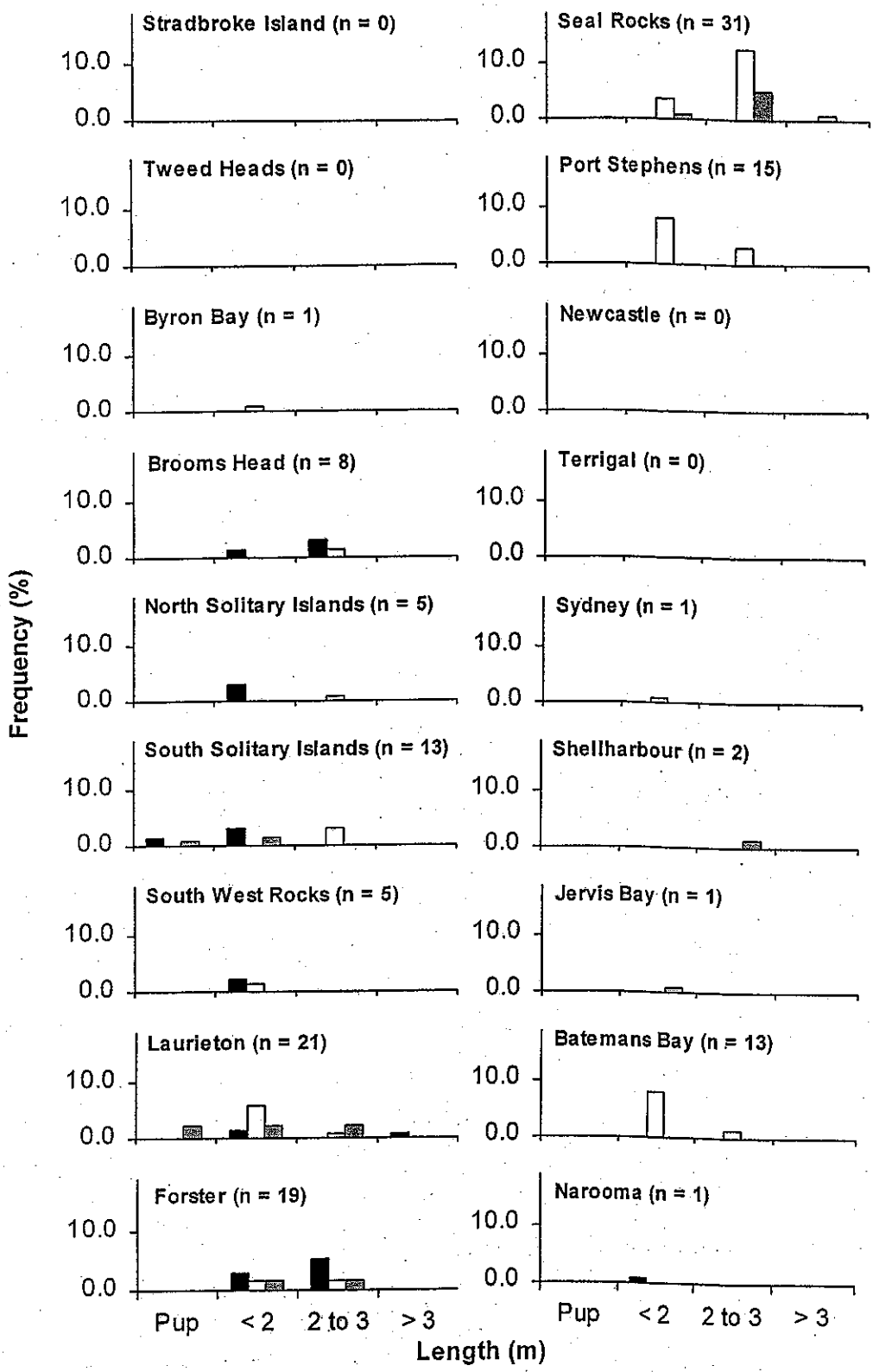


Figure 4.11 The length-frequency distributions of male and female Grey Nurse Sharks, and individuals of unknown sex at various locations along the NSW in November/December 1998 (Survey 1). Total lengths estimated visually and placed into pups and 3 other size-classes: < 2 m, 2 - 3 m and > 3 m.

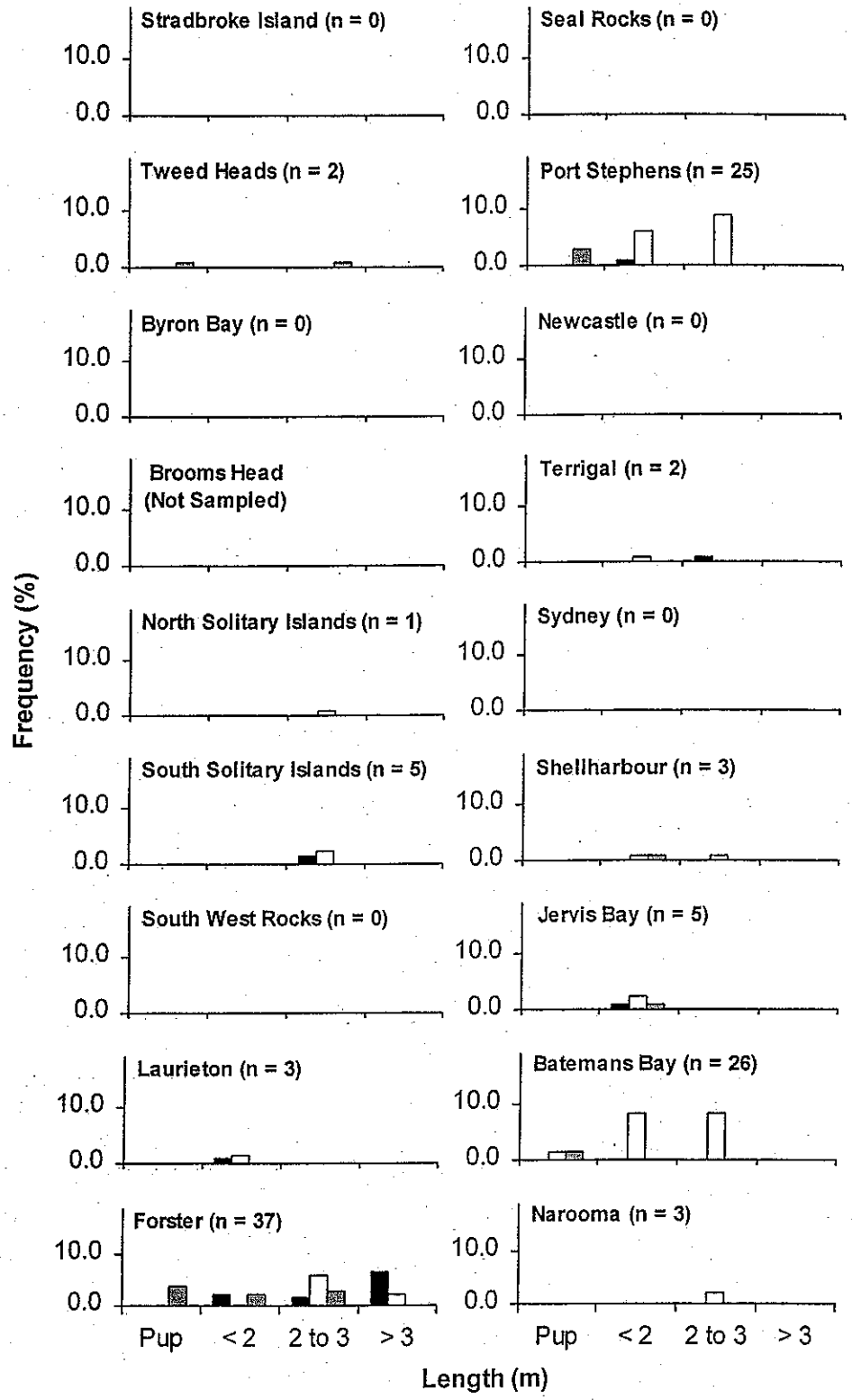


Figure 4.12 The length-frequency distributions of male and female Grey Nurse Sharks, and individuals of unknown sex pooled across the entire coast in the surveys in March/April (Survey 2). Total lengths estimated visually and into pups and 3 other size-classes: < 2 m, 2 - 3 m and > 3 m.

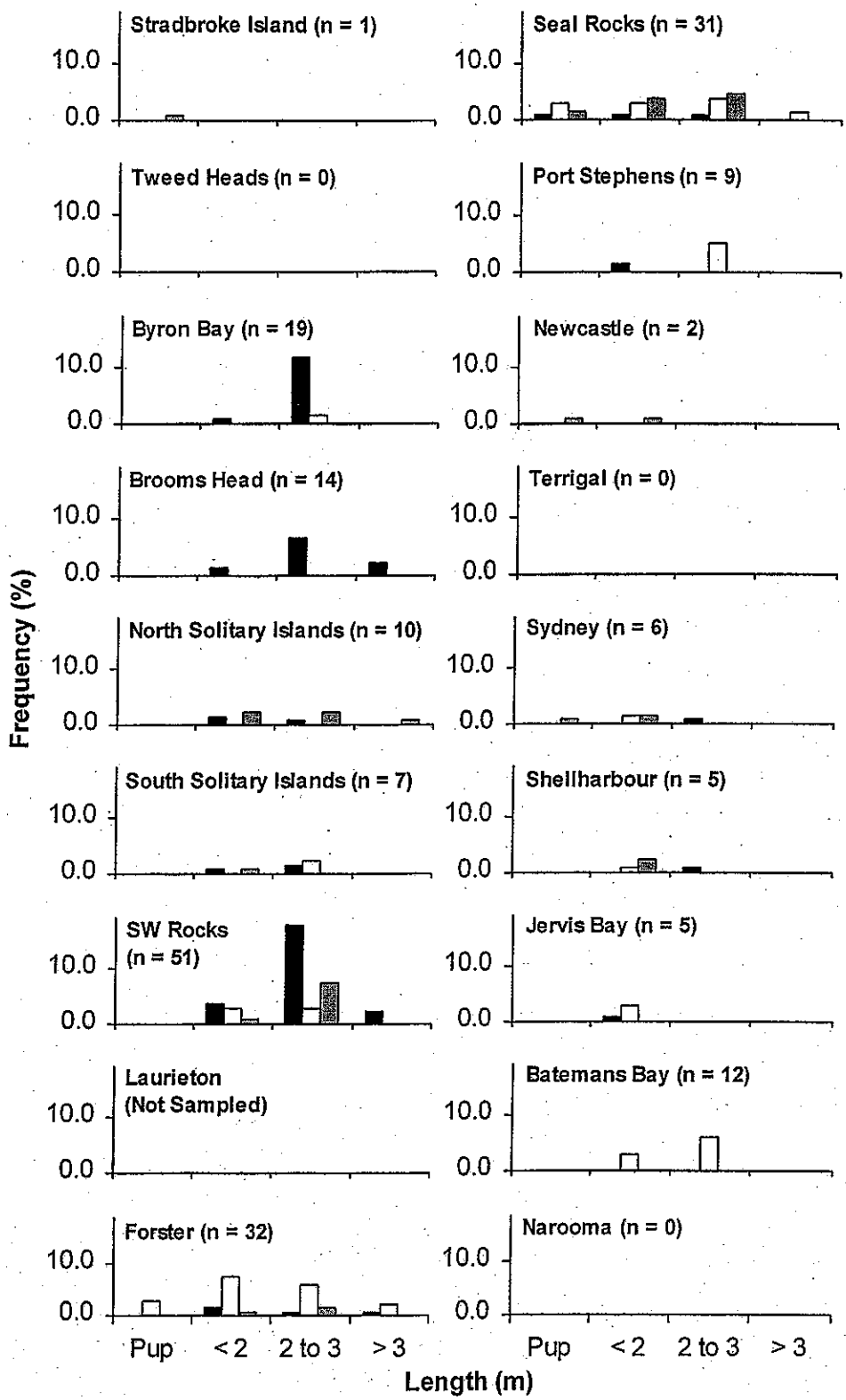


Figure 4.13 The length-frequency distributions of male and female Grey Nurse Sharks, and individuals of unknown sex pooled across the entire coast in the surveys May/June 1999 (Survey 3). Total lengths estimated visually and placed into pups and 3 other size-classes: < 2 m, 2 - 3 m and > 3 m.

4.3.2.4.1 Along the Entire NSW and Southern Queensland Coasts

For those individuals of known sex (pooled across all sites), analysis of the proportion of male to female Grey Nurse Sharks observed along the entire coast indicated that the sex ratios differed significantly among surveys (Table 4.7, $\chi^2 = 20.69$, $P < 0.001$). In November/December 1998, there were more females and fewer males than expected by chance alone giving a sex ratio of 2.2 to 1 which was significantly biased in favour of females (Table 4.7, $\chi^2 = 15.42$, $P < 0.001$). In March/April 1999, there were also more females and fewer males than expected by chance alone. This gave a sex ratio of 3.6 to 1 which was also significantly biased in favour of females ($\chi^2 = 29.40$, $P < 0.001$). Finally, in May/June (1999), there were fewer females and more males than expected by chance alone, but the number of males and females did not differ significantly from a 1:1 sex ratio (Table 4.7, $\chi^2 = 0.10$, $P > 0.10$).

Table 4.7 Numbers of male and female Grey Nurse Sharks observed along the entire NSW coast and in the 2 sections of coast (1. Forster and sites north, and 2. Seal Rocks and sites south) in the surveys in November/December 1998, March/April 1999 and May/June 1999. Note the subdivision of coastline was based on the distribution of male Grey Nurse Sharks in the first survey (see text for details).

Section	Sex	Survey 1	2	3
Entire coast				
	Male	34	20	81
	Female	75	72	85
Forster and sites north				
	Male	33	17	73
	Female	22	17	44
Seal Rocks and sites south				
	Male	1	3	8
	Female	53	55	41

4.3.2.4.2 Comparisons Between Sections of the Coast

The length frequency distributions of male and female Grey Nurse Sharks also suggested that the sex-ratios along sections of the coast would differ from that calculated for the entire coastline as there appeared to be more males than females at the northern locations, and fewer males than females across the southern locations. Consequently, the sex-ratios of the Grey Nurse Sharks along the NSW coast were re-examined by using the distribution of male Grey Nurse Sharks in November/December 1998 (Survey 1) to arbitrarily subdivide the coastline into two sections: (1) Forster and sites to the north, and (2) Seal Rocks and sites to the south.

On re-analysis, the proportions of male Grey Nurse Sharks present at sites in the 2 sections of the coast did not differ significantly among surveys (Table 4.7, $\chi^2 = 2.54$, $P > 0.10$). However, the proportions of males and females present at Foster and sites to the north compared to Seal Rocks and sites to the south

were significantly different in each of the 3 surveys (Table 4.7, $\chi^2 = 42.68$, 25.25 and 29.30 for surveys 1-3, respectively, all $P < 0.001$). Proportionally more males occurred at Foster and sites to the north.

In contrast, the proportions of female Grey Nurse Sharks present at sites in the two sections of the coast differed significantly among surveys (Table 4.7, $\chi^2 = 15.45$, $P < 0.001$). In surveys 1 and 2, there were proportionally more females present at Seal Rocks and sites to the south and fewer present at Foster and sites to the north. In survey 3, however, there were proportionally more females at Foster and sites to the north and proportionally fewer at Seal Rocks and sites to the south.

4.3.2.4.2.1 Comparisons within each section of the coast

4.3.2.4.2.2 Forster and sites to the north

The proportions of male to female Grey Nurse Sharks observed at Foster and sites to the north did not differ significantly among surveys (Table 4.7, $\chi^2 = 1.68$, $P > 0.10$). Furthermore, the numbers of males and females in surveys 1 and 2 (i.e. November/December, 1998 and March/April, 1999) did not differ significantly from a 1:1 sex ratio (Table 4.7, $\chi^2 = 2.20$ and 0.00, $P > 0.10$). However, in survey 3 (i.e. May/June, 1999) the number of male and female Grey Nurse Sharks differed significantly from a 1:1 sex ratio (Table 4.7, $\chi^2 = 7.20$, $P < 0.01$) with a ratio of 1.7:1 biased in favour of males.

4.3.2.4.2.3 Seal Rocks and sites to the south

The proportions of male to female Grey Nurse Sharks at Seal Rocks and sites to the south differed significantly among surveys (Table 4.7, $\chi^2 = 8.48$, $P < 0.05$). The proportions of males to females did not differ in surveys 1 and 2 (i.e. November/December, 1998 and March/April, 1999). However, in survey 3 (i.e. May/June, 1999) there were proportionally more males and fewer females than expected. Despite this, the numbers of males and females differed significantly from a 1:1 sex ratio in all 3 surveys (Table 4.7, $\chi^2 = 50.0$, 46.6 and 22.2 for surveys 1-3, respectively; all $P < 0.001$). The sex-ratios exceeded 1:5 and were consistently biased in favour of females.

4.3.2.5 Segregation by Size Along the NSW Coast and Southern Queensland

The size-frequency distributions of male and female Grey Nurse Sharks along the entire coast suggested that the sizes of males and females differed over the 3 surveys. To examine the statistical significance of these observations, the data for males and females were partitioned into two size classes: (1) 1 - 2 m TL, and (2) > 2 m TL. The choice of size-classes incorporates practical aspects of estimating sizes underwater and the results of reproductive studies of Grey Nurse Sharks. Studies by Bass *et al.* (1975), Gilmore *et al.* (1983) and 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. Consequently, the second size-class (i.e. individuals > 2 m TL) will be comprised of reproductively mature males and a large majority ofreproductively mature females.

4.3.2.5.1 Along the Entire NSW Coast and Southern Queensland

The proportions of male to female Grey Nurse Sharks 1 - 2 m TL observed along the entire coast did not differ significantly among surveys (Table 4.8, $\chi^2 = 3.38$, $P > 0.10$). Despite this, the numbers of males and females 1 - 2 m TL differed significantly from a 1:1 sex ratio in all 3 surveys (Table 4.8, $\chi^2 = 5.74$, 14.24 and 6.56 for surveys 1-3, respectively; all $P < 0.05$). The sex-ratios exceeded 1:1.9 and were consistently biased in favour of females.

Table 4.8 Numbers of male and female Grey Nurse Sharks in 2 size-classes (i.e. 1 - 2 m TL and > 2 m TL) observed along the entire NSW coast and in the 2 sections of coast (1. Forster and sites north, and 2. Seal Rocks and sites south) in the surveys in November/December 1998, March/April 1999 and May/June 1999. Note the subdivision of coastline was based on the distribution of male Grey Nurse Sharks in the first survey.

Section	Sex / Size class	Survey 1	2	3
Entire coast				
	Male			
	1 - 2 m	22	6	18
	> 2 m	12	14	63
	Female			
	1 - 2 m	41	28	37
	> 2 m	34	42	42
Forster and sites north				
	Male			
	1 - 2 m	21	4	13
	> 2 m	12	13	60
	Female			
	1 - 2 m	12	2	18
	> 2 m	10	15	20
Seal Rocks and sites south				
	Male			
	1 - 2 m	1	2	5
	> 2 m	0	1	3
	Female			
	1 - 2 m	29	26	19
	> 2 m	24	27	22

The proportions of male to female Grey Nurse Sharks > 2 m TL observed along the entire coast differed significantly among surveys (Table 4.8, $\chi^2 = 25.15$, $P < 0.05$). There were proportionally fewer males and more females > 2 m TL in surveys 1 and 2 (i.e. November/December, 1998 and March/April, 1999). However, in survey 3 (i.e. May/June, 1999) there were proportionally more males and fewer females > 2 m TL than expected by chance alone. Finally, the numbers of males and females > 2 m TL differed significantly from a 1:1 sex ratio in all 3 surveys (Table 4.8, $\chi^2 = 10.5$, 14.0 and 4.2 for surveys 1-3,

respectively; all $P < 0.05$). In surveys 1 and 2, the sex-ratios were biased in favour of females. However, in survey 3 the sex ratio was biased towards males.

The proportions of male Grey Nurse Sharks 1 - 2 m TL to > 2 m TL observed along the entire coast differed significantly among the 3 surveys (Table 4.8, $\chi^2 = 19.41$, $P < 0.01$). There were proportionally more 1 - 2 m TL and fewer > 2 m TL males than expected in survey 1, no differences in survey 2, and proportionally fewer 1 - 2 m TL and more > 2 m TL males than expected in survey 3. In contrast, the proportions of female Grey Nurse Sharks 1 - 2 m TL to > 2 m TL did not differ significantly among the 3 surveys (Table 4.8, $\chi^2 = 3.14$, $P > 0.10$).

4.3.2.5.2 Comparisons between sections of the coast

The length frequency distributions of male and female Grey Nurse Sharks also suggested that the sizes of Grey Nurse Sharks differed in the 2 sections of the coast. Consequently, the 2 size-classes of the Grey Nurse Sharks established above were also used to examine size segregation of Grey Nurse Sharks found at: (1) Forster and sites to the north, and (2) Seal Rocks and sites to the south.

The proportions of male Grey Nurse Sharks 1 - 2 m TL observed at sites along the 2 sections of coast did not differ significantly among surveys (Table 4.8, $\chi^2 = 4.59$, $P > 0.10$). In contrast, the proportions of female Grey Nurse Sharks 1 - 2 m TL present at Foster and sites to the north compared to Seal Rocks and sites to the south differed significantly among surveys (Table 4.8, $\chi^2 = 13.08$, $P < 0.01$). In survey 1, the proportion of females 1 - 2 m TL observed at sites in the 2 sections of the coast did not differ. In survey 2, there were proportionally more females at Seal Rocks and sites to the south and proportionally fewer at Foster and sites to the north. This contrasted with survey 3 as there were proportionally more 1 - 2 m TL females at Foster and sites to the north and proportionally fewer at Seal Rocks and sites to the south.

The proportions of males and females 1 - 2 m TL observed at the sites along the 2 sections of coast differed significantly and in a consistent manner in surveys 1 and 2 (Table 4.8, $\chi^2 = 22.96$, and 12.70, both $P < 0.001$). Proportionally more male 1 - 2 m TL Grey Nurse Sharks occurred at Foster and sites to the north and proportionally more females 1 - 2 m TL occurred at Seal Rocks and sites to the south. In contrast, the proportion of male to female Grey Nurse Sharks 1 - 2 m TL did not differ significantly in survey 3 (Table 4.8, $\chi^2 = 2.81$, $P > 0.05$). Proportionally more male > 2 m TL Grey Nurse Sharks and proportionally fewer females > 2 m TL occurred at Foster and sites to the north in all 3 surveys, and at Seal Rocks and sites to the south . In contrast, the proportion of male to female Grey Nurse Sharks 1 - 2 m TL did not differ significantly in survey 3 (Table 4.8, $\chi^2 = 2.81$, $P > 0.05$).

The proportions of male Grey Nurse Sharks > 2 m TL observed at sites along the 2 sections of coast did not differ significantly among surveys (Table 4.8, $\chi^2 = 0.81$, $P > 0.10$). Similarly, the proportions of female Grey Nurse Sharks > 2 m TL present at Foster and sites to the north compared to Seal Rocks and sites to the south did not differ significantly among surveys (Table 4.8, $\chi^2 = 2.84$, $P > 0.10$).

The proportions of males and females > 2 m TL observed at the sites along the 2 sections of coast differed significantly and in a consistent manner across all 3 surveys (Table 4.8, $\chi^2 = 17.93$, 13.70 and 31.19, all $P < 0.001$). Proportionally more male > 2 m TL Grey Nurse Sharks and proportionally fewer females > 2 m TL occurred at Foster and sites to the north in all 3 surveys. In contrast, proportionally fewer male > 2 m TL Grey Nurse Sharks and proportionally more females > 2 m TL occurred at Seal Rocks and sites to the south in all 3 surveys.

4.3.2.5.3 Comparisons within each section of the coast

4.3.2.5.3.1 (1) Forster and sites to the north

The proportions of male Grey Nurse Sharks 1 - 2 m TL to > 2 m TL observed at Foster and sites to the north differed significantly among the 3 surveys (Table 4.8, $\chi^2 = 22.84$, $P < 0.001$). There were proportionally more 1 - 2 m TL and fewer > 2 m TL males than expected in survey 1, no differences in survey 2, and proportionally fewer 1 - 2 m TL and more > 2 m TL males than expected in survey 3. The proportions of female Grey Nurse Sharks 1 - 2 m TL to > 2 m TL observed at Foster and sites to the north also differed significantly among the 3 surveys (Table 4.8, $\chi^2 = 8.27$, $P < 0.05$). There were no differences in the proportions of 1 - 2 m TL and > 2 m TL females in surveys 1 and 3. However, in survey 2 there were proportionally fewer 1 - 2 m TL and more > 2 m TL females than expected by chance.

The proportions of male to female Grey Nurse Sharks 1 - 2 m TL observed at Foster and sites to the north did not differ significantly among surveys (Table 4.8, $\chi^2 = 3.39$, $P > 0.10$). Furthermore, the numbers of males and females 1 - 2 m TL did not differ significantly from a 1:1 sex ratio in all 3 surveys (Table 4.8, $\chi^2 = 2.46$, 0.66 and 0.80 for surveys 1-3, respectively; all $P > 0.10$).

The proportions of male to female Grey Nurse Sharks > 2 m TL observed at Foster and sites to the north differed significantly among surveys (Table 4.8, $\chi^2 = 8.85$, $P < 0.05$). The proportions of males to females > 2 m TL did not differ in survey 1. However, in surveys 2 and 3 there were were proportionally more males and fewer females than expected by chance. Finally, the numbers of males and females > 2 m TL only differed significantly from a 1:1 sex ratio in the third survey (Table 4.8, $\chi^2 = 0.18$, 0.14 and 20.00; $P > 0.05$, 0.05 and 0.001 for surveys 1 - 3, respectively) with a bias of 3:1 in favour of males.

4.3.2.5.3.2 (2) Seal Rocks and sites to the south

The proportions of male Grey Nurse Sharks 1 - 2 m TL to > 2 m TL observed at Seal Rocks and sites to the south did not differ significantly among the 3 surveys (Table 4.8, $\chi^2 = 0.55$, $P > 0.10$). Similarly, the proportions of female Grey Nurse Sharks 1 - 2 m TL to > 2 m TL did not differ significantly among the 3 surveys (Table 4.8, $\chi^2 = 0.69$, $P > 0.10$).

The proportions of male to female Grey Nurse Sharks 1 - 2 m TL observed at Seal Rocks and sites to the south did not differ significantly among surveys (Table 4.8, $\chi^2 = 5.08$, $P > 0.05$). Despite this, the numbers of males and females 1 - 2 m TL differed significantly from a 1:1 sex ratio in all 3 surveys (Table 4.8, $\chi^2 = 23.14$, 20.58 and 8.16 for surveys 1-3, respectively; all $P < 0.01$). The sex-ratios exceeded 1:3 and were consistently biased in favour of females.

Similarly, the proportions of males to females > 2 m TL were not significantly different among in surveys (Table 4.8, $\chi^2 = 3.82$, $P > 0.05$). Despite this, the numbers of males and females differed significantly from a 1:1 sex ratio in all 3 surveys (Table 4.8, $\chi^2 = 24.0$, 24.14 and 14.44 for surveys 1-3, respectively; all $P < 0.001$). The sex-ratios exceeded 1:7 and were consistently biased in favour of females.

4.3.2.6 Incidence of Hooking on Bottom Setlines

Grey nurse sharks with bottom setline hooks embedded in their jaws were observed along the entire coast from Julian Rocks to Montague Island. Repetitive observations of the same shark at any given site were removed from the dataset prior to analysis. The proportions of sharks with and without hooks embedded in their jaws did not differ significantly among surveys (Table 4.9, $\chi^2 = 0.21$, $P > 0.10$).

Table 4.9. Numbers of Grey Nurse Sharks with and without bottom setline hooks embedded in their jaws observed along the entire NSW coast recorded in the surveys in November/December 1998, March/April 1999 and May/June 1999.

	Survey			
	1	2	3	Total
With Hooks	8	9	12	29
Without Hooks	128	120	195	443

Estimates of hooking rate (i.e. the number of sharks with hooks embedded in their jaws divided by the total number of individuals per survey - expressed as a percentage) from this study and those of Pollard *et al.* (1996) and Parker (unpub.) were regressed on time (Fig. 4.14). This analysis showed that hooking rate increased significantly over time ($R^2 = 0.92$, $P < 0.05$) with a tripling of the rate between 1991 and 1999.

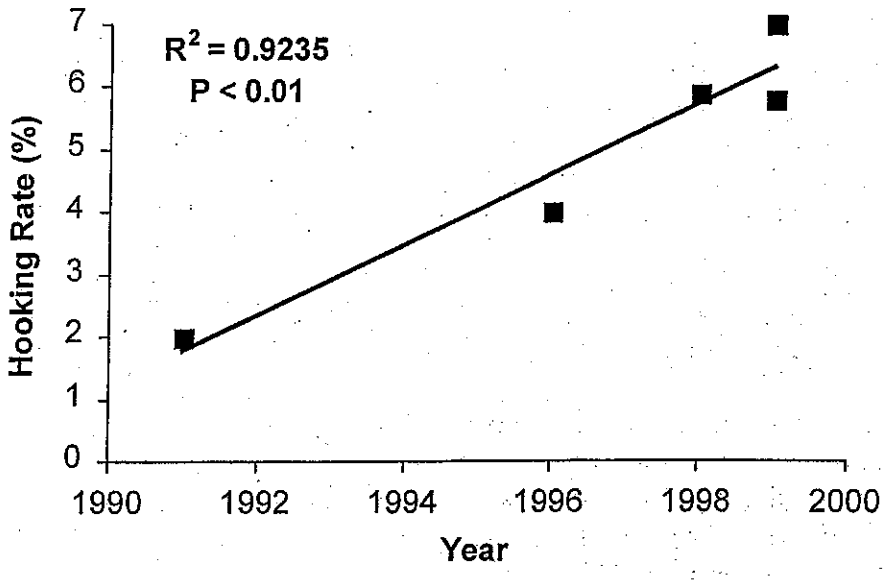


Figure 4.14. Regression of hooking rate on time. Data from this study, Pollard *et al.* (1996) and Parker (unpub.). Hooking rate is expressed as a percentage and calculated as the number of sharks with hooks embedded in their jaws divided by the total number of individuals per survey.

4.4 DISCUSSION

4.4.1 SPATIAL AND TEMPORAL VARIATION IN ABUNDANCE

There was substantial spatial variation evident in abundances of Grey Nurse Sharks at South West Rocks and Seal Rocks, and at the other 19 locations along the entire NSW coast. This spatial variation most likely prevented the detection of significant differences through time at Seal Rocks and among the 13 locations examined in the coastwide analysis of data from survey 1. However, the poisson regression-

based analysis of data from survey 1 demonstrated that there was significantly more variation in shark numbers than would be expected by chance alone at the South Solitary Islands, Laurieton, Forster, Seal Rocks, Port Stephens and Batemans Bay. Sites at these locations together with Pimpernel Rock (off Broom's Head) were the only places where aggregations of 5 or more Grey Nurse Sharks were observed during the survey. Many of these sites had aggregations of Grey Nurse Sharks in the subsequent surveys. It is likely that these sites may play an important role in pupping and/or mating activities, but additional surveys, at these and other sites, will be necessary to assess their overall significance. Why particular sites are chosen over others is unclear at this stage, especially given the physical habitats were very similar across all the sites surveyed. However, it is likely that there are, as yet unknown, biological attributes which attract the sharks to particular sites.

The lack of power to detect significant differences through time at Seal Rocks has very important implications for the future monitoring of Grey Nurse Shark numbers along the coast. The ability to demonstrate whether the population is recovering will clearly depend on the power to detect increases in the mean abundance of Grey Nurse Sharks over time. The results of this survey suggest that it will be almost impossible to detect relatively large changes in the mean abundance without a substantial increase in sampling effort. These results are, however, not unlike many studies of species in which there is a lack of basic biological information (see Toft & Shea, 1983; Sweatman, 1985; Peterman, 1990 for examples). However, several authors (e.g. Gray, 1990) have argued that the "Precautionary Principle" should be invoked in situations where the nominated level of power is not realised. Clearly, invoking the precautionary principle would be more applicable when assessing the possible processes threatening the abundance and long-term conservation of the Grey Nurse Shark (see Section 2.10 for a list of possible threatening processes).

Recovery of the Grey Nurse Shark population along the NSW coast might be demonstrated by using a population dynamic model (see Branstetter, 1990; Hoenig & Gruber, 1990; Pratt & Casey, 1990 for examples). Using data obtained in the surveys together with other biological information (see Otway & Parker, 1999 for a review) would permit the formulation of a preliminary model that might describe the Grey Nurse Shark population along the coast of NSW. Then, by running a series of scenarios simulating recovery it might be possible to identify appropriate indicators of change (recovery) that may be easier to monitor than the spatial and temporal variation in abundance. If it is possible to generate a model, it will be absolutely necessary to examine the sensitivity of any possible indicators. Clearly any attempts to construct a population dynamic model will depend on the data from these and many additional surveys. Furthermore, any such model will require the input of data from regular field surveys to enable the testing of predictions and the refinement of the model.

Finally, the total numbers of sharks (i.e. 136, 129 and 207 individuals) from 50 - 61 sites along the entire coast were very low and completely unexpected 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. The likelihood of such a scenario is probably small because of: (1) the large number of sites sampled, (2) the dispersion of the sites along the entire coast, and (3) the similar results obtained in the 3 surveys. The absence of the sharks at 50 - 69% of the sites sampled is a yet another statistic that raises concern, especially given that the sites were chosen because of their previous occupation by Grey Nurse Sharks (see Table 4.5 for a summary). Given the extremely low numbers, it is essential to ensure that the survey is repeated on a regular basis over the next few years to provide estimates of the inter-annual variation in abundance. A longer term dataset would also guard against unwarranted errors in the interpretation of data collected over short periods of time.

4.4.2 POPULATION SIZE-STRUCTURE

Previous research (e.g. Bass *et al.*, 1975; Gilmore *et al.*, 1983; Branstetter and Musick, 1994) has shown that males attain sexual maturity at a total lengths of 1.90 - 1.95 m. Consequently, of the 34 males observed along the entire NSW coast, it is highly likely that the 12 males greater than 2 m TL were

reproductively mature. It is also probable that a proportion of the males with total lengths of 1 - 2 m would also have been sexually mature. In contrast, it is unlikely that all of the 34 females observed along the coast were reproductively mature because they only attain sexual maturity on reaching 2.20 - 2.30 m TL (Bass *et al.*, 1975; Gilmore *et al.*, 1983; Branstetter, 1990; Branstetter and Musick, 1994). With this in mind and the fact that that female Grey Nurse Sharks only produce 2 pups every two years (Branstetter and Musick, 1994), the data from the 3 surveys suggest that less than 25% of the females will reproduce in any given year. Further surveys will, however, be needed to test this prediction.

The results from South West Rocks and Seal Rocks and surveys 1 and 2 along entire coast showed that the Grey Nurse Shark population exhibited a sex-ratio of at least 2.2 : 1 biased in favour of females. The previous 1991 survey at Seal Rocks also 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) and off Natal, South Africa where sex-ratios have reached 2.3 : 1 biased in favour of females (Cliff, unpub.). The biased sex-ratios in: (1) these surveys, (2) the 1991 survey, and (3) the protective beach nets is most likely due to segregation of the sexes rather than an actual difference in the abundances of males and females. Sexual segregation of male and female Grey Nurse Sharks has been documented for populations on the eastern coasts of South Africa (Bass *et al.*, 1975; Cliff unpub.) and North America (Springer, 1963; Clark and Von Schmidt, 1965; Gilmore *et al.*, 1983).

4.4.3 IMPLICATIONS FOR MIGRATORY MOVEMENTS

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 migratory movements. The size and sexual segregation of male and female Grey Nurse Sharks evident during the three surveys suggests a hypothesised pattern of movement illustrated in Figure 4.15. The hypothesised movements comprise: (1) a movement of sexually mature males into shallower water in early autumn (April) 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.

Evidence for this hypothesis is provided by short-term increases in the number of sharks (males and females) at sites such as Manta Arch (South Solitary Islands), the Tollgate Islands (Batemans Bay) and the rapid decline (to zero) in the number of male Grey Nurse Sharks at the Pinnacles at Foster . While these observations provide support for a "migration hypothesis", they could also be the result of localised (small-scale) movements. It will be important to gain further information concerning localised movements and short-term fluctuations in abundance.

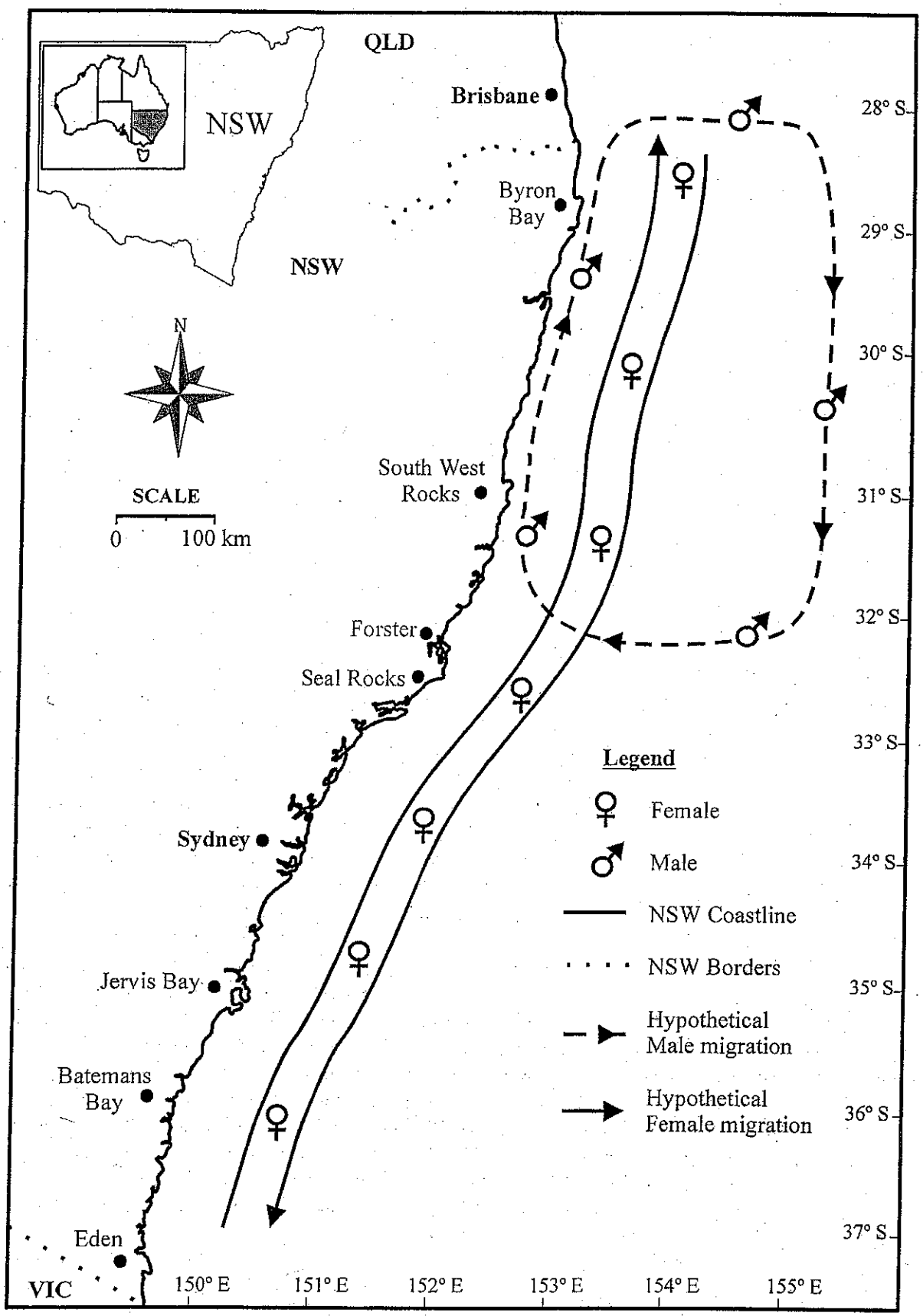


Figure 4.15 Hypothesised migratory movements of male and female Grey Nurse Sharks off the NSW and southern Queensland coasts.

4.4.4 IMPLICATIONS FOR FECUNDITY, REPRODUCTION AND RECRUITMENT

The results of the 3 surveys have substantial implications for the fecundity, reproduction and recruitment of Grey Nurse Sharks along the east coast of Australia (NSW and southern Queensland). As stated earlier, 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 (each = 1.20 m TL) every two 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 provide initial evidence suggesting that the fecundity and timing of parturition is similar to that in South Africa and along the east coast of the USA.

With this in mind, it is likely that pups born over winter 1998 would have been seen for the first time in survey 1 (November/December, 1998). Moreover, any pups observed would have been approximately 1.30 m TL and easily discernible from other individuals in the local population. However, very few pups (i.e. 6, 14 and 12 in surveys 1 - 3, respectively)were observed in the 3 surveys. If we assume that all the female Grey Nurse Sharks > 2 m TL were reproductively mature (i.e. 34, 42 and 42 in surveys 1 - 3, respectively), then there should have been 34 - 42 pups evident given an average fecundity of 1 pup per annum. It is possible that some of the pups were recorded in the next larger size-class (i.e. 1 - 2 m TL). This size-class will contain individuals aged 1, 2, 3, 4 and 5 years as previous research (e.g. Gilmore *et al.*, 1983; Branstetter and Musick, 1994) has also shown that female Grey Nurse Sharks do not attain reproductive maturity until at least 6 years of age. Consequently, if individuals in the 1 - 2 m TL size-class were summed with the number of pups and divided into 6 numerically equal size-classes, each size-class would still only comprise approximately 10 individuals, on average. This still does not permit the number of pups to be increased to the expected level.

The large difference between the number of pups observed (i.e. 6 - 14) and the number expected (i.e. 34 - 42) is cause for concern for at least two reasons. First, it suggests 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 pups (male and female) remain with the reproductvely mature females for many months after birth (Branstetter and Musick, 1994; Cliff, Unpub. MS) and the fact that divers observed 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 would have detected the pups had they been present. It is also possible that several important pupping sites may not have been identified and sampled despite the intense sampling effort (i.e. 50 - 61 sites) in the 3 separate surveys. Second, if there were indeed fewer pups than expected then this indicates that a reproductive failure may have occurred. This may have been triggered by continuously declining numbers of Grey Nurse Sharks causing fewer males and females to meet up and copulate in autumn (i.e April - May). If a reproductive failure has occurred, it is likely that it has occurred over several years given the mean numbers of individuals in the 5 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 would be less than 1 pup per annum, a rate that is clearly insufficient to sustain a population yet alone enable it to recover.

4.4.5 INCIDENTAL CAPTURE ON BOTTOM SETLINES

The surveys showed that there has been a significant increase in the rate of incidental capture on bottom setlines over the past 9 years. It is obvious that the consequences of capture on bottom setlines needs to be assessed in detail. It appears to be a threatening process that has the greatest potential to prevent the recovery of the Grey Nurse Shark population. Mitigation of this potentially threatening activity could be achieved by the declaration of marine protected areas which would exclude this fishing technique.

5. IDENTIFICATION OF MARINE PROTECTED AREAS IN THE MANNING SHELF BIOREGION

5.1 INTRODUCTION

Over the past decade there has been a world wide recognition of the dwindling numbers of sharks (Compagno, 1990; Dares & Nammack, 1998). This has resulted in the identification of a variety of management initiatives to assist with the conservation of sharks. For example, various species including the Grey Nurse Shark have been given protected status and/or listed as threatened species by the IUCN (IUCN, 1996) and management agencies (e.g. NSW Fisheries and Environment Australia).

The continued declines in recent years have also resulted in more proactive management measures to protect sharks and their habitat. For example, temporary closures are now used to prevent human disturbances of the nurse shark (*Ginghymostoma cirratum*) during its mating activities at the Dry Tortugas Islands (Carrier & Pratt, 1998). Moreover, there are many marine parks that include habitat utilised by sharks, but few, if any, marine protected areas have been declared soley for the conservation of a shark.

This chapter examines: (1) the role marine protected areas could have in the conservation of the Grey Nurse Shark, (2) the type of protection (i.e. permanent versus temporary closure), and (3) the location of potential marine protected areas in the Manning Shelf Bioregion.

5.2 THE ROLE OF MARINE PROTECTED AREAS

The results of the review (Chapter Two) and the surveys (Chapter Four) clearly show that Grey Nurse Sharks are found in or near deep, sandy-bottomed gutters or in rocky caves around inshore rocky reefs and islands at depths between 15 and 25 meters. The results of the three surveys also suggest that Grey Nurse Sharks migrate along the NSW and southern Queensland coasts at various times of the year. Similar migratory movements have been documented in detail off South Africa and along the east coast of the USA. With this in mind, it is important to evaluate whether marine protected areas can assist with the shark's conservation. When not migrating, Grey Nurse Sharks aggregate in gutters etc. (see above). The results of the three surveys have shown that 67 - 88% of the sharks observed were in aggregations, consequently if marine protected areas were declared at the known aggregating sites a large percentage of the population would receive a high degree of protection from threatening processes (e.g. the inadvertent capture on bottom setlines) that occur in similar locations.

The aggregation sites appear to be important for many activities including mating and pupping. At present the particular sites utilised for mating and pupping are not known. In the absence of this information the most parsimonious approach would be to ensure that all aggregation sites are protected.

5.3 TYPE OF PROTECTION

There are three means of providing protection to an aggregation site. First, the site could be included in a sanctuary zone within an existing or planned, multiple-use Marine Park under the *NSW Marine Parks Act, 1996*. A system of multiple-use Marine Parks is currently being set up in NSW using bioregionalisation studies. It is highly likely that the system of multiple-use Marine Parks will include the habitats utilised by Grey Nurse Sharks. Second, the site could be declared as an Aquatic Reserve under the *Fisheries Management Act, 1994*. Third, the site could be protected on a temporary basis (up to a period of five years) via a fisheries closure under Section 8 of the *Fisheries Management Act, 1994*. As outlined below the advantages of Aquatic Reserves far outweigh those of fisheries closures and provide the maximum amount of protection that can be delivered under *The Fisheries Managment Act, 1994*. Therefore, it is recommended that Aquatic Reserves be utilised for the long-term conservation of the Grey Nurse Shark along the NSW coast.

5.3.1 FISHERIES CLOSURES

Fisheries Closures can be implemented to provide protection of habitat and species. They are temporary closures for periods of up to five years and are not zoned for varying levels of use. However, a fisheries closure of long-term duration (i.e. 3 - 5 years) may provide as much protection as an Aquatic Reserve because it has the ability to remove any threatening processes. It is important to recognise that fisheries closures are not declared via a parlimentary process and therefore do not satisfy IUCN criteria. There are several advantages and disadvantages of implementing fisheries closures for the conservation of Grey Nurse Sharks.

5.3.1.1 Advantages:

- Short-term closures can be implemented on a "seasonal" basis to cover periods of time when Grey Nurse Sharks occupy a site.
- They permit multiple-use of the site when the sharks are not present.

5.3.1.2 Disadvantages:

- May restrict commercial and/or recreational fishing activities when in force.
- They require regular monitoring to document the timing and/or duration of occupation of the site by Grey Nurse Sharks.
- Requires the replacement and removal of temporary buoys to delineate the closure.
- Will only protect sharks and associated habitat for intermittent periods of time.
- The variable timing of closures from year to year is not conducive to the planning of commercial and/or recreational activities.
- Do not protect other biological attributes, as yet unknown, that attract the sharks to the site on a continuous basis.

5.3.2 AQUATIC RESERVES

Aquatic Reserves can be declared (via parlimentary process) to provide protection of habitat and species. They are permanent closures and as such meet IUCN criteria. Aquatic Reserves may be zoned to include sanctuaries and areas of restricted use. There are several advantages and disadvantages of implementing Aquatic Reserves for the conservation of Grey Nurse Sharks.

5.3.2.1 Advantages:

- They do not require regular monitoring to document the timing and/or duration of occupation of the site by Grey Nurse Sharks.
- They protect key habitats and species.
- Permanent buoys identifying the extent of the reserve can be utilised for the mooring of boats preventing anchoring and its associated habitat damage and stress on the sharks.
- Protect other biological attributes, as yet unknown, that attract the sharks to the site.
- Act as refugia for species of fish consumed by Grey Nurse Sharks that are also targeted by commercial and/or recreational fishers.
- Can allow for multiple use with varying degrees of restriction of activities.

5.3.2.2 Disadvantages:

- Will restrict commercial and/or recreational fishing activities that threaten the Grey Nurse Shark.

5.4 RECOMMENDED SITES FOR CONSIDERATION AS AQUATIC RESERVES

The three surveys showed that aggregations of Grey Nurse Sharks occurred at seven sites (Table 5.1) within the Manning Shelf Bioregion. Moreover, if these sites were marine protected areas they would provide protection for 50 - 57% of the observed population of Grey Nurse Sharks along the NSW and southern Queensland coasts. Consequently, it is recommended that these seven sites be considered for declaration as Aquatic Reserves for the long-term conservation of the Grey Nurse Shark.

Table 5.1. The location of sites with aggregations of Grey Nurse Sharks that would contribute to the conservation of the species if declared as Aquatic Reserves.

LOCATION	SITES
South West Rocks	Green Island Fish Rock
Laurieton	Cod Grounds
Forster	Pinnacles
Seal Rocks	Big Seal Rock Little Seal Rock
Port Stephens	Broughton Island

In the absence of detailed information concerning the localised, short-term movements of Grey Nurse Sharks at these sites it is recommended that small Aquatic reserves (i.e a radius of 500 - 1000 m) be declared initially at these sites. As discussed earlier it will be necessary to document the diurnal movements of Grey Nurse Shark at these sites using acoustic tags and associated computerised tracking equipment. This technique will provide the only means of documenting the localised patterns of movements around these sites. Once localised movement information is available, the size of the Aquatic Reserves should be reviewed. However, in the interim, the reserves could be augmented with specific gear closures if data suggested that the marine protected area was of insufficient size to effectively protect the Grey Nurse Sharks at the particular site.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Need for Future Surveys

These surveys have a number of limitations with respect to identifying whether a system of marine protected areas could be used to assist in the species' conservation. While the surveys were carried out at 50 - 61 sites along the NSW and southern Queensland coasts, they cannot identify: (1) the degree of inter-annual variability in the estimated abundance of Grey Nurse Sharks, (2) migratory patterns, (3) the timing and duration of occupation of any given site, (4) whether a site is used for pupping and/or mating, (5) the degree of short-term fluctuations in abundance as a result of possible localised (non-migratory) movements.

While further surveys will provide additional information concerning the relative movements of male and female Grey Nurse Sharks, it will be necessary to tag individual Grey Nurse Sharks to fully document possible migratory movements in the coastal waters of SE Australia. In doing so, it will be necessary to tag individuals at various locations along the coast and deduce their movements from subsequent sightings by divers, captures in beach protective nets, and inadvertent captures on bottom setlines. Apart from assisting in documenting the hypothesised migratory movements, a tagging study would provide information in three additional areas. First, tagging provides an alternative means of estimating the abundance of Grey Nurse Sharks in NSW waters and along the SE coast of Australia. Second, a tagging study would enable estimation of the rates of inadvertent capture (i.e. as by-catch) on bottom setlines. In doing so, it would be possible to assess the degree of threat to Grey Nurse Sharks posed by the bottom setline fishery. Third, the observations of tagged individuals by divers would enable the timing and duration of occupancy of a site to be quantified.

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 it will be important to document this because they will ultimately affect the size of marine protected areas declared to assist with the conservation of the Grey Nurse Shark. Documenting the short-term, localised movements would be best achieved by using electronic ("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 for an equivalent investment of funds.

Currently few data on the timing of reproduction exist. It will be essential to obtain all Grey Nurse Sharks that die as a result of incidental capture in beach protective nets or as a result of fishing. Autopsies of these individuals will provide the only means, short of capturing individuals from the wild population, to document the timing of reproduction along the NSW and southern Queensland coasts.

6.2 Conservation Status

At the same time as the November/December 1998 survey was being carried out, the NSW Fisheries Scientific Committee recommended that the Grey Nurse Shark be listed as a Threatened Species in NSW. The Grey Nurse Shark is now listed on Schedule 5 as a Threatened Species with VULNERABLE status as provided for under Part 7A, Division 2 of the Fisheries Management Act, 1994. In declaring the Grey Nurse Shark a threatened species, NSW is now in line with Commonwealth legislation (i.e. the Endangered Species Protection Act 1992) where the shark also appears as VULNERABLE.

It is important to note that the status of the Grey Nurse Shark on the IUCN Red List of Threatened Species was upgraded from vulnerable to endangered off the east coast of Australia in July, 1996. The decision to do so was mainly based on: (1) data from the NSW beach meshing program (i.e. at Newcastle, Sydney and Wollongong beaches), and (2) the results of the previous surveys at Seal Rocks.

The results of the three coast-wide surveys carried out in this present study suggest that the Grey Nurse Shark population in NSW coastal waters has not recovered since it was protected in 1984 and has confirmed the precarious position of the species. In light of the results of this study it is recommended that the status of the Grey Nurse Shark be reviewed by the NSW Fisheries Scientific Committee with a view to upgrading the status from VULNERABLE to ENDANGERED under the Threatened species provisions of the Fisheries Management Act, 1994.

6.3 RECOMMENDATIONS

To ensure the recovery of the Grey Nurse Shark population it will be necessary to enhance species and habitat protection and answer several additional management-related questions. Consequently, it is recommended that:

1. the status of the Grey Nurse Shark be reviewed with a view to upgrading the status from VULNERABLE to ENDANGERED,
2. Green Island, Fish Rock, Cod Grounds, The Pinnacles, Big Seal Rock, Little Seal Rock and Broughton Island be considered for declaration as aquatic reserves to assist in the long-term conservation of the Grey Nurse Shark,
3. further surveys at the various sites along the coast be done to document the short-term spatial and temporal fluctuations and inter-annual variability in abundance,
4. the location, timing and number of pups born be quantified to estimate the average rate of recruitment,
5. estimates of the number of sexually mature females be quantified and the location of mating sites be identified,
6. the timing and direction of migratory movements of Grey Nurse Sharks be quantified by using tagging techniques,
7. the proportion of Grey Nurse Sharks repeatedly observed in the surveys be quantified using tagging techniques as this will provide an independent assessment of the population status and an estimate of the total population,
8. estimates of the rates of inadvertent capture on bottom setlines be quantified, and
9. acoustic tagging techniques be used to document the localised, short-term movements as these will determine the efficable size of Marine Protected Areas.

REFERENCE LIST

Aitken, K. (1991) Australia's Grey Nurse: The seal, the Nurse and the Fisherman. *Sportdiving in Australia and the South Pacific*, **27:** 20-24.

Alcock, D. (1996) Chapter 26: The Community and Marine Conservation. *In:* Zann, L. P. (Ed). *The state of the Marine Environment Report for Australia.* Department of the environment Sport and Territories, Canberra.

Anderson, E. D. (1985). Analysis of the various sources of pelagic shark catches in the northwest and western central Atlantic ocean and Gulf of Mexico. US Dept. of Commerce, NOAA Tech. Rep. NMFS 31, 14pp.

Bass, A. J., D'Aubrey, J. D., and Kistnasamy, N. (1975) Sharks of the east coast of Southern Africa IV. The families, Odontaspididae, Scaponorhynichidae, Isuridae, Cetorhinidae, Alopiidae, Orectolobidae and Rhiniodontidae. *Oceanographic Research Institute Investigational Report,* **39:** 6-16.

Baumann, P. (1997) Beyond the Grey Nurse? Sportdiving in Australia and the South Pacific, **61:** 81-82.

Bicskos, A. A. (1985) Grey Nurse in Perspective. *Underwater*, **14:** 43-44.

Bigelow, H. B., and Schroeder, W. C. (1953) Fishes of the Gulf of Maine. *Fishery Bulletin,* **53:** 577.

Bozivich, H., Bancroft, T. A. and Hartley, H. O. (1956). Power of analysis of variance test procedures for certain incompletely specified models. *Ann. Math. Stat.*, **27**: 1017-1043.

Branstetter, S. (1990). Early life-history implications of selected carcharhinoid and lamnoid sharks of the northwest Atlantic. **In:** *Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries.* H. L. Pratt, Jr., S. H. Gruber & T. Taniuchi, eds. U.S. Dept. Commerce, NOAA Tech. Rep. NMFS 90, pp. 17-28.

Branstetter, S., and Musick, J. A. (1994). Age and growth estimates for the sand tiger shark in the Northwestern Atlantic Ocean. *Trans. Am. Fish. Soc.* **123**: 242-254.

Breder, C. M., Jr. (1942) The shedding of teeth by *Carcharias littoralis* (Mitchill). *Copeia,* **1942:** 42-44.

Britannica On-line. Sand Shark. [http://www.eb.com:180/cgi-bin/g?DocF+micro/524/2.html].

Byrnes, T., and Smith, A. (1997) Protected Marine Fish Species Sighting Sheet Program – Status Report 1997. *Fishnote*: **DF69** (ISSN 1034 7704), 6 pp.

Byron, T. (1985) Scuba Divers Guide. Northern New South Wales Coast. Weston and Co.,Kiama.

Cairn-Duff, M. (1994) Rock On. *Scuba Diver*, **Dec/Jan**; 20-22.

Carrier, J. C., and Pratt, H. J. (1998) Habitat management and closure of a nurse shark breeding and nursery ground. *Fish. Res.* **39**: 209-213.

Clark, E. and Von Schmidt, K. (1965). Sharks of the central gulf coast of Florida. *Bull. Mar. Sci.*, **15**: 13-83.

Cliff, G. (Unpublished) The breeding migration of the sand tiger shark, *Carcharias taurus*, in southern African waters. 12 pp.

Cliff, G. and Dudley, S. F. J. (1991). Sharks caught in the protective gill nets off Natal, South Africa. 4. The bull shark *Carcharhinus leucas* (Valenciennes). *S. Afr. J. Mar. Sci.*, **10**: 253-270.

Cliff, G. and Dudley, S. F. J. (1992). Protection against shark attack in South Africa, 1952-90. *Aust. J. Mar. Freshwat. Res.*, **43**: 263-272.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences*. 2nd edn. Lawrence Erlbaum Assoc. Hillsdale New Jersey.

Compagno, L. J. V. (1984) FAO Species Catalogue, Vol. 5. Sharks of the World. An annotated and illustrated catalogue of shark species known to date. Part 1 Hexanchiformes to Lamniformes. *FAO Fisheries Synopsis,* **125(4)** 249 pp.

Compagno, L. J. V. (1990). Shark exploitation and conservation. **In**: *Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries.* H. L. Pratt, Jr., S. H. Gruber & T. Taniuchi, eds. U.S. Dept. Commerce, NOAA Tech. Rep. NMFS 90, pp. 391-414.

Cropp, B. (1964) Shark Hunters. Rigby, Adelaide.

Daves, N. K. and Nammack, M. F. (1998). US and international mechanisms for protecting and managing shark resources. *Fish. Res.*, **39**: 223-228.

Dingerkus, G. (1987). Shark distribution. **In**: Sharks. J. D. Stevens ed. Golden Press, Sydney, Australia. pp. 36-49.

Ecology Lab (1991). A preliminary survey of Grey Nurse Sharks (*Carcharias taurus*) and wobbegong sharks (*Orectolobus* spp.) at Seal Rocks, NSW. The Ecology Lab Pty. Ltd., Balgowlah, NSW, Austarlia. 27 pp.

Fairweather, P. G. (1991). Statistical power and design requirements for environmental monitoring. *Aust. J. Mar. Freshwat. Res.*, **42**: 555-567.

Feldmeth, C. R., and Wagoner, J. P. III (1972) Buoyancy control in the shark *Odontaspis taurus* (Rafinesque). *Copeia,* **1972(3):** 594-595.

Garbutt, R. (1995) Sharks under attack. Grey nurse numbers take a dive in fishing conflict. *GEO Australasia,* **17(4):** 26-38.

Gilmore, R. G. (1993) Reproductive biology of lamnoid sharks. *Environmental Biology of Fishes*, **38:** 95-114.

Gilmore, R. G. , Dodrill, J. W., and Linley, P. A. (1983) Reproduction and embryonic development of the sand tiger shark, *Odontaspis taurus* (Rafinesque). *Fisheries Bulletin*, **81(2):** 201-225.

Goadby, P (1987) Big Fish and Blue Water Game fishing in the Pacific. Angus and Robertson Publishers, North Ryde.

Goadby, P. (1968) Sharks and Other Predatory Fish of Australia. Jacaranda Press Pty. Ltd, Brisbane.

Gordon, I. (1993) Pre-copulatory behaviour of captive sand tiger sharks, *Carcharias taurus*. *Environmental Biology of Fishes*, **38:** 159-164.

Govender, A., Kistnasamy, N., and Van Der Elst, R. P. (1991) Growth of spotted ragged-tooth sharks *Carcharias taurus* (Rafinesque) in captivity. *South African Journal of Marine Science* **11:** 15-19.

Grant, E. M. (1982) Guide to Fishes. Department of Harbours and Marine, Brisbane

Gray, J. (1990). Statistics and the precautionary principle. *Mar. Pollut. Bull.*, **21**: 174-176. Green, B. F. and Tukey, J. W. (1960). Complex analyses of variance: general problems. *Psychometrika*, **25**: 127-152.

Harding, J. H. (1990) Shark: Return of the grey nurse. *Sea Frontiers*, **36(4):** 30-34.

Hoenig, J. M. and Gruber, S. H. (1990). Life-history patterns in the elasmobranchs: implications for fisheries management. **In:** *Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries*. H. L. Pratt, Jr., S. H. Gruber & T. Taniuchi, eds. U.S. Dept. Commerce, NOAA Tech. Rep. NMFS 90, pp. 1-16.

Hollander, M. and Wolfe, D. A. (1973). *Non-parametrical Statistical Methods*. John Wiley, New York. 503 pp.

Hoppen, K. (1997a) Science: The Right Shark. *Scuba Diver*, **Nov/Dec:** 45-46.

Hoppen, K. (1997b) Beyond Endurance? *Sport diving in Australia and the South Pacific*, **61:** 80.

Horton, M. (1997) A Tag and Release Program for Grey Nurse Sharks. *Drum and Croaker*, **28:** 17-19.

IMCRA (1998) Interim Marine and Coastal Regionalisation for Australia: an ecosystem-based classification for marine and coastal environments. Version 3.3. Environment Australia, Commonwealth Department of the Environment. Canberra

Ireland, D. (1984) The Grey Nurse Shark. *Underwater*, **11:** 10-13.

IUCN (1996). *1996 IUCN Red List of Threatened Animals*. IUCN, Gland, Switzerland. 368 pp.

IUCN Shark Specialist Group. Newsflash: Australia Sounds Shark Alert. *In, Newsletter: White Shark and Grey Nurse Shark are now protected in Australia.* [http://www.flmnh.ufl.edu/fish/research/iucn/newsaustsharks.htm] June 1997.

Johnson, N. L. and Kotz, S. (1969). *Discrete Distributions*. John Wiley & Sons, New York. 328 pp.

Klippel, K. (1992) Wildlife Data Search: Threatened Animal Species of New South Wales. Total Environment Centre Inc., Sydney.

Krogh, M. (1994) Spatial, Seasonal and Biological Analysis of Sharks Caught in the NSW Protective Beach Meshing Programme. *Australian Journal of Marine and Freshwater Research*, **45:** 1087-1106.

Last, P. R., and Stevens, J. D. (1994) Sharks and Rays of Australia. CSIRO Division of Fisheries, Australia.

Love, R. M. (1970) The chemical biology of fishes. Academic Press, New York, New York.

Lyle, J. M. (1987). Observations on the biology of *Carcharhinus cautus* (Whitley), *C. melanopterus* (Quoy & Gaimard) and *C. fitzroyensis* (Whitley) from northern Australia. *Aust. J. Mar. Freshwat. Res.*, **38**: 701-710.

Marsh. N. (1995) A Grey Future for the Grey Nurse Shark. *Underwater Geographic*, **39:** 39-42.

McLaughlin, R. H. and O'Gower, A. K. (1971). Life history and underwater studies of a heterodont shark. *Ecol. Monogr.*, **41**: 271-289.

Moreno, J. A. and Moron, J. (1992). Comparative study of the genus *Isurus* Rafinesque, 1810), and description of a form ('Marraajo Criollo') apparently endemic to the Azores. *Aust. J. Mar. Freshwat. Res.*, **43**: 109-122.

Moss, S. A. (1984). *Sharks - An Introduction for the Amateur Naturalist.* Prentice-Hall, Inc. New Jersey, USA. 246 pp.

Otway, N. M. (1986). Realm of the Shark. **In**: *Sharks - Silent Hunters of the Deep.* Reader's Digest, Sydney. pp. 12-19.

Otway, N. M. and Parker, P. C. (1999). A review of the biology and ecology of the grey nurse shark (*Carcharias taurus*) Rafinesque 1810. Fisheries Report Series No. 1, NSW Fisheries, 36 pp.

Overstrom, N. A. (1991) Estimated Tooth Replacement Rate in Captive Sand Tiger Sharks (*Carcharias taurus* Rafinesque 1810). *Copeia* **1991(2):** 525-526.

Parker, P. (Unpublished) A study of Grey Nurse Sharks (*Carcharias taurus*) in Northern NSW. Integrated Project, Southern Cross University, Lismore, 60 pp.

Paxton, J. R., Hoese, D. F., Allen, G. R., and Hanley, J. E. (1989) Zoological Catalogue of Australia Volume 7: Pisces Petromyzontidae to Carangidae. Australian Government Publishing Service, Canberra.

Pepperell, J. G. (1992) Trends in the Distribution, Species Composition and Size of Sharks caught by Gamefish Anglers off South-eastern Australia, 1961-90. *Australian Journal of Marine and Freshwater Research*, **43:** 213-25.

Peterman, R. M. (1990). Statistical power analysis can improve fisheries research and management. *Can. J. Fish. Aquat. Sci.*, **47**: 2-15.

Pickering, G. H., and Wilkinson, N. (unpublished) Solitary Islands Underwater Research Group (S.U.R.G.) Grey Nurse Shark Survey. 6 pp.

Pollard, D. A. (1990) The conservation status of Australian marine fishes – Protected fish species in New South Wales, with Particular emphasis on the black cod and the grey nurse shark. *Australian Society for Fish Biology Newsletter*, **20:** 28-29.

Pollard, D. A., Lincoln Smith, M. P. and Smith, A. K. (1996) The biology and conservation status of the Grey Nurse Shark (*Carcharias taurus*, Rafinesque 1810) in NSW, Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **6:** 1-20.

Pratt, H. L. and Casey, J. G. (1990). Shark reproductive strategies as a limiting factor in directed fisheries, with a review of Holden's method of estimating growth parameters. **In:** *Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of the fisheries.* H. L. Pratt, Jr., S. H. Gruber & T. Taniuchi, eds. U.S. Dept. Commerce, NOAA Tech. Rep. NMFS 90, pp. 97-109.

Read, A. D., and Ward, T. (1986) Taiwanese longliners off northern Australia. *Australian Fisheries,* **August:** 6-8.

Reid, D. and Krogh, M. (1992) Assessment of catches from protective shark meshing off NSW beaches between 1950 and 1990. *Australian Journal of Marine and Freshwater Research,* **43:** 283-296.

SAS (1997). SAS/STAT Version 6.12. SAS Institute Inc., Cary, North Carolina, USA.

Scheffé, H. (1959). *The Analysis of Variance.* John Wiley & Sons, New York. 477 pp.

Schmid, T. H., Murru, F. L., and McDonald, F. (1990) Feeding habits and growth rates of bull (*Carcharhinus leucas* (Valenciennes)), sandbar (*Carcharhinus plumbeus* (Nardo)), sandtiger (*Eugomophodus taurus* (Rafinesque)) and nurse (*Giglymostoma cirratum* (Bonnaterre)) sharks maintained in captivity. *Journal of Aquariculture and Aquatic Sciences,* **Vol. V(4):** 100-105.

Scott, L. (1995) The Ultimate Dive. *Sportdiving in Australia and the South Pacific*, **48:** 39-43.

Simpfendorfer, C. (1992). Biology of tiger sharks (*Galeocerdo cuvier*) caught by the Queensland shark meshing program off Townsville, Australia. *Aust. J. Mar. Freshwat. Res.*, **43**: 33-43.

Skinner, S. (1991) NSW's Grey Nurse Sharks face extinction. The Sun-herald: August 25th.

Smith, A. (1995) NSW Fisheries Media Release: Ban on Setline Fishing and Aquarium Fish Collecting at Fish Rock.

Smith, J. L. B. (1949) The sea fishes of Southern Africa. Central News Agency Johannesburg.

Smullen, S. (1997) NMFS Protects Sharks in Bid to Halt Overfishing. NOAA Media Release 2nd April 1997.

Snedecor, G. W. and Cochran, W. G. (1980). *Statistical Methods.* Seventh edition. Iowa State University Press, Ames, Iowa. 507 pp.

Springer, S. (1948) Oviphagous Embryos of the Sand Tiger Shark, *Carcharias taurus. Copeia,* **1948(3)**: 153-157.

Springer, S. (1963). Field observations on large sharks of the Florida-Carribbean region. **In**: *Sharks and Survival.* P. W. Gilbert, ed. Heath & Co., pp. 95-113.

Stead, D. G. (1963) Sharks and Rays of Australian Seas. Angus and Robertson, Sydney.

Stevens, J. D. (1984). Biological observations on sharks caught by sport fishermaen off New South Wales. *Aust. J. Mar. Freshwat. Res.*, **35**: 573-590.

Stevens, J. D. (1992). Blue and mako shark by-catch in the Japanese longline fishery of south-eastern Australia. *Aust. J. Mar. Freshwat. Res.*, **43**: 227-236.

Stevens, J. D. and McLoughlin, K. J. (1991). Distribution, size and sex composition, reproductive biology and diet of sharks from northern Australia. *Aust. J. Mar. Freshwat. Res.*, **42**: 151-199.

Stevens, J. D. and Wiley, P. D. (1986). Biology of two commercially important carcharhinid sharks from northern Australia. *Aust. J. Mar. Freshwat. Res.*, **37**: 671-688.

Sweatman, H. P. A. (1985). The influence of adults of some coral reef fishes on larval recruitment. *Ecol. Monogr.*, **55**: 469-485.

Toft, C. A. and Shea, P. J. (1983). Detecting community-wide patterns: estimating power strengthens statistical inference. *Am. Nat.*, **122**: 618-625.

Underwood, (1997). *Experiments in Ecology*. Cambridge University Press, Cambridge, UK. 504 pp.

Underwood, A. J. (1981). Techniques of analysis of variance in experimental marine biology and ecology. *Oceanogr. Mar. Biol. Ann. Rev.*, **19**: 513-605.

Winer, B. J. (1971). *Statistical Principles in Experimental Design*. 2nd edn. International student edition. McGraw-Hill Kogakusha Ltd., Tokyo. 907 pp.

Winer, B. J., Brown, D. R. and Michels, K. M. (1991). *Statistical Principles in Experimental Design*. 3rd edn. McGraw-Hill Inc., New York. 1057 pp.

World Conservation Monitoring Centre. IUCN Red List of Threatened Animals – Species: *Carcharias taurus*. *In, IUCN Threatened Animals and Plants*. [http://www.wcmc.org.uk/cgi-bin/arl_output.p]. 8th April 1998.

GLOSSARY

Abundance: number of organisms per unit of habitat space.

Aggregation: a collection of individuals.

Anecdotal: things unpublished; a short narrative of a particular incident or occurrence of an interesting nature.

Autopsy: inspection and dissection of a body after death.

Biennial: an event happening every two years.

By-catch: the component of the catch (often discarded) excluding the targeted commercial species.

Buoyancy: the ability of an object to float in water.

Cannibal: any animal that eats its own kind.

Caudal: pertaining to the tail region.

Cave: a naturally or artificially formed hollow area, chamber, or series of chambers in rock.

Cavern: a vast subterranean hollow or underground chamber in a rock. Same as a cave, but implying large size and indefinite extent.

Claspers: modified portions of the pelvic fins in male sharks, rays and chimeras used for transferring sperm to the female.

Common Name: the informal vernacular name for a fish (or other organism), which may vary from place to place).

Congeneric: individuals or populations of the same genus.

Conservation: the act of preservation of natural resources.

Continental Shelf: the shelf-like part of the seabed adjacent to the coast extending into a depth of 200 m.

Copulation: mating between sexes associated with internal fertilisation.

Crustaceans: major group of animals, including crabs, shrimps, prawns, lobsters and crayfish.

Cusplets: small projections on the tooth.

Dorsal: pertaining to the upper part or the surface of the back.

Embryo: a developing animal.

Equatorial: pertaining to, or near the equator.

Fecundity: the total amount of eggs/young produced by a female during a single reproductive cycle.

Follicle: a small cavity, sac or gland.

Fusiform: spindle shaped, tapering at both ends.

Genus (pl. genera): a term used in classifying organisms; contains one or more related species.

Gestation: duration of development of the embryo from conception to birth.

Gonadal: pertaining to a sexual gland.

Gutter: a channel.

Heterocercal: caudal fin shape with unequal lobes, the upper lobe being larger than the lower.

Hydroid: a tiny polyp of a Cnidarian.

Inter-annual: between years.

Lanceolate: broad at base and tapering to a point; spear-shaped or lance-shaped.

Legislation: a law or body of laws enacted.

Longevity: the natural lifetime of an organism.

Maturity (Maturation): the period following attainment of full development of bodily structure and reproductive faculty.

Migrating: moving from one area of habitation to another.

Morphology: the science of form and structure of animals, as distinct from consideration of functions.

Nictating Membrane: a transparent, moveable membrane inside the eyelid (inner eyelid) that protects and helps keep the eye clean.

Nomenclature: the systematic naming of plants and animals.

Oophagous: feeding mainly or exclusively on eggs.

Oviphagy: method of embryonic nutrition where the embryo feeds on unfertilised eggs or other embryos in the uterus.

Ovoviviparous: producing eggs that hatch within the body of the parent female, but there is no placental connection.

Parturition: the act or process of birth.

Pectoral: pertaining to the breast.

Population: a biological unit; representing the individuals of a species living in a particular area.

Posterior: relating to the hind or rear portion.

Regulations: a rule or order, as for conduct, prescribed by an authority.

Reproduction: the process by which living organisms multiply.

Sagittal: section or division in median longitudinal plane.

Scientific Name: the formal binomial name of an organism consisting of the genus and specific names; a species has only one valid scientific name.

Scuba: Self Contained Underwater Breathing Apparatus.

Species: actually or potentially inter-breeding populations that are reproductively isolated from other populations; the basic rank of biological nomenclature.

Synonym (adj. synonymous): each of two or more scientific names of the same rank used to denote the same taxon (any formal taxonomic unit or category of organisms (genus, species, family, etc.).

Taxonomy: science of the classification of living organisms.

Temperate: moderate in respect of temperature, the zone of the earth's surface lying between each of the tropics and the polar circle nearest to it.

Teleost: a large group containing mostly bony fishes.

Vertebral Centra: central backbone

Other titles in this series:

ISSN 1440-3544

No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project no. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters. Final Report to Fisheries Research and Development Corporation. Project no. 94/024.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales. Final Report to Fisheries Research and Development Corporation. Project no. 95/151.

No.4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. Final report to Cooperative Research Centre for Freshwater Ecology.

No. 5 Kennelly, S.J. and Broadhurst, M. K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). Final Report to Fisheries Research and Development Corporation. Project no. 93/180.

No. 6 Allan, G.L., and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. Final Report to Fisheries Research and Development Corporation. Project no. 93/120-03.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. Final Report to Fisheries Research and Development Corporation. Project no. 93/120.

No. 8 Heasman, M.P., O'Connor, W.A., O'Connor, S.J., 1998. Enhancement and farming of scallops in NSW using hatchery produced seedstock. Final Report to Fisheries Research and Development Corporation. Project no. 94/083.

No. 9 Nell, J.A., McMahon, G.A., and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. Final report to Cooperative Research Centre for Aquaculture. Project no. D.4.2.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydney rock and Pacific oysters. Part 1: Sydney rock oysters. Final Report to Fisheries Research and Development Corporation. Project no. 93/151.

No. 11 Watford, F.A. and Williams, R.J., 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to changes in the distribution of seagrass. Final Report to Fishcare Australia. Project no. 97/003741.

No. 12 Andrew, N.L., Worthington D.G., Brett, P.A. and Bentley N., 1998. Interactions between the abalone fishery and sea urchins in New South Wales. Final Report to Fisheries Research and Development Corporation. Project no. 93/102.

No. 13 Jackson, K.L. and Ogburn, D.M., 1999. Review of depuration and its role in shellfish quality assurance. Final Report to Fisheries Research and Development Corporation. Project no. 96/355.

No. 14 Fielder, D.S., Bardsley, W.J. and G.L. Allan. Enhancement of Mulloway (*Argyrosomus japonicus*) in intermittently opening lagoons. Final Report to Fisheries Research and Development Corporation. Project no. 95/148.

No. 15 Otway, N.M. and Macbeth, W.G. The physical effects of hauling on seagrass beds. Final Report to Fisheries Research and Development Corporation. Project no. 95/149 and 96/286.

No. 16 Gibbs, P., McVea, T. and Louden, B. Utilisation of restored wetlands by fish and invertebrates. Final Report to Fisheries Research and Development Corporation. Project no. 95/150.

No. 17 Ogburn, D. and Ruello, N. Waterproof labelling and identification systems suitable for shellfish and other seafood and aquaculture products. Whose oyster is that? Final Report to Fisheries Research and Development Corporation. Project no. 95/360.

No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. and Walford, T.R. Sampling estuarine fish species for stock assessment. Includes appendices by D.J. Ferrell, B.C. Pease, T.R. Walford, G.N.G. Gordon, C.A. Gray and G.W. Liggins. Final Report to Fisheries Research and Development Corporation. Project no. 94/042.

No. 19 Otway, N.M. and Parker, P.C. The biology, ecology, distribution, abundance and identification of marine protected areas for the conservation of threatened Grey Nurse Sharks in south east Australian waters. Final report to Environment Australia