Aspects of the biology and ecotourism industry of the whale shark *Rhincodon typus* in north-western Australia

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Submitted by

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I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any University.

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ABSTRACT

The conservation status of the widely-distributed whale shark *Rhincodon typus* is presently listed as 'Indeterminate - Data Deficient'. One of the main hindrances to obtaining biological data on whale sharks that is relevant to determining its 'conservation status' is that this species has rarely been recorded as occurring in sufficient numbers to obtain quantitative data. However, *R. typus* does form aggregations at Ningaloo Marine Park (NMP), Western Australia, annually between March and June. This has enabled studies to be made of aspects of the biology of *R. typus* and of the possible impacts of the ecotourism industry on this species.

Using a position provided on vessels involved with the whale shark ecotourism industry at NMP, *R. typus* was observed on 360 separate occasions in 1995, 1996 and 1997, and it was possible to sex 90.3% of these sharks. The majority of the sexed sharks (84.6%) were male and ranged in length from 4 to 12 m, with a mean of 7.4 m, while the females ranged in length from 4.5 to 8.5 m, with a mean of 6.2 m. The size and degree of abrasion of the claspers was used as an indicator of whether or not a male shark had mated. Using such criteria, it was estimated that male whale sharks start to mature at *ca* 8 m and that *ca* 50% are mature by the time they reach 8.6m.

Observations suggested that *R. typus* feeds by using both suction and flow-through mechanisms. The prey that were observed being ingested included coral spawn, tropical krill, mysids and small jellyfish. The contents of a faecal sample contained parts of the exoskeleton of copepods and the scales of small fishes. The degree of mouth distension, which is assumed to be related to feeding activity, was low during most observation periods.

Photographs of the scars and natural patterning on the skin of individual sharks were used to construct a photographic library for subsequent identification of these sharks. The features used for identifying individual sharks were chosen because they were considered likely to remain for a protracted period. The Whale Shark Photo-

identification Library that was produced provides details on the characteristic features of 52 *R. typus* that were present at NMP. Six individuals were recorded at NMP in both 1995 and 1996, four in both 1996 and 1997, and one in both 1995 and 1997. No identified whale sharks were recorded in all three years.

Rhincodon typus was distributed widely throughout NMP, with most boat and aerial sightings lying within 1 - 2 km of the reef crest between Tantabiddi and Turquoise Bay. *Rhincodon typus* was typically sighted in water depths of 10 to 30 m. The sharks were predominantly travelling parallel to Ningaloo Reef, with significantly more moving in a northward than southward direction. Acoustic tracking of *R. typus* in 1997 suggested that this species remains within NMP for extended periods and is at the surface for *ca* 17% of daylight hours.

The number and species of fauna observed to be associated with *R. typus* were recorded, and a new species of copepod, *Pandarus* sp. nov., which lives on the skin of *R. typus* has been described. Golden trevally (*Gnathanodon speciosus*), miscellaneous trevally (*Carangid* sp.), remora (*Remora* sp.) and slender suckerfish (*Echeneis naucrates*) were common. The prevalence of *Pandarus* sp. nov. was inversely proportional to the number of *Remora* sp. and *E. naucrates* in 1996, while the opposite was true in 1997, suggesting that *Pandarus* sp. nov. were preyed on by these diskfish.

Rhincodon typus is the basis of the ecotourism industry that operates within NMP each year. While there was considerable variation in the number of tour vessels searching for whale sharks at NMP each year, the greatest mean number of vessels operating per week in successive whale shark seasons were 6.7 during Week 8 (April 19 - 25) of 1995, 6.1 during Week 7 (April 12 - 18) of 1996 and 6.9 during Week 8 (April 19 - 25) of 1997. The greatest mean numbers of whale sharks sighted per week in each year were 5.1 during Week 14 (May 31 - June 6) of 1995, 4.2 during Week 6 (April 5 - 11) of 1996 and 4.1 during Week 8 (April 19 - 25) of 1997.

Tourists, who were permitted to swim alongside *R. typus*, interacted with sharks for a mean period of 19.3 min in 1995, 14.2 min in 1996 and 9.5 min in 1997. The reduction in the duration of interaction in three successive years suggests that, over time, *R. typus* may have become slightly less tolerant of the ecotourism industry at NMP. The mean minimum distance between vessel and shark during each interaction was 20.7 m in 1995, 21.3 m in 1996 and 31.0 m in 1997. The mean minimum distance between tourist and shark during each interaction was 1.5 m in 1995, 2.05 m in 1996, and 2.1 m in 1997. The mean minimum distance of vessel and tourist from *R. typus* during each individual interaction decreased as the duration of the interaction increased. Therefore, both *R. typus* and this industry must be carefully monitored to ensure that the impacts of humans are kept to a minimum and thereby ensure that whale sharks return to NMP each year.

An ethology of whale shark behaviours, which included banking, porpoising, diving and eye-rolling, was produced in an attempt to determine whether there is evidence that the ecotourism industry has a negative impact on *R. typus* at NMP. The frequency of behavioural change was greatest in the first 0 - 5 min of an observation. Eye-rolling by *R. typus* was recorded as a reaction to flash-photography, while banking was often recorded when SCUBA was used and/or tourists swam beneath the head of the shark. The swimming speed of *R. typus* at NMP was rarely too fast for tourists to maintain proximity to the sharks.

Several sharks possessed both recent and healed scars, which were probably inflicted by vessel contact. The recent wounds indicate that vessels had caused injuries to *R. typus* within NMP. These individuals tended to display a higher frequency of avoidance behaviours and reduced interaction times.

Recommendations are provided to the Western Australian Department of Conservation and Land Management which are aimed at reducing the potential deleterious effects of the ecotourism industry on the whale sharks at NMP.

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ACKNOWLEDGMENTS

CHAPTER 1

A REVIEW OF DATA ON THE BIOLOGY OF WHALE SHARKS

(*RHINCODON TYPUS*)

1.1 Description and taxonomy

The approximately 900 - 1100 extant species of chondrichthyan fishes comprise the sharks, skates and rays (Elasmobranchii), and chimaeras (Holocephali) (Last & Stevens, 1994; Johnson & Snelson, 1996). Sharks are characterised by the fact that they have a cartilaginous skeleton, internal fertilisation, retain large amounts of urea in their blood, detect movement through a lateral line system and from weak electrical and magnetic fields through their ampullae of Lorenzini (Tricas, 1997a).

The 370 extant species of sharks belong to 31 families, representing eight orders (Compagno, 1984a; Last & Stevens, 1994). The whale shark *Rhincodon typus*, the focus of this study, belongs to the Order Orectolobiformes. The 33 species within this order are predominantly bottom-dwelling (Compagno, 1988), and possess two spineless dorsal fins, a single anal fin, five gill slits, two barbels on the underside of the snout, and a mouth that is located well forward of the eyes (Compagno, 1973; Bannister, 1996) and lack a sub-terminal notch on the caudal fin (Last & Stevens, 1994).

Rhincodon typus is the sole extant representative of the family Rhincodontidae (Last & Stevens, 1994). The original genus assigned to the whale shark was *Rhiniodon* (Smith, 1828), although, it was subsequently amended to *Rhincodon* in 1829 by the same author (Smith, 1829). The latter genus name has now been validated by the International Commission on Zoological Nomenclature (Opinion No. 1278) (Melville, 1984).

Rhincodon typus, which is seldom aggressive and is thus considered harmless to humans (Compagno, 1984), is the largest living fish (Nolan & Taylor, 1978; Castro, 1983; Clark, 1992; Last & Stevens, 1994). There is some doubt as to the

maximum size attained by this species. Devadoss *et al.* (1990) recorded a female whale shark of 14.5 m total length (TL)[1], and a whale shark captured in the Gulf of Siam was estimated as being 60 feet ($\approx$ 19.3 m) in length (Smith, 1925).

The whale shark, which is one of only three filter-feeding species of shark, has a broad, flattened head, small teeth, gill slits bearing filter screens, a large and nearly terminal mouth, and prominent longitudinal ridges on its back (Last & Stevens, 1994). This shark has a distinctive pattern of light spots and stripes over a blue/grey background, fading to a white colour ventrally. This pattern and countershading, common in pelagic fish, 'blends' the contour of the shark into its surroundings when viewed from any angle (Clark, 1992).

1.2 Distribution

Whale sharks have been found in all tropical and warm temperate seas, except the Mediterranean Sea (Compagno, 1984a; Wolfson, 1986; Last & Stevens, 1994). Although the range of this species typically lies between 30^0N and 35^0S latitude, it has occasionally been sighted as far north as 41^0N and as far south as 36.5^0S (Wolfson, 1986; Last & Stevens, 1994) (see Fig. 1.1). Whale sharks inhabit both deep and shallow coastal waters and the lagoons of coral reefs and atolls (Demetrios, 1979; Wolfson, 1983). Iwasaki (1970) reported that whale sharks are found in surface waters of temperatures between 18 and 30^0C, but are most common when these temperatures lie between 21 and 25^0C.

Although no detailed information is available on the migratory patterns of whale sharks, satellite tracking of this species has been initiated at Ningaloo Marine Park (NMP), in Western Australia and at other locations worldwide (see Chapter 5; S. Eckert, Hubbs-Sea World Research Institute, U.S.A., pers. comm.). Although Taylor (1994)

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[1] NB: All length measurements for *Rhincodon typus* are total length (TL).

considers that this species is mainly solitary, aggregations of hundreds of individuals have been recorded (Compagno, 1984a).

While aggregations of whale sharks occur only seasonally at NMP, they are found all year round off the east coast of Taiwan (Leu *et al.*, 1997) and near the Seychelles (Gudger, 1932). Other aggregations of whale sharks occur in Indian coastal waters between December and April (Silas, 1986), off the coast of Somalia in September, off Chile during October, in the Sea of Cortez in May, June, October and November, in the Gulf of Mexico between August and September (Clark & Nelson, 1997), off the Philippines between April and May (Trono, 1996), in the Coral Sea, near the Great Barrier Reef during November and December (MacPherson, 1990), and at Christmas Island in the Indian Ocean between November and January (B. Norman, unpub. data). Although whale sharks have also been sighted in numerous other regions, such sightings have been sporadic.

It has been suggested that the seasonal appearance of whale sharks in certain areas may be related to an increase in local food resources. For example, the appearance of large numbers of whale sharks at Ningaloo Reef each year is probably associated with the mass coral spawning that occurs there in March and April (Taylor, 1994). In addition, a number of whale sharks appear on the Great Barrier Reef in November each year when a similar mass spawning of both coral fish and lantern fish (Family Myctophidae) occurs (MacPherson, 1990; Simpson, 1991). Clark and Nelson (1997) suggest that the increase which takes place in whale shark numbers in the northern Gulf of Mexico between August and September is also related to a mass coral spawning which occurs at this location in the former month (Gittings *et al.*, 1992). Support for the view that seasonal aggregations are related to increases in the availability of specific food is also provided by the appearance of whale sharks at Christmas Island (Indian Ocean) at about the same time as the mass spawning at sea of the red land crab (*Gecarcoidea natalis*) (M. Orchard, Parks Australia North, Christmas Island, pers. comm.).

1.3 Abundance and biology

The first record of a whale shark was that of Smith (1828), who reported on the harpooning of a 4.8 m individual off Table Bay, South Africa. The low number and irregularity of reported whale shark sightings in the current literature probably reflect the relatively low total numbers of this species. For example, Wolfson (1986) reports that there were only approximately 300 confirmed sightings at the time of her paper.

Information on the biology of this species is therefore also scarce. For example, it was only in 1996 that whale sharks were shown by Joung *et al.* (1996) to be ovoviviparous. These workers reported that a female (*ca* 10.6 m), harpooned off Taiwan, contained approximately 300 near-term embryos, a number which also showed that this species produces by far the largest litter of any known shark (Joung *et al.*, 1996). These embryos ranged in total length from 48 to 58 cm. One, which was 58 cm at birth, survived in an aquarium for 143 days and attained a length of 139 cm (Leu *et al.*, 1997). Although the duration of gestation, breeding period and frequency of reproduction are unknown, Kukuyev (1996) believes that *R. typus* reproduces in the tropical waters of the open oceans. Chang *et al.* (1997) considers that there is a breeding ground for whale sharks close to Taiwan. A female whale shark, which was captured at 4.4 m in 1982, was raised in captivity for nearly two years (630 days) between July 1982 and March 1984 at the Okinawa Expo Aquarium, Japan. Before it died, the length of this individual had increased to 5.2 m (G. Cailliet, Moss Landing Marine Laboratories, U.S.A. pers. comm.). The lack of records on pregnant *R. typus* may indicate that these individuals migrate to deep water and rarely come to the surface, a habit reported previously for the basking sharks *Cetorhinus maximus* (Sims, 1997). Wolfson (1983) reported on seven juvenile whale sharks (35.5 to 93.0 mm), six of which were found in water depths in excess of 2600 m. However, there have been no long-term studies that have produced validated growth rates, age at maturity, or the maximum age of whale sharks.

The whale shark is one of only three species of shark that filter feeds, the other two being the megamouth (*Megachasma pelagios*) and the basking shark (*C. maximus*) (Compagno, 1984b). Unlike the megamouth and basking sharks, the whale shark does not rely on forward motion for filtration, but is able to hang vertically in the water and suction feed by drawing in water by opening its mouth (Castro, 1983; Compagno, 1984a; Clark & Nelson, 1997).

Rhincodon typus is believed to be able to sieve, through the fine mesh of their gill-rakers, zooplankton as small as 1 mm in diameter (Taylor, 1994). Individuals of this species have approximately 3000 small teeth (< 6 mm in length) in each jaw, which are covered by a flap of skin (White, 1930). These sharks typically feed on a variety of planktonic and nektonic prey, small crustaceans and schooling fishes, and may even occasionally ingest small tuna and squid (Last & Stevens, 1994; Clark & Nelson, 1997).

1.4 Threats

An ecotourism industry, based on encounters with whale sharks, has burgeoned near Ningaloo Reef, Western Australia in recent years. The number of people swimming with whale sharks during the short whale shark season, which occurs between the months of March and June, has increased markedly from 1000 in 1993 to almost 3000 in 1996 (J. Colman, CALM - Marine Branch, pers. comm.). The industry in this region has the ability, under the current set of management guidelines, to accommodate a far greater number of tourists for the experience of swimming with these sharks. However, it is possible that high levels of tourism may also have a negative effect on the behaviour of whale sharks at this location. Within Western Australian waters, whale sharks are fully protected under the Wildlife Conservation Act, and whale shark interaction activities are controlled under the CALM Act (Appendix 1).

Very little is known about whether *R. typus* are subject to predation. There have apparently been only two reports of juvenile whale shark tissue in the stomach of other species, namely a blue marlin (*Makaira mazara*) (A. Goorah, Ministry of Fisheries and Marine Resources, Mauritius, pers. comm.) and a blue shark (*Prionace glauca*) (Kukuyev, 1996). The relatively large size at birth, *i.e.* 58 to 64 cm (Joung *et al.*, 1996), and apparently rapid growth immediately following birth (see Leu *et al.*, 1997) would help ensure the survival of many *R. typus* through to the large size as previously described (see section 1.1).

One of the main threats to *R. typus* are the small harpoon fisheries that currently exist, or have been operational, in various regions of the world including the Philippines, India, Pakistan and Taiwan where these sharks are taken primarily for their meat, liver oil and/or fins (Compagno, 1984; Ramachandran & Sankar, 1990; Trono, 1996). The Taiwanese fisheries specifically target the whale shark, taking approximately 100 sharks per year (Chang *et al.*, 1997). Chen *et al.* (1997) report that whale sharks are also caught as bycatch in both set net fisheries (*ca* 158 sharks/year) and harpoon fisheries during the targeting of billfish (*ca* 114 sharks/year). Fisheries in India have taken whale sharks in previous years with one report of about 40 harpooned during April 1982 (Silas, 1986), and approximately 90 whale sharks were taken in the Philippines in 1996 (Trono, 1996). The small fishery that once existed in the Maldives has not operated since legislation, introduced in 1995, banned the taking of *R. typus* (C. Anderson, Ministry of fisheries and Agriculture, Republic of Maldives, pers. comm.).

Although Ramachandran and Sankar (1990) believe that *R. typus* is an underexploited species, there are concerns that the whale shark populations (e.g. around Taiwan) are decreasing (Joung *et al.*, 1996). Trono (1996) suggested that even the small fishery in the Philippines would be unsustainable in the long term. Holden (1974) and Natanson and Cailliet (1986) believe that the reproductive strategies employed by elasmobranchs make them highly susceptible to overfishing. Since only limited data are available on whale shark growth rates, length of gestation, frequency of reproduction,

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size at first maturity, and population numbers worldwide, estimates of maximum sustainable yield cannot be made.

There have been several reports of whale sharks impaled on the bows of steamships earlier this century (Stead, 1963). Whale shark strandings have been occasionally reported on the eastern Australian coast (Whitley, 1965) and each year on the South African coast (Beckley *et al.*, 1997). However, the rarity of beached specimens suggest that *R. typus* tends to sink rapidly after death (Tubb, 1948).

The whale shark was listed in 1994 as having an 'Indeterminate' status on the World Conservation Union's *Red List of Threatened Animals* (IUCN, 1994). This status was reported as 'Data Deficient' by the IUCN in 1996 (IUCN, 1997). With the size and imprecision of the present database, it is not feasible to make any estimate of the abundance of *R. typus* (Wolfson, 1986) or the impact that humans have had on the species.

1.5 Ecotourism at Ningaloo Marine Park

Ningaloo Marine Park was declared a national marine park in 1987 (CALM, 1989). It contains Ningaloo Reef, Australia's longest fringing reef, which is *ca* 260 km in length (CALM, 1989). This area has achieved worldwide recognition as one of the best locations to observe and swim alongside whale sharks (Piprell, 1998). Even though recreational divers have been swimming with these animals since at least 1982 (Taylor, 1994), it has only become a licenced tourism activity since 1993 (Colman, 1997). This industry is very important to the economy of the region, with, on average, each visiting diver partaking in a whale shark interaction spending almost AUS $3200 in 1995 (D. Davis, Southern Cross University, NSW, pers. comm.).

The whale shark watching industry is regulated by the Western Australian Department of Conservation and Land Management (CALM), who limit the number of commercial licences. This Department, in conjunction with the charter operators, has also

established a set of guidelines which are aimed at reducing any possible negative impacts of the whale shark watching industry on the whale sharks.

1.6 General aims

The aims of the present study on the whale sharks in the NMP were to:

1) determine the size and sex ratio of whale sharks at NMP and the age at maturity of male whale sharks,

2) describe the feeding behaviour of whale sharks,

3) produce a method for identifying individual whale sharks,

4) construct a photo-identification library of whale sharks at NMP, and use this library to determine whether some whale sharks return to NMP each year,

5) study the distribution of whale sharks within NMP and record their direction of travel,

6) describe a species of copepod that is found on whale sharks and comment on other associated fauna,

7) provide an ethogram of behaviours exhibited by whale sharks,

8) attempt to assess whether tourist interactions are having an effect on whale shark behaviour, and

9) offer suggestions for reducing any potentially deleterious impact of tourism on the whale sharks at NMP.

CHAPTER 2

GENERAL MATERIALS AND METHODS

2.1 Study area

The Ningaloo Marine Park (NMP), which is located on the north west coast of Western Australia (22^{0}00'S 113^{0}50'E), was gazetted in 1987 (CALM, 1988a) and encompasses Ningaloo Reef (Fig. 2.1). The lagoon, which lies to the east of this reef, ranges from 0.2 to 6 km in width (CALM, 1988b).

The NMP lies in arid tropical Australia and receives little rainfall except in the monsoon season. The region is exposed in the summer months to high daily temperatures and to cooler temperatures in the autumn months, when *Rhincodon typus* is most commonly sighted in the region (Fig. 2.2).

Exmouth, the nearest town in the northern part of the Park, is situated on the eastern margin of North West Cape, approximately 1300 km north of Perth. Commercial vessels conducting whale shark interaction tours usually leave from the boat ramp/safe mooring adjacent to Tantabiddi Passage (Fig. 2.3). Whale sharks are most commonly sighted within 1 - 2 km seaward of the Ningaloo Reef, between Tantabiddi Passage to the north and Turquoise Bay to the south. Most of the charter vessels that provide tourists with the opportunity to swim alongside whale sharks are concentrated in this region of NMP.

Limited observations of whale sharks have also been recorded near Coral Bay (22^{0}08'S 113^{0}46'E), approximately 150 km south of Exmouth (Fig. 2.3). Only one company operates a whale shark licence at this location, with the tour vessel travelling to an area directly north-west of the Coral Bay settlement where *R. typus* is often sighted (Fig. 2.3).

An attempt to study whale sharks at Christmas Island, Indian Ocean (10^{0}31'S 105^{0}39'E) was undertaken in January 1996. Although the island has only one

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suitable location for launching boats (Flying Fish Cove), the submarine topography and consistently large swell means that the conditions are rarely suitable to launch a vessel and conduct research. However, during that two week visit in January 1996, I had the opportunity to join tourists undertaking dive charters on four occasions. The tour operator took the vessel to one of several locations where whale sharks had previously been sighted, usually within 200 m of the shoreline. I also searched for *R. typus* at night on two occasions using a private vessel and with the assistance of staff from the Australian Nature Conservation Agency (ANCA)/Parks Australia North.

Figure 2.1 The relationship between Ningaloo Reef, Western Australia and the coastline.

2.2 Time of study at Ningaloo Marine Park

Rhincodon typus is sighted regularly each year within NMP, from early March through to late May, with sightings occasionally occurring outside this period. The dates when field work was conducted at this location were:

1) 18 March 1995 - 9 July 1995,

2) 6 March 1996 - 27 May 1996,

3) 26 March 1997 - 28 May 1997.

Charter vessels usually depart in search of whale sharks from their anchorage at Tantabiddi or Coral Bay each morning between 0800 and 0900 h.

2.3 Sampling methods

The operators of each vessel utilise light aircraft to search the area west of Ningaloo Reef for *R. typus*. When a shark is located, the pilot radios the location to the partner vessel, and directs the skipper to move forward of the shark to enable tourists to enter the water in advance of the oncoming shark. In-water observations on *R. typus* were possible while I was a passenger on CALM and industry vessels operating within NMP (Table 2.1). I joined tourists during their interactions with whale sharks, and attempted to photograph each shark for identification purposes, record information on their biology and gather data on various aspects of whale shark behaviour under differing interaction pressures.

Aerial survey work was conducted within the NMP using a single engined Cessna aircraft chartered from Exmouth Air Charter. Flights were usually undertaken in the morning, leaving from the Exmouth Light Aircraft strip, approximately 12 km south of Exmouth town.

Preliminary analysis of data was undertaken at the CALM District Office in Exmouth. Further analysis of results was completed at Murdoch University, Perth.

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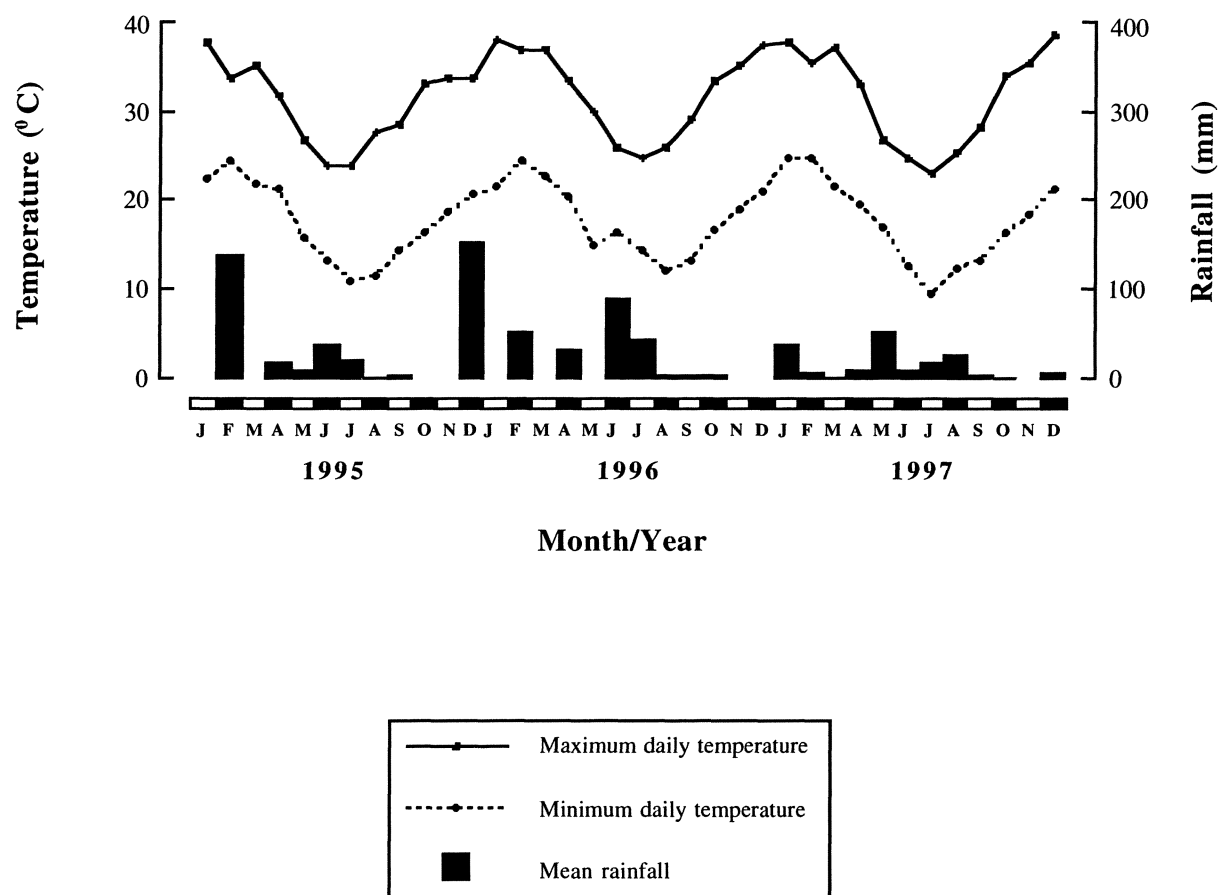
Figure 2.2 The mean monthly maximum and minimum temperatures and mean rainfall recorded at Learmonth weather station (near Ningaloo Marine Park) between January 1995 and December 1997. This data was provided by the Western Australain Bureau of Meteorology.
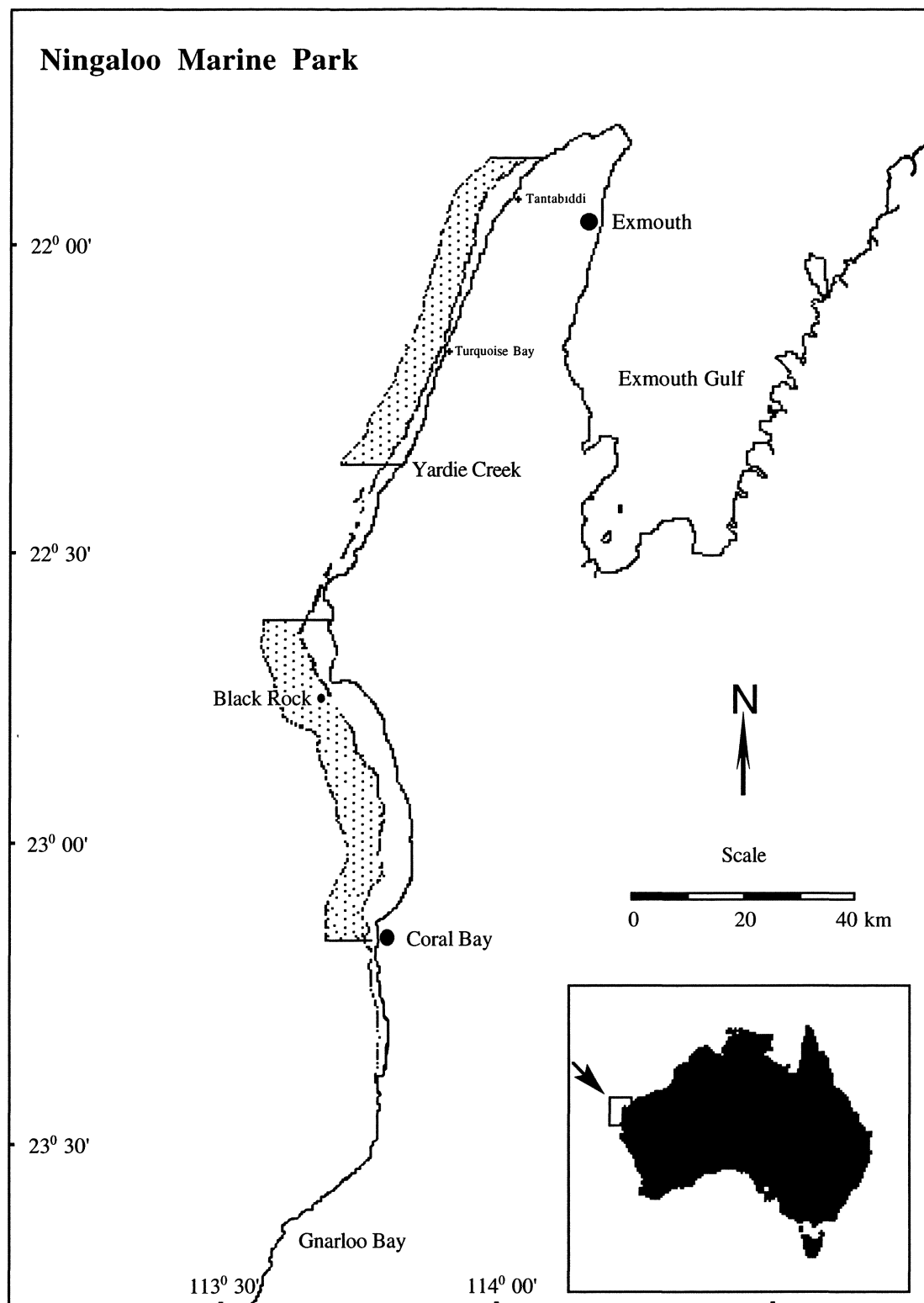
Figure 2.3   The area (stippled) within Ningaloo Marine Park where whale shark tour
operations were conducted between 1995 and 1997. The majority of tourist
activity was undertaken between Tantabiddi boat ramp and Turquoise Bay.

Table 2.1 A position was made available on the following vessels to for the acquisition

of data on *Rhincodon typus* at Ningaloo Marine Park between 1995 and 1997.

Vessel name	Whale shark interaction licence operator
Blue Horizon	Makaira 11 Charters
Concord	Exmouth Diving Centre
Coral Bay Explorer	Coral Bay Adventures
Island Princess	Nordon Fishing and Charter Co.
Jazz 11	Coral Bay Adventures
Jinbei	Exmouth Diving Centre
King Diver	King Dive Centre
Lionfish 111	Perth Diving Academy
Manta Magic	Exmouth Diving Centre
Ningaloo Blue	Ningaloo Blue Adventures
Ningaloo Business 11	Diving Business Charters
Nordon	King Dive Centre
Ocean Quest	Ningaloo Adventures
Pseudorca 11	CALM - Wildlife Branch
Reel Affair	Exmouth Diving Centre
Sans Souci	Ningaloo Adventures
Sea Trek	Diving Ventures
The Beast	Exmouth Diving Centre
True North	North Star Charters
Wave Dancer 111	Ningaloo Adventures
Wild Thing	Ningaloo Deep Charters
Willie	Starsand Luxury Yacht Charters
Yampi Queen	Exmouth Diving Centre

CHAPTER 3
SIZE, SEX RATIO, REPRODUCTIVE STATUS AND FEEDING HABITS
OF *RHINCODON TYPUS*

3.1 Introduction

Fertilisation in all elasmobranchs is internal, with the males possessing a pair of claspers that function as intromittent organs (Wourms, 1977; Last & Stevens, 1994). The appearance of the claspers is often the simplest method to assess whether male elasmobranchs have reached sexual maturity (Pratt, 1979; Joung & Chen, 1995). Claspers are generally smooth, flexible and unabraided in sexually-immature individuals, but exhibit accelerated growth during maturation (McLaughlin & O'Gower, 1971) and become calcified at maturity and often rough with use (J. Stevens, CSIRO Marine Research, Hobart, pers. comm.). The stage of maturity of females, however, cannot be determined from the external morphology of the animal, with the stage of ovarian and uterine development being most often used to determine whether female sharks are sexually mature.

The growth rate of many sharks is highly variable and thus the correlation between size and age is not always clear (McLaughlin & O'Gower, 1971; Parsons, 1985). However, it is generally accepted that sharks are long-lived, mature late and have low fecundities and extended gestation periods (Holden, 1974; Graves, 1996). Although Leu *et al.* (1997) reported that, under experimental conditions, the total length of a new-born whale shark increased from 58 cm to 139 cm over a 120 day period, the growth rate of *Rhincodon typus* in its natural environment has been subjected to only very limited study (see Caillet *et al.*, 1986; Chang *et al.*, 1997). Pauly (1997), who extrapolated to *R. typus* the growth data collected for the basking shark *Cetorhinus maximus*, suggested that *R. typus* has a slow rate of growth and that a shark of 7 m, which is close to the mean length of *R. typus* at Ningaloo Marine Park (NMP), would be approximately 20

years of age. However, the age at maturity of female *R. typus* and the frequency of reproduction have not been determined.

There have been few detailed observations of the foraging behaviour of filter-feeding elasmobranchs (Sims *et al.*, 1997). Megamouth sharks (*Megachasma pelagios*) are rarely seen, although one individual was recently tracked and shown to swim in deep water during daylight and to move to the surface at night (Nelson *et al.*, 1997). Basking sharks (*C. maximus*) are reported to feed at the surface on bright sunny days (Priede & French, 1991), while whale sharks have been seen feeding during both the day and night (Taylor, 1994; Clark & Nelson, 1997).

Whale sharks have a large mouth, small teeth, weak jaw musculature and elaborate gill rakers which filter small organisms (Moss, 1977), and must consume very large quantities of food in order to produce the energy required for maintenance (Gudger, 1941). Feeding is achieved via either a flow-through method, where water and food organisms are filtered through the pharynx while swimming forward (Compagno, 1984b), or by using a suction method. *Rhincodon typus* is closely related to the strong suction-feeding nurse sharks (*Nebrius ferrugineus*) (Clark & Nelson, 1997), which create suction by rapid expansion of the muscular pharyngeal cavity (Tanaka, 1973). Water enters the mouth as *R. typus* sinks and rises while it is in a nearly vertical position, thus allowing water and food to enter the mouth (Springer, 1957), or by creating a powerful sucking action while just below the surface (Gudger, 1941). The oesophageal sphincter is probably tightly closed when water is squeezed out through the gill slits (Clark & Nelson, 1997). The latter method results in less water being filtered per unit time, and probably means that *R. typus* is more dependant on localised concentrations of prey (Compagno, 1984a).

The limited information on the diet of *R. typus* is conflicting, with the feeding mode employed by this species having been described as herbivorous by McCann (1954), omnivorous by Silas (1986) and planktivorous by Compagno (1984b). The last of the above workers recorded the prey as ranging from small crustaceans to

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small schooling fishes. However, *R. typus* has also been observed feeding on galley waste, comprising bread crusts and tea leaves (Clucas, 1965), shrimp (Nolan & Taylor, 1978; Leu *et al.*, 1997), lantern-fish (*Benthosema pterotum*), swarms of copepods (Clark & Nelson, 1997) and Antarctic krill (*Euphausia superba*) (Leu *et al.*, 1997). At NMP, *R. typus* has been reported as feeding on tropical krill, *Pseudeuphausia latifrons* (Taylor, 1994). The seasonal appearance of whale sharks at this location is thought to be directly associated with the increased feeding opportunities created at the time when the corals of Ningaloo Reef spawn *en masse* (Taylor, 1994).

The first aim of this section of the study was to determine the length composition and sex ratio of the assemblage of *R. typus* at NMP, and to use the state of the claspers of the males to determine the length at which male whale sharks become mature. The behaviour of *R. typus* while feeding, and some of the components of the diet of this species, are also described. The degree of distension of the mouth has also been recorded as a possible indicator of the intensity of feeding.

3.2 Materials and methods

3.2.1 Lengths, sex ratio, and size at maturity of male *Rhincodon typus* at Ningaloo Marine Park

Information on the biology of *R. typus* was collected while aboard commercial and CALM vessels throughout the 1995, 1996 and 1997 whale shark seasons at NMP (see Table 2.1). To assist with estimating the length of *R. typus*, a 15 m rope (knotted at 1 m intervals) was observed underwater at regular intervals during this study, and used as a scale. Subsequently, the total length of each whale shark was estimated to the nearest 0.5 m. Estimates were further enhanced *in situ* by assuming that the length of a snorkeller swimming alongside the whale shark was on average 2 m and then extrapolating this length to the full length of the shark (see Fig. 3.1). On several occasions, accurate measurements could be obtained by holding one end of a length of

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cotton cord adjacent to the snout of *R. typus*, while it was being extended along the flank of the animal by an assistant and marked at a point adjacent to the trailing edge of the caudal fin. The marked length of rope was subsequently measured with a tape rule when onboard the accompanying vessel, thus providing an accurate record of the length of the shark.

The number, estimated total lengths (to the nearest metre) and locations of all *R. typus* sighted by industry operators between 1995 and 1997 at NMP were recorded in the Whale Shark Operator logbooks (see Fig. 3.2). As industry operators were not always in the water with *R. typus*, whale shark lengths were recorded using estimates provided by tourists, and/or by comparing the length of each shark with that of the length of the vessel.

The sex of each shark was determined by diving below the region of the pelvic fins and observing whether claspers were present (male) or absent (female).

Tests for significance between the total length of male and female *R. typus* was performed using one-way analysis of variance (ANOVA). Cochran's C-test was used to test for homoscedasticity. When data were found to be heteroscedastic, values were $Log_{10}(n+1)$ transformed which then always resulted in homoscedasticity.

The morphology of the claspers was also noted, *i.e.* male *R. typus* were recorded as immature if the claspers were smooth, flattened against the ventral surface and did not extend beyond the posterior edge of the pelvic fins (Fig. 3.3), or mature if the claspers were elongated and abraided as a result of previous sexual activity (Fig. 3.4).

Estimates of the length of male *R. typus* at first maturity (L_{50}) were based on data obtained for the lengths of sharks with smooth unabraided claspers (sexually immature) and with calcified abraided claspers (mature). A logistic function was fitted to the proportion of mature fish in each 1m interval by a non-linear technique (Saila *et al.*, 1988), using non-linear sub-routine in SPSS (SPSS Inc., 1988). The logistic equation was $P_L=[1+e^{(a+bL)}]-1$, where P_L is the proportion of fish with mature claspers at length

interval L, and a and b are constants. The L_{50}, which is the length at which 50% of the individuals possessed mature claspers , was derived from the equation $L_{50} = -ab^{-1}$.

3.2.2 Feeding behaviour of *Rhincodon typus*

Rhincodon typus were often observed at NMP between 1995 and 1997 swimming slowly at the surface with differing degees of mouth opening. When the mouth was closed, it was given a value of 0, and when it was fully open, it was given a value of 1, with intermediate values being recorded at 0.1 intervals, *i.e.* 0.1, 0.2, 0.3 etc. (Figs. 3.5, 3.6). Although prey items were rarely of sufficient size to be observed while swimming alongside whale sharks, it was assumed that, when the mouth was well distended, food-laden water was being filtered through the gill rakers (J. Stevens, CSIRO Marine Research, Hobart, pers. comm.). However, it should be recognised that the mouth has to be at least partially open to allow the entry of water and its passage over the gills for respiration. Therefore, values of between 0 and 0.1 were arbitrarily chosen to represent occasions where the sharks were primarily ram-ventilating with no associated feeding. Any value above 0.1 was taken to indicate that a shark was at least testing the water for food, whereas those above 0.4 indicated substantial feeding behaviour. The mean level of mouth distension was recorded while *R. typus* was at the surface during each successive five minute interval. This enabled the calculation of the overall mean level of mouth distension ($\pm$ 1 S.E.) per interaction.

Through personal observations and from information provided by research workers at the Australian Institute of Marine Science (AIMS) (C. Pemberton, AIMS, Dampier, pers. comm.), a mass spawning of corals occurred at Ningaloo Reef between 7-11 days after the March full moon in 1995, *i.e.* 17/3/95, and the March and April full moons in both 1996, *i.e.* 5/3/96 and 4/4/96, and 1997, *i.e* 24/3/97 and 23/4/97. This information was necessary to ascertain whether there was an increase in the mean level of mouth distension at the time of mass coral spawning.

Some observations on *R. typus* at Christmas Island, Indian Ocean, were recorded in January 1996, with the assistance of the Australian Nature Conservation Agency (ANCA)/Parks Australia North. Both private and commercial dive charter vessels were employed to locate *R. typus*, usually within 200 m of the coastline.

A small plankton net (mesh size = 333 μm) was used to sample the water in front of feeding sharks at both NMP and Christmas Island, and the contents of these samples were taken to Murdoch University for analysis.

3.3 Results

3.3.1 Total length of *Rhincodon typus* at Ningaloo Marine Park

Rhincodon typus were observed with tourists in the water during interactions at NMP on 360 separate occasions between 1995 and 1997. It was possible to estimate the total length of each shark (n = 360) and to measure accurately the lengths of seven of these individuals and thereby compare values obtained for estimated and measured lengths. The estimated lengths differed from the measured lengths by less than 0.5 m on each occasion (Table 3.1).

During 1995, the smallest length I recorded for a whale shark was *ca* 3 m, while the largest was *ca* 12 m (Table 3.2). The mean total length was 7.0 m. The measurements made by members of the tourist industry indicate that the size of the sharks they observed in 1995 ranged from 2 to 13 m, with a mean total length of 7.2 m (Table 3.2). The length range recorded during my study in 1996 was 4.5 - 12 m, with a mean of 7.6 m (Table 3.2), while in this year the industry operators recorded a minimum length of 2 m and a maximum length of 14 m (mean 7.7 m). In 1997, personal records yielded lengths of 4 - 10 m, with a mean of 6.7 m, compared with a range of 2 - 12 m and mean of 7.0 m recorded by the industry (Table 3.2). Overall, the mean total length of *R. typus* at NMP recorded during the present study was 7.3 m, compared with 7.4 m by the

industry (Table 3.2). The close correspondence between the lengths I recorded and those recorded independently by industry suggest that the measurements made by both sources are reasonably accurate.

The modal length class of whale sharks recorded during the current study in 1995, 1996 and 1997 were 6 - 7 m, 6 - 7 m, and 7 - 8 m, respectively (Fig. 3.7). The length distributions collected by industry operators during the same three years were similar (Fig. 3.7a,b).

3.3.2 Sex ratio of *Rhincodon typus*

Only thirty five of the 360 whale sharks sighted at NMP between 1995 and 1997 could not be sexed. The total of 325 individuals that were sexed comprised 275 males and 50 females, producing an overall ratio of males to female of 84.6:15.4 (Table 3.2). In 1995, 1996 and 1997, 71.7, 91.6 and 91.4% of the sexed sharks were males.

In 1995, the lengths of the female *R. typus* that were sighted ranged between 4.5 and 7 m, with a mean of 5.9 m (Table 3.3) and produced a modal length class of 6 - 7 m (Fig. 3.8). In 1996, the length range was 6 - 8.5 m with a mean of 6.7 m (Table 3.3) and a modal length class also of 6 - 7 m, as in the previous year (Fig. 3.8). The lengths in 1997 were between 5.5 and 8 m, with a mean of 6.6 m (Table 3.3), and produced two modal length classes of 5 - 6 and 7 - 8 m (Fig. 3.8). No large females, *i.e.* > 9 m, were recorded between 1995 and 1997.

In 1995, the lengths of male *R. typus* sighted ranged from 4 - 12 m, with a mean of 7.5 m (Table 3.3) and yielded a modal length class of 9 - 10 m (Fig. 3.9). In 1996, the length range was 4.5 - 11 m, with a mean of 7.7 m (Table 3.3) and the modal length class was 6 - 7 m (Fig. 3.9). The range of lengths in 1997 was between 4 - 10 m with a mean of 6.7 m (Table 3.3) and the modal length class was 7 - 8 m (Fig. 3.9).

The mean length of male *R. typus* sighted at NMP was significantly greater than females ($p < 0.001$) throughout the study period. The lengths of male

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R. typus between 1995 and 1997 ranged from 4 to 12 m, with an overall mean of 7.4 m (Table 3.3) and a modal length class of 6 - 7 m (Fig. 3.9). The lengths of female *R. typus* between 1995 and 1997 ranged from 4.5 to 8.5 m, with an overall mean of 6.2 m (Table 3.3) and a modal length class of 6 - 7 m (Fig. 3.8).

3.3.3 Length at maturity of *Rhincodon typus*

The morphology of the claspers could be seen in all of the 275 males of *R. typus* that were sighted between 1995 and 1997. Abraided claspers were not observed in any fish less than 7 m in total length (Fig. 3.10). Only 19 of the 95 fish between 7 and 9 m possessed enlarged and abraided claspers, whereas all but one of the male fish greater than 9 m in length showed evidence of previous sexual activity. The L_{50} for length at first maturity of males, based on clasper morphology and using a logistic curve fitted to the percentage of fish with abraided claspers, was 8.6 m (Fig. 3.10).

On seven separate occasions during 1995 and 1996, a whale shark was observed circling another (nose to tail). It was possible to determine the sex and estimate the size of each member of four of those pairs of individuals (Table 3.4). On each occasion, the encircling shark was the larger of the pair and was a male. The smaller female withdrew rapidly during two of the observations. No similar circling behaviour was observed during the 1997 whale shark season.

3.3.4 Feeding observations

Rhincodon typus were seen feeding by the suction method at NMP on two occasions throughout the course of the current study. On one of these, a shark of 11 m was observed sucking the surface slick of coral spawn into it's mouth while orientated at 45^0 to the surface on 23 March 1995. In the other case, a shark, also of 11 m, was seen on 1 May 1996 sucking into it's mouth large volumes of water containing tropical krill (*P. latifrons*), while orientated at 90^0 to the surface in very shallow water such that the shark's tail was almost touching the sea floor (Fig. 3.11).

Flow-through feeding by *R. typus* was witnessed at Christmas Island at around 2200 h on 16 January 1996 when a shark was seen moving slowly at the surface, feeding on a localised concentration of mysids (*Anisomysis spinata*) (Fig. 3.12) and crab megalopa (*Gecarcoidea natalis*) (Fig. 3.13). A group of seven *R. typus* was observed at NMP on 20 April 1995, swimming rapidly through a swarm of tropical krill (*P. latifrons*), with their mouth's often widely distended (Fig. 3.14) for part of the interaction.

During each observation at NMP, food items present in the water column were rarely visible. However, whale sharks were observed swimming slowly with their mouth's almost fully distended for part of each interaction on 16 March 1995 and 26 April 1995. A plankton tow at the time showed that jellyfish (*ca* 5 mm diam.) and crab megalopa (Fig. 3.15) were present in the water. It was subsequently assumed that *R. typus* was feeding when the mouth was widely distended while swimming slowly at the surface.

Between 1995 and 1997, the mean level of mouth distension exhibited by *R. typus* was recorded for 330 observations made while in the water. The length of each observation ranged from 1 - 70 minutes. The mean level of mouth distension per observation ranged from 0 - 0.75 in 1995, 0 - 1.0 in 1996 and 0 - 0.56 in 1997. Throughout the majority of observations (73.8% in 1995, 80.3% in 1996 and 84.5% in 1997), the mean level of mouth distension was less than 0.2, with only 6% of cases between 1995 and 1997 being recorded as 0.5 or above (Fig. 3.16).

The mean degree of mouth distension varied little between years, and was only 0.14 in 1995, 0.13 in 1996, and 0.11 in 1997, with an overall mean for the current study (1995 - 1997) of 0.13 (Table 3.5). It remained low throughout the day (Fig. 3.17), indicating a low overall level of feeding activity irrespective of the time of day. There was no obvious increase in the level of mouth distension on the days when mass coral spawning occurred at NMP (Fig. 3.18).

Rhincodon typus was observed defaecating at NMP on three separate occasions. The colour of this waste ranged from dark brown to pale white. The contents of one of these samples contained the exoskeletal remains of various crustaceans, including calanoid and harpacticoid copepods (< 1 mm) and larval decapods (*ca* 2 mm), together with the scales of small fishes (*ca* 2 mm) (Figs 3.19 - 3.21). In addition, *R. typus* were observed displaying a cough-like behaviour on nine separate occasions between 1995 and 1997, with white particulate matter being expelled from the shark's mouth on each occasion. This behaviour probably helps clear the fine mesh of the gill rakers from "unwanted" material and thus ensures optimum filtration of food-laden water.

3.4 Discussion

3.4.1 Total length and reproductive biology of *Rhincodon typus*

The results of the current study provide strong indications that *R. typus* at NMP ranges in length between 3 and 12 m and that the mean total lengths of sharks were similar in 1995, 1996 and 1997. A high percentage of these whale sharks were between 6 and 8 m in length. These lengths are comparable with those recorded by industry operators during the same period. Furthermore, Taylor (1994) reports that the majority of *R. typus* sighted at Ningaloo Reef between 1982 and 1993 were between 6.0 and 7.5 m in length. This is consistent with the data from the present study and those collected by commercial whale shark industry operators in 1993, which indicated that most sharks sighted were between 6 and 8 m in length (n = 303) (CALM 1993, unpub. rep.).

During the current study, the sex of *R. typus* could be determined for all but 35 of the 360 sharks observed. The majority of the sharks that could be sexed were males, *i.e. ca* 72, 92 and 91% in 1995, 1996 and 1997, respectively. A similar result was reported in 1993, when 86% of these sharks were identified as males (CALM 1993, unpub. rep.). It is not uncommon for sharks to form groups that are segregated by size

and sex (Klimley, 1987; Bres, 1993), and this is the case with *R. typus* at NMP, although the possibility cannot be excluded that the females have undergone greater mortality.

The results of the present study using clasper morphology indicate that the length at which 50% of male *R. typus* reach maturity is *ca* 8.6 m. The males of another species of large filter-feeding shark, *C. maximus*, appear to mature at a far smaller total length, *i.e.* between 4 and 5 m (Last & Stevens, 1994). Pauly (1997) has produced a tentative length growth curve for *R. typus*, extrapolating from data on *C. maximus*, which suggests that *R. typus* of *ca* 8.6 m would be almost 30 years of age. In the only literature available on the reproductive status of female *R. typus*, Pai *et al.* (1983) and Satyanarayana Rao (1986) report that two individuals of 7.9 and 8.8 m had immature ovaries. However, this could be because they were not examined during the breeding season. Since none of the females of *R. typus* seen during the present study were longer than 9 m, it is possible that the females of *R. typus* at NMP have not yet reached sexual maturity. If this is the case, the data indicate that the whale shark aggregation at NMP each year is probably not related to breeding.

Elasmobranchs are generally believed to mature after attaining about 60% of their theoretical asymptotic length (Babel, 1967; Holden, 1974). The fact that the length of male *R. typus* at maturity is *ca* 8.6 m, and the largest male whale shark reported in the literature is 13.7 m (Compagno, 1984a), is consistent with this generalisation. However, female whale sharks may attain a slightly larger size as Devadoss *et al.* (1990) recorded one female of this species measuring 14.5 m.

Sharks are often considered solitary rather than sociable animals (Myrberg & Nelson, 1991) and, although *R. typus* have been found together in large numbers (Compagno, 1984a), the data collected at NMP during the present study indicate that the members of this species are invariably encountered singly. There appeared to be very little interaction between individual *R. typus* at NMP, with only seven separate accounts of a whale shark was seen encircling another nose to tail (see Table 3.3). Similar

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behaviour was previously recorded at NMP in 1994, when two sharks were observed swimming head to tail at the the surface for approximately 15 minutes (J. Stevens, unpub. data). Although such following behaviour appears to have a reproductive function in some sharks (Johnson & Nelson, 1978), Bres (1993) witnessed sharks displaying similar behaviour in situations described as non-copulatory and suggests that it has social implications. This type of behaviour in *R. typus* may therefore be related to some type of social hierachy among its members (see Myrberg and Gruber, 1974).

3.4.2 Feeding behaviour of *Rhincodon typus*

Although suction feeding had not been previously reported for *R. typus* at NMP (Clark & Nelson, 1997), one shark was observed suction feeding on coral spawn in 1995, a food item which had also never before been documented for this species. Coral gamete bundles, resulting from the mass spawning of corals, have previously been reported to measure 2 - 4 mm (Gittings *et al.*, 1992). Given that the straining apparatus of *R. typus* has openings no larger than 2.5 mm (Clark, 1992), this spawn would therefore provide a concentrated protein source for *R. typus*. The sucking of water while stationary ensures that the sperm and egg bundles released by spawning corals are not separated and reduced to a size too small to be sieved. However, it should be noted that this spawn will disperse rapidly in strong winds or rough water (L. Smith, AIMS, Dampier, pers. comm.).

Although aggregations of swarming krill were rarely observed, seven sharks within a 100 m radius were recorded on one occasion, actively pursuing and ingesting tropical krill in a 'frenzied' manner. Myrberg & Nelson (1991) suggest that frenzies such as this may be triggered by an unusual feeding opportunity.

It seems apparent that, when plankton is located, the mouth becomes fully distended. However, the low mean degree of mouth distension exhibited by *R. typus* at NMP between 1995 and 1997 indicates that members of this species rarely feed intensively during the day, irrespective of the dates of the annual mass coral spawning

events. *Rhincodon typus* are more likely ram-ventilating and continually testing the water for larger concentrations of zooplankton.

Rhincodon typus were observed defaecating on several occasions at NMP. This has apparently been reported only once previously in the literature (Gudger, 1941). This faecal material contained the exoskeletal fragments from calanoid and harpacticoid copepods and decapods and the scales of a small fish. It appears that, while ram-ventilating, water-borne material passing through the gill rakers may cause a build-up of residual material. The cough-like behaviour exhibited by *R. typus*, and the resultant expulsion of white particulate matter indicates that this behaviour may be necessary to clear the gills and thus ensure that water flow across these structures is not restricted.

The suction filter feeding method allows small volumes of water to be filtered per unit time, which suggests that *R. typus* is dependent on larger concentrations of planktonic prey (Compagno, 1984a). The level of mouth distension was low during most daylight observations at NMP and, as prey items were rarely visible, it can be assumed that the concentration of prey at the surface was also low. Tropical krill undertake vertical migrations and are likely to be near the surface at night (Mauchline & Fisher, 1967). Acoustic tracking of *R. typus* on two separate occasions during 1997 (see Chapter 5) indicates that this species spends more time near the surface during the hours of darkness than during daylight hours, suggesting that *R. typus* is likely to feed on vertically-distributed zooplankton at these times. Indeed, it is believed that *R. typus* mainly feeds at the surface during the evening, with reports of large numbers (up to 70 individuals) feeding at dusk (Taylor, 1990; Thomson & Stevens, 1994; S. Jones, Perth Diving Academy, Perth, pers. comm.).

Presumably *R. typus*, like other elasmobranchs, are able to detect distant vibrations through their lateral line system and weak electrical fields via their ampullae of Lorenzini (Bannister, 1996). As swarming krill would create a region of concentrated vibrations within the water column, it seems probable that the weak electrical impulses emitted during muscle movement may enable *R. typus* to locate these aggregations.

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Indeed, electroreception is widely employed by *C. maximus* to locate dense energy-rich patches of zooplankton (Sims & Quayle, 1998). In addition, the olfactory sense is well developed in *R. typus* and is thus likely to assist in sensing gradation of plankton (Clark & Nelson, 1997).

Rhincodon typus are observed at NMP when conditions are most conducive to increased plankton productivity and subsequent foraging. Indeed, polychaete worms, alcyonarians, species of Mollusca and Echinodermata (Marsh, 1988; Simpson, 1991), and possibly tropical krill *P. latifrons* (Taylor, 1994) also spawn around the time of the annual intensification (March - July) of the warm southerly flow of the Leeuwin Current (Hearn & Parker, 1988; Simpson, 1991). Although *R. typus* has been seen feeding directly on coral spawn resulting from the annual mass spawning of corals at NMP, the apparent low level of feeding behaviour observed during daylight surface observations suggests that this species mainly feeds at other times. *Rhincodon typus* are more likely attracted to NMP each austral autumn because of the overall increase in productivity at this location. *Rhincodon typus* are rarely seen at NMP between August and February each year, and would probably seek locations other than NMP where optimum feeding opportunities exist. At Christmas Island, Indian Ocean, huge numbers of the red land crab *Gecarcoidea natalis* spawn at the water's edge, and the young develop through to the juvenile stage in the surrounding waters (M. Orchard, Parks Australia North, Christmas Island, pers. comm.), thus providing a potential food source for the large number of *R. typus* sighted here at this time. *Rhincodon typus* are often seen in the Coral Sea during the period when the corals of the Great Barrier Reef, and both lantern fish and tuna species spawn each year (MacPherson, 1990). However, the return of several identified *R. typus* to NMP in successive seasons (see Chapter 4), indicates that the annual migration of this species is coincident with increased feeding opportunities.
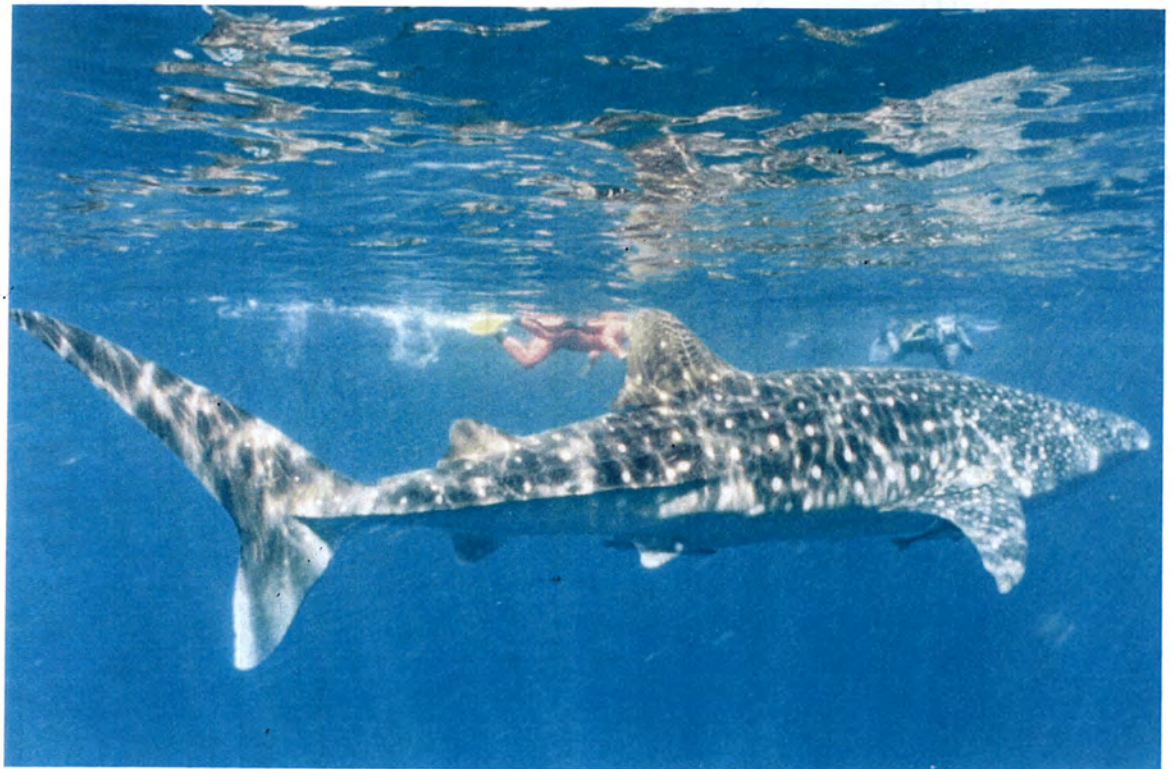
Figure 3.1 Photograph of a snorkeller (*ca* 2 m) swimming alongside *Rhincodon typus*,
to assist with length measurements.

Figure 3.2 An example of the Whale Shark Industry logbooks used by commercial whale shark tourist operators at Ningaloo Marine Park.

The form contains:

WSL 1007 — ⊝ **CALM WHALE SHARK INTERACTION LOG** — Date

Vessel		Start time		Number of Passengers	Paying		Other (F.O.C.)	Whale Shark Experience Pass	Pass Numbers	
					Adults	Children			From	To
Recorder		Finish time								

Contact number	Contact time		Position				Shark observations				Number of swimmers	Dive quality
	Start	Total	Sector	Latitude	Longitude	Water depth	Size	Sex	Heading	Behaviour		

Distinguishing features:

Figure 3.3 Photograph of a small male *Rhincodon typus* with relatively small and smooth claspers, indicating that this shark had not yet become mature.
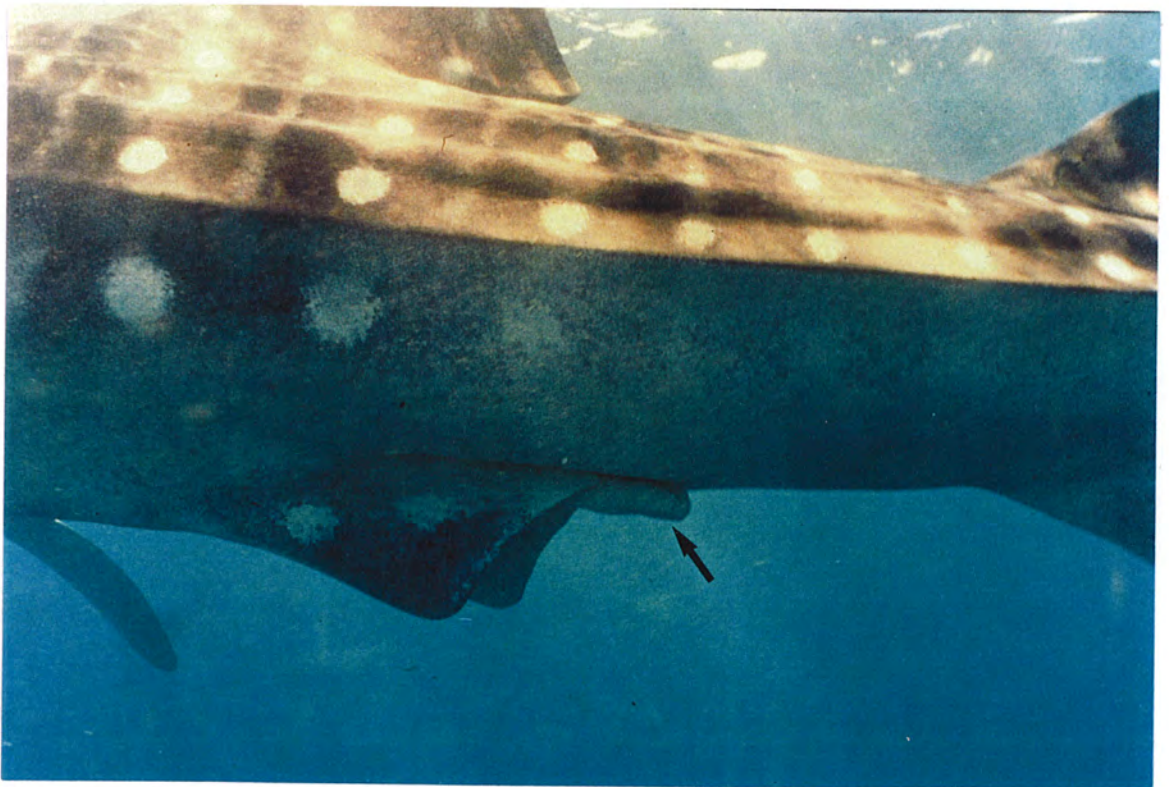
Figure 3.4 Photograph of a large male *Rhincodon typus* with relatively large and abraided claspers, indicating that this shark was mature.

Figure 3.5 Photograph of *Rhincodon typus* with mouth closed.

Figure 3.6 Photograph of *Rhincodon typus* with mouth fully distended.
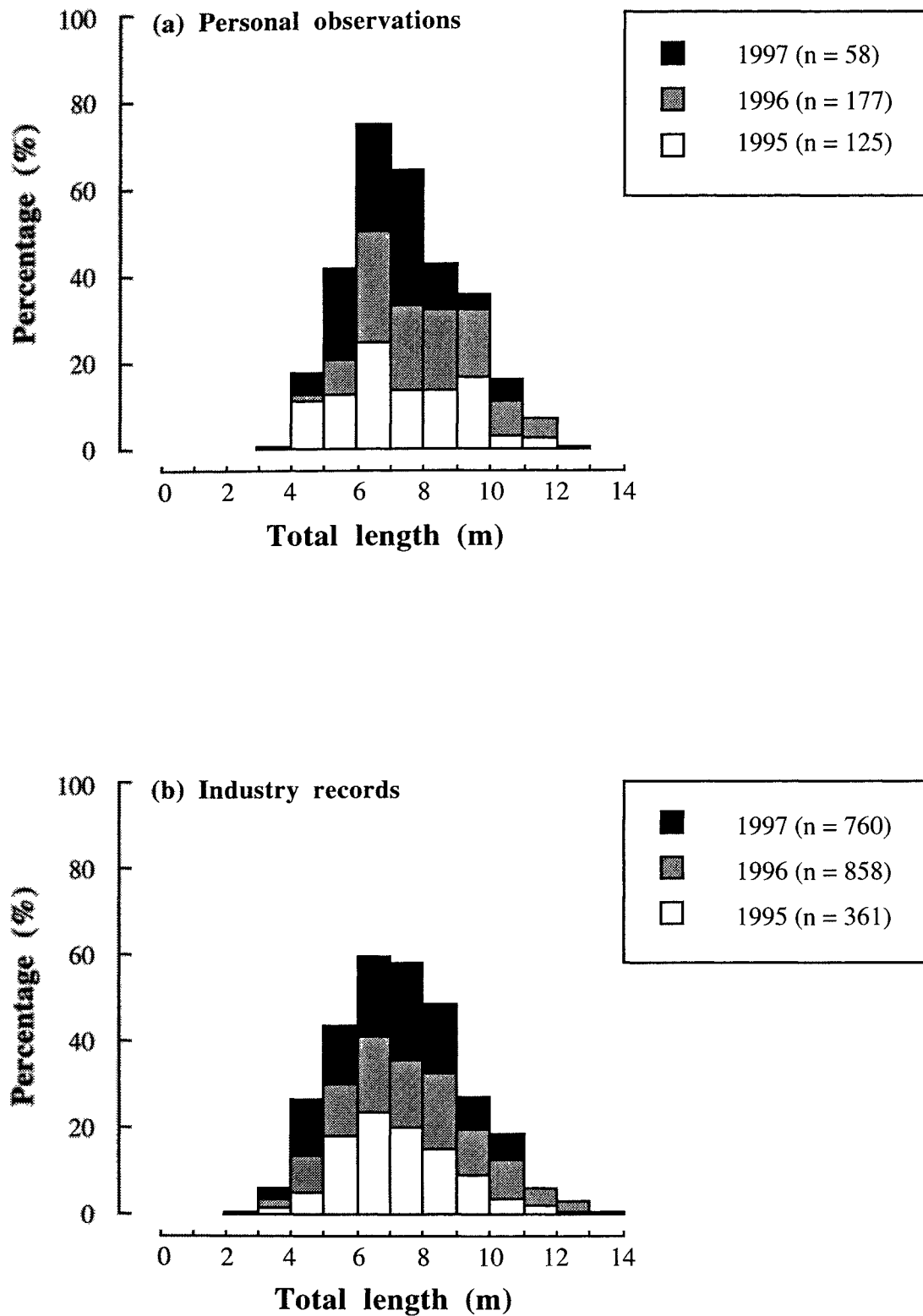
Figure 3.7   Distributions of estimated total lengths of *Rhincodon typus* at Ningaloo
Marine Park between 1995 and 1997.
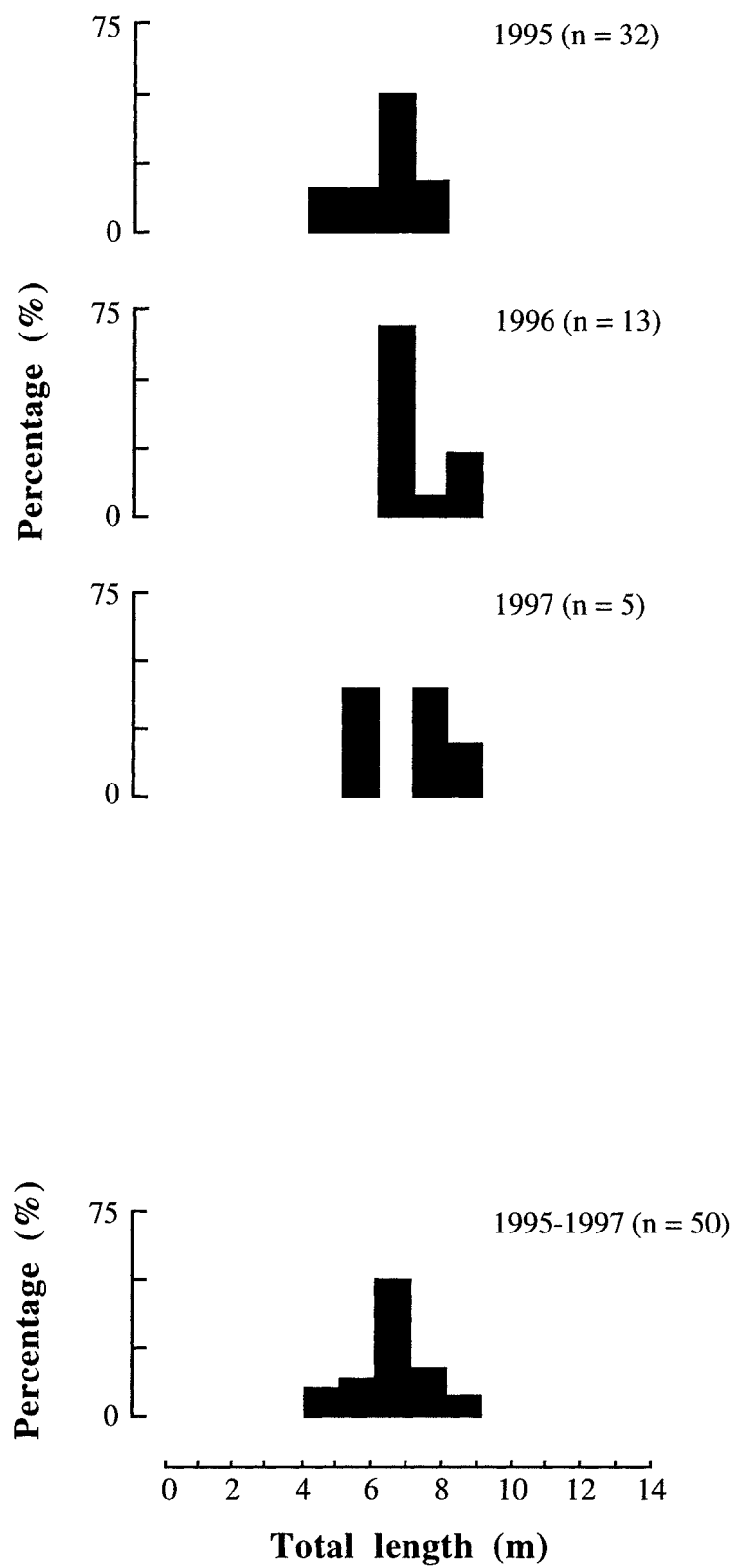
Figure 3.8 Length-frequency histograms of female *Rhincodon typus* recorded at Ningaloo Marine Park between 1995 and 1997.

75 — 1995 (n = 81)

0 —

75 — 1996 (n = 141)

Percentage (%)

0 —

75 — 1997 (n = 53)

0 —

Percentage (%)

75 — 1995-1997 (n = 275)

0 —

0   2   4   6   8   10   12   14

Total length (m)
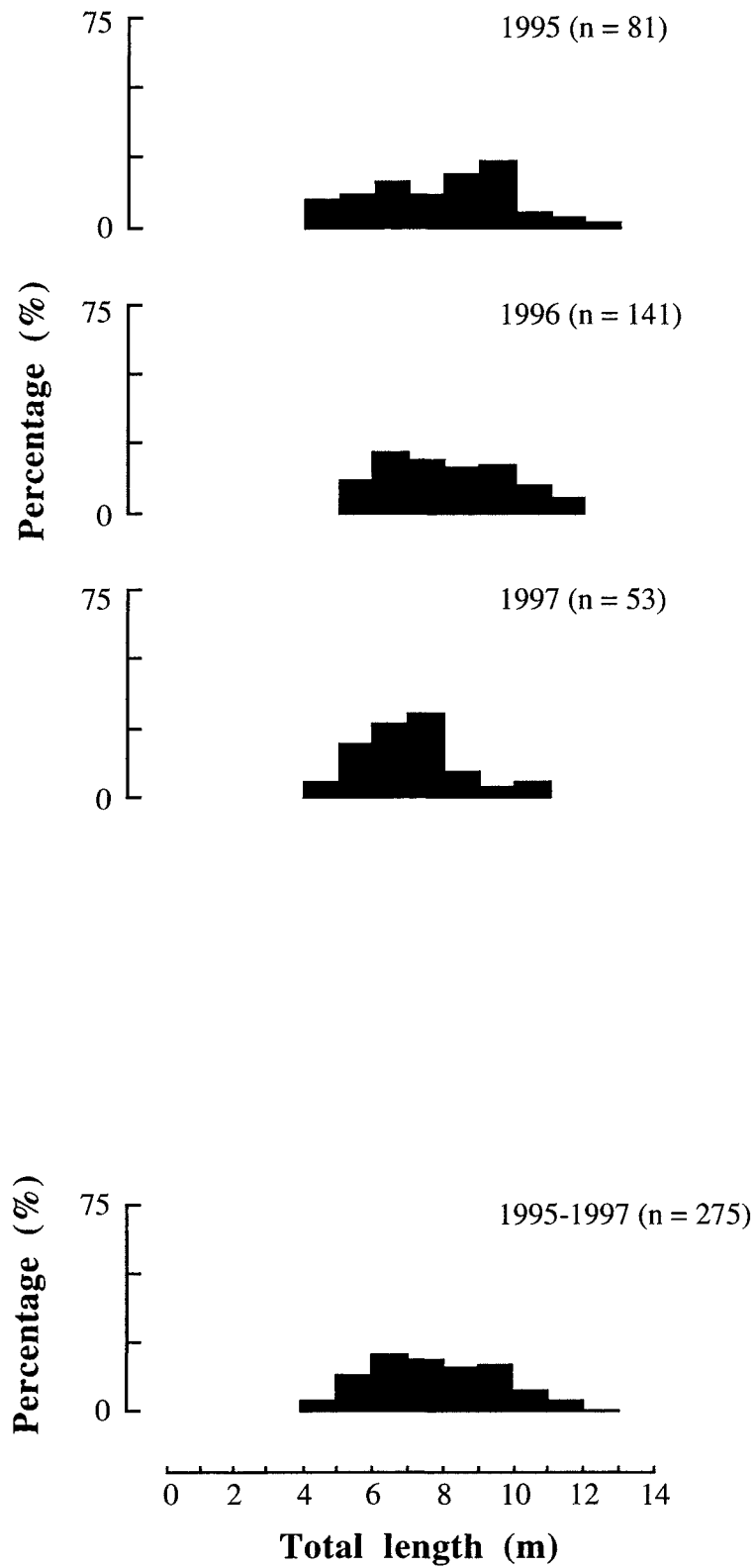
Figure 3.9   Length-frequency histograms of male *Rhincodon typus* recorded at Ningaloo Marine Park between 1995 and 1997.
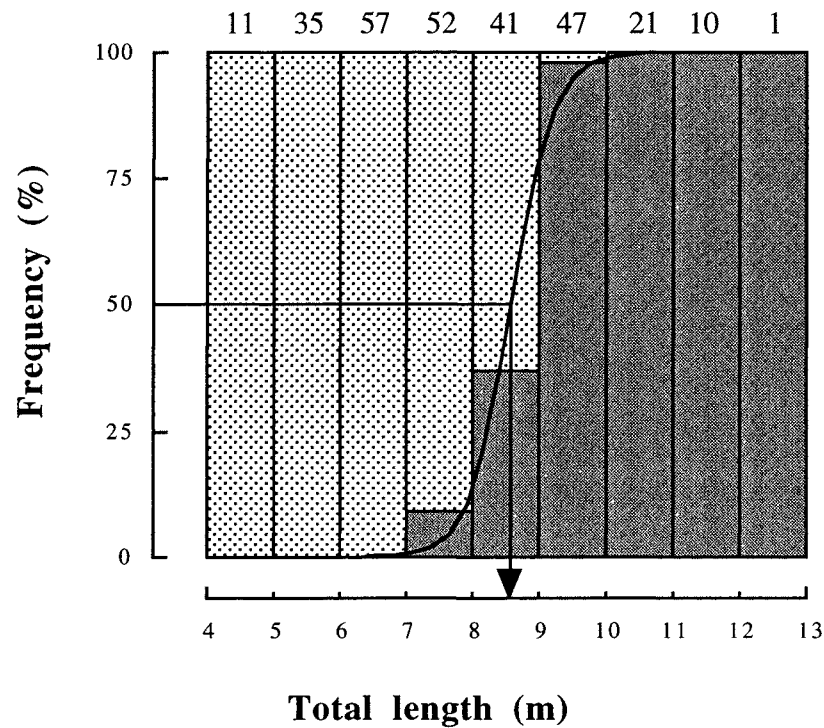
Figure 3.10   Number and percentage contribution of male *Rhincodon typus* (n = 275) with smooth and abraided claspers in successive 1 m size intervals (1995-1997). The logistic curve has been fitted to the percentage of male fish in each size interval which had abraided claspers and were thus considered to have reached the size at which maturity is attained.
NB. The number of fish in each size class is given.
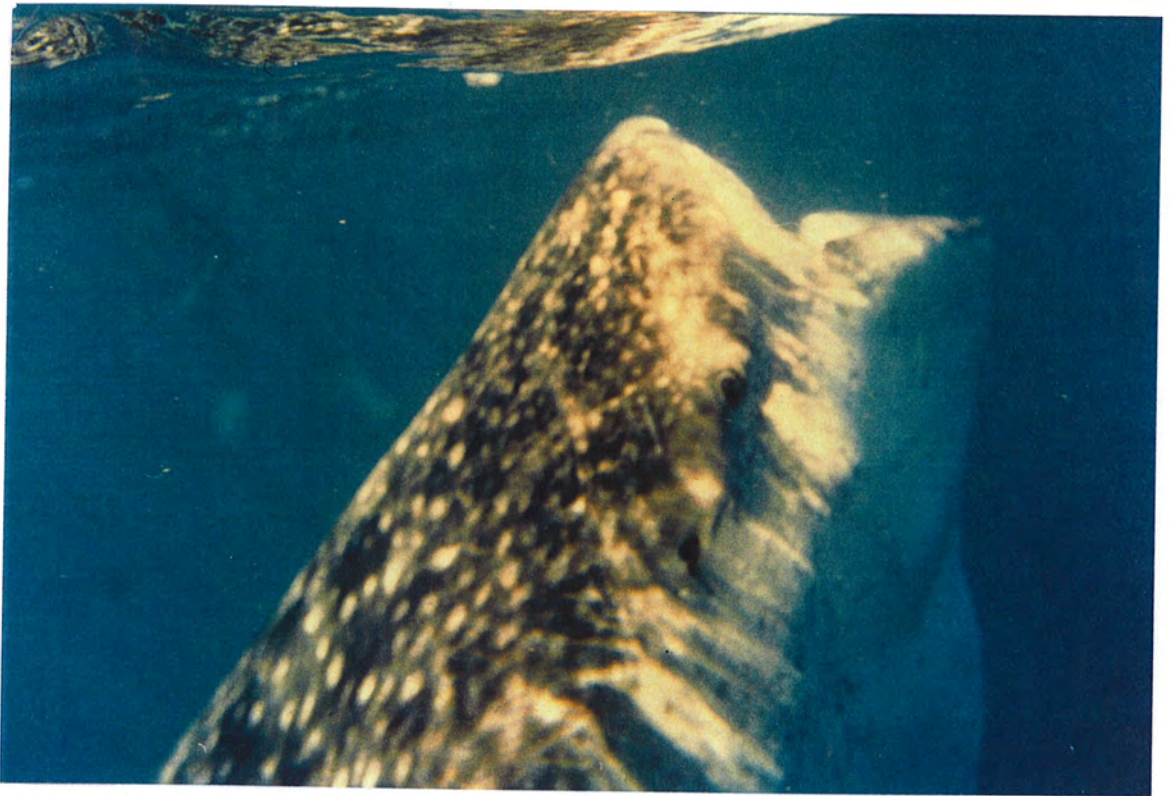
Figure 3.11 Photograph of a *Rhincodon typus* feeding on krill while orientated at nearly 90⁰ to the surface.

1mm
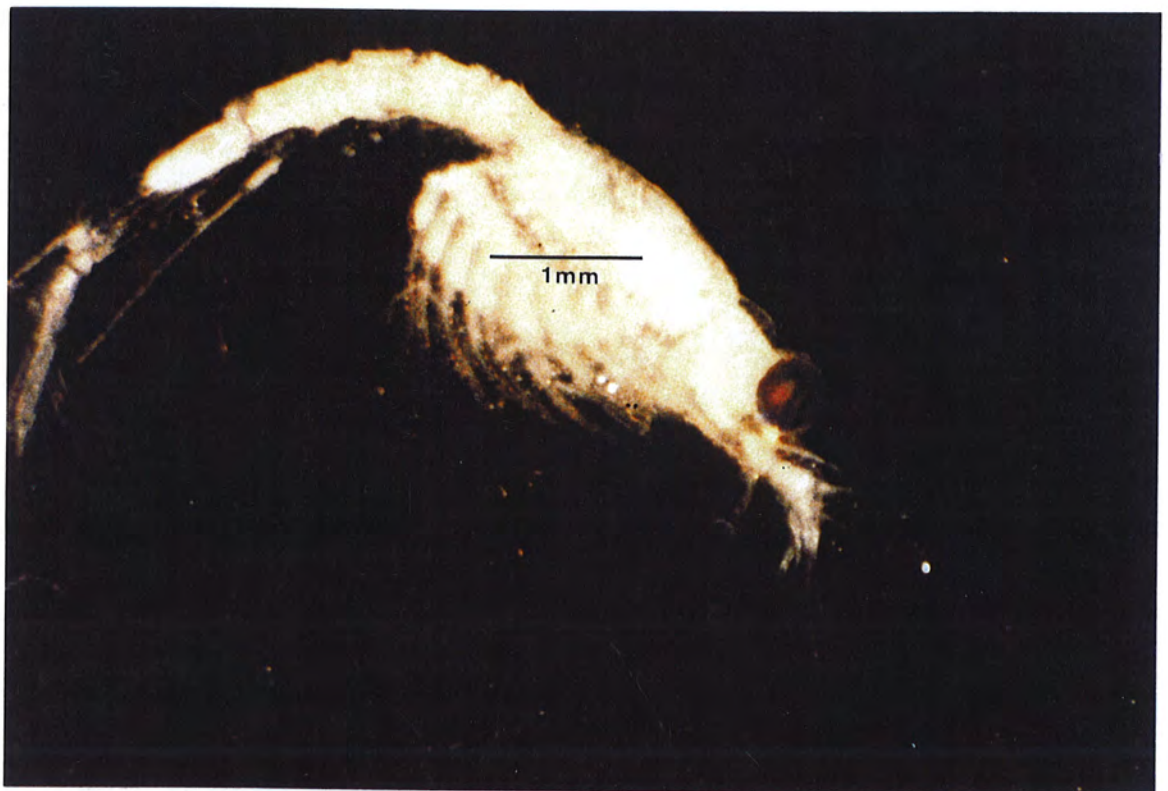
Figure 3.12 A species of mysid collected in the path of a feeding *Rhincodon typus* at Christmas Island, Indian Ocean.
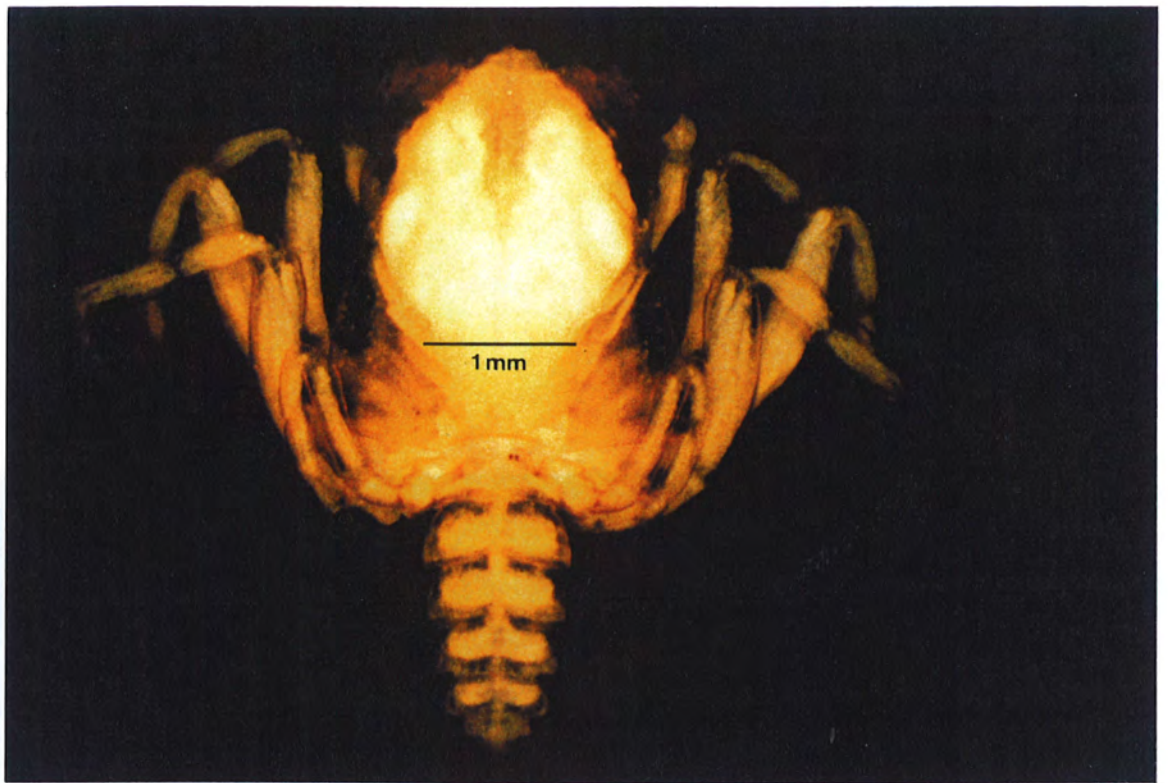
Figure 3.13 Photograph of crab megalopa (*Gecarcoidea natalis*) collected in front of a

feeding *Rhincodon typus* at Christmas Island, Indian Ocean.

Figure 3.14 *Rhincodon typus* moving rapidly through a swarm of krill during 'active'

flow-through feeding behaviour.
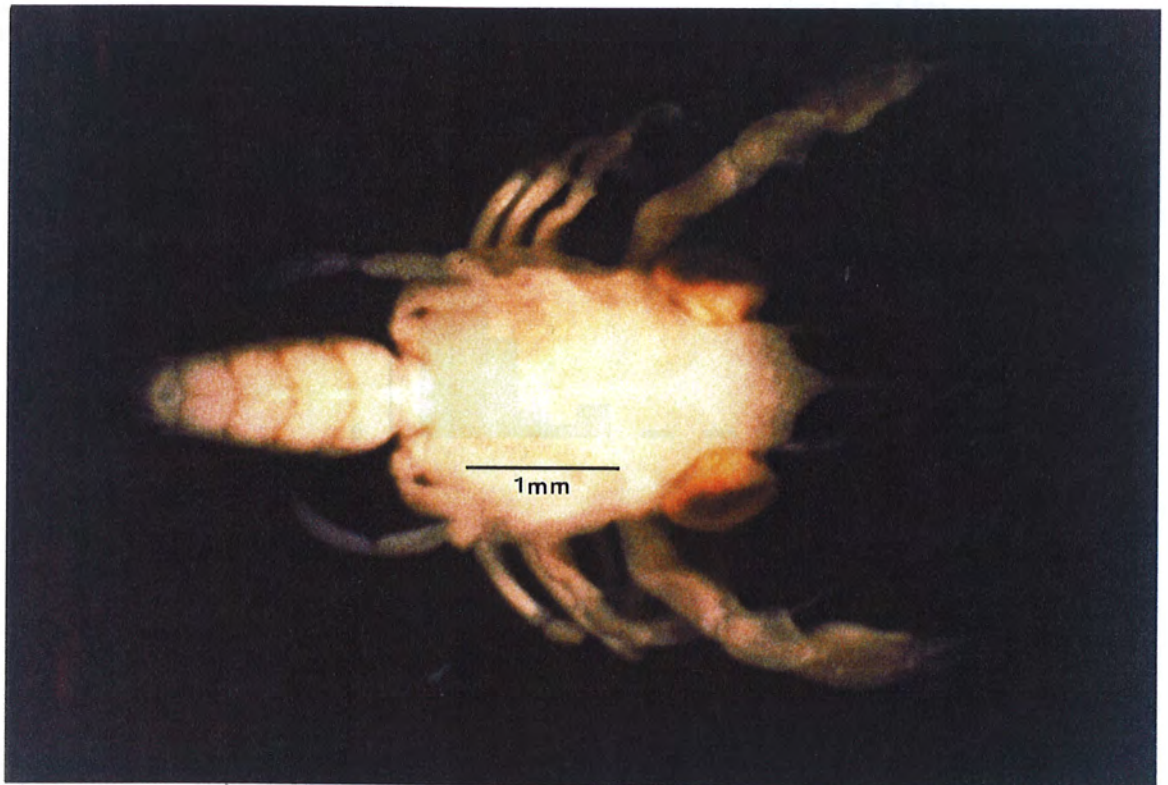
Figure 3.15 Photograph of crab megalopa taken from in front of a feeding whale shark at
Ningaloo Marine Park.

50 ⌐   1995 (n = 99)

25 ⊦

0 ⌊

50 ⌐   1996 (n = 173)

Percentage (%)

25 ⊦

0 ⌊

50 ⌐   1997 (n = 58)

25 ⊦

0 ⌊
    0   0.2   0.4   0.6   0.8   1.0

Level of mouth distension
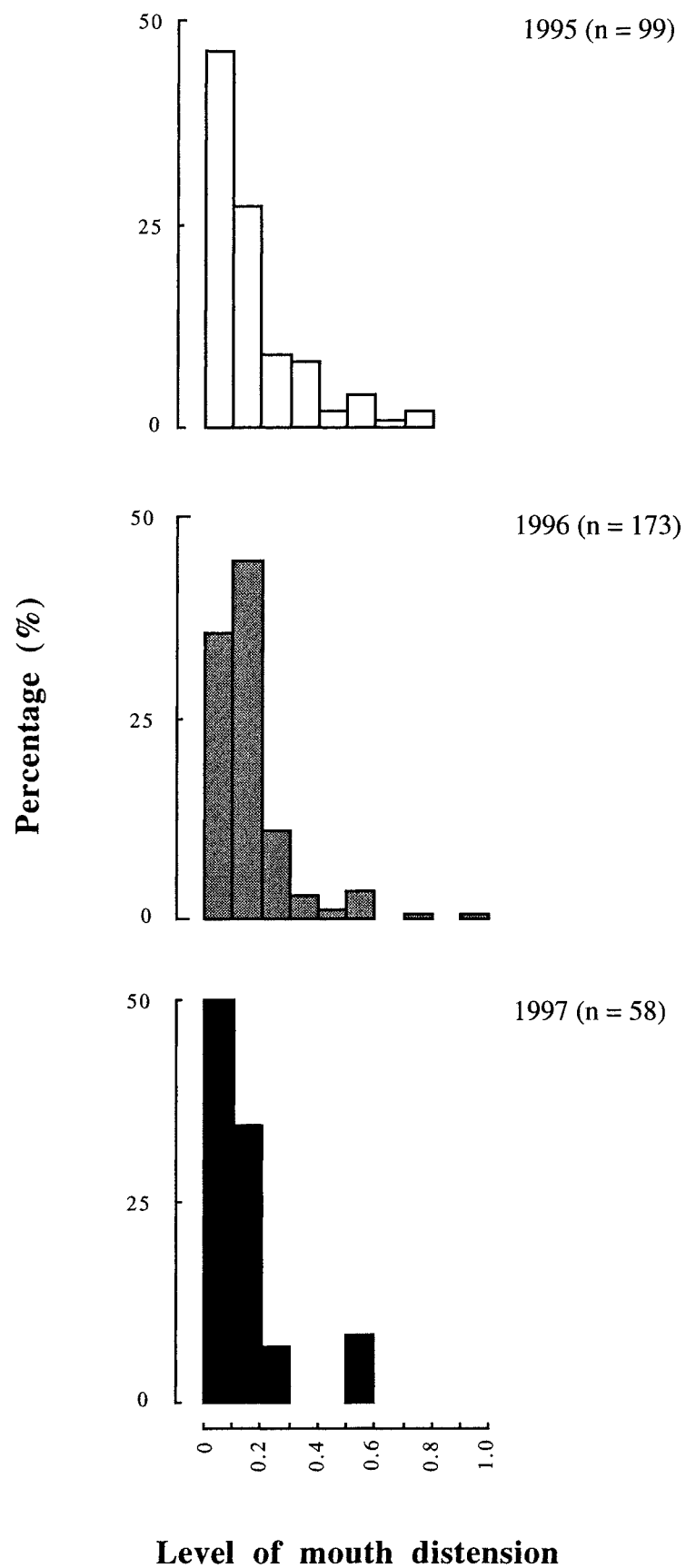
Figure 3.16   The percentage of *Rhincodon typus* observed during the day at
Ningaloo Marine Park with varying mean levels of mouth
distension ranging from 0 to 1.
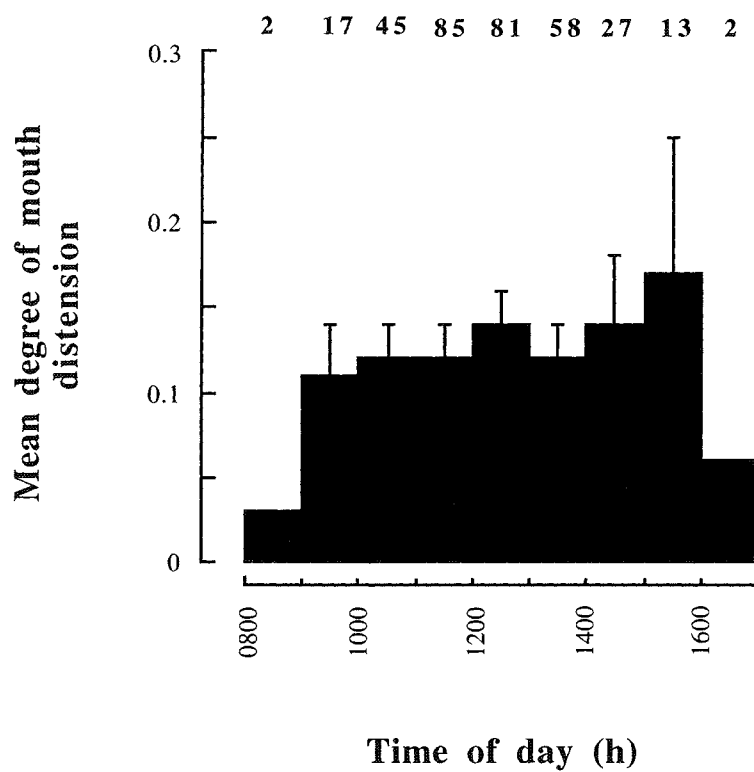
Figure 3.17 The mean values +/- 1 S.E. for the level of mouth distension of *Rhincodon typus* recorded during observations made at different periods during the day at Ninagloo Marine Park between 1995 and 1997. NB. The number of fish sighted within each time interval is also given.
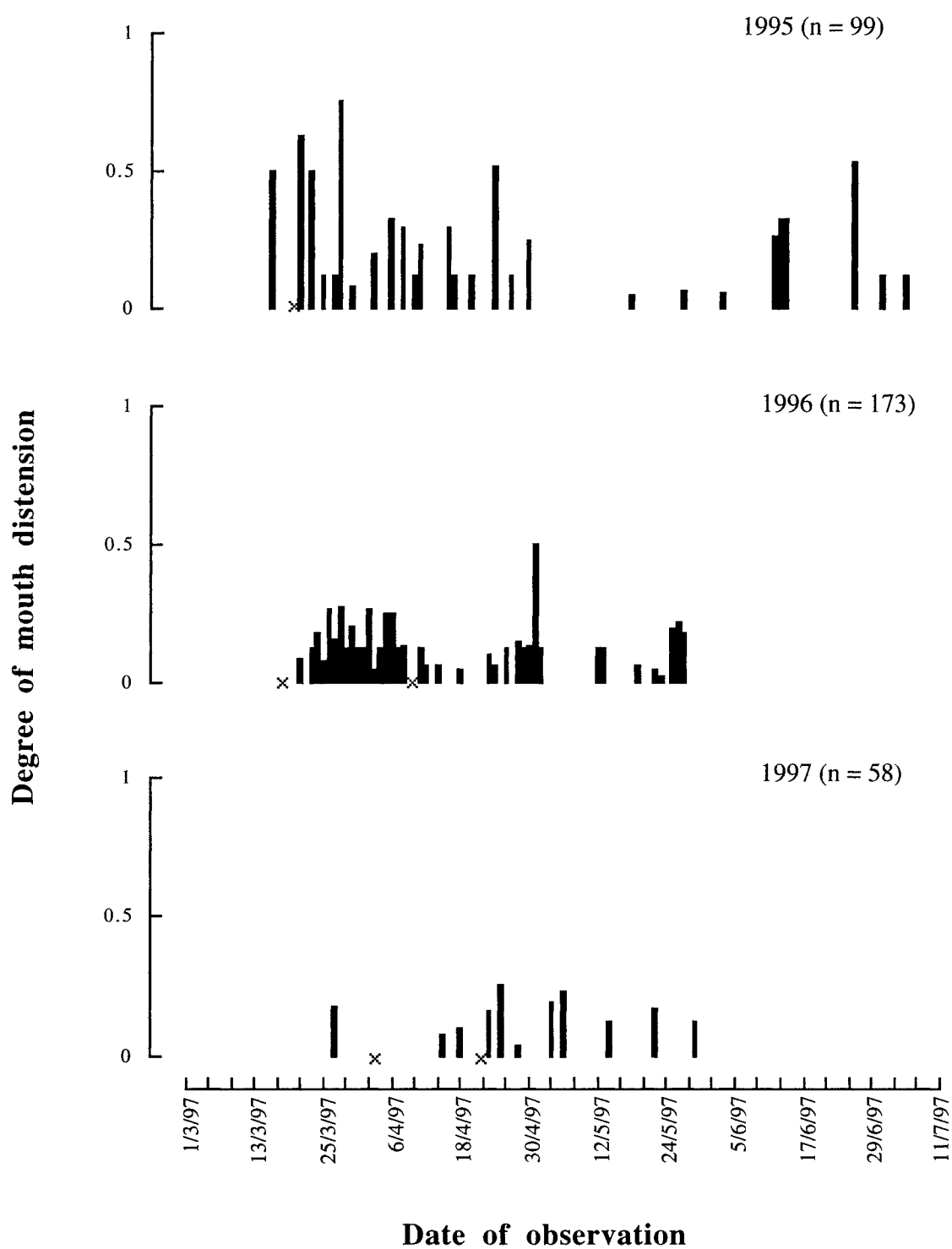
Figure 3.18   Mean degree of mouth distension recorded during daylight observations of
Rhincodon typus at Ningaloo Marine Park between 1995 and 1997.
NB. The expected dates of mass coral spawning are represented by
a cross (X).

Figure 3.19 An example of a copepod exoskeleton taken from the faecal sample of

Rhincodon typus collected at Ningaloo Marine Park.
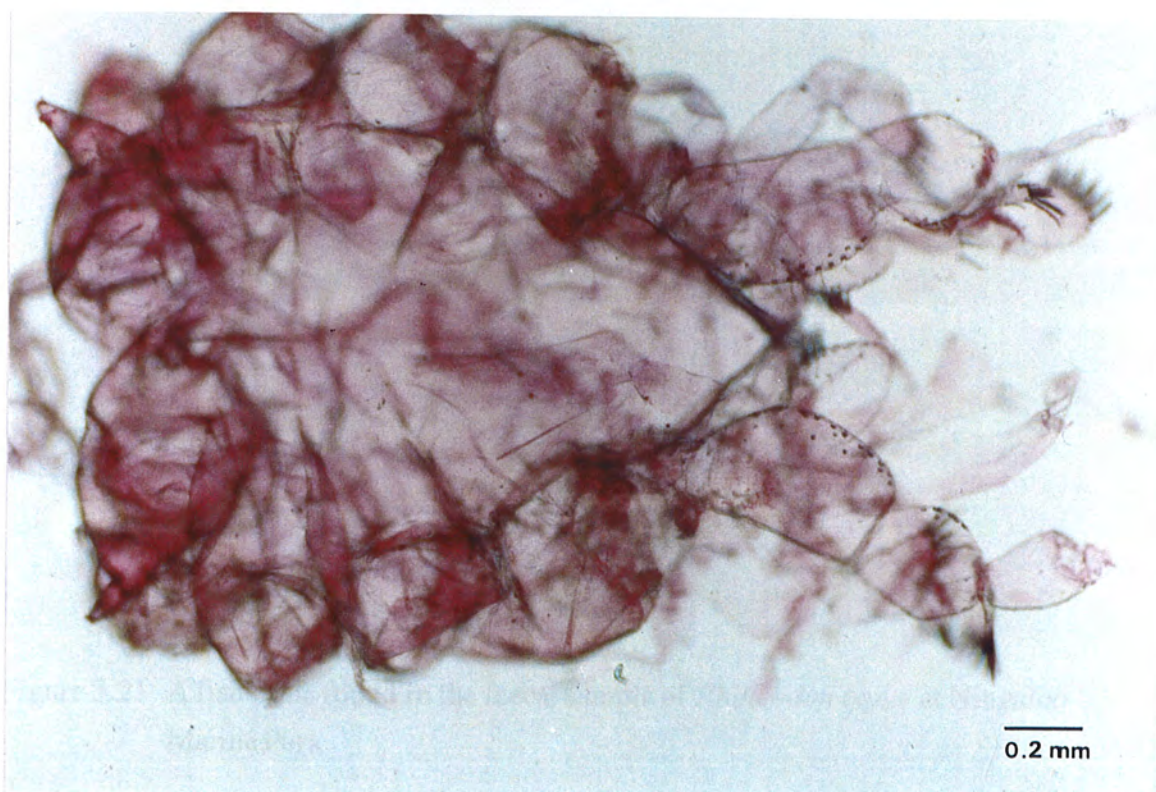
Figure 3.20 Decapod exoskeleton found in the faecal sample of *Rhincodon typus* at

Ningaloo Marine Park.

Figure 3.21   A fish scale found in the faecal sample of *Rhincodon typus* at Ningaloo
Marine Park.

Table 3.1 Comparisons between the length of seven sharks, estimated from the known lengths of a rope and swimmers in the vicinity of the shark, and the length of the shark recorded accurately using the length of a cotton cord placed alongside the shark.

Observed shark (No.)	Total length estimate (m)	Total length measurement (m)	Difference between estimated and measured length (m)
1	3.5	3.2	+ 0.3
2	4.5	4.5	0.0
3	9.0	9.5	- 0.5
4	9.0	9.1	- 0.1
5	5.0	4.9	+ 0.1
6	9.0	9.3	- 0.3
7	5.0	4.7	+ 0.3

Table 3.2 Mean total length and sex ratio of *Rhincodon typus* at Ningaloo Marine Park during 1995, 1996 and 1997. NB. In 1995

and 1996, 12 and 23 animals, respectively, were not able to be sexed. All sharks were able to be sexed in 1997.

Year		n	Mean total length (m)	Length range (m)	Percentage males (%)	n
1995	Personal observations	125	7.0 ± 0.2	3 - 12	71.7	113
	Industry Records	361	7.2 ± 0.1	2 - 13	-	-
1996	Personal observations	177	7.6 ± 0.1	4.5 - 11	91.6	154
	Industry Records	858	7.7 ± 0.1	2 - 14	-	-
1997	Personal observations	58	6.7 ± 0.2	4 - 10	91.4	58
	Industry Records	760	7.0 ± 0.1	2 - 12	-	-
Overall	Personal observations	360	7.2 ± 0.1	3 - 12	84.6	175
(1995-1997)	Industry Records	1979	7.4 ± 0.04	2 - 14	-	-

Table 3.3 Mean lengths ± 1 S.E. of male and female *Rhincodon typus* recorded at Ningaloo Marine Park in 1995, 1996 and 1997.

Year	Females			Males			All sexed sharks		
	n	Range	Mean length (m)	n	Range	Mean length (m)	n	Range	Mean length (m)
1995	32	4.5 - 7	5.9 ± 0.2	81	4 - 12	7.5 ± 0.2	113	4 - 12	7.0 ± 0.2
1996	13	6 - 8.5	6.7 ± 0.3	141	4.5 - 11	7.7 ± 0.1	154	4.5 - 11	7.6 ± 0.1
1997	5	5.5 - 8	6.6 ± 0.5	53	4 - 10	6.7 ± 0.2	58	4 - 10	6.7 ± 0.2
1995-1997	50	4.5 - 8.5	6.2 ± 0.1	275	4 - 12	7.4 ± 0.1	325	4 - 12	7.2 ± 0.1

Table 3.4 Sex and length of each pair of *Rhincodon typus* displaying a circling behaviour at Ningaloo Marine Park in 1995 and 1996.

Date	Encircling shark		Encircled shark	
	Sex	Total Length (m)	Sex	Total Length (m)
6/4/95	M	8	F	5
9/4/95	M	6	F	6
30/3/96	M	9	F	7
3/4/96	M	10	F	6.5

Table 3.5 Mean degree of mouth distension ± 1 S.E. displayed by *Rhincodon typus* during each whale

shark observation period at Ningaloo Marine Park (1995-1997).

NB. 0 = mouth fully closed; 1 = mouth fully open.

Year	n	Mean degree of mouth distension
1995	99	0.14 ± 0.02
1996	173	0.13 ± 0.01
1997	58	0.11 ± 0.02
Overall (1995-1997)	330	0.13 ± 0.01

CHAPTER 4

PHOTOGRAPHIC IDENTIFICATION OF *RHINCODON TYPUS*

4.1 Introduction

The study of animals often requires accurate identification of individuals to determine whether the same or different individuals are under observation. Body markings have been used for this purpose in the case of many species of vertebrates, including, for example, zebra, whales and seals (Briand Peterson, 1972; Hammond, 1986; Bannister, 1990; Hiby & Lovell, 1990; Whitehead, 1990). Indeed, artificial marking and tagging are often considered a prerequisite for behavioural work in the field, while subtle marks on individuals are often used to aid the study of individuals of a species in a specific area (Wursig & Jefferson, 1990).

There is sufficient variation in the natural markings on the flukes of humpback whales (*Megaptera novaeangliae*) and sperm whales (*Physeter macrocephalus*) to enable individuals of these species to be photographed, identified and tracked (Mizroch, Beard & Lynde, 1990; Whitehead, 1990), while the prevalence and pattern of head callosities on southern right whales (*Eubalaena australis*) can be used to distinguish the separate individuals of this species (Bannister, 1990). Alternatively, natural body patterning has been used to identify individuals within other species, including zebras (Briand Petersen, 1972). However, Wursig and Jefferson (1990) indicate that individuals within a species are well-marked if recognised by a matrix of marks, and not simply by a single feature.

Although tagging has been identified as an important aid for identifying individual sharks underwater (Nelson, 1977), recognition is sometimes possible through the use of other features. In a study on white sharks (*Carcharadon carcharias*) for example, Strong *et al.* (1992) were able to recognise a substantial proportion of untagged animals by scars and other markings. Individual *C. carcharias* can also be identified using

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the shape of the caudal fin and the trailing edge of the dorsal fin (K. Goldman, Virginia Institute of Marine Science, U.S.A., pers. comm.), and individual grey nurse sharks (*Carcharias taurus*) can be identified on the basis of the pattern of spots on the skin behind the second dorsal fin (P. Bowman, 540 Jerusalem Road, Moorland NSW, pers. comm.). Myrberg and Gruber (1974) were also able to use fin tears and variations in spot patterns to identify specific bonnethead sharks (*Sphyrna tiburo*).

Body patterning is present on the skin of many sharks that live on or near the ocean floor, which may serve as camouflage (Myrberg, 1991). *Rhincodon typus*, which is closely related to bottom-dwelling sharks (Chapter 1), possesses an intricate pattern of lines and spots on the dorsal surface of their body, which appears to disrupt their outline when viewed from a distance (Fig. 4.1). There is thus the potential for identifying individual *R. typus* using photographs of this patterning or the shape of the dorsal and caudal fin (Arnbom & Papastavrou, 1988; Taylor, 1994). Arnbom and Papastavrou (1988) used a deep cut in the trailing edge of the dorsal fin to distinguish an individual *R. typus* in the Galapagos Islands, while size and pattern of scars enabled a whale shark to be re-identified at different sites within the South China Sea over a seven year period, in an area encompassing about 10 000 km (O'Brien, 1994). Distinct scarring of the left pectoral fin was also used to aid in the documentation of an individual *R. typus*, resighted over four consecutive days in 1996 near Sumatra (M. van der Burg, Stingray Dive Centre, Indonesia, pers. comm.).

The aims of this section of the study were (i) to establish a method for identifying individual *R. typus* on the basis of natural and other markings, (ii) determine whether these markings change over time, (iii) to use photographs of *R. typus* exhibiting these markings to determine whether the same whale sharks are observed repeatedly during the same 'season', and (iv) whether the same whale sharks tend to return to Ningaloo Marine Park (NMP) in successive years. This process was facilitated by the constuction of the first comprehensive Whale Shark Photo-identification Library.

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4.2 Materials and methods

A Nikonos V underwater camera equipped with a 15 mm wide-angle lens and viewfinder was used to photograph scars and the natural skin patterning of *R. typus* during tourist interactions at NMP. Patterning is present on all of the dorsal and most of the lateral areas of the sharks' body. Initial attempts to use an area on the dorsal region of the head (Fig. 4.2) for identification purposes were unsuccessful as it was rarely possible to position oneself above the head of each shark for photography. Alternatively, the region immediately posterior to the fifth gill slit on the left and/or right side was selected to distinguish between individual *R. typus*.

Rhincodon typus is reported to lack a sub-terminal notch on the upper lobe of the caudal fin (Last & Stevens, 1994). However, at the beginning of the current study, several photographs were taken of sharks with what at first appeared to be a small scar at this location. All whale sharks (with caudal fin intact) observed at NMP possessed this feature, which appears to be a natural sub-terminal notch (Fig. 4.3). This feature was therefore considered not suitable as a distinguishing feature between individual *R. typus*.

Kodak Elite-100 slide film was used throughout the duration of the study (1995-1997). The time and date when these photographs were taken were archived prior to processing at Kodak-Australia (Perth).

A UMAX Vista-S6E colour scanner was purchased in 1996 using funds provided by the WA Department of Commerce and Trade, to assist with the analysis and storage of identification photographs. All photographs were scanned in greyscale and at low resolution to minimise file size (usu. 200 dpi), using Adobe Photoshop 3.0, and saved as PICT files on the hard drive of a Macintosh Performa 6200 computer. Suitable scanned photographs of scars present on the fins, dorsal surface, or the flanks of *R. typus* were stored in folders titled either 1) dorsal fin scar, 2) right pectoral fin scar, 3) left pectoral fin scar, 4) caudal fin scar, 5) miscellaneous scar (see for example Figs 4.4 - 4.8).

Photographs of natural skin patterning were stored in folders titled either 1) vertical striping (left or right side), 2) longitudinal striping (left or right side) or 3) diagonal striping (left or right side) (see for example Figs 4.9 - 4.11).

Photographs of sharks were analysed by eye, and when a shark was found that was different, a new entry in the Whale Shark Photo-identification Library was formed (Library 1). Individual whale sharks were then allocated an identification number, *i.e.* A-001 to Z-999. Filemaker Pro 3.0 was used for the establishment of this library, and each entry included the 'type' specimen identification photographs, a description of markings, and relevant sighting information, *i.e.* sex, size, date, location (Fig. 4.12).

4.3 Results

The Whale Shark Photo-identification Library was compiled from photographs taken during observations of *R. typus* at NMP between 1995 and 1997. In order to establish that the features used to distinguish individual *R. typus* do not change over time, photographs were taken of various animals and compared with those taken when those sharks were subsequently resighted. Several individual sharks were observed with what appears to be 'bite' marks which may have been inflicted by a predatory shark. These marks were mainly superficial and considered likely to fade over time.

Shark A-012 was first sighted on 24 March 1996, and then resighted on a further 13 different occasions during the 1996 whale shark season (26/3/96, 31/3/96, 3/4/96 (x3), 23/4/96 (x2), 26/4/96, 28/4/96 (x3), 2/5/96 (x2)). When first photographed (24/3/96), the shark exhibited white 'scratches' on the left flank, immediately anterior to the caudal peduncle (Fig. 4.13). However, subsequent observations showed that these scratches healed rapidly. The scarring was detectable only because the colour of the skin at this location was slightly darker when the shark was resighted on 2/5/96 (Fig. 4.14). Similarly, shark A-010 was first photographed on 28 March 1996 with a black, recently-

healed scar on the right flank and, when resighted on 26 March 1997, the discolouration to the skin at this location was still evident. Positive identification of both animals was confirmed by matching the pattern of lines and spots behind the gill slits on the left side of the animal.

However, many sharks exhibit gross scarring (e.g. A-035) and photographs taken between 1995 and 1997 indicate that this scarring remains unchanged for at least a three years (Figs 4.15, 4.16). In addition, the pattern of lines and spots immediately posterior to the gill slits on both the left and right sides of individual *R. typus* is unique, and remains unchanged between years (Figs 4.17, 4.18).

In 1995, it was possible to determine the identity of 17 individual *R. typus* from 125 observations, with eight of these animals being resighted more than once and comprised 39 of the total observations. From a further 177 observations during 1996, it was possible to identify 36 animals, 20 of which were sighted more than once (*i.e* 106 of 177 samples). Only 58 observations on *R. typus* were possible in 1997, with ten animals identified, of which seven were resighted within the season on a total of 32 occasions (Table 4.1). Between 1995 and 1997, a total of 52 separate *R. typus* could be individually identified using scars and/or natural patterning (Library 1). Six animals (A-001, A-009, A-011, A-029, A-031, A-033) were seen at NMP in both 1995 and 1996, while four individuals (A-010, A-013, A-020, A-023) were seen in both 1996 and 1997, and one shark (A-035) was recorded here in 1995 and 1997. No individual sharks were recognised at NMP in all three years (1995-1997).

4.4 Discussion

The Whale Shark Photo-identification Library produced for this thesis provides the first comprehensive attempt to identify individual *R. typus* within NMP, and document whether any of those sharks return in subsequent years. By using either body

scarring and/or the natural patterning of lines and spots on each *R. typus*, it was possible to naturally 'tag' these animals using photographs.

Wounds and abrasions on the skin of animals have previously been used to identify individual animals even though it is not certain exactly how long these marks might last (Wursig & Jefferson, 1990). Bruce-Allen and Geraci (1985) report that wounds on dolphins become 'repaired' within seven days and consider that, although the wounds are still visible as white marks, normal pigmentation is restored with time. Fish also exhibit a rapid rate of wound closure, which is important in an aquatic environment (Anderson & Roberts, 1975). However, very little information is available on the healing of skin wounds on sharks (Reif, 1978). Experiments on a leopard shark (*Triakis semifasciata*) and a nurse shark (*Ginglymostoma cirratum*), showed that wounds were covered with mucus for more than two weeks after a piece of skin was removed from each of these animals. After only three weeks, the epidermis had regenerated, leaving a scar with the same pigmentation as the normal epidermis (Reif, 1978). Blacktip Reef sharks (*Carcharhinus melanopterus*) observed at Pt Defiance Aquarium (Washington, U.S.A.), required 2-3 weeks before scar tissue had closed wounds caused by a lemon shark (*Negaprion brevirostris*) and a sand tiger shark (*Carcharias taurus*) (E. Williams, Pacific Rim Shark Studies Center, U.S.A., pers. comm.). Freeze brand scars in lemon sharks disappear within several months, while small (3 mm) scars from where tissue samples were removed are almost unnoticeable after 12 months (S. Gruber, University of Miami, U.S.A., pers. comm.).

Several whale sharks at NMP exhibit white superficial scarring on some part of their body, and these were initially believed to be useful for re-identifying individuals. However, the rapid heal rate exhibited by A-012 indicates that superficial scarring cannot be used for long-term recognition of individual sharks, although there was some evidence (*i.e.* A-010) that skin discoloration can last for up to one year. Indeed, Taylor (1994) reports that the deep gashes observed along the flank of a shark sighted in 1986 had healed without any scarring when resighted in 1993. In contrast,

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gross scarring, such as a truncated caudal fin (e.g. A-002), will not regenerate and can therefore be used as a long-term feature for the recognition of individual whale sharks.

Although several species of shark have scars that may have resulted from mating activities, the bite-like scars present on a number of *R. typus* at NMP (e.g. A-016, A-017, A-042, A-054) would not have been the result of mating activity, as the teeth of *R. typus* are very small and covered by skin (Chapter 1). These scars may, however, have been caused by other predatory sharks when the individual was very small. However, several *R. typus* observed at NMP exhibit scars or fin truncations that appear to have been the result of boat contact (see Library 1; Chapter 7).

Rhincodon typus are born with their own individual body patterning (Fig. 4.19) which is equally distinctive in both sub-adult and adult whale sharks (Fig. 4.20), and does not appear to fade with maturity. This contrasts with the striped patterning present on the skin of juvenile tiger sharks, (*Galeocerdo cuvier*) (Fig. 4.21), which fades in adults (Compagno, 1984c) (Fig. 4.22). Analysis by eye of the patterning of lines and spots behind the fifth gill slit on both the left and right sides of *R. typus*, has established that this patterning is unique to each individual and does not change over at least a three year period. It can therefore be used with confidence to distinguish between individual whale sharks.

A photograph of a whale shark taken at NMP in 1994, and published in The West Australian newspaper (15/5/94), can be identified as shark A-041 (see Library 1). Another shark (A-042) was recorded at NMP on three separate occasions during the course of the present study, and can be recognised as the same individual found there in 1986 (Taylor, 1994). Shark A-001, which had previously been tagged by CSIRO scientists in 1994 (J. Stevens, unpub. data), was recorded at NMP in both 1995 and 1996 (see Table 1). Positive re-identification of individual *R. typus* demonstrates that future input to this library from the general public would be valuable. However, attempts to obtain whale shark identification photographs from tour boat operators during the present study (1995-1997), were generally unsuccessful as very few of the photographs

were of suitable quality and/or were not accompanied by necessary sighting data. It should be noted that, unless an experienced observer swam inverted and completely below the pelvic fins of the whale shark, immature males (the most common class observed at NMP) with small claspers (Chapter 3) were often recorded by tour operators as females. The Whale Shark Photo-identification Library has been compiled using photographs and data collected by a single observer/researcher. The assistance of the general public in adding to this library in the future would be valuable, providing the necessary data accompanies any suitable photograph/s.

An identification library based on natural markings will provide the opportunity to conduct estimates of population size and return rates of *R. typus* to NMP in the ensuing years. However, as is possible in any mark-recapture study, errors in identification are more likely when using photographs of natural markings (Hammond, 1986). Several sharks identified within the whale shark identification library have been seen at NMP prior to the current study (J. Taylor, pers. comm.). Of the 52 sharks identified within the Whale Shark Photo-identification Library, 32 were sighted on more than one occasion, and 11 were sighted in separate years. Considering that only a subset of the total number of whale shark's sightings were recorded each year by the author (see Chapter 5), the size of the whale shark assemblage that returns to NMP each year may be much larger than previously suggested by Taylor (1994).

The photographic identification of whale sharks using natural markings will be facilitated over time by the refinement of the current techniques used for acquiring and storing photographs for this purpose. The whale sharks were photographed for identification purposes, while the photographer was swimming alongside the animal. However, not all sharks could be identified as there was often insufficient time to manoeuvre into a suitable position to take a useable identification photograph before the opportunity was lost. Proximity to the whale shark is very important as fine morphological details can gradually become undetectable with increasing distance from the shark (Nelson, 1977).

The method currently employed for identifying *R. typus* would be less invasive if photographs could be taken from land or a boat, as has been done in the case of dolphin research (Wursig & Jefferson, 1990). However, this is probably not possible for studies on whale sharks as, although the fins of these sharks occasionally break the surface, they usually swim with all of their body below the water surface. Present restrictions include the location of the sharks (*i.e.* in the open ocean), and both the clarity of water and the means of obtaining underwater photographs of a moving shark. Advances in technology, including the use of less bulky cameras for underwater photography, dual cameras for stereophotometry (to accurately determine shark length) and a motorised underwater propulsion unit for the researcher (to alleviate blurring), may ensure that the best photographs can be obtained of the identifiable marks and patterning present on a whale shark. It is important that this photographic identification database is (i) periodically re-assessed, (ii) updated to include the best and most recent photographs of individuals, and (iii) includes, where possible, photographs of all identifying features.
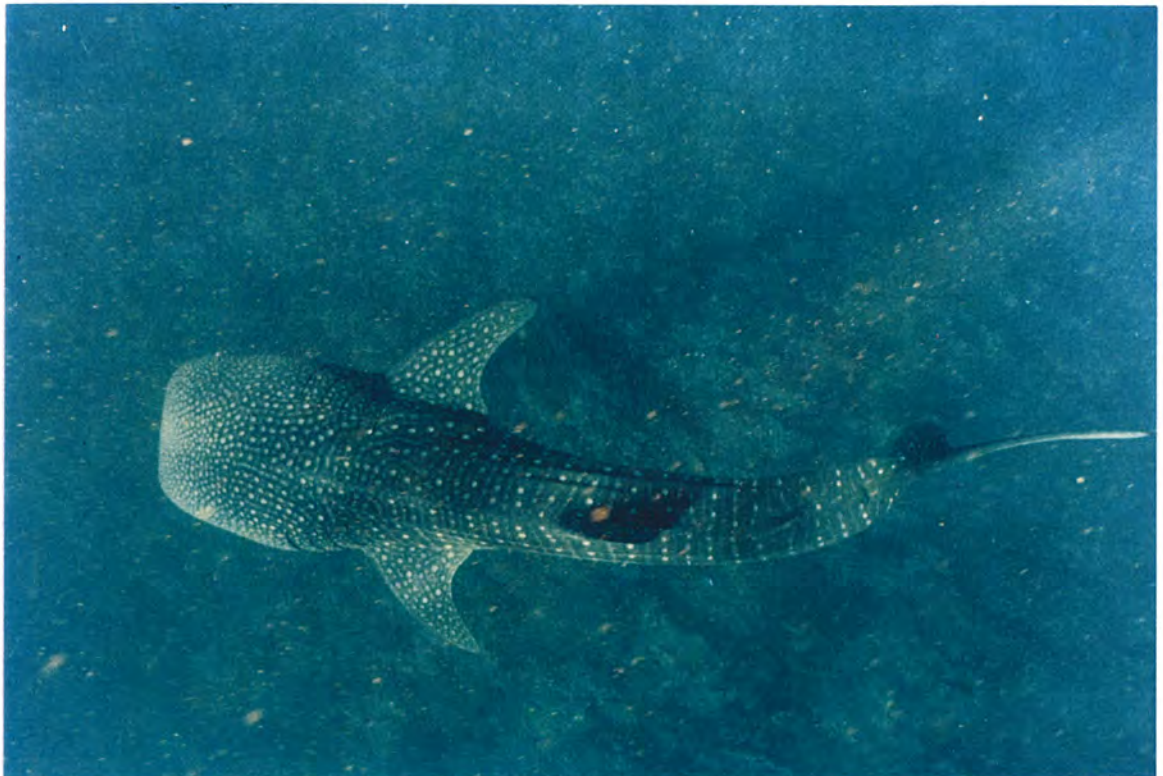
Figure 4.1 *Rhincodon typus* near the ocean floor at Ningaloo Marine Park, showing the effect of the natural patterning as camouflage.
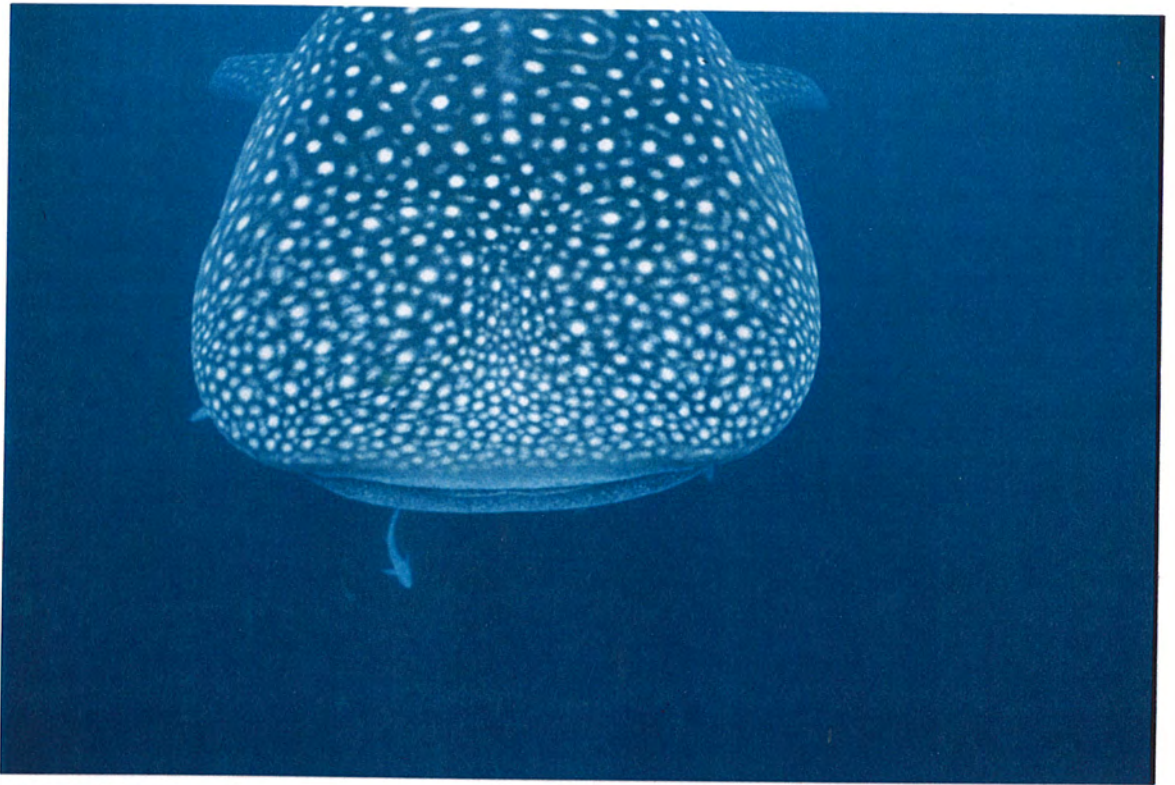
Figure 4.2 Natural patterning on the dorsal region of the head of *Rhincodon typus*.
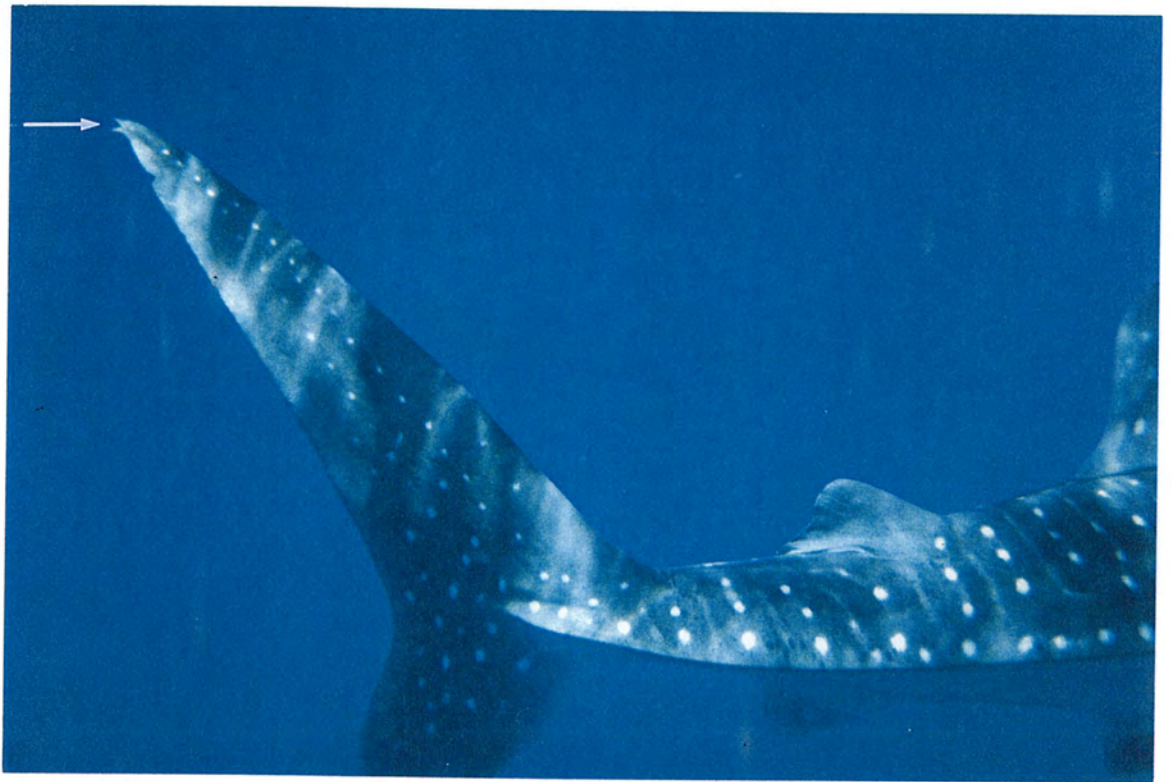
Figure 4.3 Sub-terminal notch on the upper lobe of the caudal fin of *Rhincodon typus*.
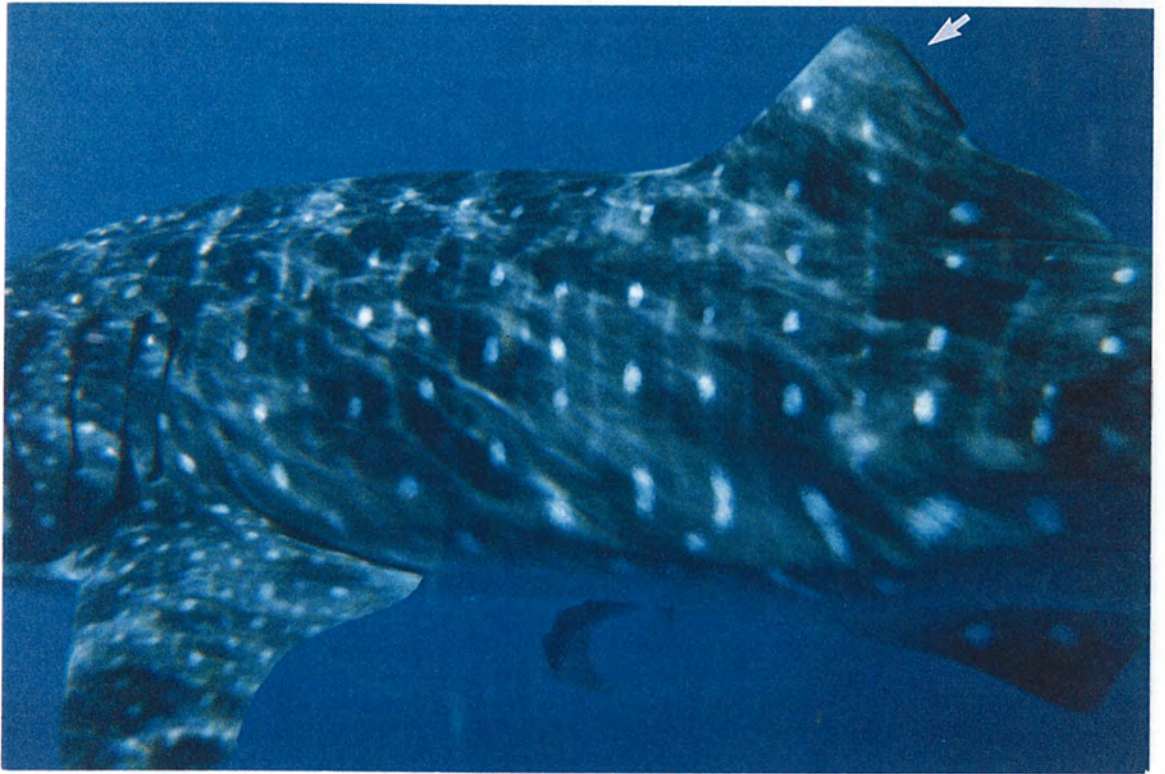
Figure 4.4 An example of dorsal fin scarring.
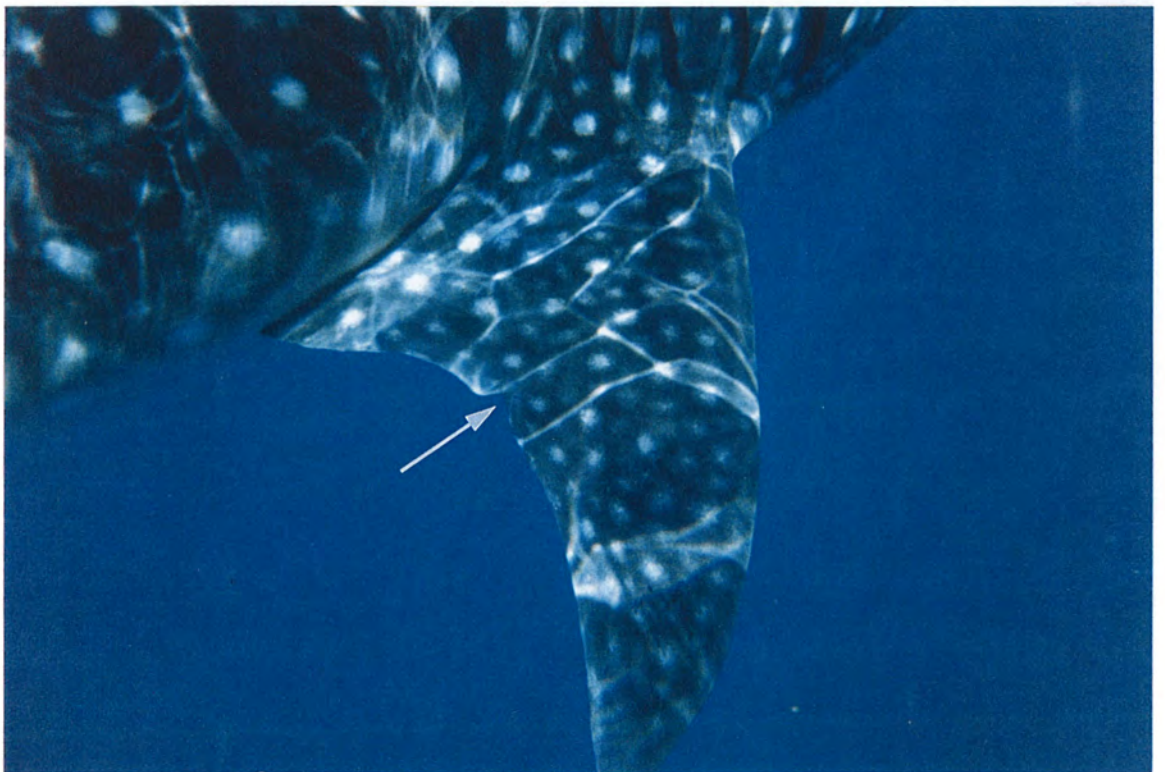
Figure 4.5 An example of right pectoral fin scarring.
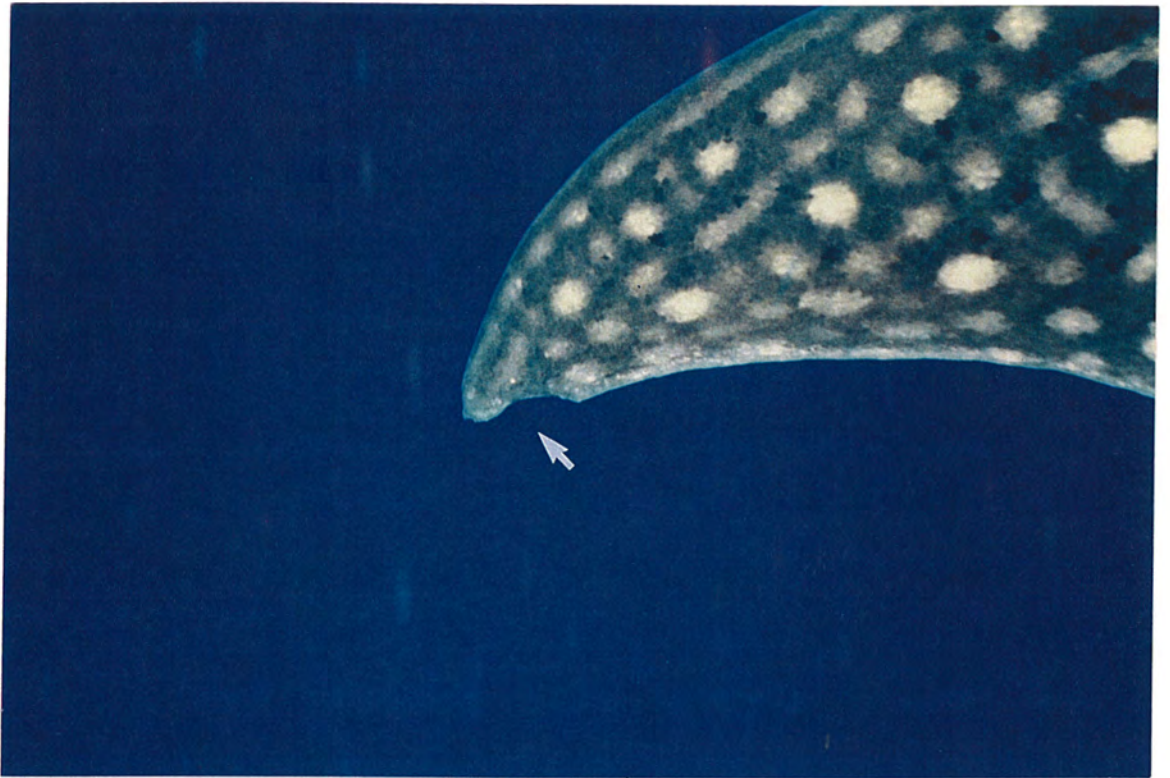
Figure 4.6 An example of left pectoral fin scarring.
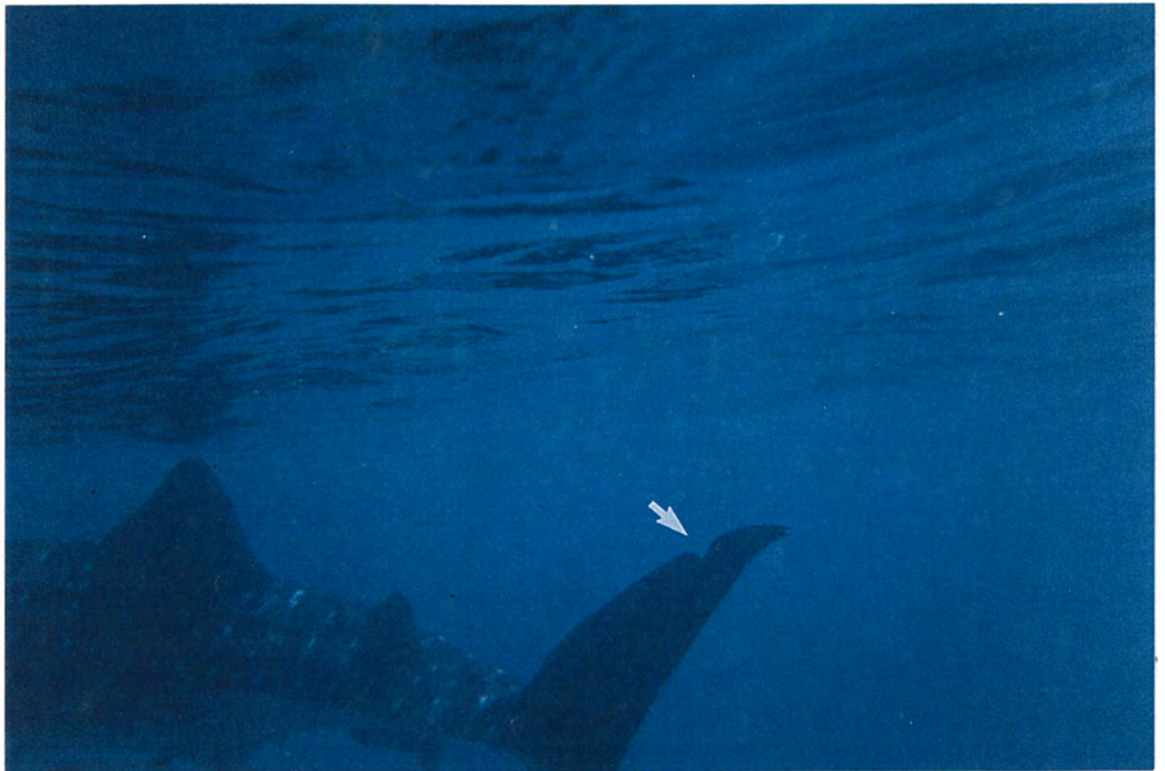
Figure 4.7 An example of caudal fin scarring.
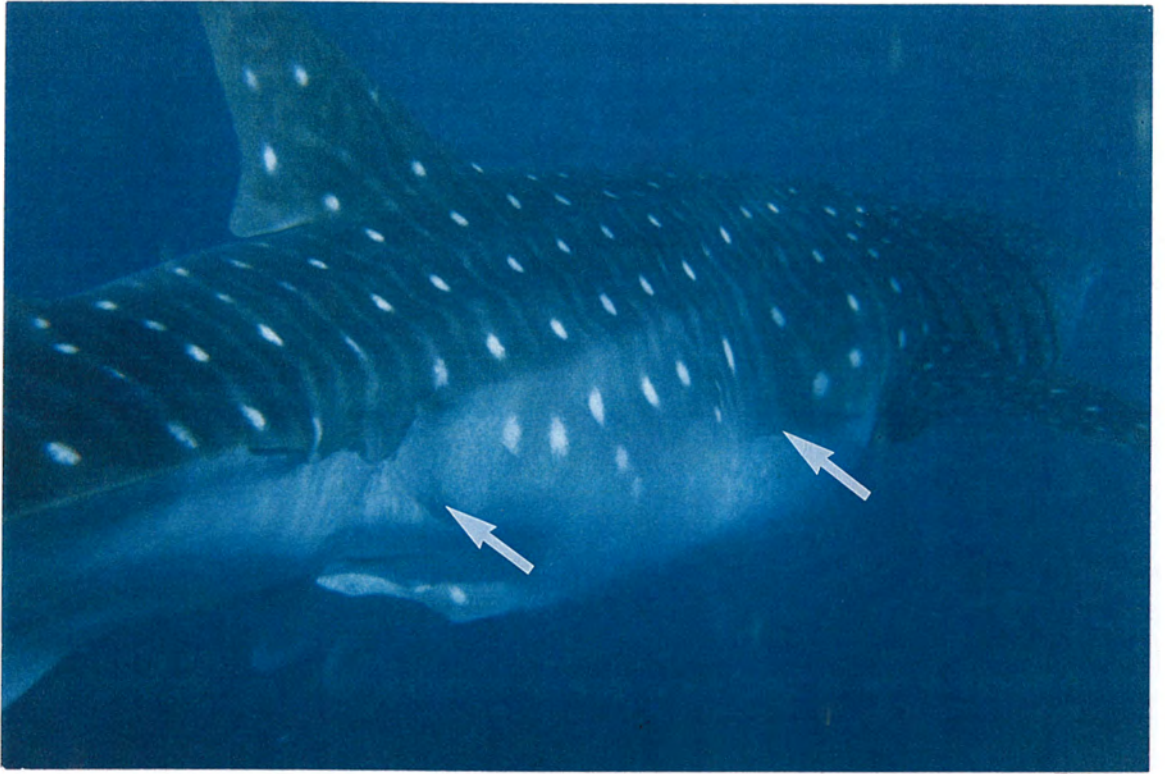
Figure 4.8 An example of miscellaneous scarring.

Figure 4.9 An example of patterning dominated by vertical striping.

Figure 4.10 An example of patterning dominated by longitudinal striping.
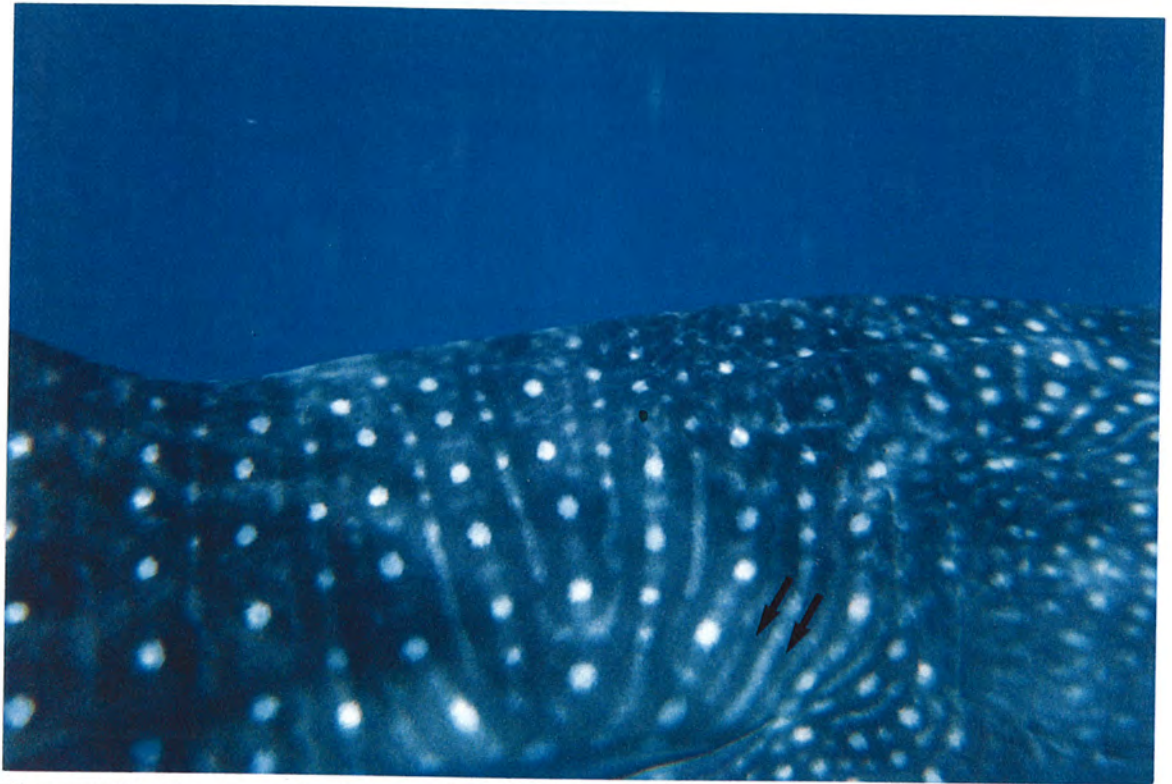
Figure 4.11 An example of patterning dominated by diagonal striping.

Whale Shark Photo-identification Library

Shark identification number: e.g. Z-999

Sex: e.g. male

Size: e.g. 10 m

Date and location of sighting:

a)   b)

e.g. 9/9/99 lat & long   e.g. 19/9/99 lat & long

a)

photo	text

b)
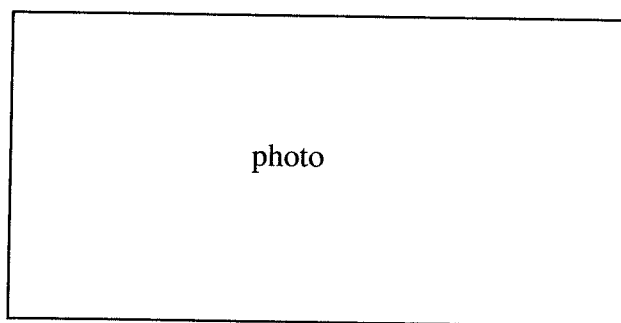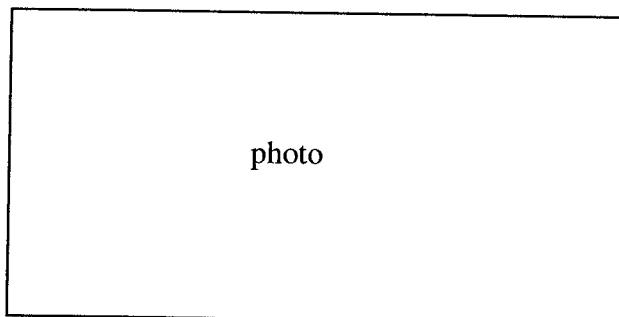
photo	text

Figure 4.12 Sample of information sheet in the Whale Shark Photo-identification Library
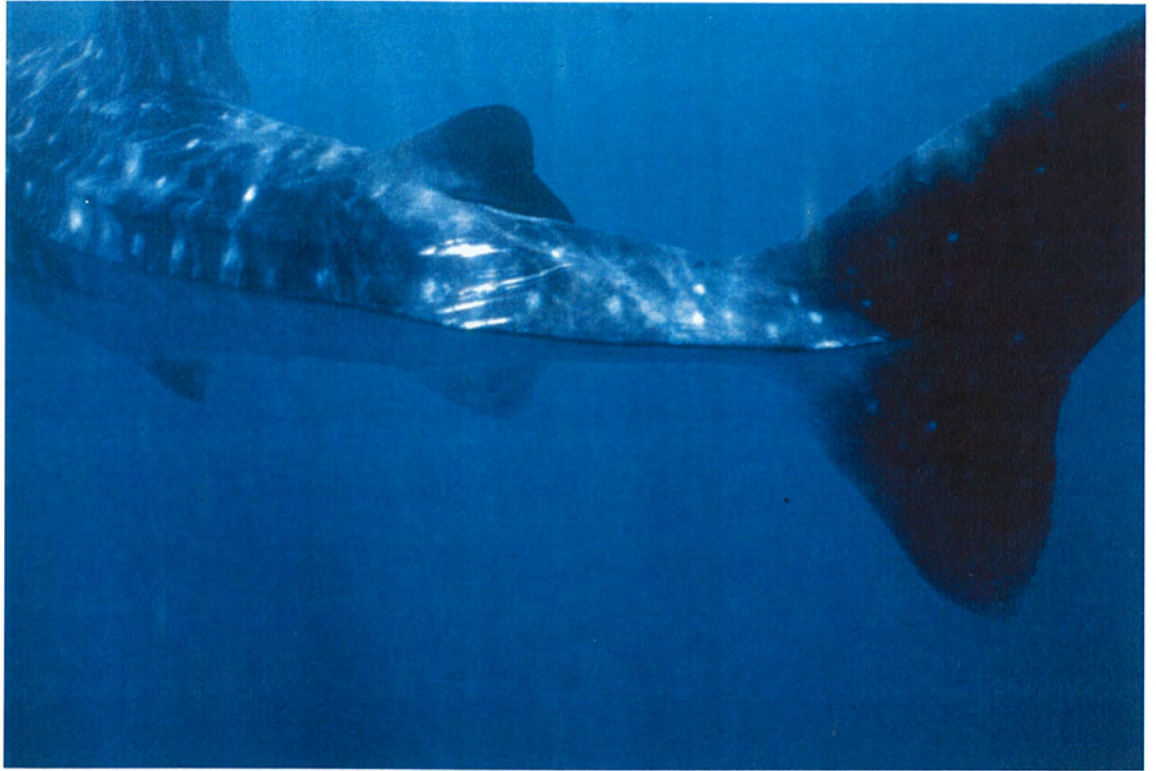
Figure 4.13 Shark (A-012) photographed on 24/3/96 with recent superficial scarring to the left flank.
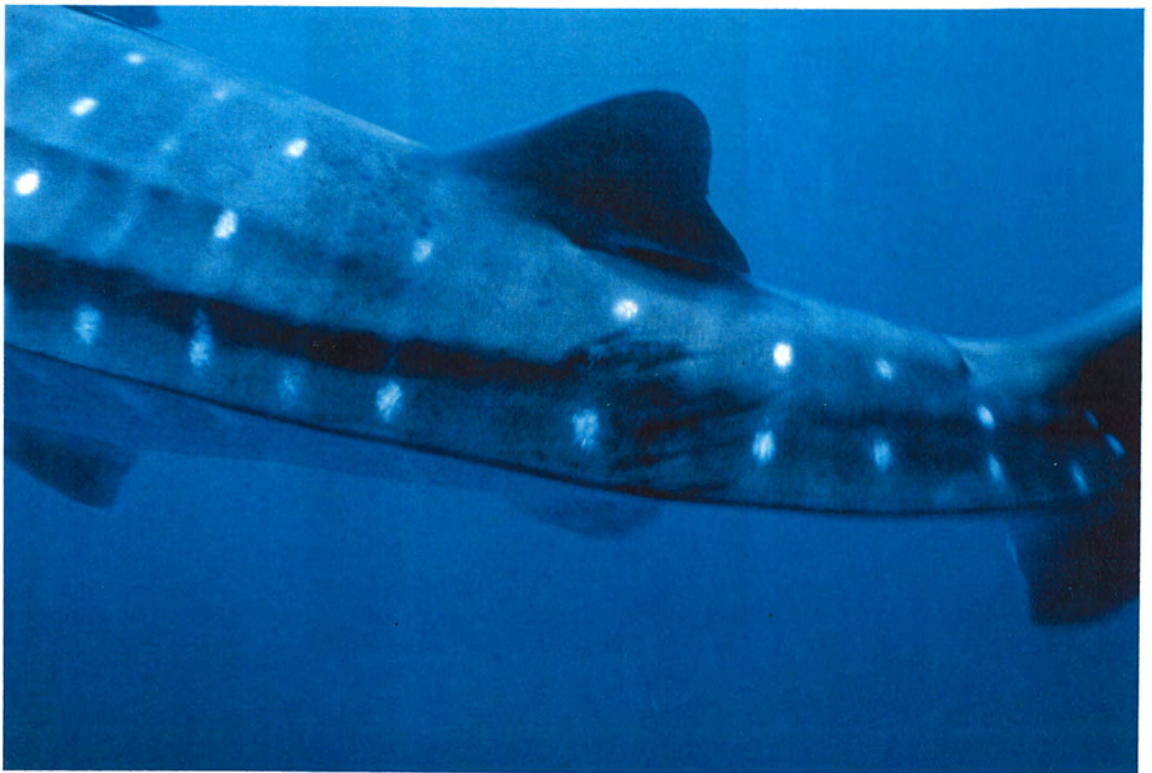
Figure 4.14 Shark (A-012) photographed on 2/5/96 with healed scar, leaving only a darkened area of skin at this site.
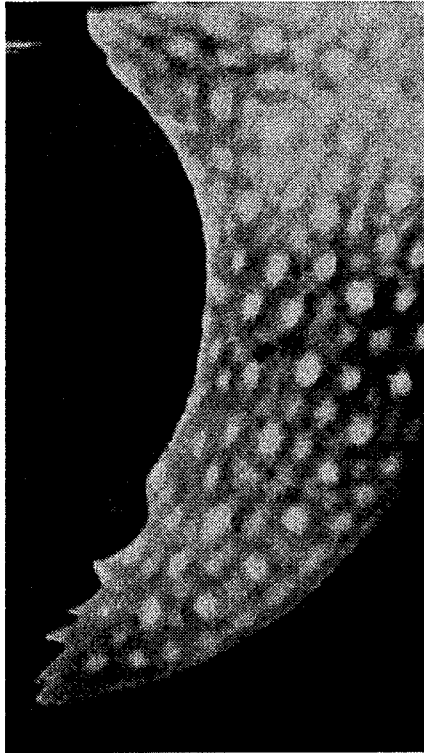
Figure 4.15 Shark (A-035) photographed in 1995 with scarring on the right pectoral fin.
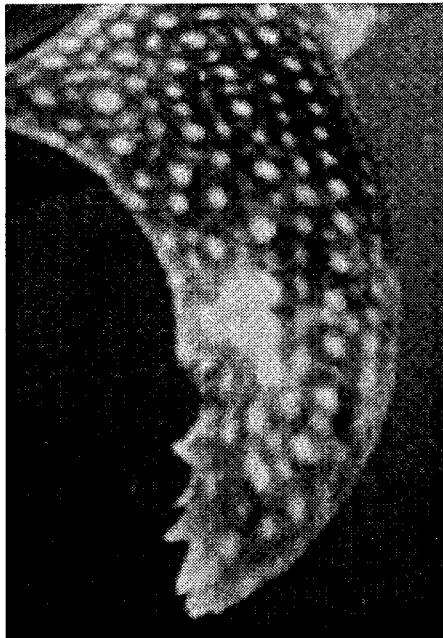
Figure 4.16 Shark (A-035) photographed in 1997 with scarring on the right pectoral fin.

Figure 4.17 Patterning on shark (A-035) photographed from the right side in 1995.
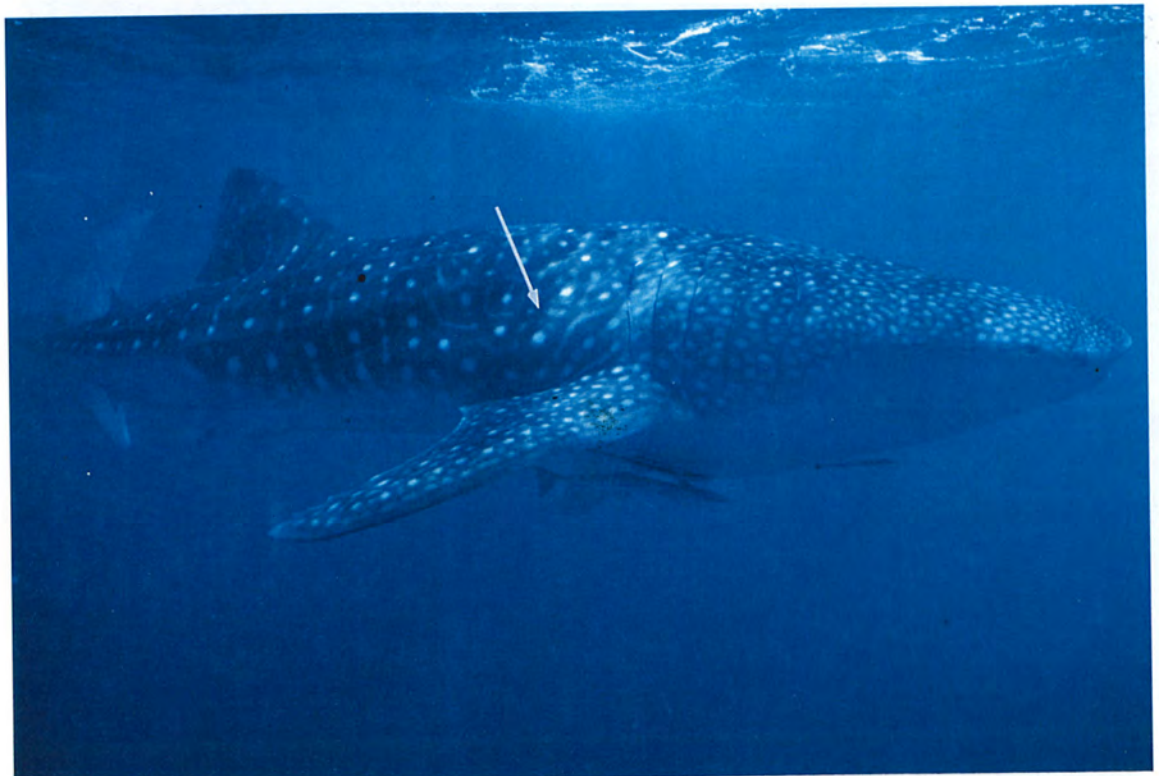
Figure 4.18 Patterning on shark (A-035) photographed in 1997.

Figure 4.19 Photograph of a juvenile *Rhincodon typus* (*ca* 0.5 m) showing intricate
body patterning.
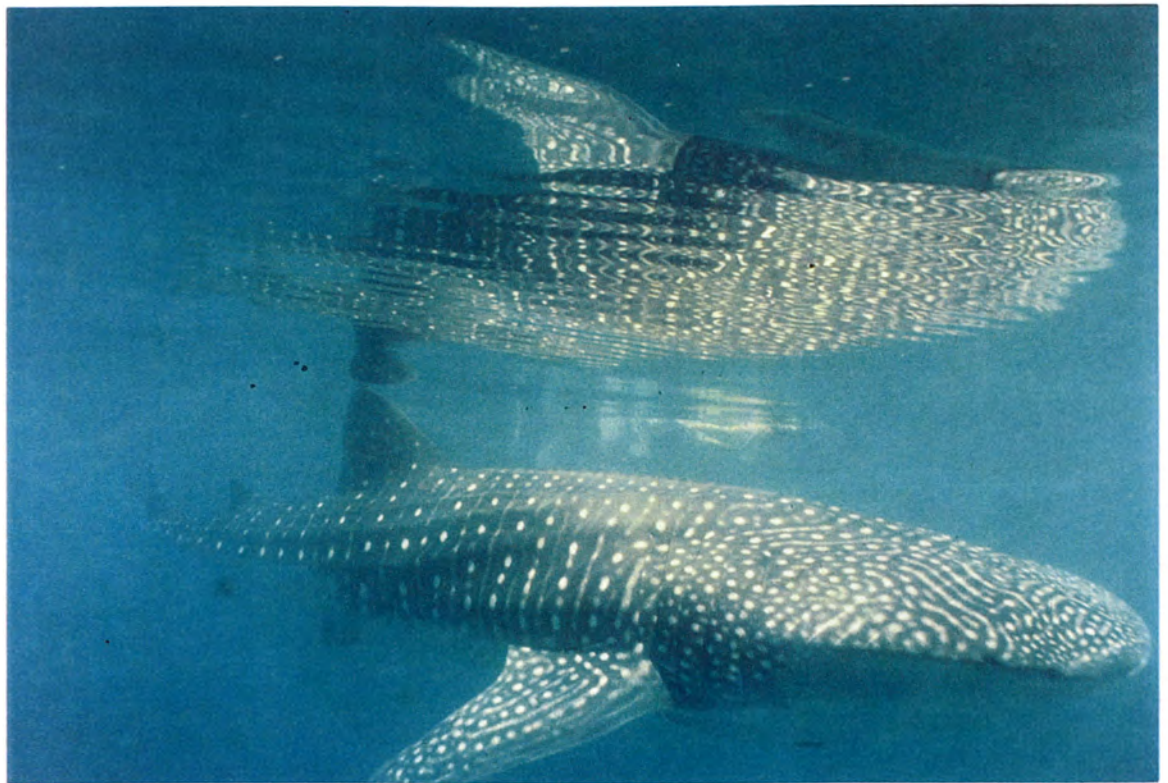
Figure 4.20 Photograph of an adult *Rhincodon typus* (*ca* 10 m) showing that the intricate
body patterning remains through to maturity.
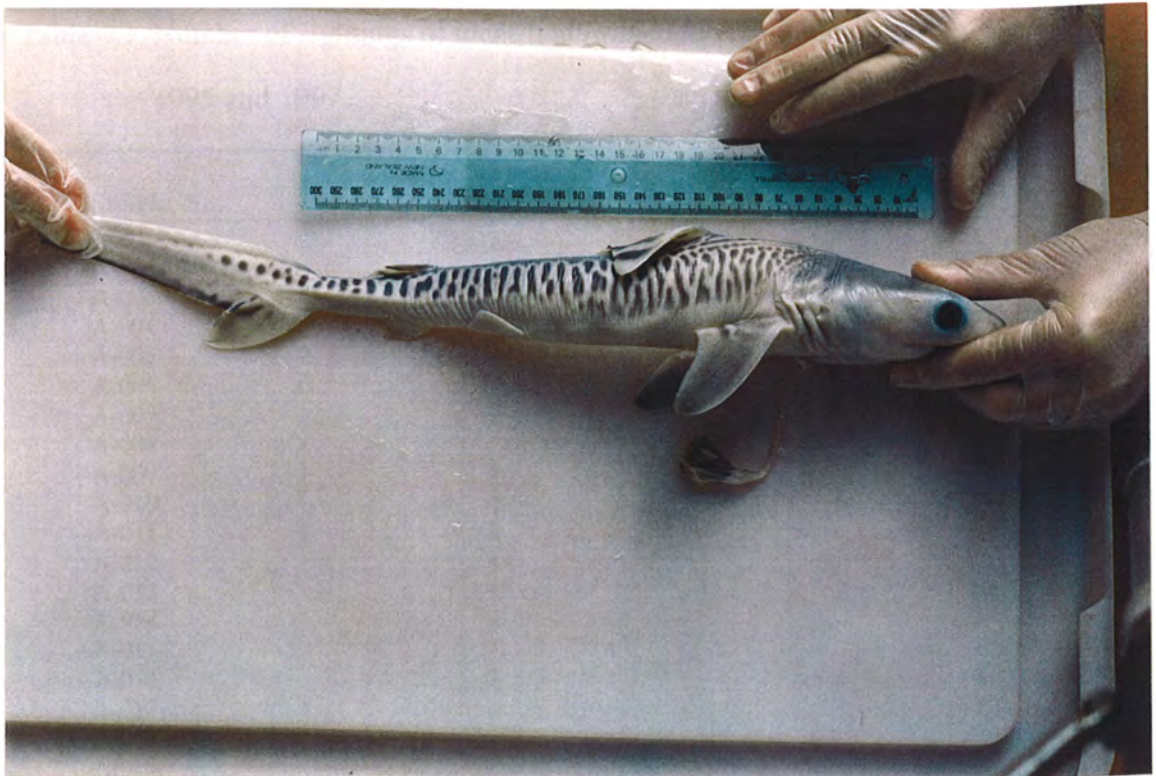
Figure 4.21 Photograph of a juvenile tiger shark (*Galeocerdo cuvier*) (0.4 m) showing intricate body patterning.

Figure 4.22 Photograph of an adult tiger shark (*Galeocerdo cuvier*) (*ca* 5 m) showing little body patterning (courtesy R. McAuley).

Table 4.1 Number of sightings of identified *Rhincodon typus* recorded between

1995 and 1997.

Shark No.	1995	Number of sightings 1996	1997	Total (1995-1997)
A-001	2	1		3
A-002		1		1
A-003	5			5
A-004		1		1
A-005	2			2
A-006	6			6
A-007		1		1
A-008	1			1
A-009	1	4		2
A-010		4	5	9
A-011	1	3		4
A-012		14		14
A-013		12	4	16
A-014		2		2
A-015		1		1
A-016		3		3
A-017	1			1
A-018				2
A-019				5
A-020		1	7	8
A-021		7		7
A-022	3			3
A-023		4	3	7
A-024		2		2
A-025		2		2
A-026		5		5
A-027		7		7
A-028		1		1
A-029	1	2		3
A-030		1		1
A-031	7	3		10
A-033	1	2		3
A-035	1		2	3
A-036		3		3
A-037			4	4
A-038		1		1
A-039		1		1
A-040		1		1
A-041	2			2
A-042	3			3
A-043	1			1
A-044		1		1
A-045		1		1
A-046		1		1
A-047		6		6
A-048		1		1
A-049	1			1
A-050		2		2
A-051			1	1
A-052			4	4
A-053			1	1
A-054			1	1
Total	**39**	**106**	**32**	**177**

Library 1

Whale Shark Photo-identification Library
Ningaloo Marine Park
(1995 - 1997)

Whale Shark Photo-identification Library

Shark identification number: A-001

Sex: male

Size: 7.5 m

Date and location of sighting:

a) 13/06/95 - $21^0$59.587S $113^0$53.943E   b) 19/05/96 - $22^0$47.263S $113^0$39.163E

a) Left patterning highlighted by few lines, while spot sequence is orientated downwards at *ca* 30^0.

b) Upper lobe of caudal fin severely damaged, resulting in this lobe being far smaller than the lower lobe.

c) Right patterning is highlighted by few lines, with spots orientated downwards at *ca* 30^0.

Whale Shark Photo-identification Library

Shark identification number: A-002

Sex: male

Size: 8 m

Date and location of sighting:

a) 03/04/96 - $21^0$56.148S $113^0$54.956E

a) Left patterning is simple with lines and spots evenly spaced. A bright white spot is obvious at the most dorsal point of the 4th gill slit.
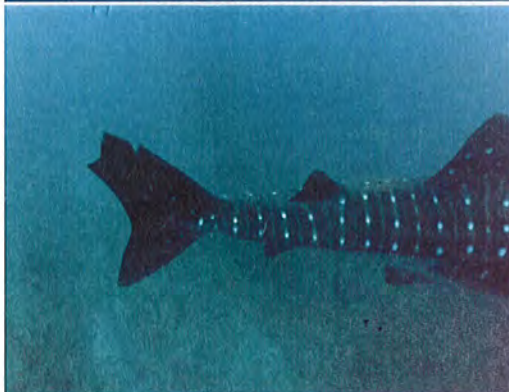
b) Upper lobe of caudal fin has been truncated, approximately 1/3 of the distance from the terminus. A vertical cut is conspicuous on the leading edge of this fin, ventral to the point of truncation.

Whale Shark Photo-identification Library

Shark identification number: A-003

Sex: male

Size: 5.5 m

Date and location of sighting:

a) 26/06/95 - 22^{0}03.005S 113^{0}52.839E
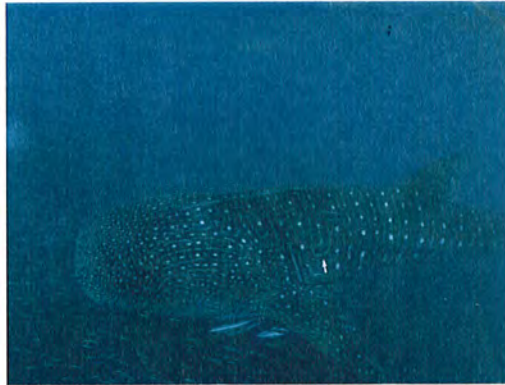
a) Left patterning highlighted by an essentially vertical stripe immediately posterior to the 5th gill slit. Immediately dorsal to the insertion point of the trailing edge of the left pectoral fin, two vertical lines are fused via a longitudinal stripe to form a U-shaped pattern.

b) Trailing edge of the first dorsal fin is serrated.

c) The terminal section (*ca* 5 mm) of the upper lobe of the caudal fin has been vertically truncated.

Whale Shark Photo-identification Library

Shark identification number: A-004

Sex: male

Size: 8.5 m

Date and location of sighting:

a) 04/04/96 - 21^{0}55.407S 113^{0}54.270E
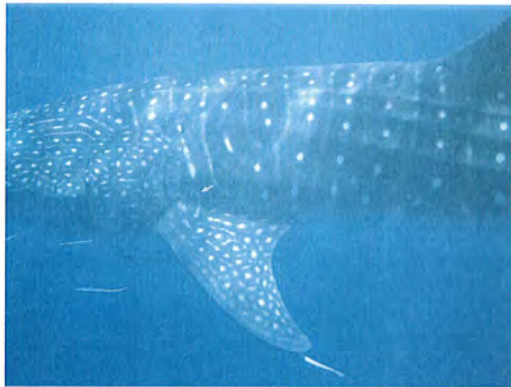
a) Left patterning is lightly defined. A small but conspicuous anteriorly-directed crescent-shaped line can be seen immediately posterior to the lower portion of the 5th gill slit.

b) Right patterning characterised by spots aligned vertically between the 4th and 5th right gill slits. Near the ventral origin of the right pectoral fin, three lines project horizontally to the posterior insertion point of the pectoral fin.

c) A large bulge (*ca* 10 cm in diameter), extends on either side of the upper lobe of the caudal fin, and is proximally located *ca* 50 cm from the terminus of this fin.

Whale Shark Photo-identification Library

Shark identification number: A-005

Sex: male

Size: 4.5 m

Date and location of sighting:

a) 30/05/95 - $21^0$53.00S $113^0$56.20E

a) Left patterning distinguished by spots and lines behind the 5th gill slit orientated downward at an angle of approximately 30^0.

b) Right patterning orientated in a predominantly vertical arrangement. Immediately dorsal to the insertion point of the trailing edge of the left pectoral fin, two vertical lines are fused via a horizontal stripe to form a U-shaped pattern.

c) A small triangular piece (*ca* 15 cm) of the trailing edge of the upper lobe of the caudal fin is missing from a point *ca* 20 cm from the terminus.

d) Several small nicks can be seen *ca* 15 cm from the most ventral part of the trailing edge of the 1st dorsal fin.

Whale Shark Photo-identification Library

Shark identification number: A-006

Sex: male

Size: 8 m

Date and location of sighting:

a) 06/06/95 - $21^0$53.00S $113^0$56.4E   b) 12/06/95 - $22^0$06.50S $113^0$52.00E

c) 14/06/95 - $22^0$03.294S $113^0$53.084E

a) Left patterning characterised by two vertical lines that have almost joined to form an 'hour-glass' configuration, adjacent to the mid-point of the left pectoral fin

b) Right patterning is distinguished by spots and lines posterior to the 5th gill slit that appear well-defined, and essentially orientated downward at an angle of approximately 30^0.

c) A number of closely spaced nicks are present just proximal to the terminus of the trailing edge of the upper lobe of the caudal fin. NB: These are distinct from the sub-terminal notch.

d) Left side anal fin has 3 small semi-circular pieces missing from trailing edge.

Whale Shark Photo-identification Library

Shark identification number: A-007

Sex: male

Size: 9.5 m

Date and location of sighting:

a) 14/04/96 - 21^{0}58.907S 113^{0}54.543E
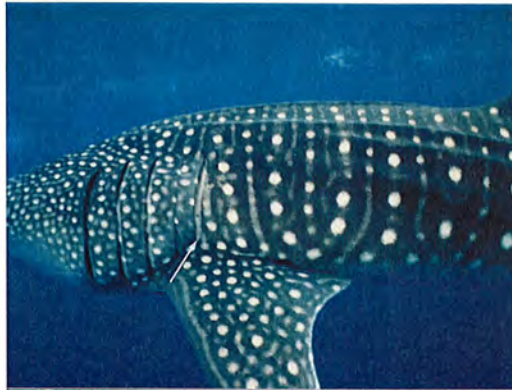
a) Left patterning characterised by sharply defined spots, predominantly orientated vertically. Immediately posterior to the 5th gill slit, a line of spots appear tightly 'bunched' to form an essentially vertical line.

b) Right patterning distinguished by spots and lines behind the 5th gill slit orientated downwards at *ca* 30^0, although a longitudinal line is directed caudally from the most dorsal point on the 5th gill slit.

c) A small (*ca* 8 cm) crescent-shaped piece of flesh is missing from a point on the trailing edge of the left pectoral fin, immediately proximal to the terminus.

d) The trailing edge of the upper lobe of the caudal fin is characterised by having an additional nick missing, immediately anterior to the subterminal notch.

Whale Shark Photo-identification Library

Shark identification number: A-008

Sex: .   male

Size: 8 m

Date and location of sighting:

a) 06/04/95 - 21^{0}58.00S 113^{0}54.40E

a) White scarring is located near the anterior dorsal region of the shark's head, predominantly on the right side.

b) Right patterning consists mainly of spots that are almost vertically aligned, with a concentration of these immediately posterior to the 5th gill slit.

Whale Shark Photo-identification Library

Shark identification number: A-009

Sex: male

Size: 9 m

Date and location of sighting:

a) 26/06/95 - $22^0$05.390S $113^0$52.589E   b) 28/03/96 - $21^0$55.477S $113^0$54.955E
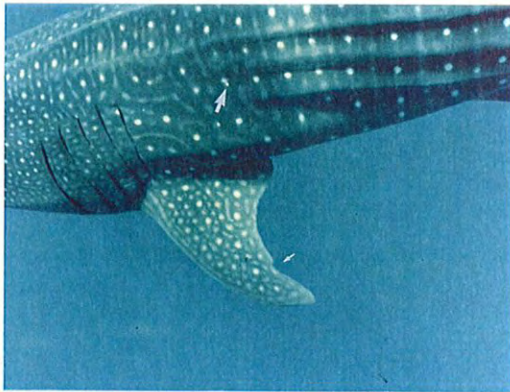
a) Left patterning lacks obvious order. The remnant of a yellow game fish tag (see Taylor, 1994) is present at a point immediately dorsal to the trailing edge of the left pectoral fin, and adjacent to the most dorsal region of the gill slits. A crescent shaped piece of flesh (*ca* 8 cm) is missing from the trailing edge of the left pectoral fin, *ca* 20 cm from the terminus.
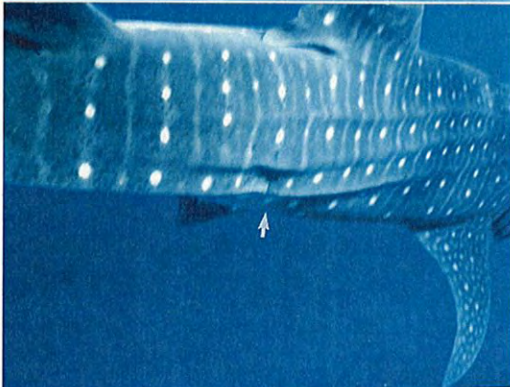
b) An indentation scar is obvious immediately posterior to the trailing edge of the 1st dorsal fin, between the 2nd and 3rd dorsal ridges on the right flank.
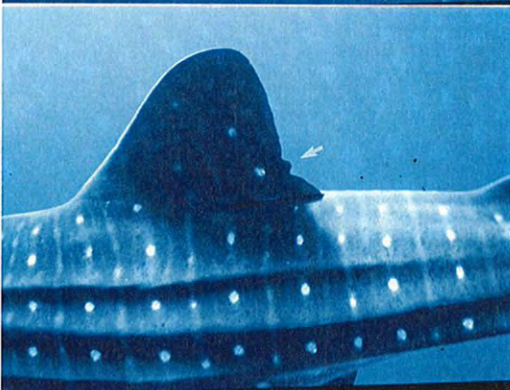
c) Two closely-spaced triangular pieces of fin (*ca* 5 cm each) are missing from a point beginning at *ca* 10 cm from the proximal margin of the trailing edge of the 1st dorsal fin.

Whale Shark Photo-identification Library

Shark identification number: A-010

Sex: male

Size: 10 m

Date and location of sighting:

a) 28/03/96 - 21^{0}54.030S 113^{0}55.704E   b) 03/04/96 - 21^{0}55.988S 113^{0}54.924E

c) 04/04/96 - 21^{0}55.335S 113^{0}55.184E   d) 26/03/97 - 21^{0}57.500S 113^{0}54.620E

e) 17/04/97 - 21^{0}55.838S 113^{0}54.678E

a) Left patterning characterised by a small line (*ca* 30 cm) angled down at 45^0 from a point adjacent to the mid-point of the left pectoral fin and halfway down the 5th gill slit .

b) Right patterning with a vertical line composed of 'joined' spots from a point midway down and immediately posterior to the 5th gill slit. A crescent-shaped piece of flesh (*ca* 5 cm diameter) is missing from a region *ca* 15 cm from the most distal point of the trailing edge of the right pectoral fin.

c) A black inverted Y-shaped scar originating at a point on the first dorsal ridge is orientated caudally at *ca* 45^0 to the 3rd dorsal ridge, mid-way between the right pectoral fin and 1st dorsal fin.

d) The trailing edge of the 1st dorsal fin is slightly curved.

Whale Shark Photo-identification Library

Shark identification number: A-011

Sex: female

Size: 6 m

Date and location of sighting:

a) 12/06/95 - $22^0$06.500S $113^0$52.000E   b) 30/03/96 - $21^0$55.585S $113^0$55.252E

c) 31/03/96 - $21^0$59.211S $113^0$54.108E   d) 14/04/96 - $21^0$56.495S $113^0$54.797E

a) Left patterning is orientated in a predominantly downward direction at an angle of *ca* 45^0. Two vertical lines are joined by a horizontal bar to form a U-shape adjacent to the trailing edge of the left pectoral fin.

b) The 1st dorsal fin is deformed. Although the overall shape is retained, the height of this fin is *ca* 50% of its normal size.

c) The gill slit region on the right side is deformed. The 4th gill slit flap is *ca* half normal size and fused mid-way along the 3rd gill slit flap.

Whale Shark Photo-identification Library

Shark identification number: A-012

Sex: male

Size: 6 m

Date and location of sighting:

a) 24/03/96 - $21^0$54.195S $113^0$55.781E   b) 26/03/96 - $21^0$54.808S $113^0$55.267E

c) 31/03/96 - $21^0$58.478S $113^0$54.547E   d) 03/04/96 - $21^0$54.963S $113^0$55.405E

e) 23/04/96 - $21^0$57.050S $113^0$54.490E   f) 26/04/96 - $21^0$55.999S $113^0$54.797E

g) 28/04/96 - $21^0$55.426S $113^0$55.356E   h) 02/05/96 - $21^0$54.940S $113^0$55.590E

a) Left patterning characterised by a horizontal line (*ca* 20 cm) extending posteriorly from the most ventral point of the 5th gill slit. Three large spots are located parallel and immediately ventral to this location.

b) Right patterning is characterised by a horizontal line (*ca* 20 cm) which extends posteriorly from just behind the most ventral point of the 5th gill slit.

c) A crescent-shaped piece of flesh (*ca* 10 cm) is missing from the distal margin of the trailing edge of the right pectoral fin.

d) An area adjacent to the leading edge of the 2nd dorsal fin, and immediately dorsal to the left lateral keel, has black scratch-like scarring.

Whale Shark Photo-identification Library

Shark identification number: A-013

Sex: male

Size: 7 m

Date and location of sighting:

a) 23/03/96 - 21^{0}59.023S 113^{0}54.137E   b) 24/03/96 - 21^{0}52.575S 113^{0}56.383E
c) 25/03/96 - 21^{0}55.680S 113^{0}55.290E   d) 26/03/96 - 21^{0}54.808S 113^{0}55.267E
e) 05/04/96 - 21^{0}54.715S 113^{0}55.497E   f) 08/04/96 - 21^{0}59.112S 113^{0}54.385E
g) 11/04/96 - location not recorded   h) 13/04/97 - 21^{0}58.000S 113^{0}54.400E
i) 05/05/97 21^{0}54.910S 113^{0}55.200E

a) The remnant of a yellow game fish tag (see Taylor, 1994) is present adjacent to the trailing edge of the left pectoral fin and dorsal of the first dorsal ridge.

b) Right patterning is characterised by four large spots positioned vertically on the leading edge of the 5th gill slit.

c) An indented scar is present on the right caudal keel, at a position adjacent to the anal fin.

Whale Shark Photo-identification Library

Shark identification number: A-014

Sex: male

Size: 9.5 m

Date and location of sighting:

a) 13/05/96 - 21⁰56.270S 113⁰54.440E

a) Right patterning is pale and indefinite, with white flecks present at the lower portion between the 4th and 5th gill slits.

b) Massive recent scarring present on the latero-dorsal surface of the right side between the 1st dorsal and caudal fins. A second white scar with its origin immediately anterior to the 1st dorsal fin, extends downwards at 45⁰ to the 3rd right dorsal ridge, adjacent to the middle of the 1st dorsal fin.

Whale Shark Photo-identification Library

Shark identification number: A-015

Sex: male

Size: 8 m

Date and location of sighting:

a) 18/04/96 - 21°55.996S 113°55.075E
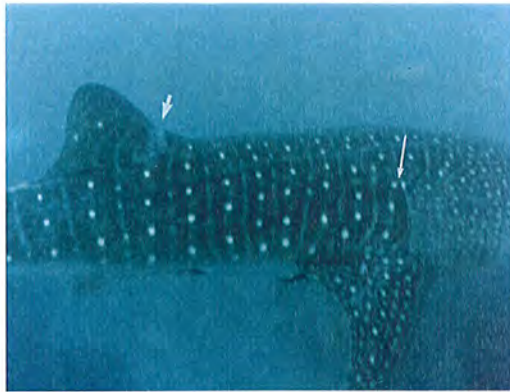
a) A white scar extends from the lower anterior margin of the 1st dorsal fin, and slightly across to the right side. Two bright spots, one immediately anterior and the another immediately posterior, to the posterior margin of the 5th gill slit on the right side.

b) A semi-circular piece of flesh (*ca* 6 cm diameter) is missing from an area *ca* 15 cm ventral to the sub-terminal notch on the trailing edge of the upper lobe of the caudal fin.

Whale Shark Photo-identification Library

Shark identification number: A-016

Sex: male

Size: 8 m

Date and location of sighting:

a) 01/04/96 - 21^{0}55.223S 113^{0}55.345E   b) 06/04/96 - 21^{0}54.195S 113^{0}55.559E

c) 25/05/96 - 22^{0}47.991S 113^{0}39.432E

a) A large bite-like scar (*ca* 20 cm diameter) is present on the trailing edge of the right pectoral fin. A second scar has its posterior margin immediately forward of a point adjacent to the leading edge of the 1st dorsal fin, and its anterior margin just posterior of the right pectoral fin, while extending ventrally from the 3rd dorsal ridge. A healed deep scar extends caudally from a point adjacent to the pelvic fin, to a point immediately anterior to the anal fin, and ventral to the 2nd dorsal fin.

Whale Shark Photo-identification Library

Shark identification number: A-017

Sex: male

Size: 4.5 m

Date and location of sighting:

a) 18/05/95 - 22°07.957S 113°51.475E

a) White scarring extends proximally from the distal margin to a point mid-way along the leading edge of the right pectoral fin.

b) Three small nicks are seen in a region on the trailing edge of the left pectoral fin, *ca* 30 cm from the insertion point of this fin.
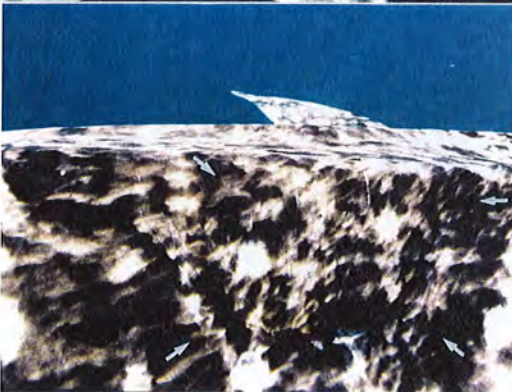
c) A healed circular outline, possibly a bite scar (*ca* 20 cm diameter), is located centrally on the dorsal surface, forward of the anterior margin of the 1st dorsal fin.

Whale Shark Photo-identification Library

Shark identification number: A-018

Sex: male

Size: 6 m

Date and location of sighting:

a) 05/04/96 - $21^0$54.079S $113^0$55.619E   b) 07/04/96 - $21^0$55.665S $113^0$55.104E
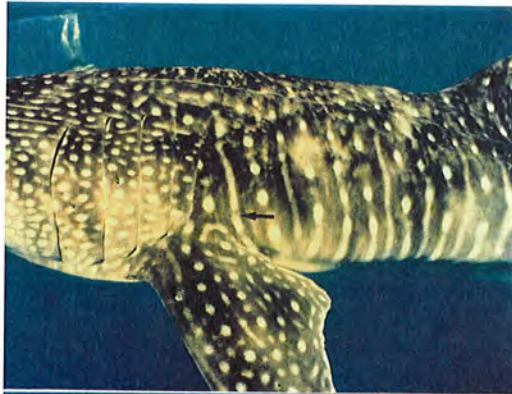
a) Left patterning characterised by lines and spots in a predominantly vertical orientation. A distinct line extends downwards from a position ventral to the 3rd dorsal ridge and adjacent to the middle of the left pectoral fin.

b) The trailing edge of the left pectoral fin is characterised by small nicks extending along this margin.

c) A small semi-circular piece (*ca* 3 cm diameter) is missing from the most distal point of the right pectoral fin.

Whale Shark Photo-identification Library

Shark identification number: A-019

Sex: male

Size: 5.5 m

Date and location of sighting:

a) 17/04/96 - $21^0$58.720S $113^0$54.517E   b) 30/04/96 - $21^0$58.541S $113^0$54.481E

c) 01/05/96 - $22^0$05.268S $113^0$52.512E

a)   Left   patterning   shows predominantly vertical orientation.
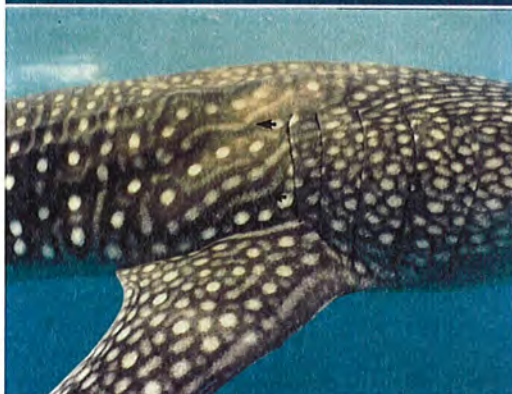
b) Right patterning is characterised by lines and spots in an almost horizontal orientation.

c) A small piece of flesh (*ca* 2 cm in diameter) is missing from a point on the trailing edge 1/3 the height of the 1st dorsal fin.

d) A small piece of flesh (*ca* 2 cm in diameter) is missing from a point mid-way along the trailing edge of the lower lobe of the caudal fin.

Whale Shark Photo-identification Library

Shark identification number: A-020

Sex: male

Size: 6 m

Date and location of sighting:

a) 01/04/96 - 21^{0}55.281S 113^{0}55.032E

b) 06/04/97 - 21^{0}56.170S 113^{0}54.870E

c) 07/04/97 - 21^{0}52.150S 113^{0}57.900E

d) 10/04/97 - location not recorded

e) 14/04/97 - 21^{0}51.936S 113^{0}56.397E

f) 28/04/97 - 21^{0}54.638S 113^{0}58.410E

g) 30/04/97 - 21^{0}52.670S 113^{0}57.850E

a) Left patterning is predominantly vertical in orientation. Several spots have fused to appear as a line, from a point adjacent to the top of the 5th gill slit and extending downward, to a point adjacent to the middle of the left pectoral fin.

b) Right patterning has spots dispersed evenly in a slightly angled orientation.

c) A crescent-shaped piece of flesh (*ca* 6 cm diameter) is missing from a point *ca* 1/3 the length of the trailing edge of the right pectoral fin.

Whale Shark Photo-identification Library

Shark identification number: A-021

Sex: male

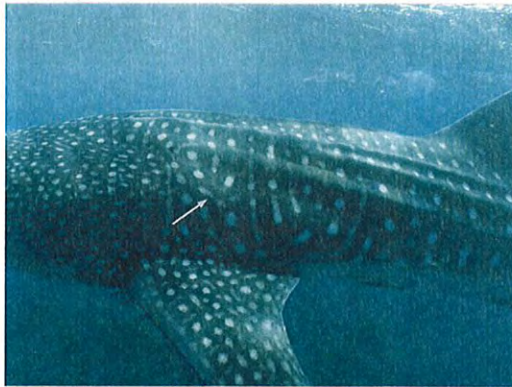**Size:** 10 m

Date and location of sighting:

a) 28/04/96 - 21°53.367S 113°56.292E
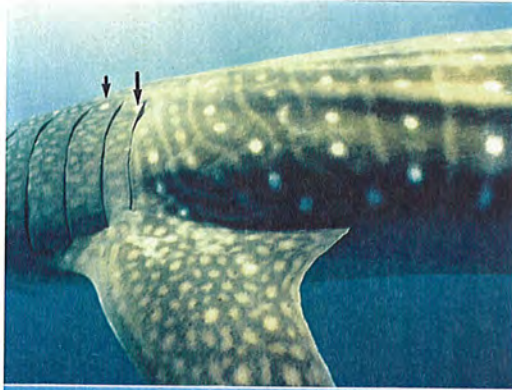
a) Left side patterning is pale, although two vivid white spots exist at the top of the trailing edge of the 4th and 5th gill slits. The patterning is predominantly angled downwards at *ca* 45°.
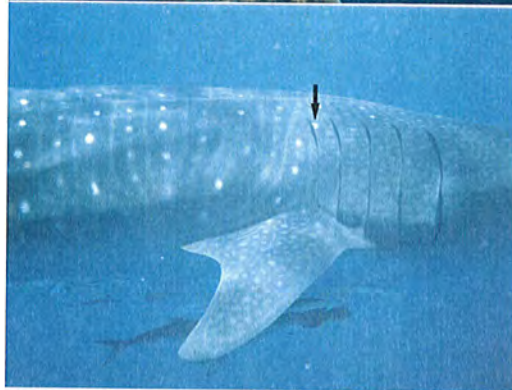
b) Right side patterning is also very pale, with a bright white spot at the most dorsal point of the leading edge of the 5th gill slit.

c) The lower 1/3 of the trailing edge of the 1st dorsal fin is characterised by the presence of several small nicks.

d) The trailing edge of the 2nd dorsal fin is characterised by three semi-circular serrations (*ca* 2cm diameter).

Whale Shark Photo-identification Library

Shark identification number: A-022

Sex: male

Size: 9 m

Date and location of sighting:

a) 08/04/95 - $22^001.400S$ $113^053.600E$ b) 25/05/95 - $21^058.500S$ $113^054.200E$

a) The 1st dorsal fin has been truncated from a point mid-way along the leading edge. The truncation extends upward at an angle of approximately 45^0.

Whale Shark Photo-identification Library

Shark identification number: A-023

Sex: male

Size: 6 m

Date and location of sighting:

a) 27/03/96 - 21°53.266S 113°56.627E   b) 02/04/96 - 21°56.570S 113°54.693E
c) 05/04/96 - 21°53.784S 113°55.973E   d) 13/05/97 - 21°56.342S 113°54.902E
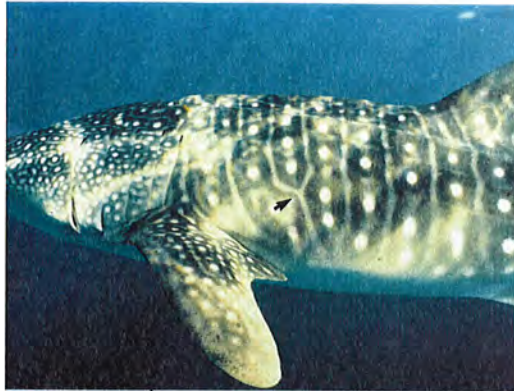
a) Left patterning characterised by two vertically directed lines (adjacent to the trailing edge of the left pectoral fin), that join just below the 3rd dorsal ridge and resemble the letter 'Y'.

b) Right patterning also characterised by two vertically directed lines (adjacent to the trailing edge of the right pectoral fin) that join immediately below the 3rd dorsal ridge forming a 'Y' shape.

c) The trailing edge of the 1st dorsal fin is cut inwardly *ca* 1/3 from the top.

d) A small semi-circular piece of flesh (*ca* 3 cm diameter) is missing from the trailing edge of the junction of the upper and lower lobe of the caudal fin.

Whale Shark Photo-identification Library

Shark identification number: A-024

Sex: male

Size: 7.5 m

Date and location of sighting:

a) 14/04/96 - $21^0$58.135S $113^0$54.493E   b) 26/05/96 - $22^0$47.562S $113^0$39.222E
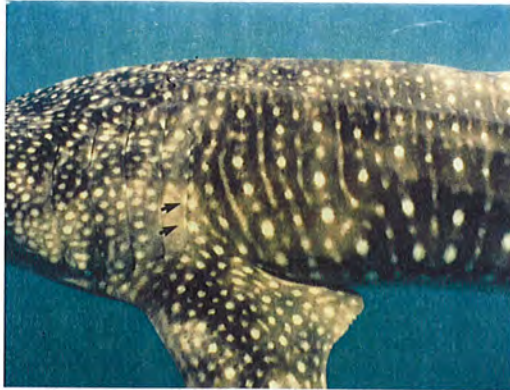
a) Left patterning is relatively uniform in its vertical orientation. The trailing edge of the 5th gill slit has several distinct spots that almost overlap other spots immediately posterior to this location.

b) Three relatively large crescent-shaped pieces of flesh (*ca* 6 cm diameter) are missing from the trailing edge if the 1st dorsal fin.

c) A large semi-circular piece of flesh (*ca* 10 cm diameter) is missing from the trailing edge of the 2nd dorsal fin.

d) The top 1/4 of the upper lobe of the caudal fin has been horizontally truncated. Two semi-circular pieces of flesh (*ca* 10 cm diameter) are missing from separate areas on the trailing edge of upper caudal lobe.

Whale Shark Photo-identification Library

Shark identification number: A-025

Sex: male

Size: 11 m

Date and location of sighting:

a) 29/04/96 - 21°53.559S 113°56.488E

a) Left patterning is very pale. More lines than spots are obvious posterior to the 5th gill slit. These are orientated downwards at *ca* 45°.

b) Right patterning is mainly vertical in orientation posterior to the 5th gill slit, although just ventral to the dorsal margin of gill slits 2-3 and 3-4, a small horizontal line is present.

c) A number of separate oblique white scratches are obvious on the right dorsal surface: 1) dorsal to the 3rd gill slit; 2) adjacent to the centre of the right pectoral fin; 3) mid-way between right pectoral fin and 1st dorsal fin, and immediately ventral to the 1st dorsal ridge.

Whale Shark Photo-identification Library

Shark identification number: A-026

Sex: male

Size: 8 m

Date and location of sighting:

a) 01/04/96 - 21^{0}54.958S 113^{0}54.714E

c) 25/05/96 - 22^{0}47.554S 113^{0}38.989E

b) 02/04/96 - 21^{0}56.258S 113^{0}54.774E

d) 26/05/96 - 22^{0}47.429S 113^{0}38.371E

a) Left patterning is very pale. Two spots have almost fused to form a small line directed posteriorly and diagonally from a point anterior to the trailing edge of the left pectoral fin.
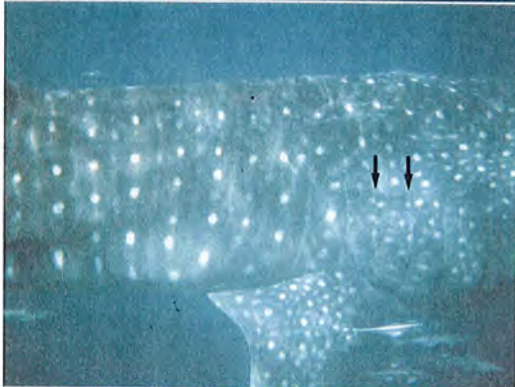
b) Right patterning is mainly vertical in orientation, with spots lining the edges of the 3rd and 4th gill slits.

c) A white scratch (*ca* 15 cm) exists on the dorsal surface, *ca* 60 cm forward of the anterior margin of the 1st dorsal fin.

Whale Shark Photo-identification Library

Shark identification number: A-027

Sex: male

Size: 6.5 m

Date and location of sighting:

a) 01/04/96 - 21^{0}55.101S 113^{0}55.240E   b) 07/04/96 - 21^{0}55.665S 113^{0}55.104E

c) 22/04/96 - 21^{0}59.083S 113^{0}54.110E   d) 23/04/96 - 21^{0}57.970S 113^{0}53.850E

e) 24/04/96 - 21^{0}54.215S 113^{0}55.624E

a) Left patterning characterised by two vertically-directed lines in a U-shaped orientation, in an area mid-way between the trailing edge of the left pectoral and 1st dorsal fin, immediately ventral to the 3rd dorsal ridge.

b) Right patterning is bold, with most lines and spots in a slightly diagonal orientation. Immediately adjacent to the trailing edge of the right pectoral fin, two vertically directed lines form a U-shaped orientation, just ventral to the 3rd dorsal ridge.

c) The distal portion (*ca* 3cm) of the right pectoral fin is missing. A crescent-shaped piece of flesh (*ca* 5 cm diameter) is missing from a point on the trailing edge, approximately 2/3 the length of the right pectoral fin.

Whale Shark Photo-identification Library

Shark identification number: A-028

Sex: male

Size: 9 m

Date and location of sighting:

a) 29/03/96 - 21°55.518S 113°55.102E
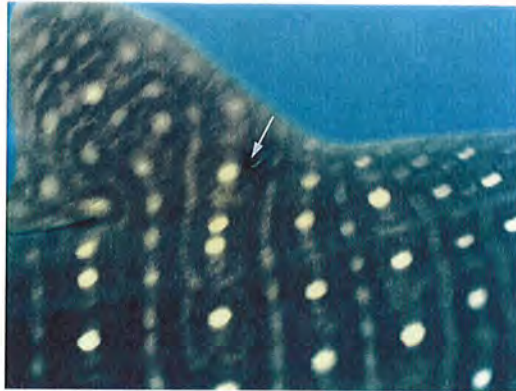
a) The remnant of a small yellow gamefish tag (see Taylor, 1994) is present near the base and anterior margin of the right side of the 1st dorsal fin.

Whale Shark Photo-identification Library

Shark identification number: A-029

Sex: male

Size: 7 m

Date and location of sighting:

a) 26/06/95 - 22^{0}01.400S 113^{0}53.600E   b) 28/03/96 - 21^{0}53.295S 113^{0}57.091E

c) 01/04/96 - 21^{0}55.024S 113^{0}55.142E

a) Left patterning is characterised by four spots vertically aligned between the 1st dorsal ridge and the trailing edge of the left pectoral fin: one spot between the 1st and 2nd dorsal ridge; one spot between the 2nd and 3rd dorsal ridge; and the remaining two spots close together below the 3rd dorsal ridge.

b) A small V-shaped piece of flesh (*ca* 3cm) is missing from a point almost mid-way along the trailing edge of the 1st dorsal fin.

c) A small crescent-shaped piece of flesh (*ca* 3cm diameter) is missing from a point mid-way along the trailing edge of the right pectoral fin.

d) The lower portion of the trailing edge (*ca* 20 cm length; 1 cm width) of the lower lobe of the caudal fin is missing.

Whale Shark Photo-identification Library

Shark identification number: A-030

**Sex:** male

Size: 10 m

Date and location of sighting:

a) 06/04/96 - 21^{0}54.061S 113^{0}55.676E
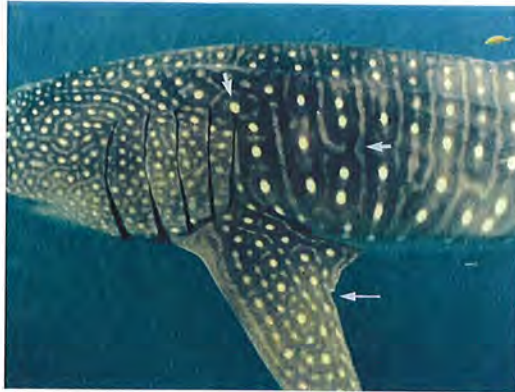
a) Left side patterning is characterised by bold lines and spots. A bright spot, encircled by a line is present at the most dorsal point of the 5th gill slit. Two vertical lines adjacent to the trailing edge of the left pectoral fin are joined by an essentially horizontal line immediately ventral to the 3rd dorsal ridge. A crescent-shaped piece of flesh (*ca* 8cm diameter) is missing from the trailing edge of the left pectoral fin, *ca* 1/3 from the proximal margin.

Whale Shark Photo-identification Library

Shark identification number: A-031

Sex: female

Size: 6.5 m

Date and location of sighting:

a) 21/03/95 - $22^0$06.500S $113^0$52.000E   b) 28/03/95 - $21^0$59.300S $113^0$54.200E

c) 30/03/95 - $21^0$59.300S $113^0$54.200E   d) 02/04/95 - $22^0$06.500S $113^0$52.000E

e) 06/04/95 - $21^0$59.300S $113^0$54.200E   f) 25/03/96 - $21^0$51.500S $113^0$58.000E

g) 26/03/96 - $21^0$54.555S $113^0$35.532E   h) 03/04/96 - $21^0$56.882S $113^0$54.611E

a) Left pattern of lines and spots well ordered, with a slight diagonal orientation immediately posterior to the 5th gill slit, while angled diagonally forward posterior to the trailing edge of the left pectoral fin.

b) Right patterning is characterised by lines and spots vertically orientated. A group of three bright white spots above the 5th gill slit orientated caudally and ventrally at 45^0.

c) A small V-shaped piece of flesh (*ca* 3 cm) missing from a point 1/3 the height of the trailing edge of the 1st caudal fin.

d) Right pectoral fin is scarred significantly. Triangular shape of the fin is retained, although the distal 1/3 has been truncated.

Whale Shark Photo-identification Library

Shark identification number: A-033

Sex: male

Size: 10 m

Date and location of sighting:

a) 27/05/95 - $22^0$01.400S $113^0$53.600E   b) 03/04/96 - $21^0$56.794S $113^0$54.681E

c) 18/04/96 - $21^0$58.120S $113^0$54.405S

a) Left side patterning characterised by lines and spots in an almost S-shaped curve, beginning dorsal and posterior to the 5th gill slit. Two bold spots are aligned vertically between the 3rd dorsal ridge and the trailing edge of the pectoral fin.

b) Right patterning bold with most lines and spots directed vertically. Immediately dorsal to the trailing edge of the right pectoral fin, two vertical lines are fused with a small horizontal line to form a U-shape pattern.

Whale Shark Photo-identification Library

Shark identification number: A-035

Sex: male

Size: 4.5 m

Date and location of sighting:

a) 01/07/95 - $22^0$01.400S $113^0$53.600E   b) 28/05/97 - $21^0$55.800S $113^0$55.020E

a) Left patterning consists mainly of lines and spots angled downward at *ca* 30^0. Three vivid white spots have a triangular orientation at the ventral locale between the 3rd and 4th gill slits.

b) Right patterning has little regularity, with spots interspaced with short horizontal lines. Significant scarring to the right pectoral fin, beginning at the distal point of the trailing edge, and extending basally to a point 1/3 the length. The scarring has produced a jagged edge.

Whale Shark Photo-identification Library

Shark identification number: A-036

Sex: female

Size: 6 m

Date and location of sighting:

a) 29/03/96 - $21^0$53.655S $113^0$56.605E   b) 30/03/96 - $21^0$55.925S $113^0$55.048E

a) Left side patterning characterised by lines and spots orientated downward at *ca* 30^0. Three spots are aligned at 45^0, immediately dorsal to insertion point of left pectoral fin, adjacent to the most ventral point of the gill slits. [i]

Whale Shark Photo-identification Library

Shark identification number: A-037

Sex: male

Size: 6 m

Date and location of sighting:

a) 24/04/97 - $22^0$02.175S $114^0$02.030E
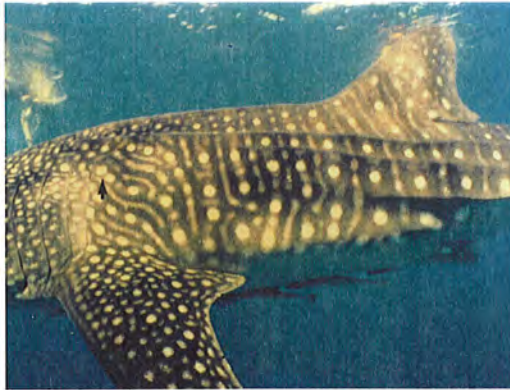
a) Left patterning of lines and spots angled at *ca* 60^0, with two spots closely associated and orientated caudally at 45^0, immediately posterior to the dorsal margin of the 5th gill slit.

b) Right patterning of lines and spots characterised by a concentration of diagonally-oriented shorter lines posterior to the lower half of the 5th gill slit.

Whale Shark Photo-identification Library

Shark identification number: A-038

Sex: not determined

Size: 9 m

Date and location of sighting:

a) 12/04/96 - 21^{0}52.155S 113^{0}57.794E

a) Left patterning is very pale, with four large bright spots almost vertically aligned, adjacent to centre of left pectoral fin, extending to the height of the most dorsal margin of the gill slits.

Whale Shark Photo-identification Library

Shark identification number: A-039

Sex: not determined

Size: 7 m

Date and location of sighting:

a) 06/03/96 - 21⁰57.307S 113⁰54.844E

a) Left patterning with two large bright spots aligned vertically, immediately below 3rd dorsal ridge, and adjacent to the centre of left pectoral fin.

Whale Shark Photo-identification Library

Shark identification number: A-040

Sex: male

Size: 5 m

Date and location of sighting:

a) 06/04/96 - location not recorded

a) Left patterning is aligned posteriorly at *ca* 30^0, with an absence of spots immediately dorsal to the lateral margin of the left pectoral fin.
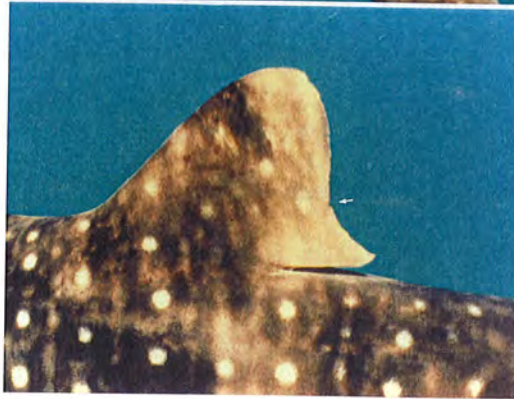
b) Trailing edge of 1st dorsal fin has a tattered appearance, with a small semi-circular piece of flesh (*ca* 2 cm diameter) missing from a point 1/3 the height of the trailing edge of fin.

Whale Shark Photo-identification Library

Shark identification number: A-041

Sex: male

Size: 9 m

Date and location of sighting:

a) 27/05/95 - $22^001.400S$ $113^053.600E$
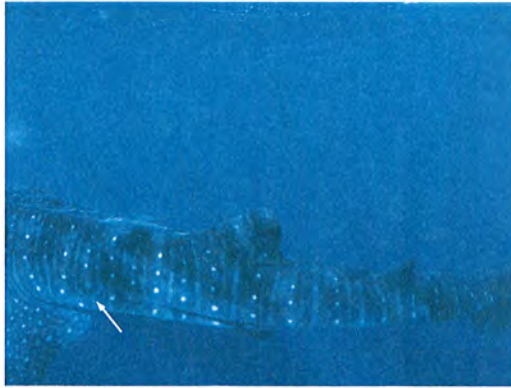
a) Left patterning is very pale, with two vertical lines fused to form a Y-shaped pattern, adjacent to the trailing edge of the left pectoral fin, and mid-way between the ventral and dorsal margins of the gill slits.

b) The upper lobe of the caudal fin exhibits significant scarring, with a healed flap of skin resulting from a horizontal cut approximately 1/4 the height of the leading edge of the upper lobe.

Whale Shark Photo-identification Library

Shark identification number: A-042

Sex: male

Size: 8 m

Date and location of sighting:

a) 16/03/95 - 21^{0}54.229S 113^{0}55.914E   b) 18/03/95 - 21^{0}53.000S 113^{0}56.400E

c) 25/03/95 - location not recorded

a) Left pectoral fin with large bite-like scar (*ca* 40 cm diameter), midway along the trailing edge. White 'splotches' present at posterior margin of 5th gill slit.

Whale Shark Photo-identification Library

Shark identification number: A-043

Sex: male

Size: 6 m

Date and location of sighting:

a) 21/03/95 - $21^0$59.300S $113^0$54.200E

a) A V-shaped indentation (*ca* 5cm) is centrally located at the most dorsal and anterior margin of head.

Whale Shark Photo-identification Library

Shark identification number: A-044

Sex: male

Size: 8 m

Date and location of sighting:

a) 30/04/96 - 21^{0}57.359S 113^{0}54.643E

a) Left patterning has little regularity, with some small lines facing anteriorly. A large white spot present near the lateral insertion point of left pectoral fin, immediately posterior to 5th gill slit is surrounded by a circular line.

b) Right patterning shows little order. Two small horizontal lines are posteriorly directed from a point mid-way between the most dorsal and ventral points of the 5th gill slit. Three spots are aligned with the upper trailing edge of 5th gill slit.

Whale Shark Photo-identification Library

Shark identification number: A-045

Sex: male

Size: 7 m

Date and location of sighting:

a) 12/04/96 - 21^{0}52.657S 113^{0}55.966E

a) Left patterning is pale with most spots and lines directed diagonally. A large white spot immediately posterior to the lower portion of the 5th gill slit is surrounded by a circular line.

Whale Shark Photo-identification Library

Shark identification number: A-046

Sex: male

Size: 11 m

Date and location of sighting:

a) 01/05/96 - 22^{0}04.722S 113^{0}53.007E

a) Left patterning shows a predominantly horizontal orientation. The trailing edge of the 5th gill slit with four spots aligned vertically. A small semi-circular line located posterior to the top of the 5th gill slit faces caudally.

b) Right patterning mainly vertical in orientation, although several short horizontal lines are present. A spot is obvious at the dorsal point of the trailing edge of 4th gill slit, and another at the corresponding location of 5th gill slit.

Whale Shark Photo-identification Library

Shark identification number: A-047

Sex: male

Size: 9.5 m

Date and location of sighting:

a) 20/03/96 - $22^0$10.979S $113^0$50.498E   b) 21/03/96 - $22^0$06.847S $113^0$52.239E

c) 02/04/96 - $21^0$56.356S $113^0$54.481E   d) 07/04/96 - $21^0$55.665S $113^0$55.104E

a) Left patterning features a Y-shaped line adjacent to the trailing edge of the left pectoral fin, immediately ventral to 3rd dorsal ridge. Two large white spots are orientated posteriorly at 45^0 from a point immediately posterior to the trailing edge of the 5th gill slit.

b) A small semi-circular piece of flesh (*ca* 2 cm diameter) is missing from a point mid-way along the length of the trailing edge of left pectoral fin. A larger (*ca* 5 cm diameter) piece of flesh is missing from a point 2/3 along the length of the same edge.

c) Two small semi-circular pieces of flesh (*ca* 1 cm diameter) are missing from points *ca* 2/5 and 3/5 of the way along the length of the trailing edge of 1st dorsal fin.

Whale Shark Photo-identification Library

Shark identification number: A-048

Sex: male

Size: 10 m

Date and location of sighting:

a) 27/03/96 - 21^{0}53.932S 113^{0}55.682E

a) Left patterning is characterised by two vertical lines which converge to produce an 'hour-glass' shape, dorsal to the trailing edge of the left pectoral fin and immediately ventral to the 3rd dorsal ridge.

b) Right side patterning characterised by a bright white spot present between the most dorsal tips of the trailing edges of the 3rd and 4th gill slit. Two vertical lines end and almost converge to produce a U-shaped pattern at a point adjacent to the trailing edge of the right pectoral fin and ventral to the 3rd dorsal ridge. A small horizontal line is located immediately anterior to this point.

Whale Shark Photo-identification Library

Shark identification number: A-049

Sex: male

Size: 10.5 m

Date and location of sighting:

a) 12/06/95 - 22^{0}06.487S 113^{0}51.979E

a) Right patterning characterised by a concentration of spots around the 5th gill slit. Lines and spots posterior to this area are mainly vertical in orientation.

Whale Shark Photo-identification Library

Shark identification number: A-050

Sex: male

Size: 7 m

Date and location of sighting:

a) 28/03/96 - 21^{0}54.030S 113^{0}55.704E
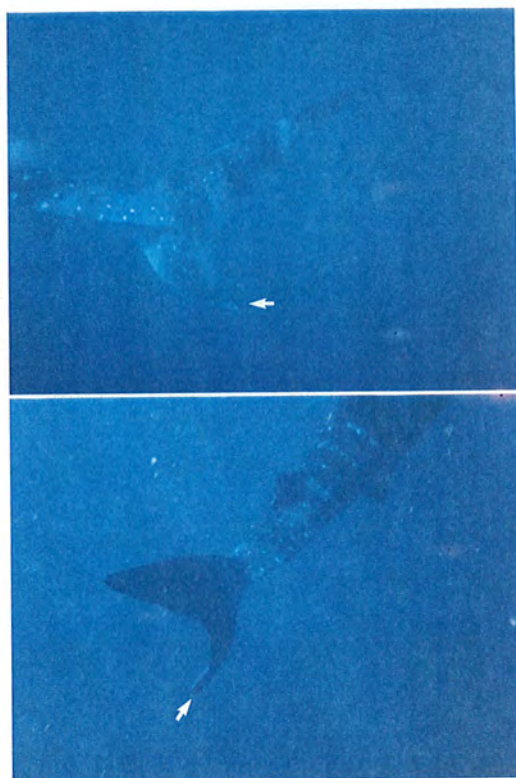
a) The ventral section of the lower lobe of the caudal fin is 'curled' under to the left side.

Whale Shark Photo-identification Library

Shark identification number: A-051

Sex: male

Size: 7 m

Date and location of sighting:

a) 17/04/97 - 21⁰55.646S 113⁰53.768E

a) Left patterning with three large white spots extending vertically from a point immediately adjacent to the trailing edge of left pectoral fin. A U-shaped line continues from a point on the 3rd dorsal ridge.

Whale Shark Photo-identification Library

Shark identification number: A-052

Sex: male

Size: 7.5 m

Date and location of sighting:

a) 24/04/97 - 22⁰53.535S 113⁰56.315E b) 28/04/97 - 21⁰54.638S 113⁰58.416E

a) Left patterning between 5th gill slit and an area adjacent to the middle of the left pectoral fin is mainly vertical in orientation. Small vertical, diagonal and horizontal lines are concentrated posterior to this area. A bright white spot is present at the most ventral tip of the trailing edge of the 5th gill slit.

b) Right side patterning characterised by two merged lines forming an inverted U-shaped pattern *ca* 1/4 the distance between the 5th gill slit and the trailing edge of the right pectoral fin.

c) A small crescent-shaped piece of flesh (*ca* 5 cm diameter) is missing from the distal margin of the trailing edge of upper lobe of the caudal fin.

Whale Shark Photo-identification Library

Shark identification number: A-053

Sex: male

Size: 4 m

Date and location of sighting:

a) 27/04/97 - $22^0$00.159S $113^0$53.883E
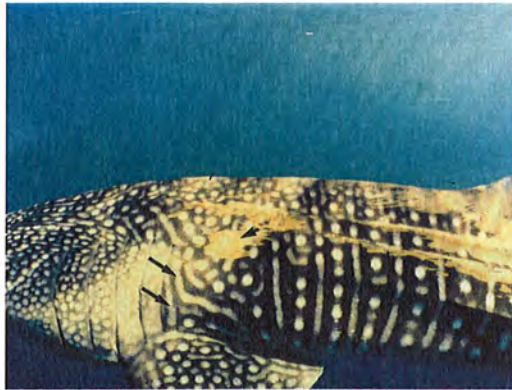
a) Left patterning has a characteristic vertical line immediately posterior to the 5th gill slit. A vertical line immediately posterior to this changes to a horizontal then diagonal orientation mid-way down the length of the gill slits. Conspicuous beige paint-like markings exist from above this area to beyond the 1st dorsal fin.
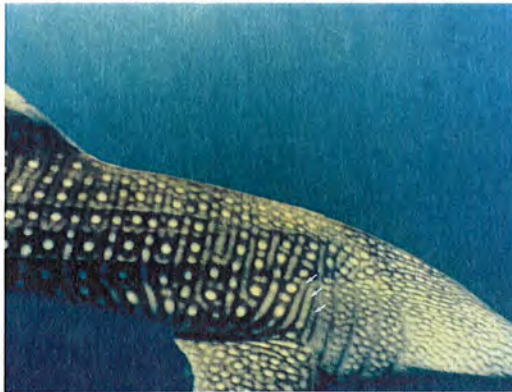
b) Right side patterning with three uninterrupted vertical lines located immediately posterior to the 5th gill slit.

c) The upper 1/2 of trailing edge of 1st dorsal fin has three small nicks. Upper 1/2 of 2nd dorsal fin has been truncated, leaving a small healed flap hanging over on right side.

d) The lower portion of the trailing edge (*ca* 20 cm length; 3 cm width) of lower lobe of caudal fin is missing.

Whale Shark Photo-identification Library

Shark identification number: A-054

Sex: male

Size: 4 m

Date and location of sighting:

a) 22/04/97 - 21°52.989S 113°56.188E

a) Left patterning is essentially horizontal in orientation, with lines extended caudally to a region beyond the area adjacent to the trailing edge of the left pectoral fin.

b) Right side patterning shows little regularity. A small, distinct dorsally directed semi-circular line exists immediately anterior to the 3rd dorsal ridge, adjacent to the trailing edge of the right pectoral fin.

c) Approximately 10cm below the subterminal notch, a small piece of flesh is missing from the trailing edge of the caudal fin. A semi-circular pattern of healed teeth marks (*ca* 15cm in diameter) is also present a further 20cm below this (not obvious on photograph).

CHAPTER 5

DISTRIBUTION OF *RHINCODON TYPUS* IN NORTH-WESTERN AUSTRALIA

5.1 Introduction

The distributions of the different species of sharks vary greatly, with some species being restricted to certain areas while others are migratory (Tricas, 1997b). In the case of migratory sharks, their distributions may include areas spanning different water temperatures, *i.e.* they occur in both tropical and temperate regions, or different water depths *i.e.* they live in oceanic and coastal waters (Dingerkus, 1987). The daily and seasonal movements of sharks are often related to feeding and reproduction, respectively (Bres, 1993).

The majority of the data on the distribution of *Rhincodon typus* has been obtained through incidental boat sightings. Indeed, there are many reports from the early part of this century of whale sharks becoming impaled on the bows of ships (Gudger, 1938a, 1938b; Stead, 1963). More recently, information on the distribution of this species has been obtained from the commercial fishing industry that operates in certain waters (Silas, 1986; Chen *et al.*, 1997).

The first documented sighting of *R. typus* in Australian waters was in 1936 off the coast of New South Wales (Wolfson, 1986). Very few subsequent sightings have been recorded in the scientific literature in Australian waters, apart from those at Ningaloo Marine Park (NMP) on the northwest coast of Western Australia, where shark aggregations were first reported in the early 1980s (Taylor, 1994). The seasonal appearance of this species near Ningaloo Reef coincides approximately with the annual mass spawning of corals in that region (CALM, 1988a; Taylor, 1994, 1996).

Conventional tagging, *i.e.* where non-electronic tags are implanted on the skin, provides information on differences between the location where a fish was first

tagged and where it was subsequently re-captured, thus allowing an estimate to be made of the minimum range in the distribution of that particular fish (Priede & French, 1991). Such tagging programmes, albeit on a small scale, have been carried out on *R. typus* at various locations, including South Africa and the Seychelles, the Gulf of Mexico and the Ningaloo Marine Park (Taylor, 1994; Gourlay, 1997; J. Stevens, CSIRO Marine Research, Hobart, pers. comm.). In contrast to this 'passive' tagging, acoustic and satellite tracking provide the opportunity to acquire data on movements over a finer temporal scale, albeit usually over a restricted period of time. These methods have been successfully used to study the movements of certain marine species, including sharks (e.g. Nelson, 1974; Priede & French, 1991; Goodyear, 1993).

When it is possible to distinguish between individuals of a particular species using natural markings, a photograph of specific area(s) on a shark can be used as a form of non-invasive tagging, provided that the marks have previously been shown to remain for at least a substantial period (see Chapter 4). When the same animal is subsequently photographed at the same locality or other localities, that photographic data thus provide some information on the distribution and movement patterns of that individual (Norris *et al.*, 1985; Wells *et al.*, 1990; Wursig & Jefferson, 1990).

Aerial surveying has recently been employed in efforts to estimate the abundance and distribution of large marine species, including sharks (Marsh & Sinclair, 1989; P. Arscott, Exmouth Air Charters, Exmouth, pers. comm.). At Ningaloo Reef, aerial survey flights have been undertaken since 1989 in attempts to determine the numbers of whale sharks in that area (Taylor, 1996). However, the number of *R. typus* recorded has varied greatly. One flight in April 1989, between Tantabiddi and Fraser Island (Fig. 5.1), located 44 whale sharks, whereas only four were sighted on a second flight in the same region six days later (Taylor, 1996). Thirteen whale sharks were recorded in July 1989 by research workers who were surveying for dugongs north of Norwegian Bay (Fig. 5.1) at NMP (Taylor & Grigg, 1990; Preen *et al.*, 1997), while only 15 whale sharks were sighted there between March and June of 1990, despite the

number of survey flights being extended to ten (Taylor & Grigg, 1990). Although 61 whale sharks were sighted during 19 survey flights in 1991, either none or only one whale shark was sighted on ten of those surveys (Taylor & Grigg, 1991). One hundred and thirty six sharks were sighted during 40 h of aerial surveying at NMP in 1992 (Taylor, 1996). Although *R. typus* is obviously migratory (Compagno, 1984a; Dingerkus, 1987), there are virtually no data on the broad-scale movements of this species. However, there is some information on the movement patterns of this species while they are within NMP (Taylor, 1996).

Compagno (1984a) suggests that *R. typus* prefers locations where upwellings occur. Near NMP, the 200 m depth contour is only 10 km offshore (Hearn & Parker, 1988) and the edge of the continental shelf is closer to land than at any other location on the Australian coastline (CALM, 1989). Although occasional episodic pulses of cold water are found in this region (Holloway *et al.*, 1985), the warm Leeuwin Current, which flows southwards down the coast of Western Australia, apparently suppresses such upwellings (Pearce, 1991).

The main aim of this part of the study was to use aerial and boat surveys (independent of commercial operations), commercial vessel log sheets and acoustic tracking of *R. typus* to obtain information on the distribution and direction of travel of whale sharks within NMP and to record the depth of water where whale sharks are observed. Where applicable, the results are compared with those obtained by Taylor (1996) in earlier years. Preliminary studies using satellite tracking was also employed to determine the pattern of movement of *R. typus* over a restricted time period. The above data, together combined with sightings from nearby locations, are used to suggest possible migratory routes for this species.

5.2 Materials and methods

5.2.1 Water temperature at Ningaloo Marine Park

In 1995, I recorded surface water temperatures on 30 separate days between 16 March and 5 July at NMP by submerging a thermometer from the side of the whale shark commercial tour vessels to a depth of *ca* 30 cm. Officers from the Western Australian Department of Conservation and Land Management (CALM) on the CALM vessel *Pseudorca 11* recorded surface water temperatures on 50 separate days between 11 March and 14 May 1996 and on 34 days between 12 April and 21 May 1997, using the temperature function on the vessel's echo sounder. The maximium ambient temperature during each day between March and June (1995-1997) was recorded at the Learmonth weather station by the Bureau of Meteorology.

5.2.2 Distribution of *Rhincodon typus* within Ningaloo Marine Park
5.2.2.1 Boat surveys

The commercial whale shark tour operators working within NMP were each provided with a Whale Shark Operator logbook to complete during each observation of whale sharks as part of the CALM licence requirements. After the 1995 season, CALM responded to suggestions that the Whale Shark Operator logbooks should be revised in order to acquire data on various aspects on the biology of *R. typus* and the exposure to ecotourism of whale sharks at NMP (see Chapter 7). The new format for the log sheets was used throughout the 1996 and 1997 whale shark seasons at NMP (see Fig. 3.2). The completed Whale Shark Operator logbook sheets were available for analysis at the end of 1995, 1996 and 1997.

Spotter aircraft were employed by commercial whale shark tour operators to search for whale sharks within NMP. The greater percentage of searches (especially at the beginning and end of the day), usually concentrated within the area of easiest access to commercial vessels mooring at Tanatabiddi boat ramp (*i.e.* between Sectors 2 and 5).

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Search effort was also concentrated mainly within *ca* 3 km of the reef front and where the water depth was usually less than *ca* 60 m. The duration and search pattern of each flight were different, with the effort spent searching for sharks varying on a daily basis.

When a whale shark was sighted, the pilot would radio the position of the shark to the skipper of the partner vessel, who would position that vessel near the shark. Since *R. typus* could be observed in the water both by myself and industry employees at NMP, it was possible to collect accurate data on their swimming direction. The time and location of each *R. typus* sighting was recorded using either a hand-held or vessel-mounted Global Positioning System (GPS). The water depths at these locations were obtained from electronic depth recorders on each vessel. To facilitate comparisons between the results collected during the current study and those collected by industry, all GPS positions were allocated to the most appropriate sector (Fig. 5.2).

5.2.2.2 Aerial surveying

Since the majority of the whale shark tourism industry is located in the northern region of NMP, the focus of the study in 1995 was concentrated in this region, although one survey did extend southwards of Yardie Creek (sector 13). The northern region was divided into sectors, *i.e.* sectors 1 - 13, which could be easily distinguished by breaks in the reef or by prominent geomorphological reference points on the shore (Fig. 5.2). After consultation with Dr H. Marsh and Dr T. Preen of James Cook University, Townsville, a zig-zag pattern of aerial surveys adjacent to Ningaloo Reef was initially considered. However, financial restraints and the safety aspect of flying the single engine aircraft to the most westerly point of these surveys (> 5 km offshore), meant that surveys had to be restricted to waters parallel to the reef in an essentially north-south direction and at a distance no further than 3 km from land.

Fifteen survey flights were undertaken at NMP in 1995 in order to record the number, location and direction of travel of whale sharks. Surveying was initiated at a location adjacent to Jurabi Point (21°52.5S 113°58.0E, *i.e.* sector 1) and continued in a

southerly direction to either Turquoise Bay, Osprey Bay, Yardie Creek or Coral Bay (Figs 5.1, 5.2), depending on the time of day and plane/pilot availability. The mean duration ± 1 S.E. of each of the 15 surveys was 74.2 ± 10.7 min. Oakley polarising sunglasses were worn by the observer and, where possible, flights were conducted during the middle of the day to minimise glare.

Streamers were attached to the wing struts of an Exmouth Air Charter Cessna 172 during each aerial survey. Using trigonometry, the angle from the line of view of the observer to the wing strut was calculated so that, while travelling at a height of 484 m, the distance between each streamer marked a 900 m strip of ocean immediately west of the Ningaloo Reef which was surveyed while travelling south and looking out of the port side of the aircraft. When travelling north, the observer looked out of the starboard side of the aircraft and streamers on the starboard wing strut were aligned with the reef front to mark an area between 1100 - 2000 m seaward of the Ningaloo Reef crest. If sharks and commercial vessels were observed outside this marked area, they were not recorded.

In March 1997, I was invited by CALM to assist with implementing an aerial survey program. An Exmouth Air Charter Cessna 206 was used for each of the 13 separate surveys between March and May. CALM staff, volunteers and/or myself were employed as observers during these surveys. Simple trigonometry was used to calculate the area of ocean 0 - 500 m and 800 - 1300 m west of the reef to be surveyed. The altitude was ca 387 m and the air speed 100 knots. The mean duration ± 1 S.E. of each of the 13 surveys was 156 ± 4.3 min. Each flight commenced at the northern end of the commercial whale shark watching area (sector 1), and flew south parallel to Ningaloo Reef to Gnarloo Bay, near the southern-most boundary of NMP (Fig. 5.1). A similar track was taken on the northerly run, with information on sightings being recorded by an observer on both the starboard and port sides of the aircraft, surveying an area of 500 m each.

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An area of ocean directly below the aircraft (*ca* 800 m) was not surveyed because the fuselage and undercarriage of the aircraft restricted the observers' line of sight. If sharks and commercial vessels were observed outside the survey area, they were not included in the survey data. The distance covered during each survey was restricted by financial costs, time restraints and the availability of both plane and pilot.

Two regions, either north or south of sector 13, were analysed separately during both 1995 and 1997, as the major area of whale shark tourism was north of sector 13.

Comparisons between data on the swimming direction of *R. typus* at NMP during both aerial and boat surveys were subjected to a χ^2 test.

5.2.3 Telemetry and tracking

On two separate visits to NMP, *i.e.* between 30 March and 15 April 1997 and between 26 May and 4 June 1997, several attempts were made to attach electronic tags to whale sharks using the privately chartered vessel *Wild Thing* and the CALM vessel *Pseudorca 11*. Tracking equipment comprised a Vemco 40 KHz V22TP-01 transmitter, a V-11 hydrophone and VR-60 receiver, and a Garmin 100 Global Positioning System (GPS). The GPS position and swimming depth were recorded at one second intervals. The range of the acoustic tags was approximately 1.8 km, with battery power sufficient for more than seven days. The hydrophone was mounted over the port side of the vessel (Fig. 5.3). Shark location and swimming speed were assumed to be the same as that of the tracking vessel.

The satellite tags (Telonics ST-10), which were mounted in a syntactic foam float designed by I. Helmond, CSIRO Marine Research, Hobart, transmitted location data to the overhead ARGOS satellites. Earth-based receiving stations and computer link-ups enabled these data to be received at CSIRO Marine Research, Hobart. The tags were attached to detachable speargun heads, using either a 2 or 5 m stainless

steel tether. The tether lengths were chosen so that on a shark of average size at NMP, *i.e. ca* 7 m, the attachment of the tag to an area just below the first dorsal fin at the level of the first dermal ridge, would ensure that the tag would be towed either in front of or behind the caudal fin (Fig. 5.4).

The spear was fired from a Woodie 1000 speargun, which was fitted with twin 16 mm diameter rubbers (Fig. 5.5) from a distance of approximately 1 m and at an angle of approximately 90^0 to the surface of the whale shark to reduce the likelihood of the spear bouncing off the skin

Recognition of individual *R. typus* was assisted by photographic identification (see Chapter 4). Identifications of individual sharks on two or more occasions enabled some short-term movements to be documented.

5.2.4 Sightings from other nearby locations

Data on whale shark sightings in 1994 and 1995 around Christmas Island, Indian Ocean, were obtained both personally and by Australian Nature Conservation Agency (ANCA)/Parks Australia North staff from the log sheets of commercial fishing/diving vessels operating in this area.

After consultation with Mr R. Blundell (President - Kalbarri Professional Fisherman's Association) in 1996, fishers within the Kalbarri region were asked to collect information on the location of whale shark sightings and to estimate the size of each individual.

Information on whale shark sightings near Ashmore Reef in the Timor Sea was recorded by Mr Steve Tester (Parks Australia North) on data sheets supplied to the ANCA in 1995.

5.3 Results

5.3.1 Water temperature at Ningaloo Marine Park

Water temperatures at NMP remained relatively uniform between March and June inclusive, despite the fact that ambient temperatures undergo pronounced fluctuations (Fig. 5.6). The mean surface water temperature was 28.2^{0}C in 1995, 27.1^{0}C in 1996 and 26.9^{0}C in 1997. Analysis of industry data indicate that the mean time of sighting of *R. typus* at NMP was 12:16 h, with *ca* 81% of sightings between 1000 and 1400 h (Fig. 5.7).

5.3.2 Distribution of *Rhincodon typus* within Ningaloo Marine Park

5.3.2.1 Boat surveys

Personal observations

In 1995, 1996 and 1997 *R. typus* was most frequently sighted in sector 5, *i.e.* 25.6%, during 1995 and in sector 3 in both 1996, *i.e.* 39.5%, and 1997, *i.e.* 41.4% (Fig. 5.8a).

Rhincodon typus were recorded travelling parallel to Ningaloo Reef during the majority of observations made from boats in 1995 (81.1%), 1996 (73.1%) and 1997 (85.1%), with a greater frequency of individuals travelling north than south in 1995 (46.1 *vs* 35.0%), 1996 (43.4 *vs* 29.7%) and 1997 (44.4 *vs* 40.7%) (Table 5.1).

The depths of water in which *R. typus* was recorded ranged from 8 - 82 m in 1995, 8 - 71 m in 1996 and 10 - 90 m in 1997 (Table 5.2). The modal depth class was 10 - 19.9 m in 1995 (29%), 10 - 29.9 m in 1996 (52.8%) and 10 - 29.9 m in 1997 (50%) (Fig. 5.9a). The mean depth was 32.3 m in 1995, 30.6 m in 1996 and 33.5 m in 1997. The mean depth of water in which *R. typus* were sighted during the study (1995-1997) was 31.8 m (Table 5.2).

Commercial operator data

Commercial boat operators recorded the GPS coordinates and/or the sector division for most occasions when *R. typus* was sighted at NMP throughout 1995 (n = 479), 1996 (n = 884) and 1997 (n = 772) (Fig. 5.8b). The frequency of observations in 1995 was highest in sector 5 (18.8%). However, the greatest prevalence of sightings of *R. typus* was recorded in sector 3 during both 1996 (31.6%) and 1997 (27.2%).

Data obtained from the CALM Whale Shark Operator logbooks show that *R. typus* was seen by these operators at NMP on 501 occasions in 1995, 914 occasions in 1996 and 783 occasions in 1997. The direction of travel by *R. typus*, which was recorded for 797 sightings in 1996, was typically parallel to Ningaloo Reef, with sharks moving in a northerly direction on 48.7% of occasions and southerly on 36.9% of occasions (Table 5.3). During 1997, the direction of travel of *R. typus* was recorded on 742 occasions, with *R. typus* moving north on 45.1% of occasions and south on 39.1% of occasions (Table 5.3). The log books used in 1995 did not record information on the swimming direction of *R. typus*.

The Whale Shark Operator logbooks used in 1996 and 1997 recorded information on the water depths over which *R. typus* were sighted within NMP on 807 occasions in 1996 and 735 in 1997. The depths ranged from 4.5 to 75 m in 1996 and from 4 to 84 m in 1997 (Table 5.2). The modal depth class was 10 - 29.9 m in both 1996 and 1997 (Fig. 5.9b). The mean depth was 27.8 m and 31.8 m in 1996 and 1997, respectively, with the overall mean depth for these two years being 29.8 m (Table 5.2).

5.3.2.2 Aerial surveying

In 1995, 30 *R. typus* were observed, with the number sighted ranging from 0 to 9 per survey (Table 5.4). The mean number of sharks ± 1 S.E. sighted per survey was 2.0 ± 0.67. No animals were recorded during five of the 15 survey flights. The greatest number of sharks sighted, *i.e.* 9, was recorded during the extended flight past Yardie Creek (sector 13) to Coral Bay (Table 5.4).

Whale sharks were most frequently sighted between sectors 5 and 7, with 57.7% of the sightings being recorded in these sectors (Fig. 5.10). The highest frequency of whale shark sightings in 1995 was recorded in early April (Table 5.4).

Rhincodon typus was observed travelling in a southerly direction on 56.7% of surveys and in a northerly direction on 36.7% of surveys, with one individual moving west and another east (Table 5.5).

In 1997, the number of *R. typus* observed per survey ranged from 1 to 20, with 72 sharks being sighted in total (Table 5.6). The mean number of sharks ± 1 S.E. sighted per survey was 5.5 ± 1.47, with a total of 36 sharks being recorded between sectors 1 and 13. Fifty five percent of the sharks sighted within this northern region (sector 1 - 13) were between sectors 5 and 9 (Fig. 5.10). However, it should be recognised that all flights in 1997 included the area south of sector 13, whereas, in 1995, only one of the 15 surveys included this region.

The direction of travel of *R. typus*, which was recorded on 46 occasions, was northwards during 52.2% of surveys and southwards during 37.0% of sightings (Table 5.7). Two sharks were moving toward the coast (east), while three others were moving in a westerly direction away from the coast.

A χ^2 test, utilising all of the data that were obtained on the swimming direction of *R. typus* by personal observations by air and from boats (Tables 5.1, 5.5), indicated that there was no significant difference between the number of sharks swimming either northwards or southwards in 1995 (p > 0.05). However, on the basis of boat and aerial survey data collected personally, and data collected by commercial operators, significantly more animals were travelling northwards than southwards in both 1996 (p < 0.05) and 1997 (p < 0.05) (Tables 5.1, 5.3, 5.7). On the basis of the data for all years, *i.e.* 1995 - 1997, there were significantly more *R. typus* swimming in a northward direction (p < 0.05).

5.3.3 Telemetry and tracking

On April 6 1997, an acoustic tag was attached to a 7 m whale shark, which was located within sector 3 and later identified as A-020 (see Chapter 4: Library 1). The shark was tracked for 18 h from the chartered vessel *Wild Thing*, and for an additional 7 h using the CALM vessel *Pseudorca 11* (Fig. 5.11). During daylight hours, the shark spent 17% of its time at or near the surface compared to 65% during the hours of darkness (see also Fig. 10 in Stevens *et al.*, 1998).

Following unsuccessful attempts to place another acoustic transmitter on an additional two *R. typus* on 10 April 1997, shark A-020 was relocated at sector 5, with the tag attached previously on 6 April 1997 still emitting a strong signal (Fig. 5.12). Tracking of shark A-020 recommenced, and continued for a further 14.6 h. This shark was again recorded at or near the surface for approximately 17% of daylight hours, although only approximately 20% of darkness hours were spent at or near the surface.

The acoustic telemetry study provided the opportunity to calculate the mean swimming speed of whale shark A-020 at NMP. The mean swimming speed was calculated to be *ca* 0.85 m/sec or 3.06 km/h (see also Fig. 9 in Stevens *et al.*, 1998), which corresponded approximately with the speed observed during underwater studies of the behaviour of *R. typus* during the present study (see Chapter 7).

A satellite tag with a 5 m wire tether was successfully attached to shark A-020 on 7 April 1997 within sector 1 around mid-day (Fig. 5.13). This shark was resighted with damage to the wire tether attaching the satellite tag to the shark on 10 April 1997. As the tag would have soon been shed from the shark, it was manually removed without reaction from the shark.

Although it would have been possible to determine the identity of shark A-020 using natural markings (see Chapter 4), this shark could be immediately recognised through it's possession of the attached acoustic transmitter. This shark was resighted within NMP on 14 separate days after the initial tag had been attached (Table 5.8). The sighting co-ordinates were plotted in order to describe broadly the short-term movements

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of A-020 within NMP over a 28 day period (Fig. 5.14). This shark mainly occupied the area between sectors 1 and 4 inclusive.

An attempt to attach a satellite tag to shark A-013 on 13 April 1997 was unsuccessful. Although the spearhead was firmly embedded in the sub-cutaneous tissue of *R. typus*, rapid acceleration by the shark before the tagging apparatus was free resulted in the loss of this equipment. The tag was seen floating at the surface within NMP on 17 April 1997 and was recovered immediately. Shark A-013 was resighted on 18 April 1997 with the spearhead still embedded. The wire trace had broken at the swivel, resulting in a remnant of trace protruding approximately 30 cm from the surface of the shark (Fig. 5.15). Interactions between snorkellers and this shark were successfully conducted on 18 and 22 April 1997 and on 5 and 23 May 1997, indicating that the shark was not adversely affected by the tagging experience.

5.3.4 Sightings from other nearby locations

Results collected from fishers at Kalbarri between 1995 and 1997 reveal that, on all but one occasion, several *R. typus* were sighted near this locality between December and March. The estimated mean total length of *R. typus* was 7.0 m (n = 6) and the mean water depth where *R. typus* was sighted was 23.9 m (Table 5.9).

Rhincodon typus was sighted near Ashmore Reef in the Timor Sea by Coastwatch Aircraft during routine surveillance on 16 November 1997. Additional records from this region demonstrate that, apart from one sighting, *R. typus* were recorded there in November and December of each year between 1994 and 1997 (Table 5.10).

A total of 128 whale shark sightings were recorded at Christmas Island, Indian Ocean between November 1994 and May 1995 (Table 5.11)

5.4 Discussion

5.4.1 Water temperature at Ningaloo Marine Park

Rhincodon typus is reported as preferring areas where surface sea-water temperatures lie between 21 and 25°C (Iwasaki, 1970). However, the surface water temperatures recorded at NMP during the current study were ca 27°C and thus considerably higher than these values. Similar water temperatures were recorded by CSIRO at NMP in 1994 and 1997, with values ranging between 27 and 28°C in the 0 - 10 m immediately below the surface (Stevens et al., 1998; J. Stevens, unpub. data). Clark and Nelson (1997) also report that the water temperature when R. typus were sighted near La Paz Mexico was between 27 and 28°C. Most sightings of R. typus occurred around the middle of the day (Fig. 5.7) when the sun was almost directly overhead. These results suggest that the generalisation made by Iwasaki (1970) concerning the preferred water temperature of this species is not universally valid.

5.4.2 Distribution of Rhincodon typus within Ningaloo Marine Park

Boat surveys at NMP in 1995, 1996 and 1997 yielded a greater number of whale shark sightings within the northern sectors, i.e. sectors 2 - 6, than in other regions (Fig. 5.8). The greatest number of whale sharks were recorded within sector 5 in 1995 and in sector 3 in both 1996 and 1997. Since the vast majority of these surveys were carried out using commercial tourist operations, and the financial considerations of the commercial operators limited the extent to which the boats extended their operation from their base at Tantabiddi boat ramp, i.e. adjacent to sector 2, the effort spent searching was focused in sectors 2 - 5 and then decreased in intensity in a southwards direction.

Although aerial surveying in 1995 was concentrated in the northern region of NMP and recorded most sightings of R. typus between sectors 5 and 7, some sharks were sighted to the south of these sectors. In 1997, the majority of sightings in the northern sectors were recorded between sectors 5 and 9. The survey regime in 1997 was

far more comprehensive and incorporated a much larger area of NMP than had been previously surveyed either by air in 1995 or by boats between 1995 and 1997. The aerial survey results in 1997 were thus far less subject to commercial pressures to focus in a given area. Although equal numbers of whale sharks, *i.e.* 36, were sighted to the north and south of sector 13 (Table 5.6), it should be recognised that the latter region encompassed an area of NMP *ca* 2.5 times greater than that of the area surveyed to the north of sector 13. However, these data still demonstrate that *R. typus* was widely distributed throughout NMP.

Taylor (1996) reported that *R. typus* aggregated north of Yardie Creek between 1983 and 1988, but conducted no searches south of this location. Most of the aerial surveying carried out subsequently between 1988 and 1994 by Exmouth Air Charter (P. Arscott, Exmouth Air Charter, Exmouth, pers. comm.) concentrated in the region north of Turquoise Bay, *i.e.* equivalent to sectors 1 - 8 in the present study (Fig. 5.2), as whale sharks had often been sighted by boats in this region. Formal aerial surveys for *R. typus* were first undertaken in 1989 when two flights located sharks only to the south of Yardie Creek (Taylor, 1996). Shark numbers were greatest adjacent to or south of Yardie Creek again in 1990, although the numbers to the north of that locality increased in 1991 and 1992 (Taylor, 1996).

Several identifiable *R. typus* were resighted at NMP both within the same year and between years. Furthermore, shark A-020 was observed in the same region of the reef on 14 occasions during a 28 day period, which suggests that whale sharks exhibit a degree of site attachment for at least a limited period. Such a situation would parallel that found with white sharks (*Carcharodon carcharias*), which were resighted in a restricted area over consecutive days to months (Strong *et al.*, 1992).

Since acoustic tagging showed that whale sharks spend time in deeper waters (see section 5.3.3), and whale sharks can only be observed when they are near the surface, fewer sharks are probably sighted than are actually present. Indeed, wildlife surveys can result in up to 50 - 60 % of the animals in an area not being detected (Marsh

& Sinclair, 1989), with the probability of missing an animal increasing as the survey distance increases away from the transect line (Quang & Lanctot, 1991). The aerial survey programs that have been undertaken at NMP, including those during the present study, have only covered the area 5 km out from the reef crest. Thus, an expanded aerial survey program at NMP in the future would result in the acquisition of more extensive data on the distribution of *R. typus* at the surface at NMP in general.

The fact that most *R. typus* were sighted in relatively shallow water within NMP suggests that *R. typus* 'prefers' areas close to the Ningaloo Reef, where productivity would probably be greatest. Since the depth of water where *R. typus* was sighted further south near Kalbarri was similar to that at NMP, *R. typus* may always prefer shallow waters when it migrates to all inshore waters of Western Australia.

Data from aerial and boat surveys conducted between 1995 and 1997 indicate that *R. typus* swims predominantly parallel to the reef. Furthermore, in the two years when there were the most data on the swimming direction of *R. typus*, *i.e.* 1996 and 1997, a significantly greater number of sharks were swimming northwards than southwards. Likewise, Taylor (1996) also found that those *R. typus* sighted during aerial surveys between 1990 and 1992 tended to swim parallel to Ningaloo Reef, and they showed a greater tendency to swim in a northerly direction ($p < 0.05$).

5.4.3 Telemetry and tracking

Generally, sharks exhibited little or no change in behaviour when attempts were made to attach tags to individual *R. typus* at NMP during the 1997 season. In an earlier telemetry study conducted on the tiger shark (*Galeocerdo cuvier*), a transmitter was attached via a stainless steel dart to an area of the shark adjacent to the first dorsal fin. No overt response by *G. cuvier* was reported when the tag was applied (Tricas *et al.*, 1981). This situation paralleled the results obtained for whale sharks at NMP in 1994, when several whale sharks were tagged through the first dorsal fin and showed little reaction (J. Stevens, unpub. data). During the present study on *R. typus*, the only

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observed change in behaviour of tagged sharks occurred when an individual increased swimming speed and dived away during manual detachment of the spear from the spearhead.

Shark A-013, which was identified as tagged previously with a passive tag in 1992 (J. Taylor, pers. comm.), was sighted on four occasions subsequent to the unsuccessful attempt to attach a satellite tag to this individual in 1997. Snorkellers swam with this shark on 12 separate occasions at NMP during 1996 (see Table 4.1). Shark A-020 was sighted on 14 separate days in 1997, with commercial tour operators reporting extended periods of tourist interaction with this shark, and little change in the shark's behaviour throughout the course of the interaction (Table 5.8; P. Lake, M. Landon, M. Toole, Whale Shark Steering Committee, Exmouth, pers. comm.). Tagging thus usually appears to have little detrimental impact on *R. typus*.

Acoustic tracking undertaken in 1997 provided data over two separate day/night periods, during which whale shark A-020 spent 83% of time below the surface and out of view during the daylight hours. Given that there is a predominance of immature male whale sharks present at NMP (see Chapter 3), and if shark A-020 (*ca* 7 m male) was representative of the group of *R. typus* at this location, there is only a 17% probability of sighting *R. typus* during aerial surveys at NMP. It thus also follows that the number of whale sharks sighted in 1997 was likely to be considerably less than those that were present but out of survey view.

The data obtained during acoustic tracking work in 1997 showed that the tracked shark (A-020) travelled essentially parallel to the reef front. Although the shark often changed direction throughout the acoustic tracking periods, it remained well within the boundaries of the NMP. If the average swimming speed of this animal, *i.e.* *ca* 3 km/h, is representative of the sharks at this location (see Chapter 7), the maximum distance travelled in a straight line by *R. typus* within a four week period would be around 2000 km. Therefore, individuals of this species have the ability to migrate large distances during the period when not seen at NMP.

5.4.4 Sightings from other nearby locations and possible migratory routes of *Rhincodon typus*

Since a significantly greater number of the whale sharks observed at NMP are moving northwards rather than southwards (see section 5.3.2), it seems reasonable to suggest that *R. typus* migrate northwards after leaving NMP in July. Although there are few supporting data, it seems likely that the whale sharks seen further north in the Timor Sea may have migrated from NMP. Iwasaki (1970) suggests that this species prefers waters where higher salinity cold water upwells into lower salinity warm water, which would likely occur at locations near the edge of the continental shelf, e.g. Ashmore Reef.

Rhincodon typus begin to appear in November at Christmas Island, Indian Ocean around the time of the annual mass spawning of crabs in that region and thus when there was an increase in food resources (see Chapter 3). Although it is not known whether some of the sharks at Christmas Island, Indian Ocean had migrated from NMP, such a situation seems feasible given the known swimming speed of *R. typus* (see section 5.3.3) and the proximity of Christmas Island, Indian Ocean.

Whale sharks are occasionally sighted near Kalbarri, further south than NMP, during December to March, *i.e.* just prior to when they start appearing in abundance at NMP (Table 5.10). Furthermore, regular sightings were recorded near Shark Bay, to the north of Kalbarri, in April and May (R. Blundell, Kalbarri Professional Fisherman's Association, Kalbarri, pers. comm.). While currently unsubstantiated, it is possible that *R. typus* seen at these southern locations may move northward along the WA coastline to NMP and continue through to lower latitudes. The migratory routes of *R. typus* could be determined in the future through using sophisticated tracking technology, especially satellite tagging, together with photographic records housed in the Whale Shark Photo-identification Library (see Chapter 4).
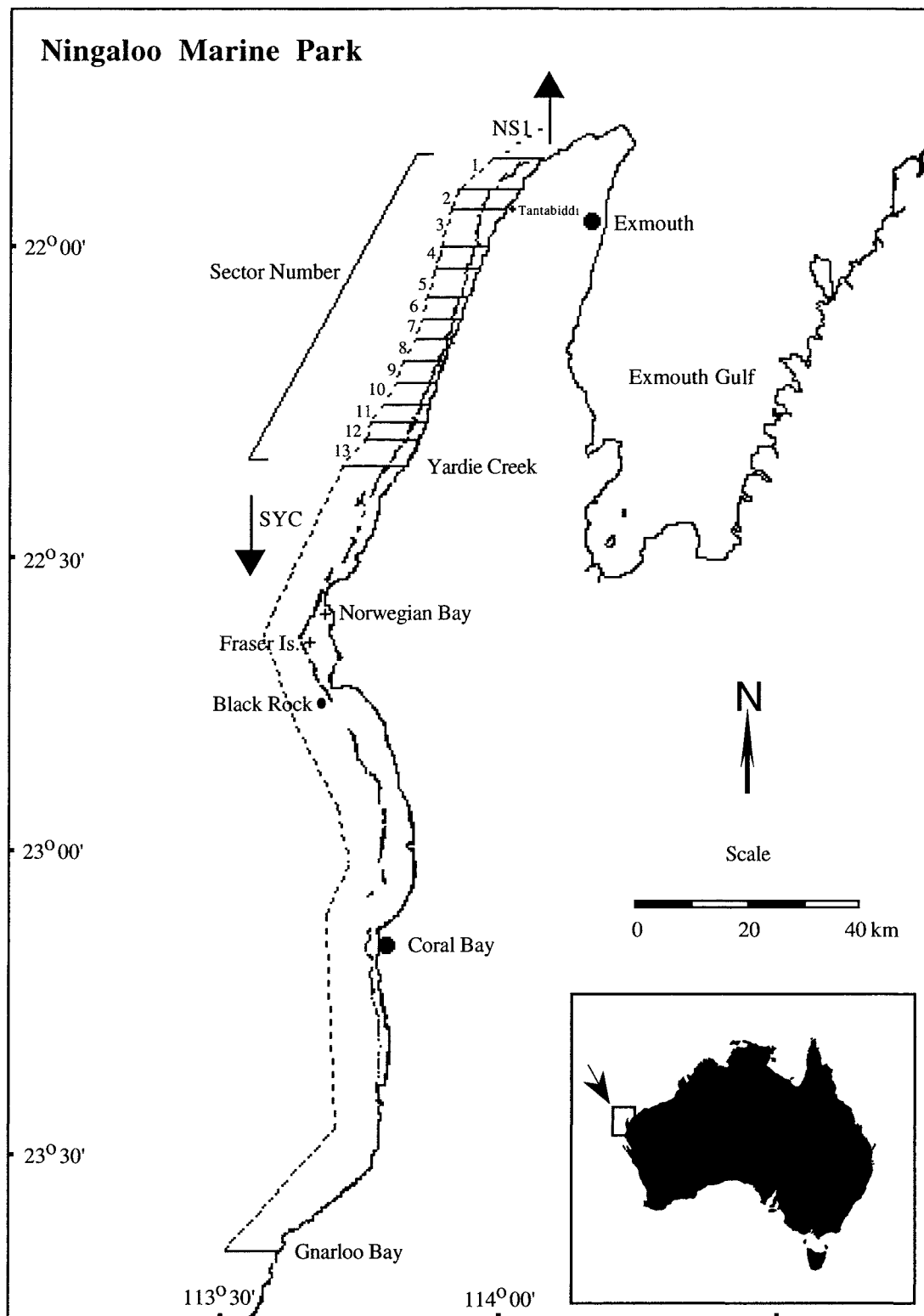
Figure 5.1 The area within Ningaloo Marine Park where whale shark tour operations were conducted between 1995 and 1996. The area immediately west of the northern reaches of Ningaloo Reef is divided into 13 sectors for the purpose of documenting the distribution of *Rhincodon typus* and the associated industry vessels. NB. NS1 = north of Sector 1; SYC = south of sector 13 and Yardie Creek.
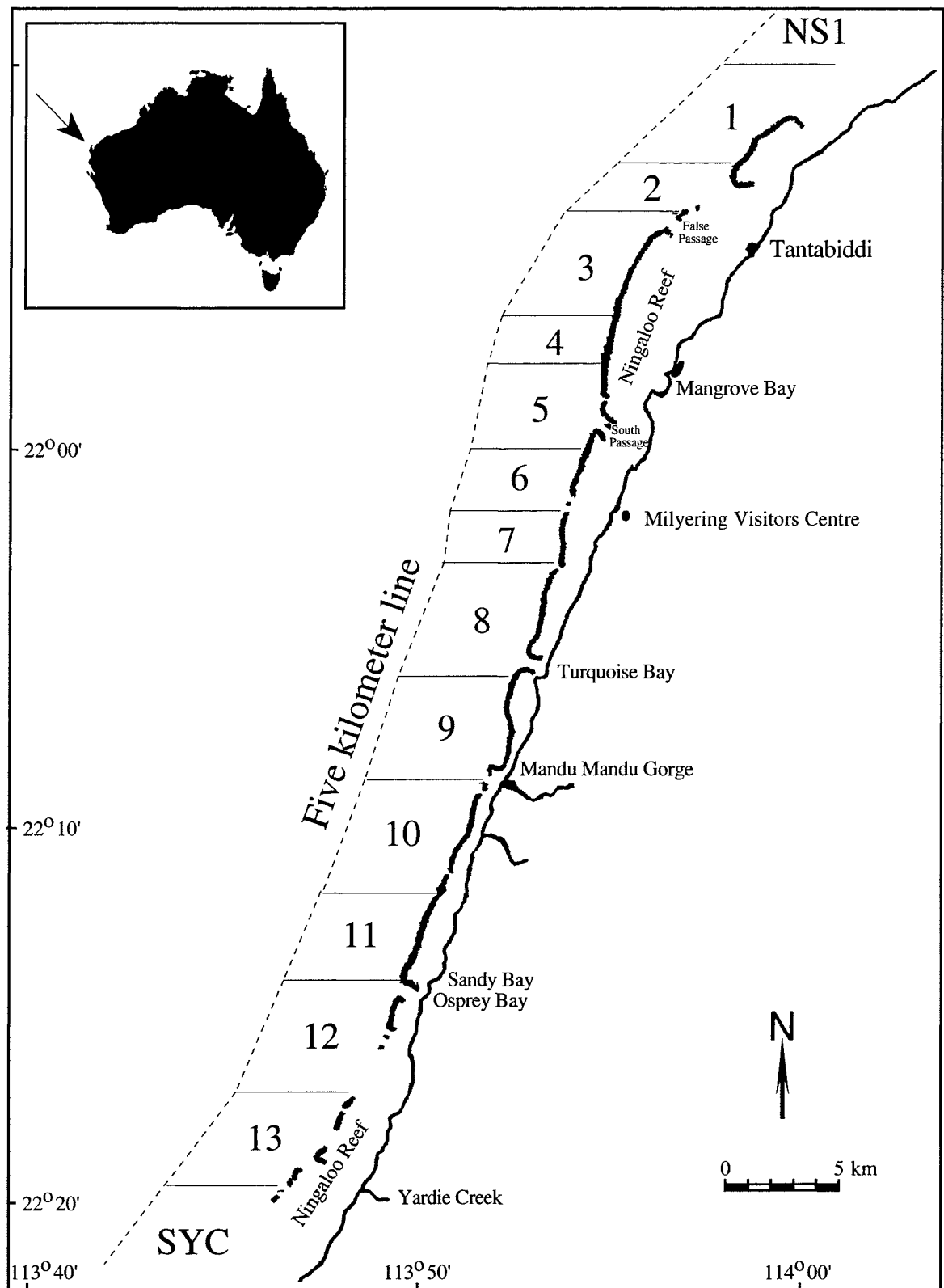
Figure 5.2 The northern commercial whale shark watching area of Ningaloo Marine
Park was divided into the 13 sectors shown on the map. The numbers of
Rhincodon typus within these sectors were recorded during aerial and boat
surveys between 1995 and 1997.

Figure 5.3   Hydrophone attached to the gunwhale of the vessel used during the acoustic

tracking of *Rhincodon typus* at Ningaloo Marine Park in 1997.
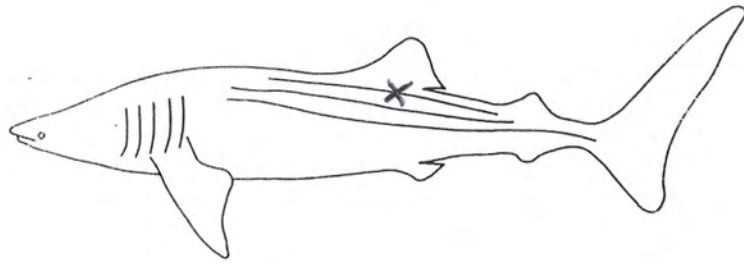
Figure 5.4 Preferred attachment site (X) for acoustic, archival, and satellite tags on
Rhincodon typus.

Figure 5.5 Tag attached to spear head prior to firing from Woodie 1000 speargun.
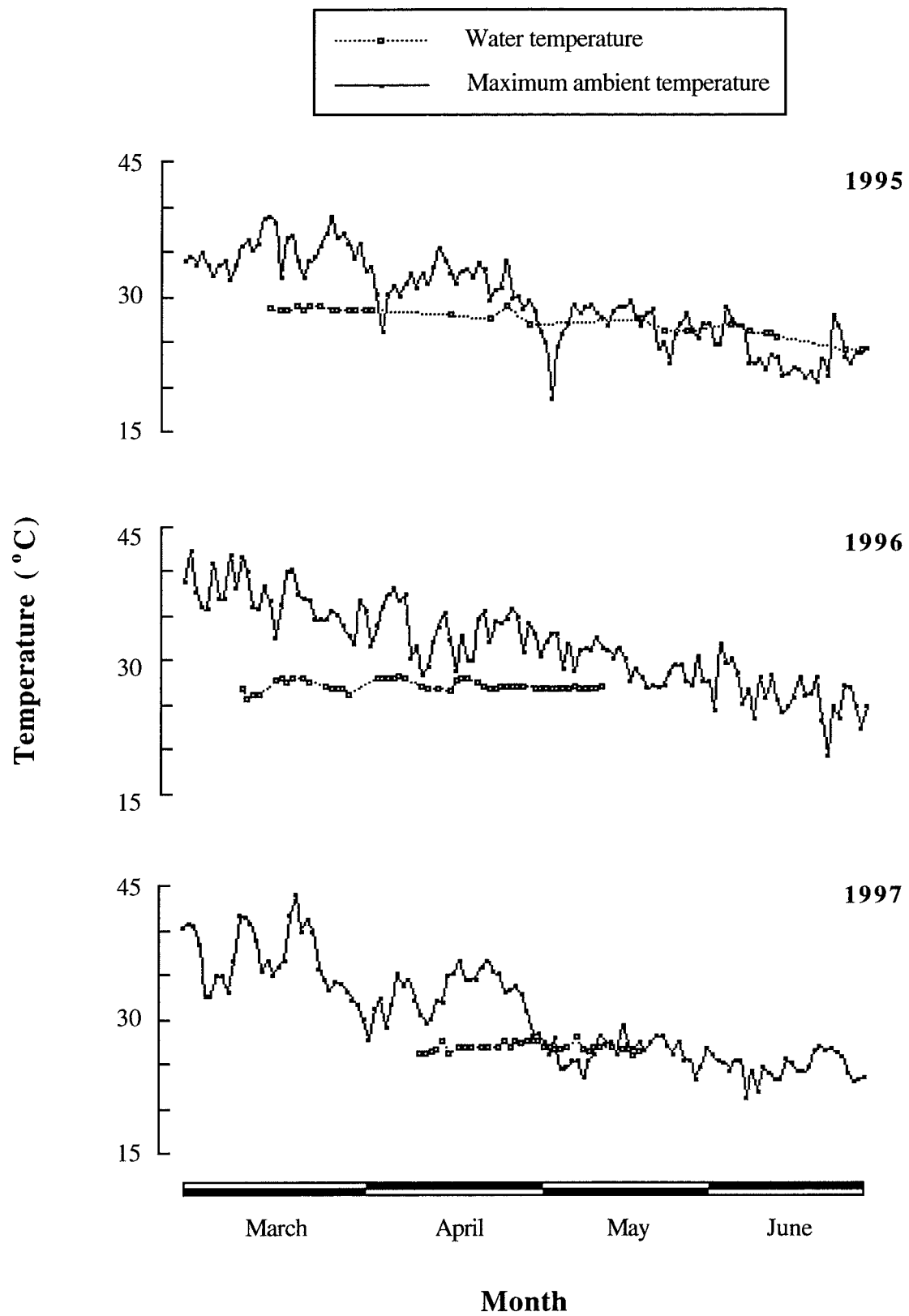
Figure 5.6   Surface water temperatures and maximum ambient temperatures at Ningaloo Marine Park in March to June of 1995, 1996 and 1997.
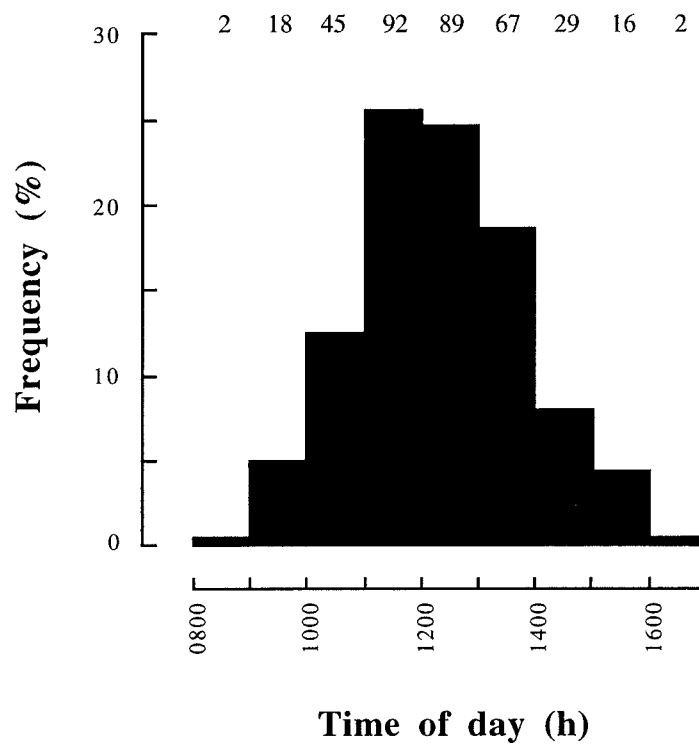
Figure 5.7 Frequency of observations of whale sharks from boats at different
periods during the day at Ningaloo Marine Park between 1995
and 1997. The majority of searches were conducted between 0900
and 1600 h. The number of fish sighted within each time interval
is also given.

(a) Personal observations

Legend:
- 1997 (n = 55)
- 1996 (n = 176)
- 1995 (n = 125)

(b) Industry records

Legend:
- 1997 (n = 772)
- 1996 (n = 884)
- 1995 (n = 479)
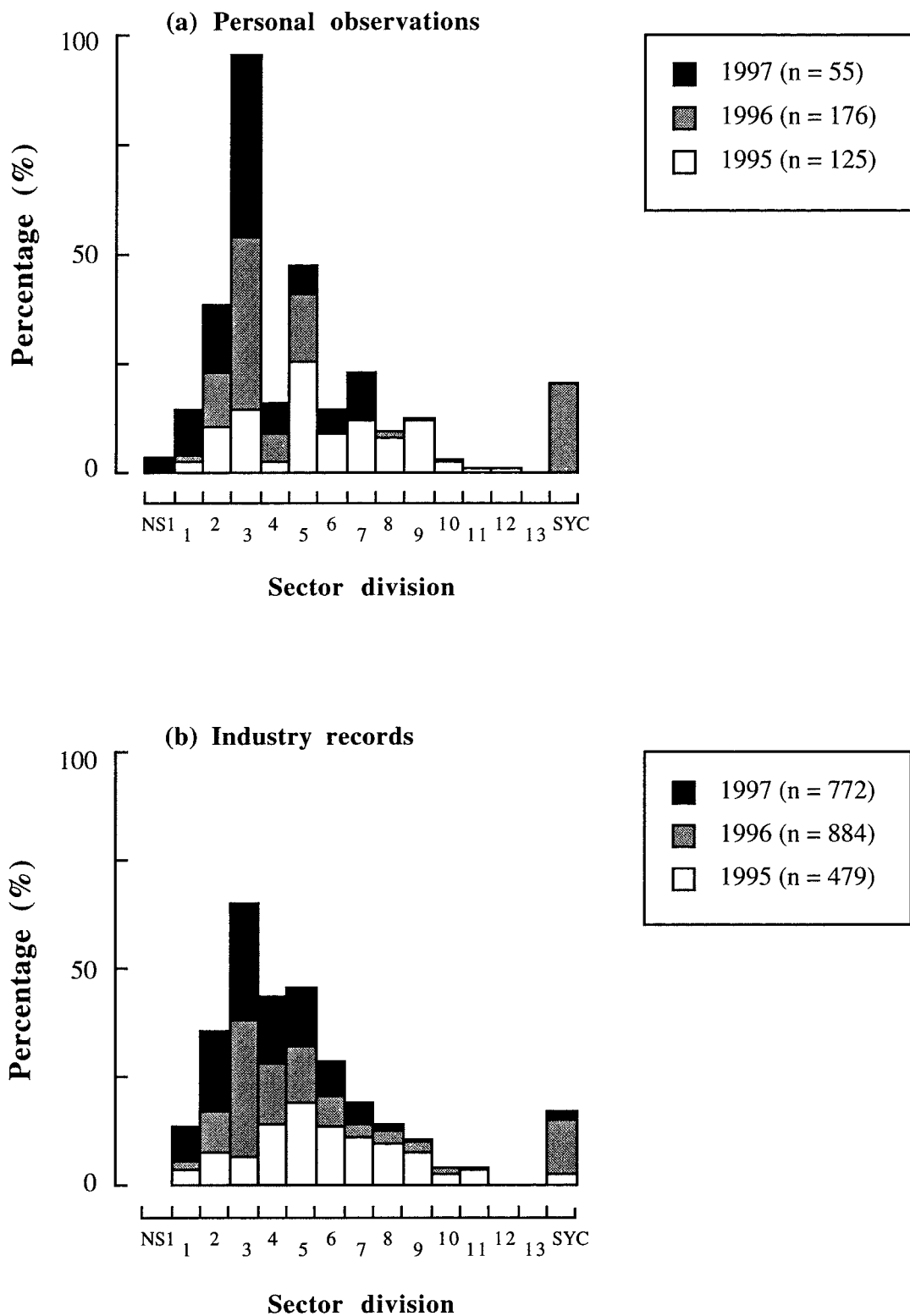
Figure 5.8 The percentage of *Rhincodon typus* that were recorded by observations from boats in each of the different sector divisions (see Figs 5.1, 5.2) during (a) personal observations and by (b) industry operators. NB. NS1 = the region north of sector 1, while SYC = the region south of sector 13 and Yardie Creek.
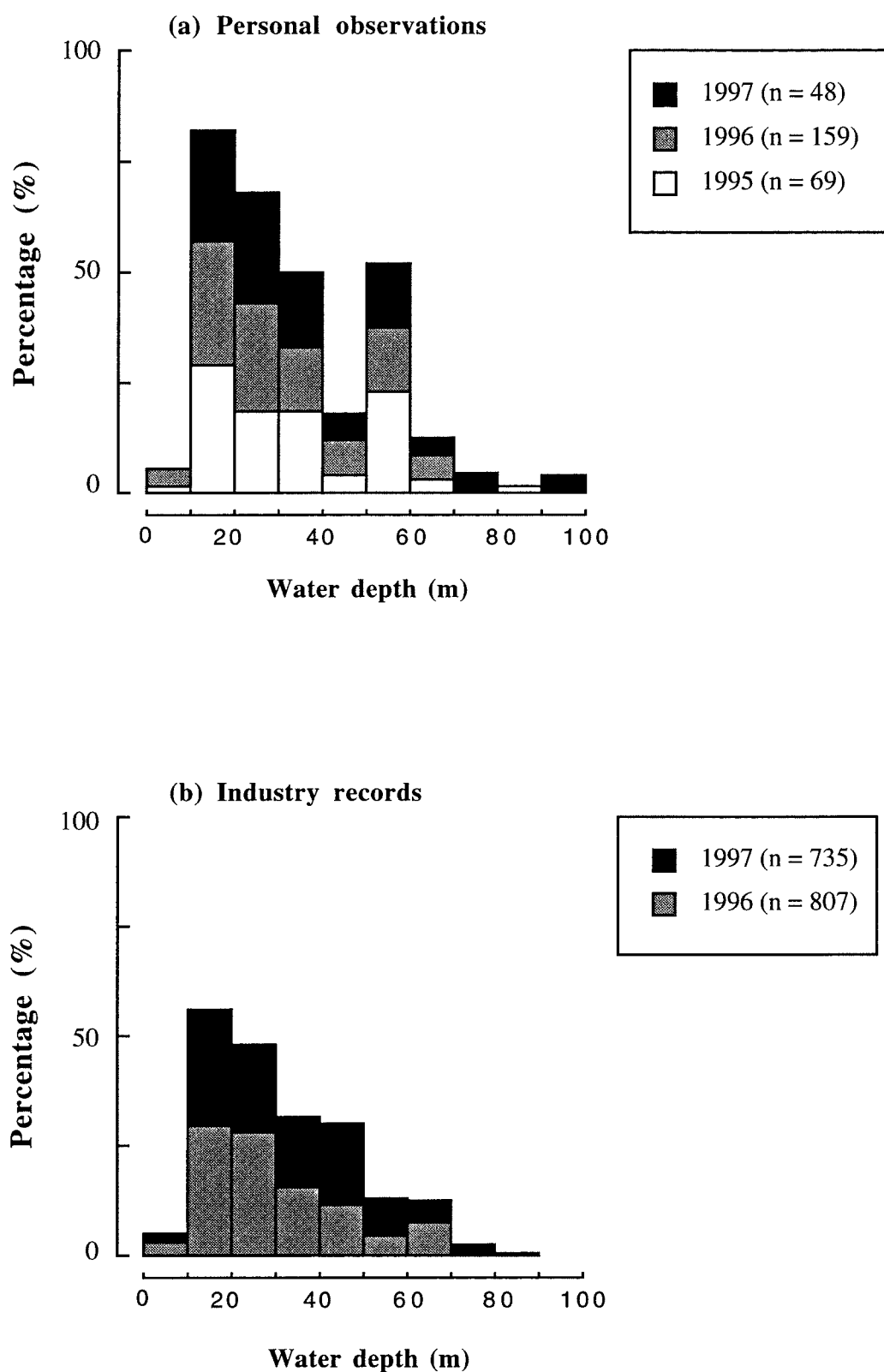
Figure 5.9   The percentage of *Rhincodon typus* that were sighted from boats during (a) personal observations and by (b) industry operators in sequential water depth intervals in Ningaloo Marine Park.
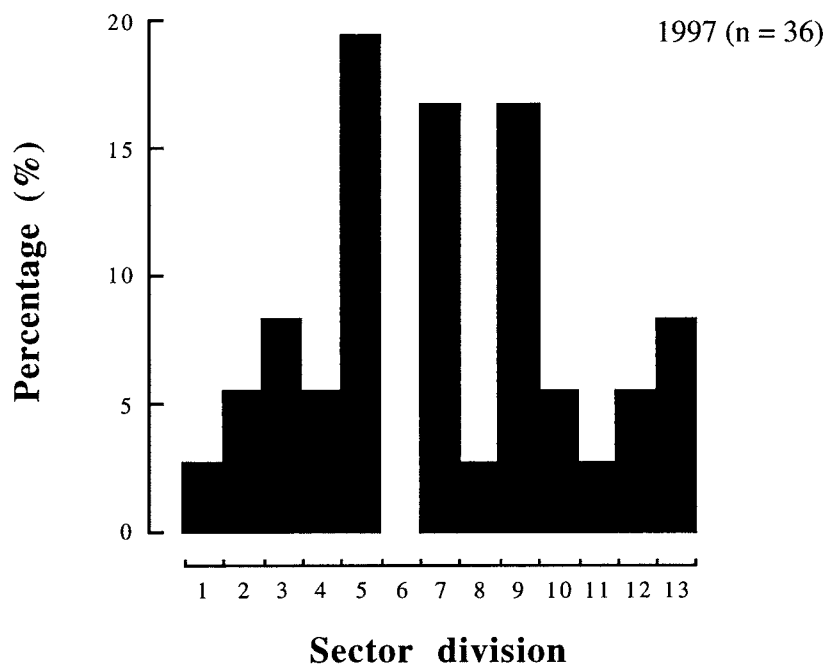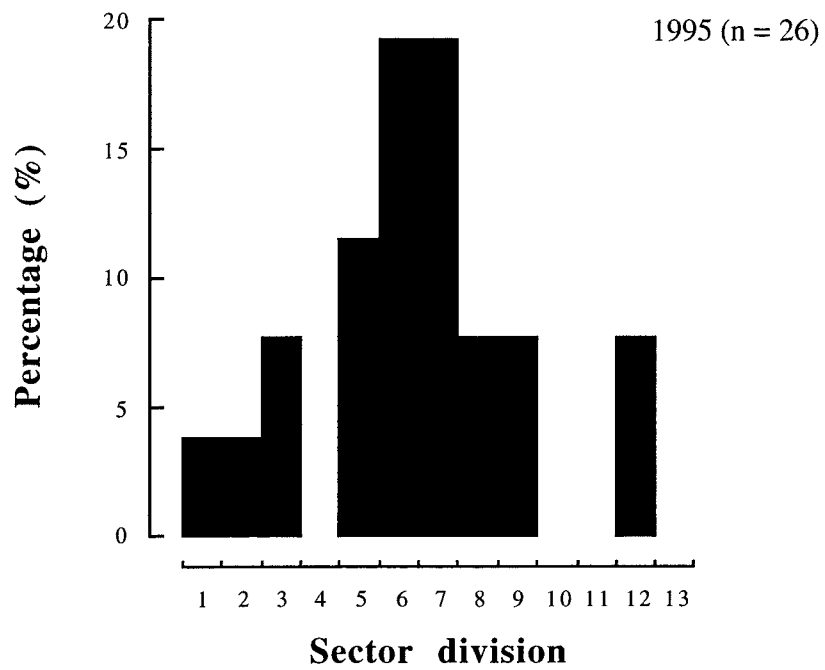
Figure 5.10 Frequency of sightings of *Rhincodon typus* by air within the 13 sectors (see Figs 5.1, 5.2) in the northern commercial whale shark watching area of Ningaloo Marine Park during aerial surveys in 1995 and 1997. n = number of individual whale shark sightings.
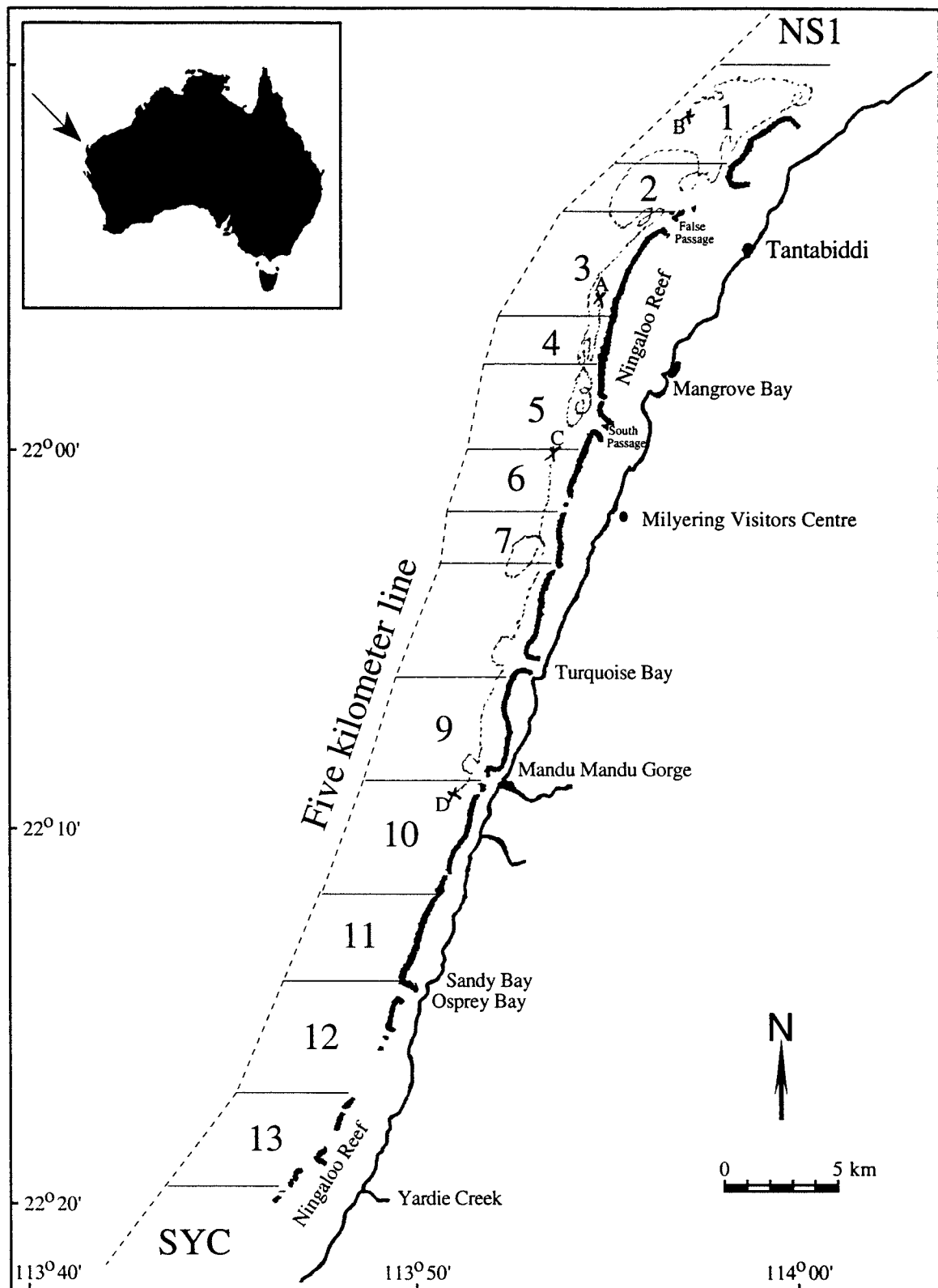
Figure 5.11 The movement pattern of shark A-020 during two separate acoustic tracking periods at Ningaloo Marine Park in 1997. NB. Track #1: A = start (6/4/97); B = finish (7/4/97). Track #2: C = start (10/4/97); D = finish (11/4/97).
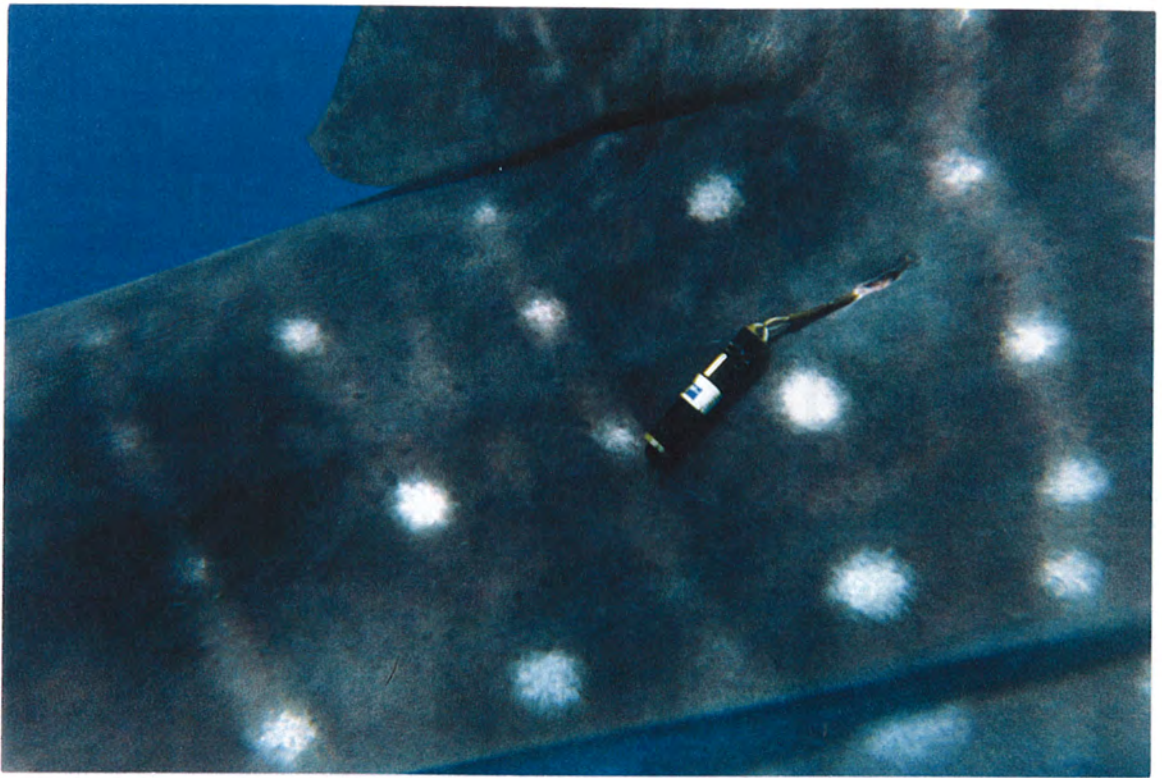
Figure 5.12 Acoustic tag attached to *Rhincodon typus* at Ningaloo Marine Park in 1997.
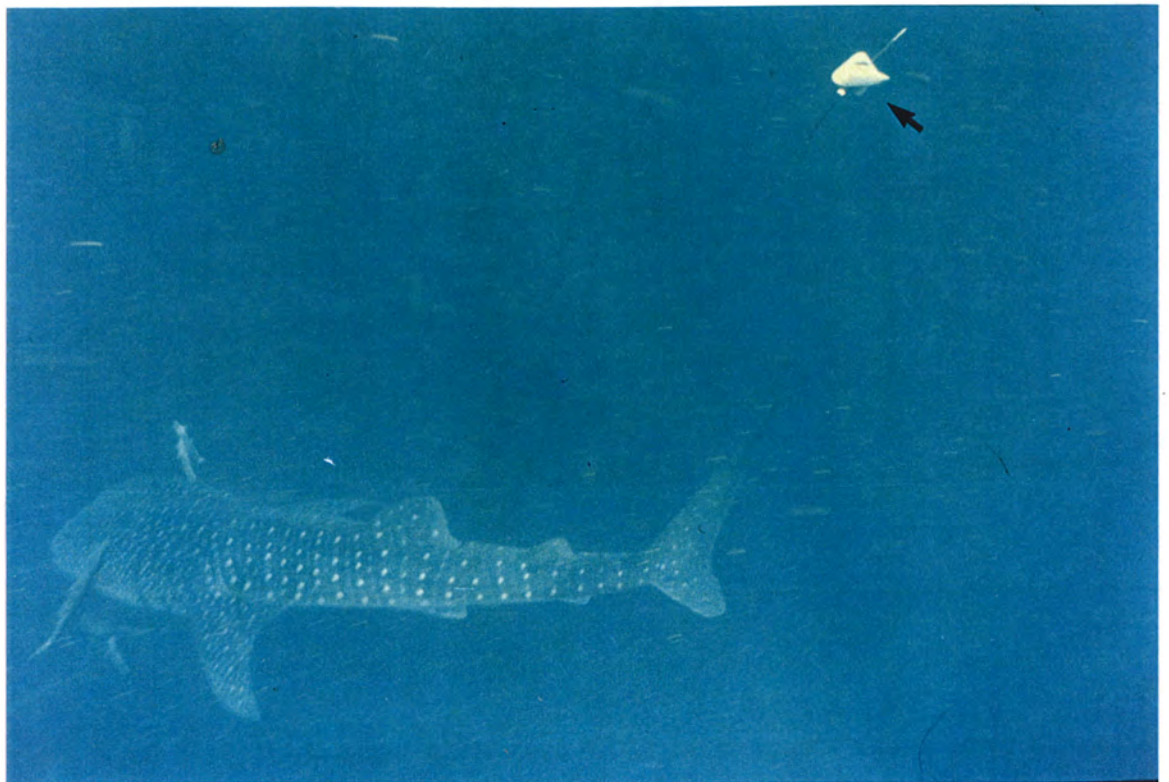
Figure 5.13 Photograph of *Rhincodon typus* with attached satellite tag at Ningaloo
Marine Park.
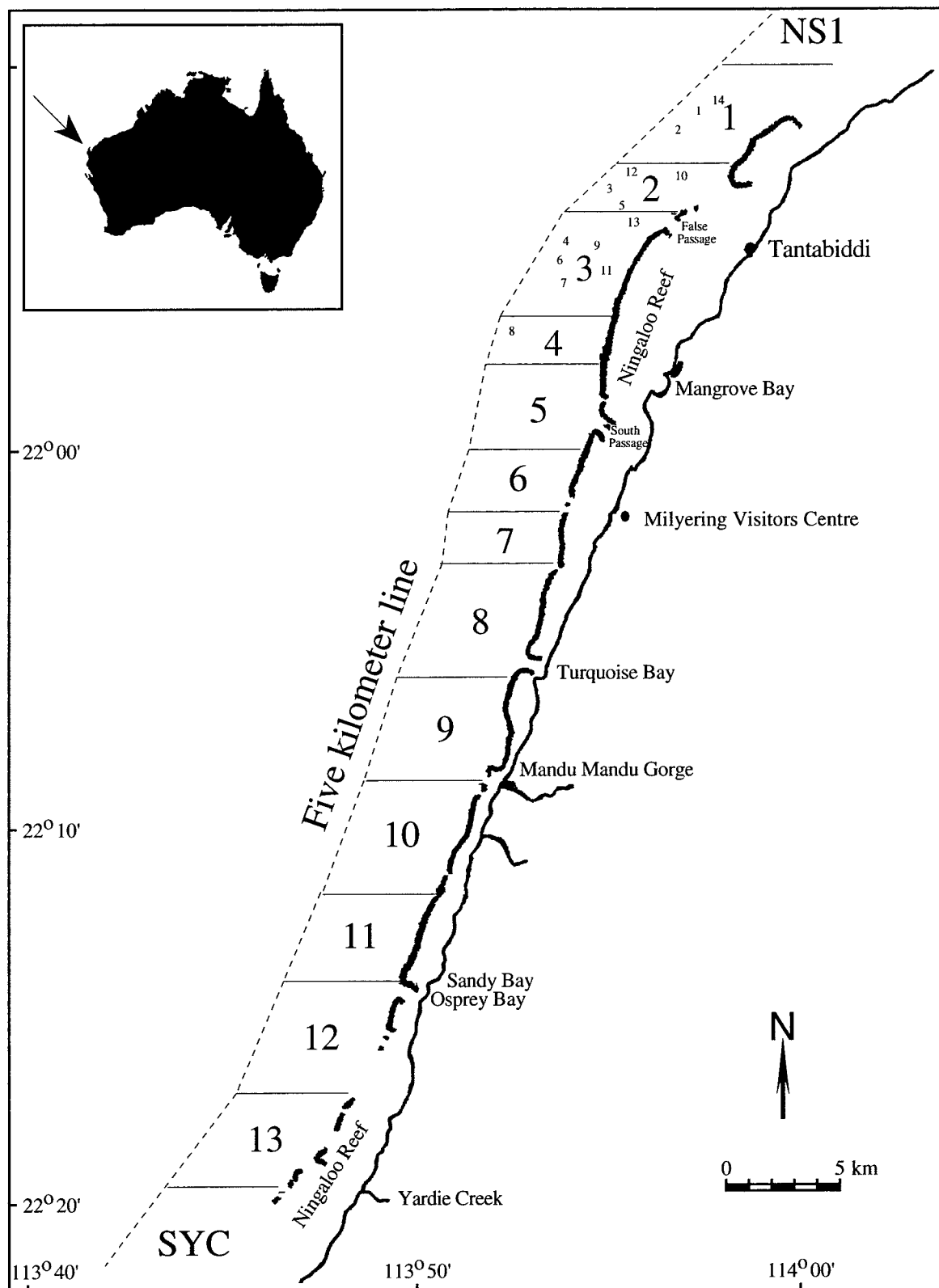
Figure 5.14 The locations where shark A-020 was repeatedly sighted within the northern area of Ningaloo Marine Park over a 28 day period in 1997. NB. The marked numbers within sectors 1 - 4 represent the days of each repeat sighting (see Table 5.8).
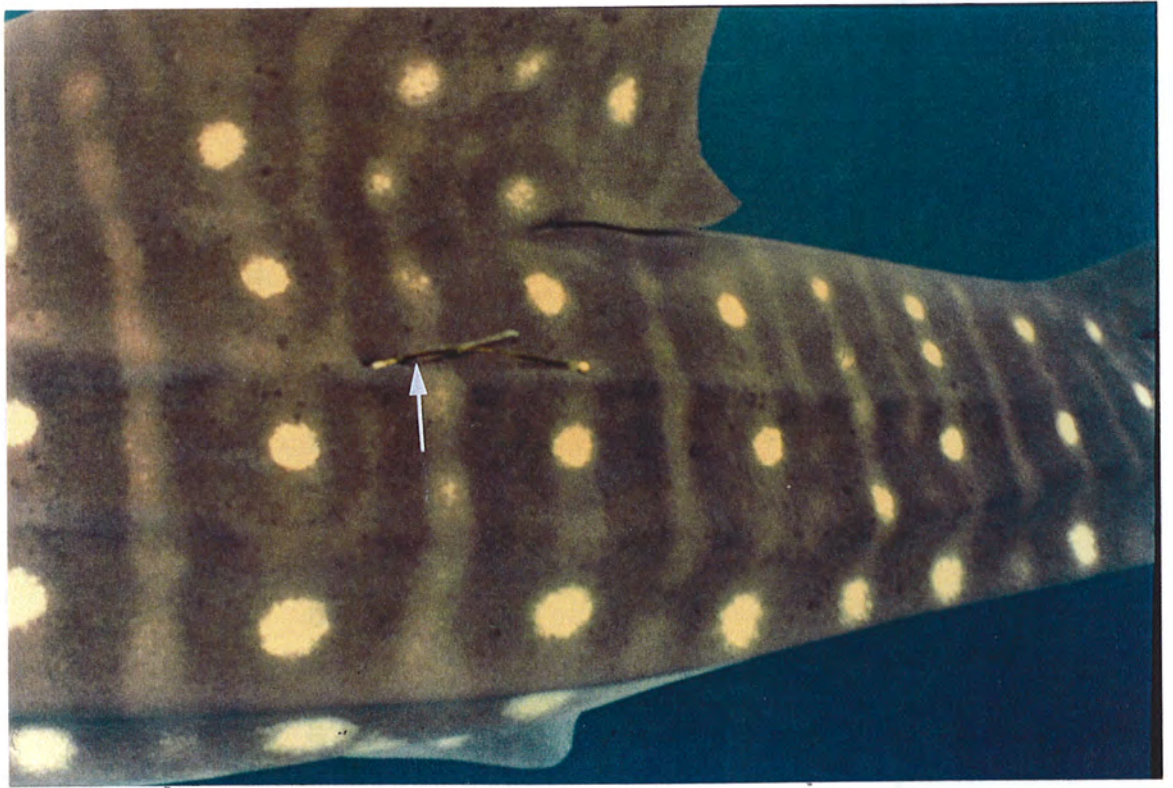
Figure 5.15 Trace remnant from satellite tag remaining attached to *Rhincodon typus* at Ningaloo Marine Park in 1997.

Table 5.1 Percentage of individuals of *Rhincodon typus* travelling in different directions, recorded from personal boat observations during the current study at Ningaloo Marine Park between 1995 and 1997.

| Year | n | Direction of travel | | | | | |
		North (%)	South (%)	East (%)	West (%)	Circling (%)
1995	117	46.1	35.0	0.1	4.2	13.6
1996	175	43.4	29.7	7.4	4.0	15.4
1997	54	44.4	40.7	0	3.7	11.1

Table 5.2 Depths of water over which *Rhincodon typus* were sighted at Ningaloo Marine Park during personal observations (1995 - 1997) and by the observations of Industry Operators (1996 - 1997).

NB. Industry did not keep records on the depths of sighting in 1995, na = not available

Year	n		Depth range (m)	Mean sighting depth (m)
1995	71	Personal observations	8 - 82	32.3 ± 2.01
	-	Industry records	na	na
1996	160	Personal observations	8 - 71	30.6 ± 1.34
	807	Industry records	4.5 - 75	27.8 ± 0.52
1997	48	Personal observations	10 - 90	33.5 ± 3.04
	735	Industry records	4 - 84	31.8 ± 0.62
Overall	279	Personal observations	8 - 90	31.8 ± 1.06
(1995-1997)	1542	Industry records	4 - 84	29.8 ± 0.40

Table 5.3 Percentage of individuals of *Rhincodon typus* that were recorded as moving in specific directions on Whale Shark Operator logsheets at Ningaloo Marine Park between 1996 and 1997.

| Year | n | | | Direction of travel | | | |
		North (%)	South (%)	East (%)	West (%)	Circling (%)
1996	797	48.7	36.9	2.5	2.9	8.9
1997	742	45.1	39.1	2.3	2.4	10.8

Table 5.4 The location and number of *Rhincodon typus* during 15 aerial surveys conducted at Ningaloo Marine Park in 1995.
NB. ns = not surveyed.

Survey No.	Date	Start Time	No. Sharks	Survey duration (min.)	SECTOR #													South of Sector 13 & Yardie Creek
					1	2	3	4	5	6	7	8	9	10	11	12	13	
1	17/3/95	12:30 pm	1	ca 60	-	1	-	-	-	-	-	-	ns	ns	ns	ns	ns	ns
2	24/3/95	12:55 pm	1	55	-	-	1	-	-	-	-	-	ns	ns	ns	ns	ns	ns
3	1/4/95	13:05 pm	4	55	-	-	-	-	1	1	1	1	ns	ns	ns	ns	ns	ns
4	7/4/95	12:51 pm	3	58	-	-	-	-	-	-	3	-	ns	ns	ns	ns	ns	ns
5	12/4/95	12:43 pm	5	57	-	-	1	-	-	1	1	1	1	-	ns	ns	ns	ns
6	15/4/95	14:06 pm	2	66	-	-	-	-	-	2	-	-	-	ns	-	-	-	ns
7	19/4/95	13:02 pm	3	73	-	-	-	-	-	-	-	-	1	-	-	-	2	ns
8	22/4/95	13:35 pm	0	65	-	-	-	-	-	-	-	-	-	-	-	-	-	ns
9	29/4/95	12:30 pm	0	60	-	-	-	-	-	-	ns	ns	ns	ns	ns	ns	ns	ns
10	3/5/95	12:45 pm	1	68	-	-	-	-	1	-	-	-	-	-	-	ns	-	ns
11	10/5/95	13:25 pm	0	70	-	-	-	-	-	-	-	-	-	-	-	-	-	ns
12	17/5/95	12:50 pm	1	80	-	-	-	-	1	-	-	-	-	-	-	ns	-	ns
13	24/5/95	12:51 pm	0	70	-	-	-	-	-	-	-	-	-	-	-	ns	-	ns
14	2/6/95	10:00 am	9	216	1	-	-	-	-	1	2	1	-	-	-	-	-	4
15	7/6/95	12:16 pm	0	60	-	-	-	-	-	-	-	-	ns	-	-	ns	ns	ns

Table 5.5 Direction of travel of *Rhincodon typus* recorded during 15 aerial surveys conducted at Ningaloo Marine Park in 1995.

Sector No.	No. of shark sightings	Direction of travel			
		South	North	West	East
1	1	-	1	-	-
2	1	1	-	-	-
3	2	2	-	-	-
4	0	-	-	-	-
5	3	2	1	-	-
6	5	3	2	-	-
7	7	4	3	-	-
8	3	3	-	-	-
9	2	1	1	-	-
10	0	-	-	-	-
11	0	-	-	-	-
12	2	-	2	-	-
13	0	-	-	-	-
South of Sector 13	4	1	1	1	1
Total %	100	56.7	36.7	3.3	3.3

Table 5.6 Location and number of *Rhincodon typus* during 13 aerial surveys conducted at Ningaloo Marine Park in 1997.

Survey No.	Date	Start Time	No. Sharks	Survey duration (min.)	SECTOR									#				South of Sector 13 & Yardie Creek
					1	2	3	4	5	6	7	8	9	10	11	12	13	
1	27/3/97	8:50am	2	163	-	-	-	-	-	-	-	-	-	-	-	-	-	2
2	3/4/97	10:58am	2	108	-	-	-	-	1	-	-	-	-	-	-	-	-	1
3	5/4/97	10:05 am	4	160	1	-	-	-	1	-	-	-	-	-	-	-	-	3
4	9/4/97	10:09 am	2	161	1	-	-	-	-	-	-	-	-	-	-	-	-	1
5	12/4/97	10:03 am	3	157	-	-	-	-	-	-	-	-	-	-	-	-	-	3
6	16/4/97	10:15 am	7	164	-	1	1	1	2	-	-	-	-	-	-	-	-	3
7	18/4/97	9:12 am	8	167	-	-	-	1	-	-	-	-	-	-	-	-	-	7
8	22/4/97	9:07 am	5	158	-	-	1	-	1	-	1	-	-	-	-	-	-	4
9	26/4/97	9:05 am	10	160	-	-	1	-	-	-	5	-	4	-	1	-	-	5
10	30/4/97	9:10 am	20	162	-	-	-	-	2	-	5	1	4	1	-	1	2	4
11	6/5/97	9:03 am	4	161	-	-	1	-	-	-	-	-	1	1	-	-	-	1
12	13/5/97	9:08 am	4	154	-	-	-	-	-	-	-	-	-	1	-	-	-	2
13	21/5/97	9:26 am	1	150	-	-	-	-	-	-	-	-	-	-	-	-	1	-

Table 5.7 Direction of travel of *Rhincodon typus* recorded on 46 occasions during 13 aerial surveys conducted at Ningaloo Marine Park in 1997.

Sector No.	No. of shark sightings	Direction of travel			
		South	North	West	East
1	1	-	-	-	-
2	2	-	-	-	-
3	3	-	-	-	-
4	2	-	-	-	1
5	7	1	4	-	-
6	-	-	-	-	-
7	6	2	2	-	-
8	1	-	-	-	-
9	6	1	4	-	-
10	2	1	1	-	-
11	1	-	-	-	-
12	2	1	-	-	1
13	3	2	-	-	-
South of Sector 13	36	9	13	3	-
Total %	100	37.0	52.2	6.5	4.3

Table 5.8 Sighting locations and directions of travel of shark A-020 recorded during tourist interactions at Ningaloo Marine Park in 1997.

Date sighted	Position	Sector No.	Swim Direction
7/4/97	21°52.32S, 113°56.00E	1	circling
13/4/97	21°51.805S, 113°57.583E	1	circling
14/4/97	21°53.493S, 113°56.00E	2	north
16/4/97	21°55.84S, 113°54.80E	3	north
20/4/97	21°53.514S, 113°55.432E	2	circling
21/4/97	21°55.066S, 113°55.117E	3	circling
23/4/97	21°54.60S, 113°54.70E	3	south
24/4/97	21°52.345S, 113°57.899E	1	south
25/4/97	21°57.330S, 113°54.180E	4	southwest
26/4/97	21°54.060S, 113°55.037E	3	north
28/4/97	21°53.727S, 113°55.725E	2	south southwest
29/4/97	21°54.50S, 113°55.00E	3	south
30/4/97	21°52.67S, 113°57.85E	2	south
4/5/97	21°54.96S, 113°55.25E	3	south

Table 5.9 Sightings of *Rhincodon typus* recorded by fishers near Kalbarri between 1995 and 1997.

Date	No. of sharks	Estimated total length (m)	Location	Water depth (m)
June '95	1	8	27^{0}18.51S 113^{0}59.71E	23.2
March '96	1	7	27^{0}20.98S 114^{0}00.55E	32.9
2/12/96	1	7	27^{0}29.63S 114^{0}05.58E	15.5
15/12/96	1	7	27^{0}21.02S 114^{0}01.45E	15.5
27/2/97	1	7	27^{0}17.78S 113^{0}58.70E	32.9
28/2/97	1	9	27^{0}18.81S 113^{0}59.89E	23.2
28/2/97	2	na	27^{0}38.00S 113^{0}58.70E	-

Table 5.10 Sightings of *Rhincodon typus* recorded by Parks Australia North ranger near Ashmore Reef between 1994 and 1997.

Date	Location	Observer	Number of Sharks
Nov 16, 1997	Ashmore Reef	Coastwatch	1
Dec 12, 1996	Ashmore Reef	Mr S. Tester	1
Nov, 1995	Ashmore Reef	HMAS Dubbo	1
July, 1995	Scott Reef	Umar Join	1
Dec, 1995	Roti, Indonesia	Basu	1
Nov, 1995	Ashmore Reef	Harrudin	2
Nov, 1994	Ashmore Reef	Amin Minta	1
Nov, 1994 & 1995	Ashmore Reef	Halid Badsideh	1

Table 5.11 Sightings of *Rhincodon typus* recorded by commercial fishing/diving vessel operators and Australian Nature Conservation Agency staff at Christmas Island, Indian Ocean between November 1994 and May 1995.

Date	Location	Number of sharks
November 1994	Christmas Island, Indian Ocean	11
December 1994	Christmas Island, Indian Ocean	37
January 1995	Christmas Island, Indian Ocean	20
February 1995	Christmas Island, Indian Ocean	2
March 1995	Christmas Island, Indian Ocean	17
April 1995	Christmas Island, Indian Ocean	24
May 1995	Christmas Island, Indian Ocean	18

CHAPTER 6

THE VARIOUS FAUNA ASSOCIATED WITH *RHINCODON TYPUS* AT NINGALOO MARINE PARK

6.1 Introduction

6.1.1 Marine copepods attached to *Rhincodon typus*

Parasitic copepods commonly infect elasmobranch and teleost fishes (Yamaguti, 1963). Indeed, the numerous associations between parasitic copepods and fishes, which vary in host species and site specificity, demonstrate that there has been extensive co-evolution between these two groups in the marine environment (for example Wilson, 1932; Yamaguti, 1963; Cressey, 1967; Pillai, 1967; Hewitt, 1979; Kabata, 1979; Rokicki & Bychawska, 1991; Oldewage & Smale, 1993; Simpfendorfer, 1993). Moreover, a number of different species of copepod are commonly found on individual sharks. Hewitt (1979) recorded eight species of copepod on a single white shark, *Carcharodon carcharias,* and observed that, on this shark, *Pandarus satyrus* occupied a different site from that it typically occupies, a difference that may reflect the influence of competition.

Although the slow-swimming speed of *Rhincodon typus* would be likely to make them prone to external parasites, information on the parasitic fauna associated with *R. typus* is scarce (Cleave, 1994). The copepod *Proseates rhinodontis* has previously been described from the gill region of two *R. typus* (Wright, 1877), while another copepod, *Dysgamus atlanticus,* has been recorded in the mouth of *R. typus* (Williams & Williams, 1986). *Pandarus smithi* has also been observed on *R. typus* off the Cape Peninsula, South Africa (Barnard, 1948), while Heyerdahl (1973) reported several unidentified parasites attached to the body of *R. typus.* However, there have also been several unsuccessful searches for parasitic infections of *R. typus* (see Chierchia,

1884; Pai, *et al.*, 1983; Satyanarayana Rao, 1986; Gupta, *et al.*, 1991; Seshagiri Rao, 1992).

Copepods of the genus *Pandarus* Leach, 1816 are ectoparasitic on the skin or fins of elasmobranchs (Yamaguti, 1963). The number of recognised valid species epithets was reduced from 30 to 11 species by Kabata (1979), following the discovery that, *inter alia*, the males of *Pandarus* were often described as belonging to the genus *Nogaus*, which is a synonym of *Nogagus* as used by Yamaguti (1963) and Cressey (1967). This chapter describes the new species of copepod, *Pandarus* sp. nov., that was collected from *R. typus*, and uses the morphology of this species to deduce aspects of its biology. NB. Since the description of this new species of copepod has been submitted for publication, the species name is not included in this chapter in order to avoid problems that might arise through precedence of publication (J.B. Hutchins, pers. comm.).

6.1.2 Protection for marine teleosts, elasmobranchs and copepods provided by *Rhincodon typus*

Many different marine species utilise coral reefs, rocky outcrops and seagrasses as shelter (Hutchins, 1994). In the open ocean, however, such shelter is relatively restricted and many fish seek protection provided by swimming alongside a larger fish (Eibl-Eibesfeldt, 1970). Since *R. typus* is the largest of all living fish (Last & Stevens, 1994) and is slow moving, it is well suited to provide shelter for other smaller and more vulnerable fish (Fig. 6.1).

Several species of mackerel (Scombridae) tend to shelter in the wake of *R. typus* (Prater, 1941), while dorados, *Coryphaena hippurus*, jacks, *Caranx latus*, and cobia, *Rachycentron canadus*, crowd around *R. typus* as they bask at the surface (Baughman & Springer, 1950). Schools of stromateid fish (Stromatidae) (Tubb, 1948; Chackow & Mathew, 1954), barracuda, *Sphyraena jello*, and mackerel, *Scomberomorus commerson*, have also been reported as associating with *R. typus* (Bishop & Abdul

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Ghaffar, 1993). The fact that certain commercial fish species, such as tuna (Scombridae) (Baughman, 1955; Iwasaki, 1970; Silas, 1986; Au, 1991), striped bonito (most likely *Katsuwonus pelamis*) (Baughman & Springer, 1950) and *Caranx gymnostothoides* (Gudger, 1932) aggregate in the region of *R. typus* has been used by fishers as a means of detecting these species.

In addition, several species of elasmobranchs associate with *R. typus* (Silas, 1986), including manta rays, *Manta birostris* (Tubb, 1948; Taylor, 1990) and black-tipped sharks, *Carcharhinus* sp. (Bishop & Abdul Ghaffar, 1993), while others, including tiger sharks, *Galeocerdo cuvier*, and hammerhead sharks, *Sphyrnidae* sp., have been observed swimming within 10 m of *R. typus* (Arnbom & Papastavrou, 1988; B. Norman, unpub. data).

The first report of an association between *Remora* spp. and *R. typus* was in 1883, when a whale shark was found to have several remora in its' mouth (Chierchia, 1884). Subsequently, diskfish, which include these species and *Echeneis naucrates* have been recorded with *R. typus* on many occasions (see Tubb, 1948; Cressey & Lachner, 1970; Nammalwar *et al.*, 1992; Bishop & Abdul Ghaffar, 1993; Cleave, 1994). *Remora* spp. and *E. naucrates,* that were found in the stomachs of two *R. typus,* were thought to have been accidentally ingested (Kishinouye, 1901; Karbhari & Josekutty, 1986).

At Ningaloo Marine Park (NMP), golden trevally, *Gnanthanodon speciosus*, pilot fish, *Naucrates ductor*, *R. canadus* and diskfish including *E. naucrates* and *Remora* sp. have been previously observed with *R. typus* (Taylor & Grigg, 1991; Taylor, 1994; J. Stevens, unpub. data). Several species of fauna were seen to be associated with *R. typus* with sufficient regularity during the present study to suggest that such an association may enhance the survival of individuals of these species. The aim of this part of the study was to determine the type, relative abundance and location of various species associated with *R. typus* at NMP each year.

6.2 Materials and methods

6.2.1 Collection and identification of copepods

Sixteen individuals of an undescribed species of copepod were collected from *R. typus* as they were swimming in the waters of NMP between March and June, 1995. The following description is based on all of these specimens, which included two females and one male, whose appendages were removed for close examination. Measurements were made using an eye piece graticule fitted to an Olympus BH2. The terminology used to describe the appendages follows that of Kabata (1979). The following type material has been lodged in the Western Australian Museum: Holotype female WAM C 23238; Allotype male WAM C 23239; Paratypes WAM C 23240. Illustrations and scanning electron micrographs were produced by D. Newbound and T. Stewart of the University of Western Australia.

6.2.1.1 Diagnosis of Genus *Pandarus* Leach (Family Pandaridae)

Females of the genus *Pandarus* are distinguished by their possession of three distinct segments between the cephalothorax and the dorsal plates, paired dorsal or dorsolateral plates on at least one of these segments, and adhesion pads on the ventral surface, and also through the location and distribution of the caudal rami (Cressey, 1967; Kabata, 1979). Males resemble females in that their cephalic appendages lack dorsal plates, and legs 1 - 4 are biramous with all rami 2-segmented (Cressey, 1967).

6.2.2 Identification and relative abundance of teleosts, elasmobranchs and copepods associated with *Rhincodon typus* at Ningaloo Marine Park

The various fauna observed with *R. typus* at NMP in 1995 were photographed, which were later analysed at Murdoch University to identify each of these species. It was possible to record, while swimming alongside *R. typus* on 177 and 58

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occasions, respectively, in 1996 and 1997, the number of each species that was directly association with *R. typus*. From a viewing distance of between 1 and 6 m, data were recorded on waterproof data sheets attached to a perspex slate (see Fig. 7.4). When the observation time was brief or a considerable number of a species was associated with *R. typus*, the number of individuals of a particular species was estimated.

6.3 Results

6.3.1 Taxonomic description of *Pandarus* sp. nov.

Female

Body form is shown in Figures 6.2a and 6.2b. Mean total length (10 specimens) is 7.6 mm. Greatest width (mean 4.1 mm, n = 10) occurs at the widest part of the cephalon, just anterior to the cephalon/thoracic junction. Height is 1.4 mm (n = 10). Although the dorsal surface of the body is smooth, pores are scattered across this surface. Lateral margins of the carapace are fleshy and with frill (Fig. 6.3a).

Frontal plates are well developed and narrow mesial extensions meet in the midline. First thoracic segment fused with head; hinder margin of the cephalon with 4 or 5 robust spines (sometimes heavily eroded), with another 2 on each extension of the cephalon. Dorsal thoracic plates on body segments 2 - 4. Segment 2: plates separate, extending beyond the tip of segment 3 almost to the level of the posterior limit of the plates of segment 4; straight posterior margin (sometimes) with 4 sharp spines. Plates of segments 3 and 4 fused at their bases; posterior margins indented medially by broad, shallow sinuses. Plates of segment 4 extend over the base of the genital segment. Genital segment: almost circular; with well-defined posterior projections (separated by a narrow sinus), each bearing an upturned triangular projection dorsally; often with a sub-marginal setospine on either side near the base of the sinus (but lacking in the Holotype). Abdomen 1-segmented covered dorsally by plate longer than wide and not extending to the level of the tips of the caudal rami; the margins at the greatest width of the dorsal plate

are curved ventrally, giving the appearance, from the dorsal aspect, of a slight projection: ventrally, joined broadly to genital segment and posteriorly terminating in broad plate extending between bases of caudal rami. Caudal rami stout, curved, L-shaped in cross section; lateral surface is oblique proximally and follows the line of the abdomen to just beyond the widest point of the dorsal abdominal plate beyond which level the ramus is deflected outwards and tapers to a terminal spine which recurves slightly back towards the midline of the animal. The upper margin of the ramus is sharply defined beyond the stout spine, which marks the beginning of the curve outwards and carries a second smaller spine; ventral surface with tubercle near the proximo-lateral corner and with thin seta and small spine on the mesial edge.

Oral area : Adhesion pads present at bases of first antennae, second antennae and the maxillipeds. The surface structure of a pad is illustrated in Figures 6.3b and 6.3c. Pads also present anteriorly on the lateral expansions of thoracomere 2. First antennae (Fig. 6.2c) of 2 articles: article 1 bearing setospines of varying size from small to large and stout but all specimens with one narrow corner seta, 1 or 2 may bear some plumose expression; article 2 bearing 7 naked, mostly curved, setae (not all of which may be present but the numbers are clearly countable from the remnant bases). Second antenna of 3 articles (Fig. 6.2d): terminal article bearing large curved terminal spine and 2 spines marginally; article 2 with 2 ventral spines, one mid-article on broad base the other at the distal margin. Mouth tube (Fig. 6.2e): of 10 females measured, oral cones 0.5 - 1.0 mm long, average 0.7 mm. Labrum ends in complex structure (Fig. 6.3d). Labium with 2 terminal fringes of backwardly-directed denticles (Fig. 6.3d). Mandible (Fig. 6.3d), with slender shaft flattened and dentate near the tip. First maxilla (Fig. 6.2f) of 2 articles: basal article bearing 0 - 2 short setae; terminal article with large terminal, plus 1 small, spine. Second maxilla brachiform (Fig. 6.2g): article 1 (lacertus) unarmed; article 2 (brachium) without flabellum, but with 2 distal spines, longer one fringed, shorter plumose; calamus bearing large claw with rows of spinules and apical patch of spinules. Maxilliped (Fig. 6.2a) of 2 articles: basal article (*corpus maxillipedus*) stout and with

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nacreous-like pad; article 2 (subchela) unequally bilobed, with a nacreous-like pad, which works against the pad of article 1.

Both rami of legs 1 - 3 (Figs 6.4a-c) with 2 articles. Both rami of leg 4 (Fig. 6.4d) with 1 article; endopodite lacking spines. Leg 5 (Fig. 6.4e) consisting of outer seta and inner lobe with single terminal spine. Adhesion pads and denticulate areas are illustrated in Figures 6.4a-c. Figure 6.3e shows detail of a denticulate region.

Egg strings (Fig. 6.4f) slender, approximately same length as body, slightly curved. Eggs disc shaped.

Adult females vary in the extent of their coloration. Colour patches dark chocolate-chestnut brown centrally shading outwards to transparent amber. Three colour patches occur on the cephalon, one anterior and triangular patches posterio-laterally. The considerable variation in the extent of separation to fusion between these 3 patches, resulting in considerable variation in the extent of amber coloured areas about the eye spots, may be due to ontogenetic differences. Colour patches also occur on the frontal lobes; separately on segments 2 and 3 and at the bases of the genital lobe projections; across most of segment 4 and the abdominal segment (Fig. 6.2a).

Male

The body form is as shown in Figures 6.5a-b. The length, not including setae on caudal rami, is between 5.2 - 7.2 mm and mean 6.0 mm (n = 5), while width, measured at the widest point, is 2.9 - 4.3 mm and mean 3.3 mm (n = 5). Cephalon rounded when viewed dorsally with head and first thoracic segment fused. Segment 2 bears 2 pairs of dorsal spines; segments 3, 4 and 5 each bear one pair of dorsal spines. Thoracic segments 2 - 4 free, without dorsal plates except for lateral wing-like plates on segment 2. Genital segments with posterior corners terminating in a prominent triangular projection. Coiled spermatophores visible within genital segment. Abdomen 2-segmented. Caudal ramus bearing 4 long, plumose seta and a series of fine setules along the inner margin. Oral area as in female except for distribution of adhesion pads. Adhesion pad (Fig. 6.5b) present at the base of first antenna (Fig. 6.5c) is approximately

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half the length, and positioned at a greater angle towards the centre of the cephalon, than is the case in the female. Small adhesion pad situated on the base of the second antenna (Fig. 6.5d). Absence of adhesion pads at the base of the maxilliped (Fig. 6.5e) and on the lateral projections of the second segment. Legs 1 - 4 (Figs 6.6a-d) show the distribution of adhesion pads and denticulate areas. Leg 5 borne on genital segment as lateral projection with 3 setae and 1 stout terminal spine. Leg 6 consisting of 2 setospines, outer longer than inner, borne on genital segment near the origin of the abdomen.

Colour in life is pale pink and generally devoid of darker pigment.

6.3.2 Identification and relative abundance of teleosts, elasmobranchs and copepods associated with *Rhincodon typus* at Ningaloo Marine Park

Several species of teleost, *i.e.* *E. naucrates*, *Remora* spp., *G. speciosus*, *Caranx* spp., *R. canadus* (Figs 6.7-11), one species of elasmobranch, *i.e.* *M. birostris* (Fig. 6.12) and one species of copepod, *i.e.* *Pandarus* sp. nov. (Fig. 6.13), were recorded in association with *R. typus* at NMP. Although the precise locations of all of the species present on the body of *R. typus* were not always recorded, *E. naucrates* and *Remora* sp. were most commonly observed swimming close to or attached to the ventral surface of *R. typus*, *G. speciosus* and *Caranx* sp. were seen most frequently swimming in front of the mouth (Fig. 6.14), and occasionally near the caudal and pectoral fins, while *R. canadus* was mainly seen swimming near the ventral surface of *R. typus*. Similarly, female *Pandarus* sp. nov. was observed either at the apex of the mouth or on the pectoral or caudal fins of *R. typus*, while the smaller pale coloured male pandarids were seen across the body, although mainly on the first dorsal fin.

A slender suckerfish (*E. naucrates*) was observed on 28 March 1996, swimming from one whale shark host and attaching to another whale shark close by. While low numbers of small *Caranx* sp. were often observed swimming either in front of

the mouth or fins of *R. typus*, a school of large *Caranx* sp. (*ca* 30 - 40 cm TL) were also observed close to *R. typus* on two occasions in 1996 (29/3/96 and 26/4/96).

The number of *E. naucrates* per *R. typus* in 1996 and 1997 ranged between 0 - 9 and 0 - 14 respectively, with corresponding means of 0.9 and 5.2 (Table 6.3). The number of *Remora* sp. recorded with each *R. typus* ranged from 0 - 8 in both 1996 and 1997, with means of 1.0 and 2.8 respectively. The number of *G. speciosus* recorded per shark ranged between 0 - 20 and 0 - 3 in 1996 and 1997, with means of 2.7 and 0.4, respectively. The number of *Caranx* sp. observed with *R. typus* ranged between 0 - 80 and 0 - 60 in 1996 and 1997, with means of 2.2 and 17.8 respectively. The number of *R. canadus* sighted with *R. typus* ranged between 0 - 3 and 0 - 1 in in 1996 and 1997 respectively, with a mean of 0.1 for both years. A total of nine *M. birostris* were seen with *R. typus* on two separate occasions when both species were actively feeding on a swarm of krill. The number of *Pandarus* sp. nov. recorded per shark ranged between 0 - 100 and 0 - 50 respectively, with corresponding means of 5.3 and 3.3 (Table 6.3).

In 1996 and 1997, the mean number of *E. naucrates* and *Remora* sp. per *R. typus* collectively were 1.9 and 8.1 respectively (Table 6.3). The number of copepods recorded on several identified *R. typus* (see Chapter 4; Library 1), had declined in nine cases from 2 - 25 to 0 when subsequently resighted, but in two other cases rose from 0 to 8 and 80, respectively (Table 6.4).

6.4 Discussion

6.4.1 Taxonomy of *Pandarus* sp. nov.

The characteristics of the copepod described in this chapter clearly demonstrate that this species should be placed in the genus *Pandarus*. There are numerous differences between *Pandarus* sp. nov. and the copepod *Prosaetes rhinodontis*, which has also been found on *R. typus* (Wright, 1877). For example, the lobes on

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segments 3 and 4 are absent, and the abdomen is concealed below the genital segment. Within the genus *Pandarus*, *Pandarus* sp. nov. appears to be most closely related to *P. cranchi*, with both species possessing triangular abdomens just shorter than the curved caudal rami and genital segments with clearly defined posterior projections. However, there are differences between these two species. Thus, in *Pandarus* sp. nov., the plates of segment 2 are shorter, the posterior margin of the cephalon is armed with 4 tubercules, the shape of the caudal rami differs, and the numbers and distributions of spines and setae on the thoracic appendages are different. The setal formula of *Pandarus* sp. nov. also differs from that of *P. cranchi* with respect to the presence of plumose *versus* non-plumose setae.

6.4.2 Ecology of *Pandarus* sp. nov.

The number of *Pandarus* sp. nov. per whale shark was estimated as ranging from 0 to *ca* 100. Forty three of the whale sharks studied in 1996, *i.e.* 26%, were infested with *Pandarus* sp. nov.. However, it is possible that, on a very few occasions, these recordings were based on observations of the same shark on different days. An accurate estimate of the numbers of copepods could not be obtained because of the difficulty in recording those numbers over the whole body of the shark as it swam past the observer.

The copepods were always facing in an anterior direction on the shark, and were most frequently located on the leading edges of the fins and lips where the boundary layer might be expected to be thin. This may reflect a response to the direction of water flow over the shark. Given the position of this copepod on the shark, and the speed with which the sharks swim (see Chapter 5), the drag forces on the copepods must be substantial. Thus, the copepods would be likely to be dislodged unless they possessed a mechanism which prevented this from occurring. As with other pandarids, *Pandaru* sp. nov. displays some of the classic features predicted in an animal adapted to reduce drag forces, such as streamlining of the body shape, with the widest point

occurring at 36% of body length (Vogel, 1981). However, the projecting caudal rami and the broadly-rounded posterior end of the abdomen do not conform in this respect. It is relevant that *Pandarus* sp. nov. possesses an extensive battery of devices to help it maintain position on the host. Benz (1992) has described the way in which the maxilliped of this genus is used for attachment. Hooks of antenna 2 and on the pereopods are also used. Figures 6.3b and 6.3c show the 'fingerprint' surface detail of an adhesion pad but how these achieve adhesion has yet to be determined. The fringed margins of the carapace may also help make a seal with the host, thereby helping to generate a vacuum in the sub-thoracic space.

There are two lines of evidence which raise the question as to whether *Pandarus* sp. nov. feeds on the whale shark to which it is attached. First, at 11 cm thick, the subcutaneous layer of *R. typus* is by far the thickest of all sharks (Stead, 1963). Second, at < 1 cm, the oral cone would hardly be able to penetrate the skin to reach underlying tissues, and it is also difficult to visualise how the mandibles could scrape or penetrate the skin. Furthermore, because of the posteriorly-directed apical denticle on the labium, it would be difficult to withdraw an oral cone once it had been inserted. Figure 6.3f shows the surface detail of a whale shark with marks interpreted to be areas where grazing had previously occurred.

We suggest that the copepod is almost certainly a commensal, rather than an ectoparasite, obtaining bacteria and other micro-organisms from surface irregularities on the skin of *R. typus*. Since the oral cone can move downwards and forwards (D. Newbound, University of W.A., pers. comm.), it is capable of being pressed into surface irregularities on the skin of the shark. The mandibles would then seem to be ideally adapted for scraping micro-organisms into the entire oral cone which presumably functions like the nozzle of a vacuum cleaner.

A final speculation is appropriate. If *Pandarus* sp. nov. is a commensal, and the other species in the genus are ectoparasites, it should be possible to root a phylogenetic tree of the taxon since it is highly unlikely that a species would revert to

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commensalism after evolving an ectoparasitic habit. This also raises the question as to how this association originated. Although *R. typus* are generally solitary animals, ranging widely through tropical waters, they do form aggregations. Pandarids are not found associated with all shark orders. They occur predominantly on members of the Carcharhiniformes, and much less frequently on members of the Lamniformes and Orectolobiformes. This point is emphasised by the fact that, for example, Cressey (1967), has listed *P. cranchi* as occurring on eight species of shark of which seven belonged to the Order Carcharhiniformes and one to the Lamniformes, *i.e. Isurus oxyrinchus. Pandarus smithi*, which has also once been collected from a *R. typus*, has been recorded from 11 species of shark, in different oceans, of which nine were carcharhiniforms and two were lamniforms, including *I. oxyrinchus*. Just why the host range is so restricted is not readily apparent, but presumably reflects, in part, the past ecological relationships between sharks and copepods and highlights the need for substantially more information than is currently available concerning shark-copepod associations.

6.4.3 Possible reasons for the association of teleosts, elasmobranchs and copepods with *Rhincodon typus* at Ningaloo Marine Park

Teleosts and elasmobranchs comprised the majority of the fauna observed in association with *R. typus* at this location between 1996 and 1997. Although the type of fauna associated with *R. typus* each year was similar, the mean number of individuals of each species per shark varied between years.

Diskfish, including *Remora* sp. and *E. naucrates*, have a special cephalic laminated adhesive disk (Cressey & Lachner, 1970), which enables them to attach to larger marine animals and thus be transported by the host (Gomon *et al.*, 1994). My observations at NMP indicate that *E. naucrates* is slightly more mobile and more often swam over the surface of *R. typus* than was the case with *Remora* sp., which appeared more sedentary. Very small (< 15 cm) *Remora* sp. were observed on many occasions in

the entrance to the spiracle of *R. typus*, a location which would provide considerable protection for these animals (Taylor, 1994; B. Norman, unpub. data).

Cressey and Lachner (1970) report that *R. remora* is typically an offshore species, whereas *Echeneis* sp. is mainly located inshore and is also more free-swimming. The number of *R. typus* sighted on the day when *E. naucrates* was seen swimming towards and then attaching to separate *R. typus* was high (B. Norman, unpub. data), suggesting that *E. naucrates* exchanges hosts at NMP. Cressey and Lachner (1970) suggest that those periods when the hosts of echeneids are relatively inactive, provide this group with the opportunity to attach or rendevous with a host. Thus, the aggregation of *R. typus* at NMP would provide the opportunity for these diskfish to exploit a variety of individual sharks.

Juvenile golden trevally (*G. speciosus*) were often observed by Taylor (1994) to be swimming with *R. typus* at NMP, while juvenile golden trevally were associated with most of the 30 *R. typus* observed by researchers over a ten day sample period at NMP in 1994 (J. Stevens, unpub. data). These results are consistent with those recorded during the 1996 and 1997 whale shark seasons at NMP. However, it should be noted that the mean number of *G. speciosus* associated with *R. typus* was considerably less in 1996 than 1997.

The lengths of most individual carangids, excluding those of *G. speciosus*, which were associated with *R. typus*, were small (< 15 cm), indicating that these fish were juveniles. The higher mean number of these fish recorded per shark in 1997 than 1996 may have been the result of a lower number of *R. typus* available at NMP for these small teleosts to colonise, or that there were fewer small members of these species in 1996 compared with 1997.

Although manta rays, *M. birostris*, were only occasionally seen in close association with *R. typus* during the present study, such a situation had not been previously reported. Manta rays are filter feeders (Last & Stevens, 1994) and would be

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likely to feed on similar food items as *R. typus* (see Chapter 3). This may account for the apparent association of these species during the current study.

The copepod discovered during the present study has been identified as a new species of the genus *Pandarus*, and is apparently found only on whale sharks. Pandarids are common on many other species of shark, with females tending to cluster on the fins while males are often found over any part of the sharks' body (Cressey & Lachner, 1970). The observations made during this study at NMP are consistent with this distribution.

Echeneis naucrates is reported as feeding on the external crustacean parasites of their hosts (Gomon *et al.*, 1994), while there have been previous reports of pandarid species in the stomachs of remora using sharks as hosts (Cressey & Lachner, 1970). These findings suggest that parasitic copepods may form an important part of the diet of diskfishes, and that the diskfish associated with *R. typus* prey upon *Pandarus* sp. nov. The mean numbers of *Remora* sp. and *E. naucrates* sighted per whale shark in 1997 were greater than in 1996, whereas the reverse was true for copepods (Table 6.3). This suggests that predation on copepods by these diskfish was higher in 1997 than 1996 and may be indicative of a predator - prey relationship amongst suckerfish and copepods commonly found on *R. typus*.

The data from repeat sightings of nine out of eleven identified *R. typus* at NMP indicate that, on nine of these occasions, copepod prevalence was greater when first sighted than when observed later in the season. Since *E. naucrates* is an inshore species and feeds on copepods, it may have reduced the number of copepods on *R. typus* by preying on them while the sharks were at NMP.

No pilot fish (*N. ductor*) were found associated with *R. typus* during the present study. However, such an association has been previously reported at NMP by Taylor (1994). The numerous observations of large teleosts around *R. typus* at NMP during the current study, similarly recorded by Arnbom and Papastavrou (1988) at the

lands, suggest that *R. typus* may be exploited for protection by larger ater extent than previously suggested.
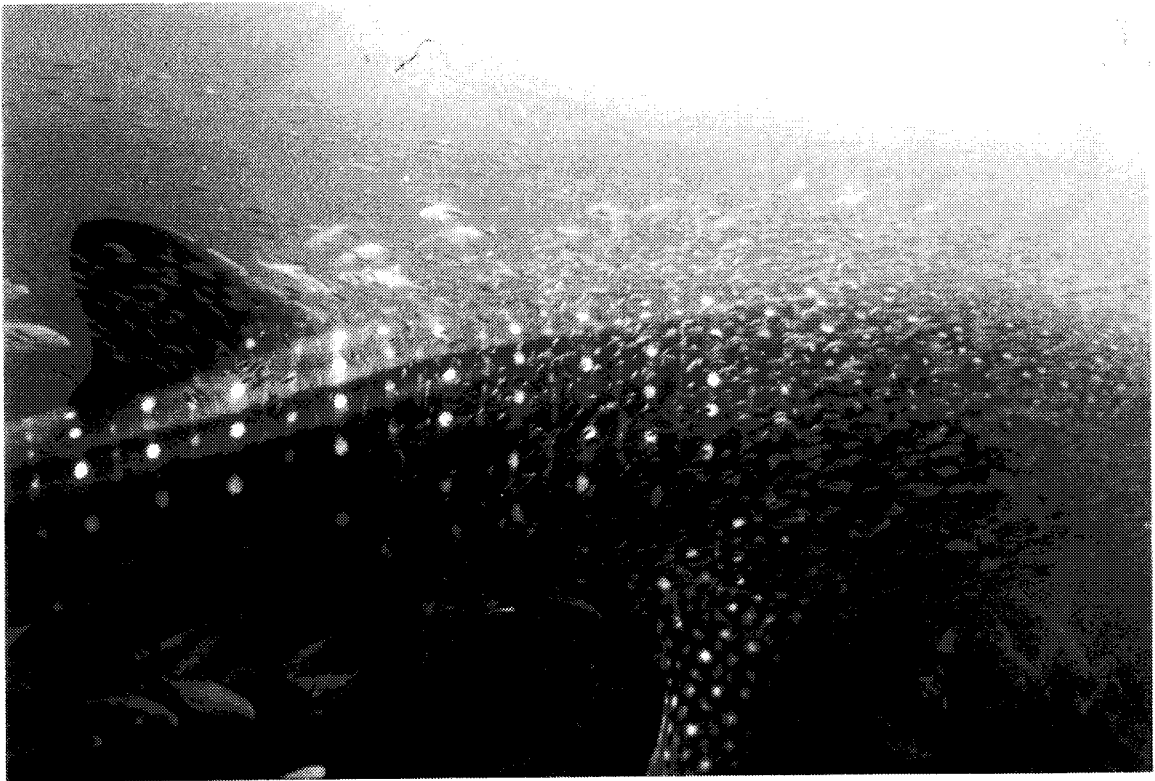
Figure 6.1 A school of fish associated with *Rhincodon typus* at NMP.
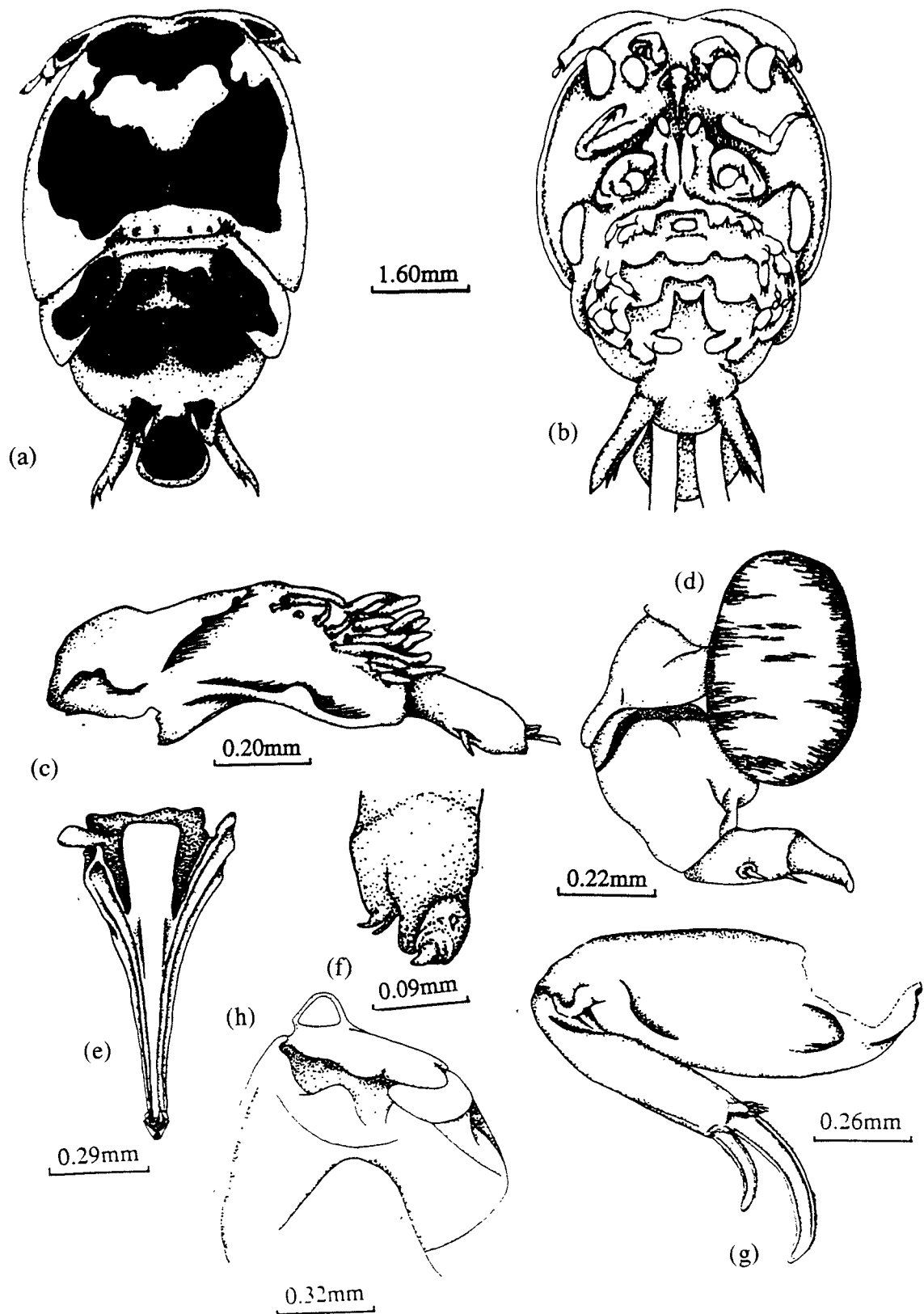
Figure 6.2 Female *Pandarus* sp. nov. overview and cephalothoracic appendages: (a) dorsal overview; (b) ventral overview; (c) first antenna; (d) second antenna; (e) mouthparts: labrum, labium and mandibles; (f) first maxilla; (g) second maxilla; (h) maxilliped.
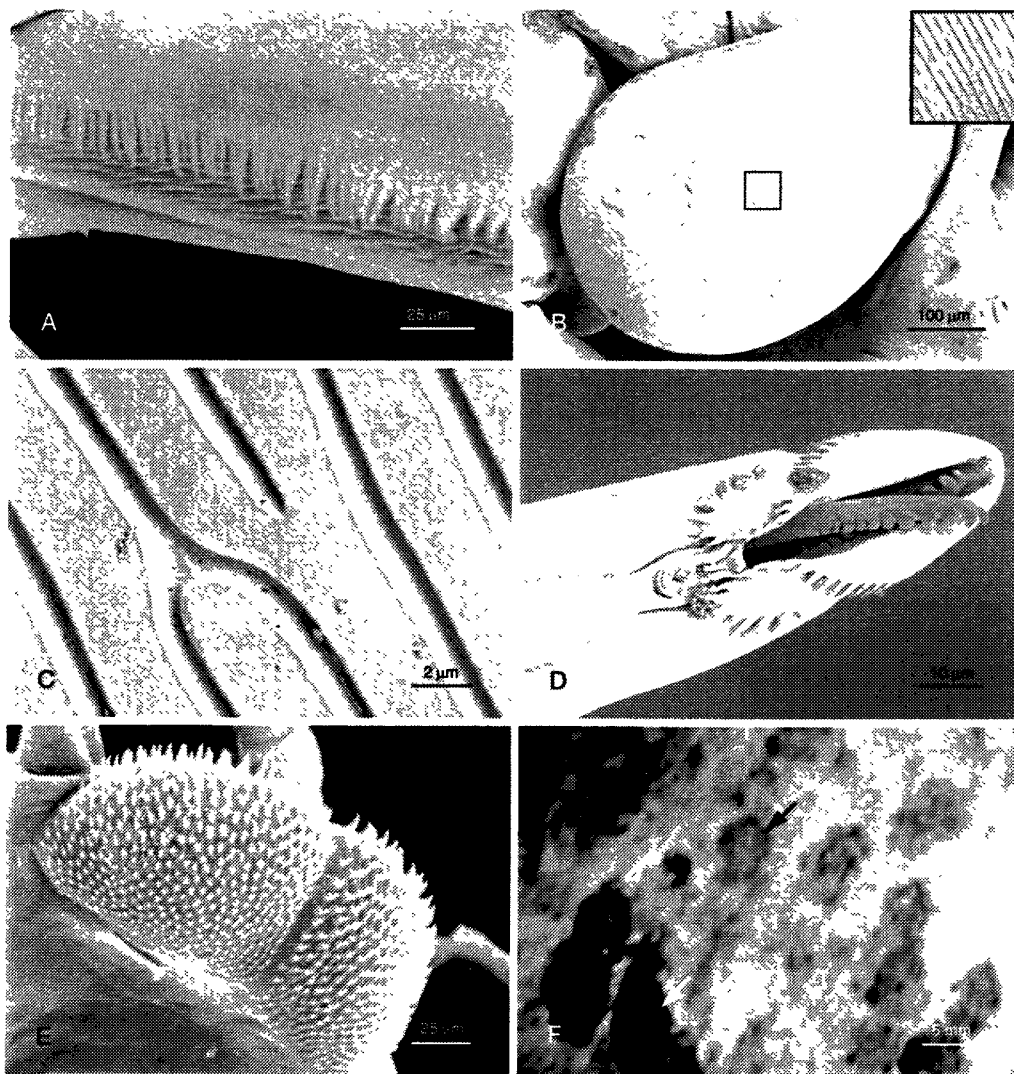
Figure 6.3 Scanning electron micrographs showing structures on the ventral surface of the cephalothorax of the female, and areas of the host skin grazed by *Pandarus* sp. nov.: (a) lateral margin of carapace showing 'frill'; (b) surface structure of an adhesion pad situated on the cephalothorax, the insert shows surface detail at higher magnification; (c) magnification of 2b; (d) labrum, labium and mandible; (e) denticulate region on perepod; (f) photograph of a region of whale shark skin grazed by *Pandarus* sp. nov.: black arrow to scar, white arrow to copepod.
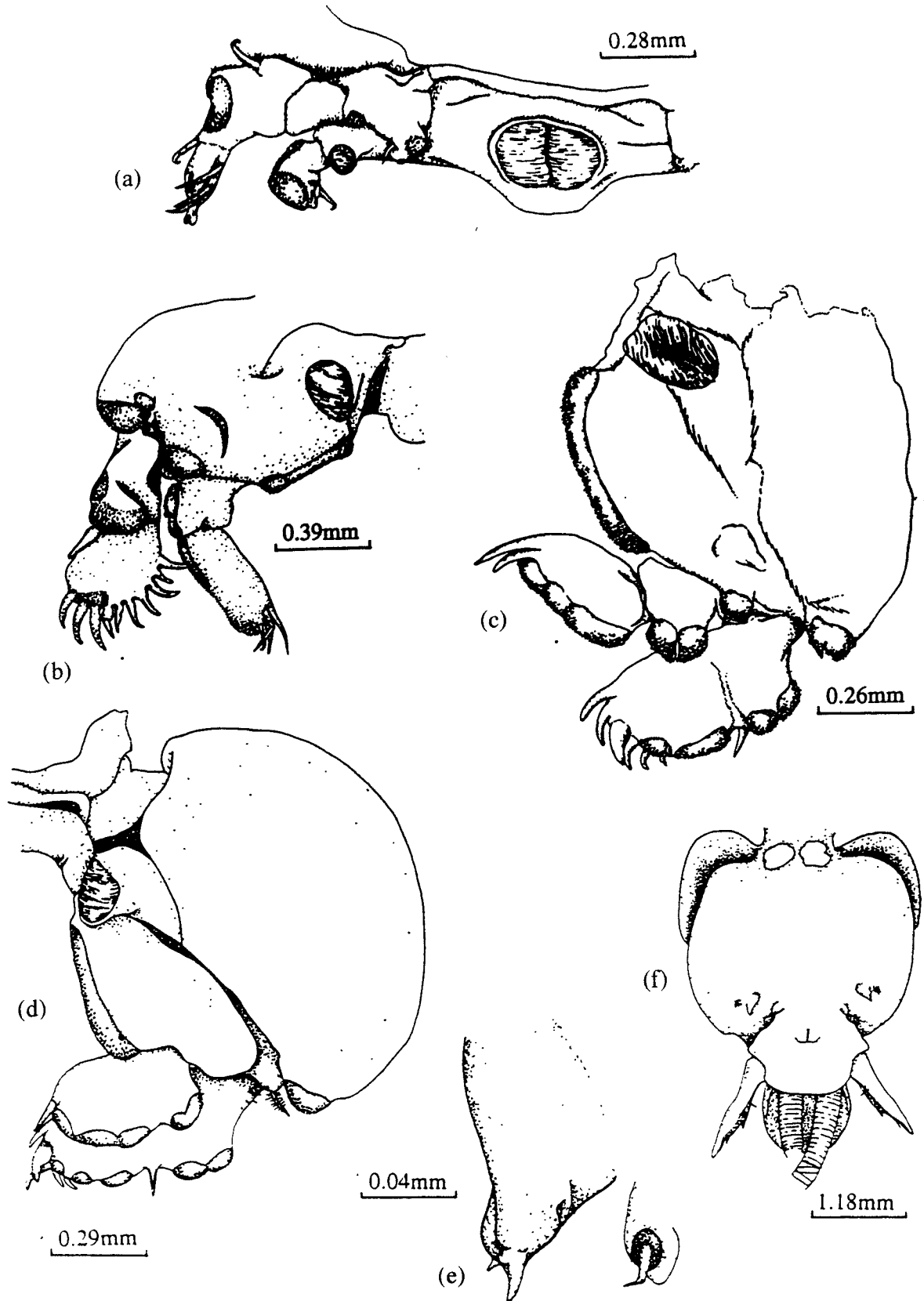
Figure 6.4 Female *Pandarus* sp. nov.: thoracic appendages, genital segment and abdomen: (a-e) legs 1-4, showing adhesion pads, setae and denticulate regions; (f) genital segment, abdominal plate, caudal rami and egg strings.
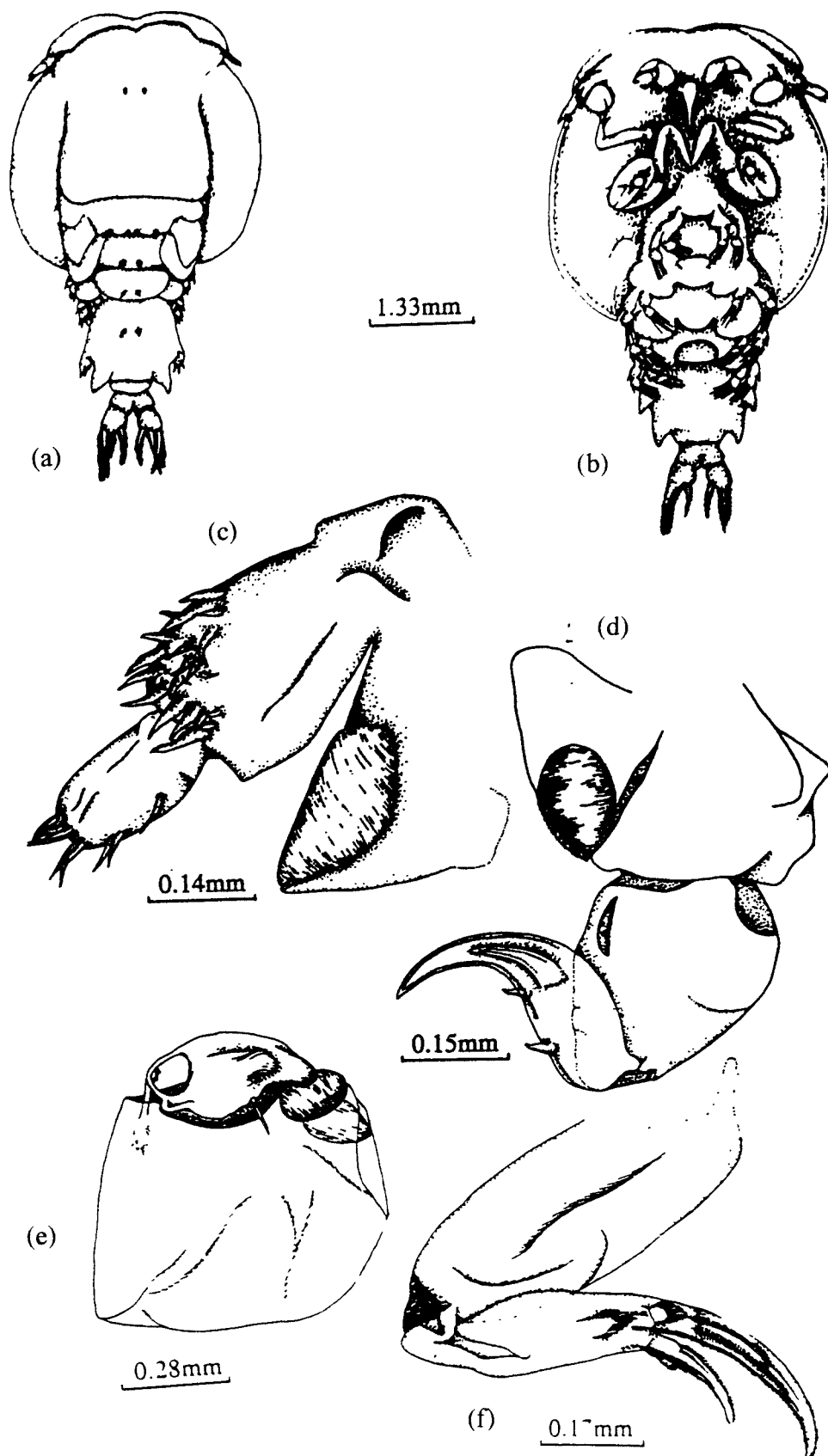
Figure 6.5 Male *Pandarus* sp. nov.: overview and cephalothoracic appendages: (a) dorsal overview; (b) ventral overview; (c) first antenna; (d) second antenna; (e) maxilliped; (f) second maxilla.
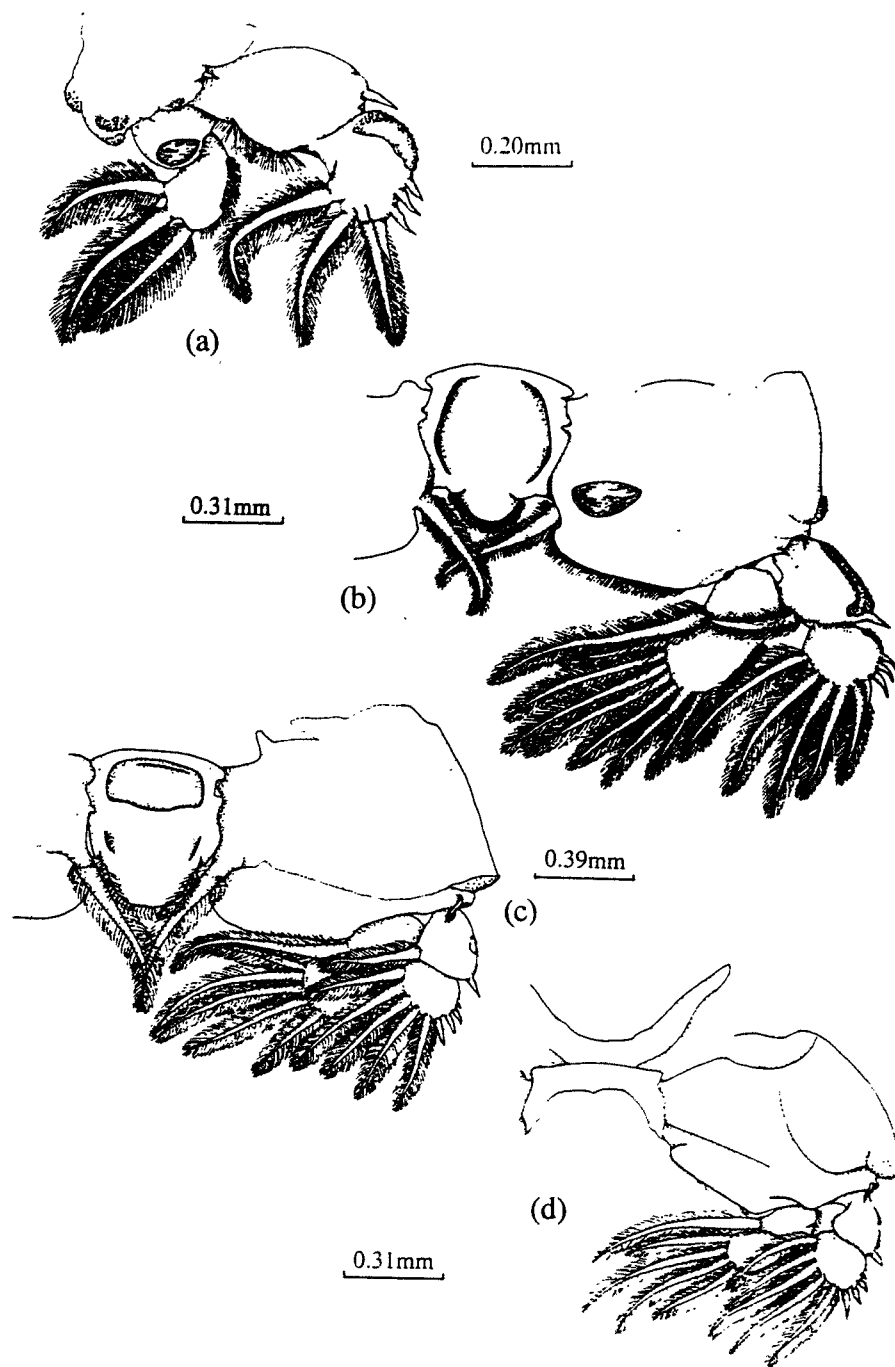
Figure 6.6 Thoracic appendages of male *Pandarus* sp. nov.: (a-d) legs 2-4, showing adhesion pads, denticulate regions, bipennate setae and spines.
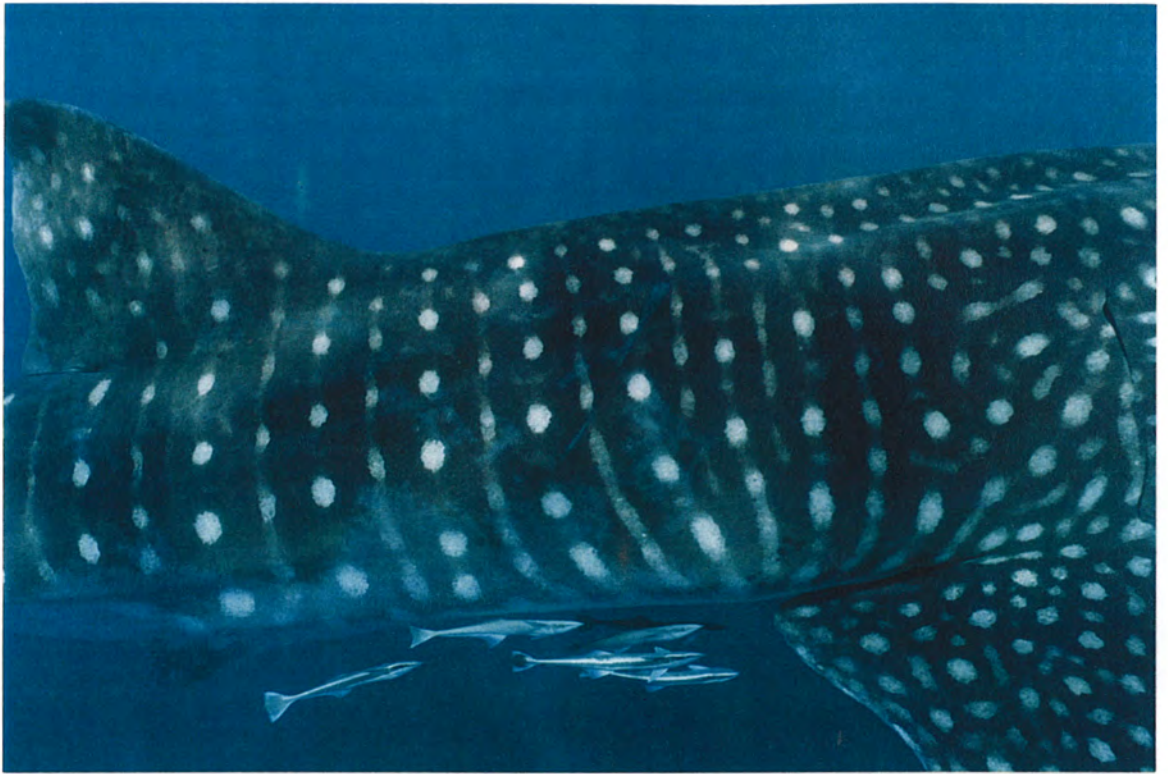
Figure 6.7 Slender suckerfish (*Echeneis naucrates*) swimming with *Rhincodon typus*.

Figure 6.8 *Remora* sp. observed with *Rhincodon typus*.
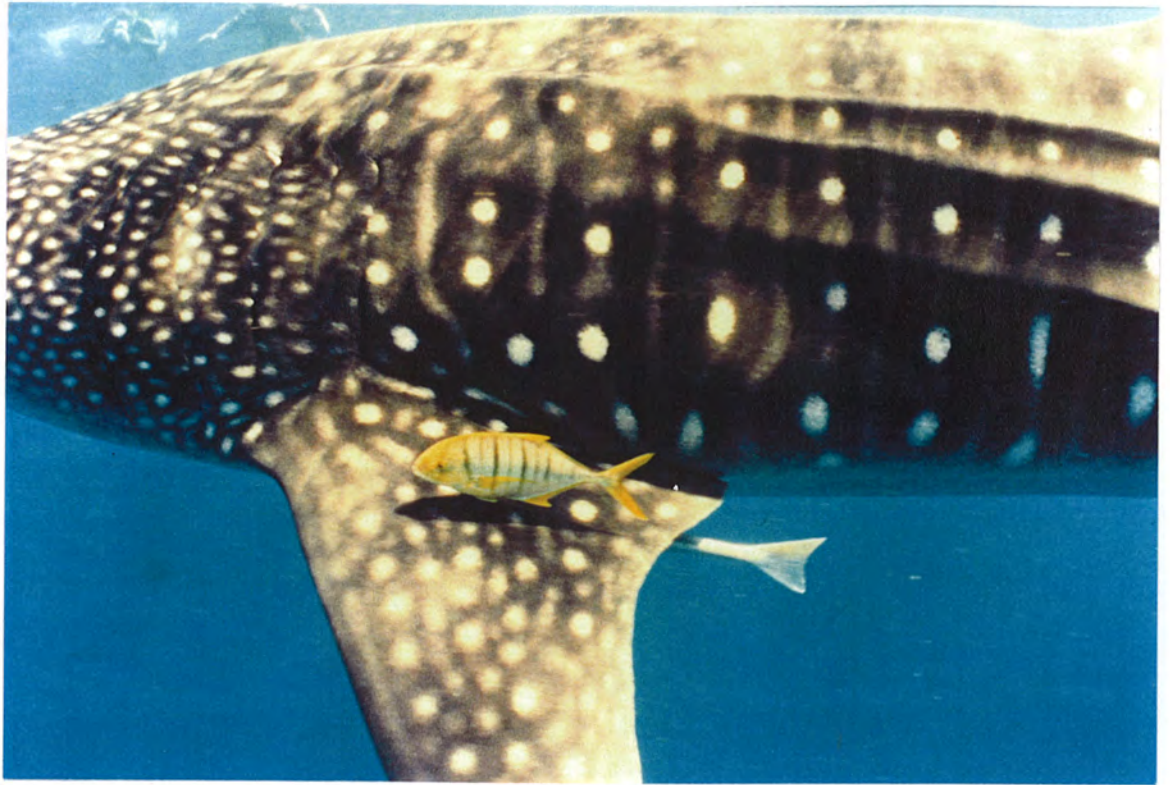
Figure 6.9 Golden trevally (*Gnathanodon speciosus*) in association with *Rhincodon typus*.
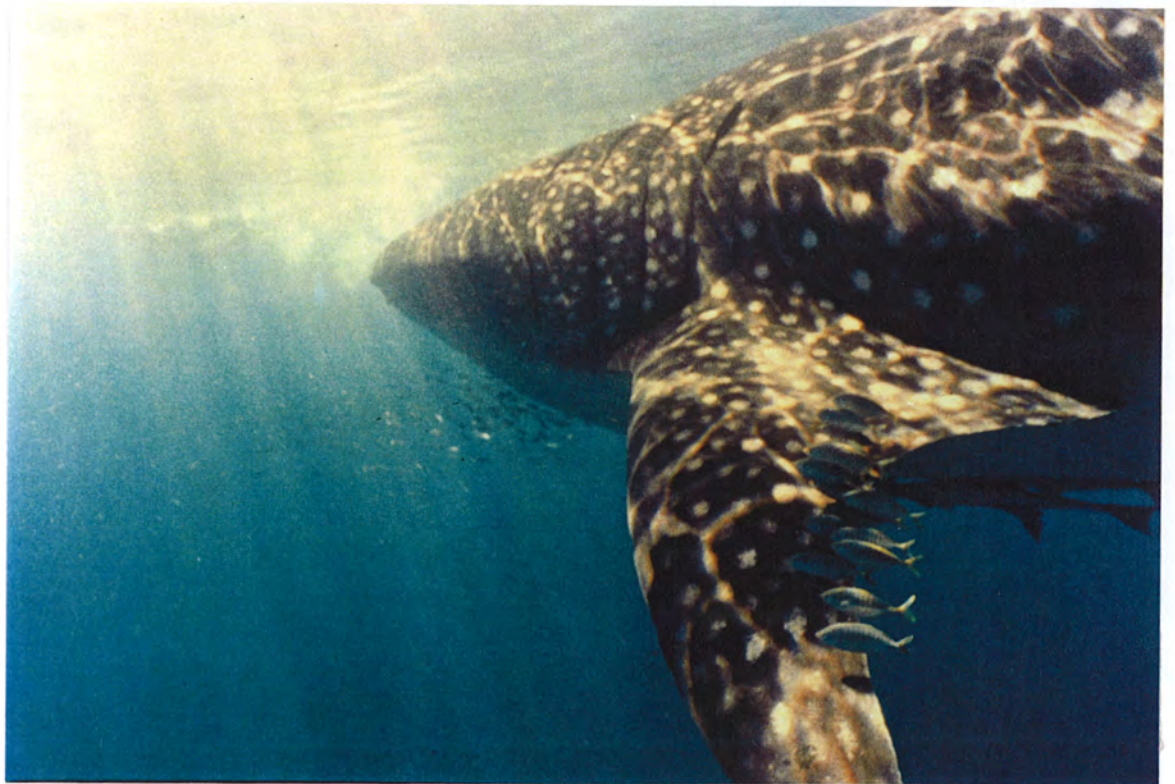
Figure 6.10 Carangids (*Caranx* sp.) swimming with *Rhincodon typus*.
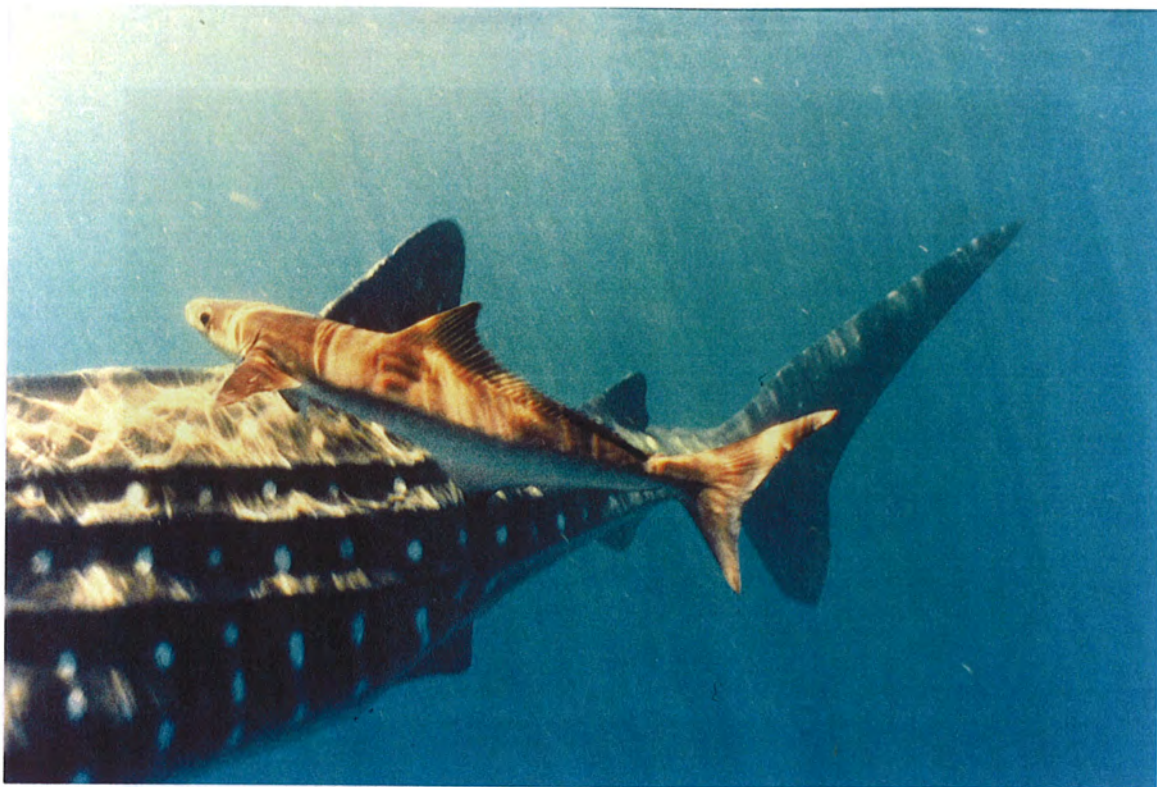
Figure 6.11 Cobia (*Rachycentron canadus*) associated with *Rhincodon typus*.

Figure 6.12 A manta ray (*Manta birostris*) swimming near *Rhincodon typus*.

Figure 6.13 A copepod (*Pandarus* sp. nov.) found on the skin of *Rhincodon typus*.
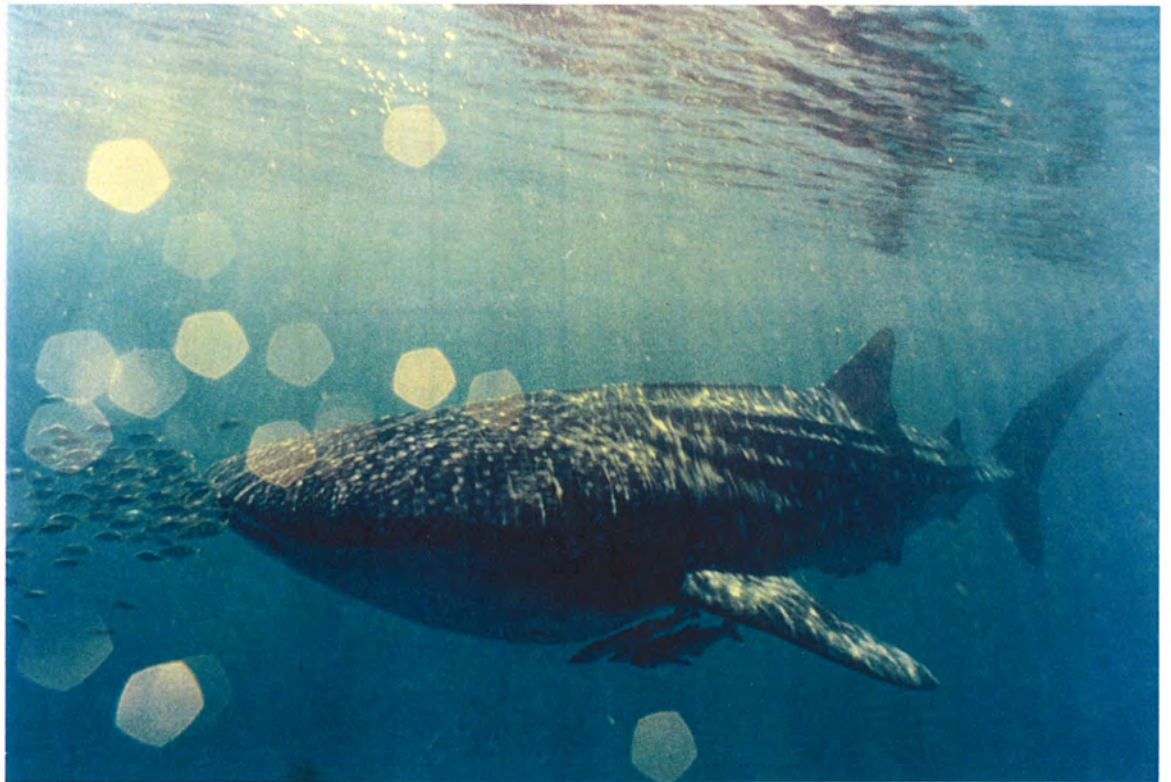
Figure 6.14 Photograph showing several fish swimming in the pressure wave in front of the mouth of *Rhincodon typus*.

Table 6.1 Legs 1–4 of *Pandarus* sp. nov. are biramose with spine and setal formula as follows:

	leg 1		leg 2		leg 3		leg 4	
	exp	end	exp	end	exp	end	exp	end
art 1	0:0	0:0	I:0	0:0	I:0	0:0	VII	1
art 2	I:6	I:2	X	V	VI	2	-	-

[Arabic numerals: nonplumose setae. Roman numerals: plumose setae]

Table 6.2 Legs 1-4 of *Pandarus* sp. nov. are biramose, each ramus of 2 articles, with spine

and setal formula as follows:

	leg 1		leg 2		leg 3		leg 4	
	exp	end	exp	end	exp	end	exp	end
art 1	T:0	0:0	T:1	T giga	I:1	T giga	T	T giga
art 2	III:4	III	V:4	VIII	V:4	V	V:4	IV

[T: bipennate setae. Arabic numerals: nonplumose setae. giga: a gigantic seta]

Table 6.3 The numbers of each taxon observed in association with *Rhincodon typus* at Ningaloo Marine Park in 1996 and 1997, provided as a range per shark, total for all sharks and mean number ± S.E. per shark. n = number of observations of sharks.

Taxa associated with whale sharks	1996 (n = 177)			1997 (n = 58)		
	Range	Total No.	Mean no. per shark	Range	Total No.	Mean no. per shark
Slender suckerfish (*Echeneis naucrates*)	0 - 9	161	0.9 ± 0.14	0 - 14	303	5.2 ± 0.53
Remora (*Remora* sp.)	0 - 8	179	1.0 ± 0.12	0 - 8	165	2.8 ± 0.20
Golden trevally (*Gnathanodon speciosus*)	0 - 20	479	2.7 ± 0.36	0 - 3	23	0.4 ± 0.12
Cobia (*Rachycentron canadus*)	0 - 3	25	0.1 ± 0.04	0 - 1	4	0.1 ± 0.03
Other trevally (*Caranx* sp.)	0 - 80	390	2.2 ± 0.71	0 - 60	1035	17.8 ± 2.53
Manta rays (*Manta birostris*)	0 - 5	9	0.05 ± 0.00	0	0	0
Copepods (*Pandarus* sp. nov.)	0 - 100	927	5.3 ± 1.33	0 - 50	191	3.3 ± 1.29

Table 6.4 Numbers of *Pandarus* sp. nov. observed with *Rhincodon typus* when first and last sighted at Ningaloo Marine Park in 1995 and 1996.

Shark Number	Date first sighted	Copepod number	Date last sighted	Copepod number
A-010	26/3/97	3	17/4/97	0
A-011	30/3/96	3	14/4/96	0
A-014	24/3/96	6	2/5/96	0
A-013	23/3/96	5	11/4/96	0
A-016	1/4/96	0	25/5/96	8
A-018	5/4/96	20	7/4/96	0
A-019	17/4/96	6	1/5/96	0
A-020	14/4/97	2	30/4/97	0
A-024	14/4/96	8	26/5/96	0
A-026	1/4/96	0	26/5/96	80
A-036	29/3/96	25	30/3/96	0

CHAPTER 7

VARIABLES RELATING TO ECOTOURISM ON
RHINCODON TYPUS AT NINGALOO MARINE PARK

7.1 Introduction

While many shark populations are currently targeted, and in some cases threatened, by established fisheries, several species of shark including, for example, blue sharks (*Prionace glauca*), hammerhead sharks (*Sphyrna* sp.), zebra sharks (*Stegostoma fasciatum*), white sharks (*Carcharodon carcharias*) and whale sharks (*Rhincodon typus*) are, at present, the focus of a blossoming ecotourism industry (Anderson, 1994; Taylor & Deacon, 1997). This relatively new nature-based industry is dependent on ecological sustainability (Allcock *et al.*, 1994), and is internationally regarded as the strongest growing tourism sector (Smith, 1996). Ecotourism thus encourages the sustainable management of natural resources and promotes the conservation of species. As an example of the benefits that such an industry can bring to the community, a study conducted in the Maldives showed that a living grey reef shark (*Carcharhinus amblyrhynchos*) may be worth up to US$33000 per annum in tourism income, compared to a one-off value of only US$32 (landed) to a local fisherman (Anderson, 1994).

One species with a huge potential for ecotourism is the whale shark, *R. typus*. Indeed, this species is experiencing the worldwide focus of a rapidly developing tourism industry. For example, *R. typus* is, at present, targeted for tourist activities at several locations throughout the world, including the Galapagos Islands, the west coast of Thailand, the Sea of Cortez, Baja California, the Maldives, the Seychelles, the Philippines and at Ningaloo Marine Park (NMP), Western Australia (M. Alava, Worldwide Fund for Nature, Philippines, pers. comm.; C. Anderson, Ministry of Fisheries and Agriculture, Republic of Maldives, pers. comm.; Gourlay, 1997). The rapidly expanding commercial whale shark-watching industry officially began at

Ningaloo Reef in 1993 under the Wildlife Conservation Act (Colman, 1997). It is regulated by the Western Australian Department of Conservation and Land Management (CALM), which advertises a policy that embodies the concept of 'take only photos, leave only footprints' within the National Parks and Reserves that it manages.

In order to determine whether there is any evidence that this burgeoning ecotourism industry is having an adverse impact on *R. typus* at NMP, it is necessary to conduct a detailed behavioural study. Both close and repeated careful observations of movements and posture are required to analyse the complex interactions between external stimuli and varying behavioural patterns in animals (Carthy, 1979; McFarland, 1985). Such studies are, however, often difficult to conduct when working with sharks in the wild, as these animals may be wide-ranging, shy of divers and live in a concealing environment (Nelson, 1974). These factors have impeded long-term observations on sharks and, as a consequence, the behaviour of most shark species remains virtually unknown (Gruber & Myrberg, 1977). The first studies aimed specifically at undertaking repetitive observations of shark behaviour were carried out in 1954, that study being conducted on a captive colony of smooth dogfish (Gruber & Myrberg, 1977). The main emphasis of the limited number of behavioural studies that have been undertaken on large sharks are usually with regard to shark attack.

In order to be able to analyse the behaviour of a species in the wild, it is crucial that individual animals can be identified (Nelson, 1977). While identification of animals underwater is often difficult, this problem, in the case of *R. typus* at NMP, has been largely overcome through the establishment of the Whale Shark Photo-identification Library (see Chapter 4).

Whale shark ecotourism at Ningaloo Marine Park

With regard to *R. typus* at NMP, CALM regulations stipulate that the maximum time that a vessel carrying tourists can be within the 250 m contact zone around *R. typus* is 90 minutes (Fig. 7.1), while the period permitted for tourists to swim with

sharks, subsequently referred to as a shark/tourist interaction, must not exceed 60 minutes (see Appendix 2). The maximum number of persons permitted in the water during each of these whale shark/tourist interactions is ten, while the minimum distance permitted between vessel and shark is 30 m. The Code of Conduct for whale shark watching remained unchanged throughout the duration of the study, *i.e.* 1995 - 1997 (Figs 7.1, 7.2), except that the minimum permissible distance between a diver and a shark was increased from 1 m in 1995 to 3 m from the head and body and 4 m from the tail of *R. typus* for the 1996 and 1997 seasons.

To assist with the sustainable development of the whale shark ecotourism industry within NMP, it is necessary to determine the effect of industry on the valuable whale shark resource, and if and how it changes under varying levels of tourism 'pressure'. No attempt had previously been made to study the impacts of the tourism industry on the behaviour of *R. typus*. Thus, the main aim of the work described in this chapter was to gather baseline information on whale shark behaviour throughout whale shark/tourist interactions at NMP. This was then used to elucidate whether there was any evidence that alterations to external conditions caused by the ecotourism industry resulted in changes in the behaviour of *R. typus* and thus indicate the extent to which whale sharks are affected by the associated ecotourism industry.

The initial part of the study used industry records to determine whether the number of vessels and whale shark/tourist interactions altered throughout the course of each whale shark season in 1995, 1996 and 1997. The study also determined the number of snorkellers swimming with each *R. typus* during a subset of all whale shark/tourist interactions during these years. The minimum distance between both vessels and tourists from the sharks and the duration of each shark/tourist interaction was analysed to determine whether there was any change in these variables during the same three years. The effect of SCUBA and flash photography on this species was also studied. It is important to analyse these various criteria as ecotourism industry harassment may result in the whale sharks learning to avoid tourists (Thompson & Stevens, 1994).

7.2 Materials and methods

7.2.1 Number of industry vessels and whale shark/tourist interactions

The number of vessels involved in whale shark tourism and the number of occasions when people were swimming with sharks, *i.e.* interacting during each day of the whale shark tourist season at NMP in 1995, 1996 and 1997, were obtained from data recorded by industry operators in the Whale Shark Operator logbooks (see Fig. 3.2).

7.2.2 Personal observations of whale shark/tourist interactions at Ningaloo Marine Park

A position aboard whale shark vessels, which was made available through the combined efforts of CALM and members of the Whale Shark Steering Committee and Whale Sharks WA Ltd, enabled the author to document a subset of 360 whale shark/tourist interactions between 1995 and 1997 (Fig. 7.3). The number of snorkellers swimming with *R. typus* during each of these interactions was recorded. The minimum distance between swimmers and *R. typus* during each interaction was estimated by visually comparing that distance with the length of a typical snorkeller (*ca* 2 m). In addition, at regular intervals throughout the study, a 15 m rope (knotted at 1 m intervals) was used as a scale underwater to assist with these estimations. An estimate of the minimum distance between vessel and shark during each five minute period of each interaction was assisted by visually comparing that distance with the known length of each vessel. The start and finish of each interaction between whale sharks and swimmers were recorded. An interaction was considered complete when the shark dived or swam away at a speed too great for the tourists to maintain, or if the shark was 'passed on' to another industry vessel.

7.2.3 Behaviour of *Rhincodon typus*

The behaviour of *R. typus* was recorded for 125 shark/tourist interactions on 52 days in 1995, 177 interactions over 45 days in 1996 and during 58 interactions over 17 days in 1997 (Table 7.2). The vast majority of these involved tourists who were using snorkelling equipment, although it was possible to view the effect of SCUBA on whale shark behaviour on nine occasions. Since observations were mainly conducted from commercial vessels, which each carried up to 16 passengers who would swim with *R. typus*, there were few opportunities to witness the behaviour of *R. typus* when only one or two snorkellers were present. The behaviours of *R. typus* that could be readily distinguished were i) diving, ii) porpoising, iii) banking and iv) eye rolling. The time spent swimming with each shark was recorded. The number of each different behaviour in sequential five minute intervals was recorded on waterproof data sheets while swimming alongside individual *R. typus* (Fig. 7.4).

A dive by *R. typus* (Fig. 7.5) was defined as a descent to where the visibility and water depth resulted in the shark being out of view to the observer either briefly or indefinitely . A porpoise was recorded when the shark moved away from the surface (up to 20 m) but not out of sight, and returned to the same swimming depth, usually *ca* 1 m below the surface (Fig. 7.6). A bank resulted in a partial body roll such that the dorsal surface of the shark was orientated towards the swimmer or associated tour vessel (Fig. 7.7). Each eye roll (Fig. 7.8) was recorded when near the anterior of the animal.

The relative swimming speed of each shark was also recorded and, although this was subjective, *i.e.* slow/medium/fast, it was always noted by the same observer (B. Norman). A slow speed was defined as when a snorkeller of average fitness could swim comfortably alongside the shark throughout the interaction ($\leq$ 1 knot). A medium swimming speed was identified when the observer was required to 'fin' strongly in order to keep pace with the animal (1-2 knots). A fast swimming speed was recorded when the snorkeller could not keep pace with the shark.

On most occasions, an underwater camera was used in an attempt to photograph each *R. typus* for the purpose of re-identification (see Chapter 4). After the Whale Shark Photo-identification Library was established (see Chapter 4: Library 1), it became possible to distinguish between many individual *R. typus* and therefore assess whether a resighted shark exhibited similar behaviour.

Analytical methods

Tests for significance between the above different parameters were performed using one-way analysis of variance (ANOVA). Cochran's C-test was used to test for homoscedasticity. When data were found to be heteroscedastic, values were $Log_{10}(n+1)$ transformed which then always resulted in homoscedasticity. When ANOVA showed that there was a significant difference, Scheffe's *a posteriori* test was used to identify which values were significantly different at the 0.05 level of probability.

7.3 Results

7.3.1 Number of industry vessels and whale shark/tourist interactions

Industry records

The number of whale shark vessels operating daily at NMP during each week of the whale shark season ranged from 0.3 - 6.9 in 1995, 1996 and 1997 (Table 7.1; Fig. 7.9). The number of commercial vessels operating weekly at NMP at the start of each season was initially only 0.3, 0.7 and 0.7 per day per week in 1995, 1996 and 1997, respectively. It rose to peak values between weeks 5 and 9 from April 5 - May 2 (Fig. 7.9), when the mean values were 5.3, 5.6 and 5.7 vessels per day per week, respectively, before decreasing towards the end of each season to 0.7, 0.9 and 0.3 per day per week.

Industry operators recorded 501, 914 and 783 shark/tourist interactions in 1995, 1996 and 1997, respectively (Fig. 7.10). On the days when industry vessels were

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searching for *R. typus* within NMP, the number of interactions between swimmers and sharks ranged from 0 - 26, with a mean of 1.8/day in 1995, which was found to be significantly lower than the 2.6/day recorded for both 1996 and 1997 (Table 7.2; Fig. 7.10).

The number of interactions between swimmers and *R. typus* were generally highest between late March and late April in 1995, between mid-March and late April in 1996 and during April in 1997 (Fig. 7.10). The mean number of occasions when tourists swam with whale sharks per boat per day, based on weekly data, were 1.7, 2.3 and 2.0 in 1995, 1996 and 1997, respectively. In 1995, the values were highest during weeks 5, 6 and 14, *i.e.* 2.8, 3.0 and 5.1, respectively. In 1996, peak values of 3.8, 4.0 and 4.2 were recorded during weeks 4, 5 and 6 respectively. In 1997, the highest values of 3.5, 4.1 and 3.4 were recorded in weeks 7, 8 and 11, respectively. During weeks 5 - 9, when the maximum number of vessels were operating, the mean number of interactions between swimmers and *R. typus* were 2.0, 3.0 and 2.9 per day, respectively.

Personal records

Personal observations indicate that tourists entered the water to swim with *R. typus* on up to 7, 13 and 6 separate occasions per day in 1995, 1996 and 1997, respectively, with a significantly lower mean number of such interactions occurring in 1995 (2.4) than in both 1996 and 1997, *i.e.* 3.9 and 3.4, respectively (Table 7.2).

7.3.2 Personal observations of whale shark/tourist interactions at Ningaloo Marine Park

Number of swimmers with Rhincodon typus

In 1995, the number of swimmers recorded each time a boat discharged tourists into the water to swim with sharks ranged from 1 to 15 with a mean of 10.5 (Table 7.3) and a mode of 11 (Fig. 7.11). In 1996, the number ranged from 1 to 16, with

a mean and mode of eight. In 1997, the range was between 1 and 16, with a mean of 8.3 and a mode of 11. There were significantly more swimmers per interaction in 1995 than in both 1996 and 1997 ($p < 0.05$). The mean number of snorkellers recorded per interaction throughout the study period was 8.9 with a mode of 11 (Table 7.3; Fig. 7.11).

Distance of swimmers from Rhincodon typus

The minimum distance between swimmers and *R. typus* in 1995, 1996 and 1997 ranged from 0 - 5, 0 - 12 and 0 - 5 m, with means of 1.5, 2.0 and 2.1 m, respectively (Table 7.3). The modal minimum distance in each of the three years was 0 - 0.9, 1 - 1.9 and 0 - 0.9 m, respectively (Fig. 7.12). The mean minimum distance between snorkellers and sharks was significantly greater in both 1996 and 1997 than in 1995. Between 1995 and 1997, the overall mean minimum distance was 1.9 m, with a modal interval of 1 - 1.9 m (Table 7.3; Fig. 7.12).

Distance of vessels from Rhincodon typus

In 1995, 1996 and 1997, the minimum distance between industry vessels and *R. typus* on each occasion when snorkellers were swimming with *R. typus* ranged from 0.5 - 50, 0 - 60 and 5 - 100 m, respectively (Table 7.3). The mean values for these minimum distances were 20.7, 21.3 and 31.0 m in 1995, 1996 and 1997, respectively. The modal minimum distance between vessel and shark during each whale shark/tourist interaction was 20 - 29 m in both 1995 and 1996 and 40 - 49 m in 1997 (Fig. 7.13). The mean minimum distance between vessels and *R. typus* during each interaction was significantly greater in 1997 than in both 1995 and 1996. Between 1995 and 1997, the mean minimum distance per was 22.6 m, with a modal minimum distance interval of 20 - 29 m (Table 7.3; Fig. 7.13).

Duration of interactions between swimmers and Rhincodon typus

The duration of each interaction between swimmers and *R. typus* in 1995, 1996 and 1997 ranged from 1 - 65, 1 - 63 and 1 - 70 min and produced means of 19.3, 14.2 and 9.5 min, respectively (Table 7.4). The mean duration of each interaction in 1995 was significantly greater than in 1997. However, in each year, many of the interactions were less than 10 min, with a modal time interval of 0 - 4 min in both 1995 and 1996 and of 5 - 9 min in 1997 (Fig. 7.14). The overall mean duration of each whale shark/tourist interaction throughout the current study from 1995 - 1997, was 15.2 min (Table 7.4).

The mean minimum distance between swimmers and *R. typus* throughout the current study (1995-1997) was greatest in the 0 - 4 min time interval and least in the 40 - 44 min interval, with values of 2.3 and 1.3 m, respectively (Fig. 7.15). During the study, the mean minimum distance between tourists and *R. typus* decreased as the duration of the interaction increased (Fig. 7.15).

The mean minimum distance between industry vessels and *R. typus* on those occasions when snorkellers were swimming with sharks was greatest in both the 5 - 9 and 10 - 14 min intervals (26.2 m) and least in the 60 - 64 min interval (11.0 m). The distance between vessel and shark declined as the duration of the interaction increased (Fig. 7.15).

7.3.3 Behaviour of *Rhincodon typus*

When swimmers were alongside *R. typus* at NMP, the mean number of dives by sharks per minute of interaction was *ca* 0.2 in each year of the study (Table 7.5). The mean number of porpoise movements recorded per minute of interaction lay between 0.04 and 0.06 in each year, while the mean number of banks recorded per minute of interaction was either 0.07 or 0.08. The mean number of eye rolls recorded per minute of interaction was between 0.02 and 0.04 in all years (Table 7.5).

The greatest number of behavioural changes displayed by *R. typus* occurred in the first five minutes of interactions, with either one or two behavioural changes being recorded on *ca* 41 and 15% of all occasions (Table 7.6). The percentage of sharks displaying no behavioural change in this same period decreased from 44% in 1995 to 39% in 1996 and 29.3% in 1997.

The proximity of a vessel to *R. typus* appeared to result in a shark displaying either a dive, porpoise, bank, eye roll or a change in swimming speed (Table 7.7), especially as swimmers were further than 5 m from *R. typus* on 17 separate occasions. Shark A-022 was sighted on 8 April 1995 with considerable healed damage to the dorsal fin (Fig. 7.16), and porpoised each time the vessel was 20 - 40 m away. This shark remained at the surface when only snorkellers were present. Several sharks were marked with blue anti-fouling paint similar to that found on the hulls of many vessels operating within NMP.

Between 1995 and 1997, *R. typus* was observed 'sucking' the bubbles created by boat propellers during nine separate interactions (Fig. 7.17). On each occasion, the vessel had moved well clear of the whale shark, and no physical contact between boat and shark was recorded. *Rhincodon typus* was observed closely following the bubbles from the outboard motor of a tender vessel at NMP on three occasions. On 9 May 1997, a small whale shark (*ca* 5 m) moved toward and repeatedly positioned its' mouth clear of the surface under the flow of water from the deck hose of a charter vessel (M. Landon, Ningaloo Blue Charters, Exmouth, pers. comm.), suggesting that the shark was attracted to this area of concentrated water movement.

A medium swimming speed was recorded during 43.2, 50.8 and 27.6% of observations when snorkellers were swimming alongside *R. typus* at NMP in 1995, 1996 and 1997, respectively, whereas a slow mean swimming speed was recorded during 34.8, 37.8 and 72.4% of observations in these years (Table 7.8). While few sharks swam at a fast speed in 1995 and 1996 (*i.e* 18.4 and 11.4%, respectively), there were no *R.typus* recorded swimming at this pace during in 1997.

Contact between swimmers and Rhincodon typus

Physical contact between swimmers and *R. typus* were recorded on 6, 14 and 3 occasions in 1995, 1996 and 1997, respectively (Table 7.9). The response of *R. typus* ranged from no reaction (43.5%), to either diving (30.4%), porpoising (17.4%), banking (17.4%), eye rolling (4.3%), or an active attempt to move away from the tourist by increasing swimming speed (8.7%) (Table 7.9).

During several of these interactions, *R. typus* often banked when a snorkeller 'duck-dived' near the shark's head region (Table 7.10), whereas banking was recorded on only three occasions when snorkellers 'duck-dived' near the rear of *R. typus*. In addition, an eye roll was recorded most frequently when snorkellers were within 0 - 1 m of the eye region of the shark (Table 7.11).

Use of SCUBA and flash photography during interactions with Rhincodon typus

The response of *R. typus* to SCUBA was observed while swimming alongside whale sharks at NMP in 1995 and 1996, and ranged from no reaction (1 occasion), to either a bank (4 occasions), a dive (4 occasions), a porpoise (1 occasion) or a substantial increase in swimming speed (2 occasions) (Table 7.12). On three occasions, when SCUBA exhaust bubbles came in contact with the underside of the 'chin' of *R. typus*, the shark swam upwards and away from the diver (Fig. 7.18). There was only one opportunity to observe the response of *R. typus* to flash photography throughout the current study. When this occurred on 18 March 1995, the shark reacted immediately with an eye roll.

7.3.4 *Rhincodon typus* with body scarring

Several *R. typus* were observed with recent and/or healed scarring on their flanks and dorsal surface, which ranged from superficial scratches, where the upper layers of skin were removed leaving a white area exposed, to deep 'fleshy gashes', to the truncation of significant portions of the fins (Figs 7.16, 19-21; Table 7.13). The white

scarring on the left flank near the anal fin of shark A-012 (Fig. 7.20) and on the leading edge of the right pectoral fin of shark A-017 (see Chapter 4: Library 1), may have resulted from these individuals scraping a hard surface such as the reef at NMP. Shark A-053 had conspicuous scarring on the second dorsal fin, the lower lobe of the caudal fin and below the first dorsal fin on the left flank (see Chapter 4: Library 1). A brown paint-like substance was also present on the dorsal surface and left flank of A-053 (Fig. 7.21).

Approximately 80% of the dorsal fin of a shark sighted on 19 May 1996 had been recently truncated, leaving a bloodied margin. When an approaching industry vessel was still more than 30 m away, the shark responded by rapidly diving. This individual was only observed for a short time (*ca* 1 min) on each of the two occasions it was sighted. On 22 May 1996, a shark with recent scarring, which probably resulted from contact with a boat propeller, was observed for only 1 min before diving (Table 7.13). Another *R. typus* with similar wounds (Fig. 7.19) was seen twice on 3 June 1995, with the period during which snorkellers were able to swim alongside this shark being only 2 min on each occasion. The mean duration of each interaction between swimmers and *R. typus* with substantial recent scarring was only 1.4 min (Table 7.13).

7.4 Discussion

7.4.1 Number of industry vessels and whale shark/tourist interactions

Fifteen whale shark interaction licences were issued by CALM to commercial tour operators within NMP, of which 14 were utilised annually between 1995 and 1997 (Colman, 1997). The number of vessels operating at NMP peaks between weeks 5 and 9 of each short whale shark season at NMP, at the time when productivity is apparently high (see Chapter 3). However, the mean number of boats operating within these weeks was always ≤ 5.7 per day, well below the number of vessels licensed by CALM to conduct whale shark tours (Table 7.1).

Although the number of occasions when snorkellers were swimming with *R. typus* at NMP fluctuated during 1995, 1996 and 1997, industry and personal records demonstrate that the number of such interactions per vessel per day were greater in 1996 and 1997 than in 1995. Personal observations suggest that this increase resulted from greater industry co-operation, where whale sharks were shared between several operators.

The unusually high number of 5.1 interactions per day per week in week 14 of 1995 reflects the fact that one operator at Coral Bay recorded interactions with as many as 26 sharks on 31/5/95 (Fig. 7.9). In both 1995 and 1996, the number of interactions decreased after week 6, whereas the number of vessels continued to increase until week 10, before beginning to decline (Fig. 7.9). This suggests that either *R. typus* started declining in numbers at NMP in week 6 of those two years, or that the increased number of vessels in weeks 6 - 10 caused sharks to avoid vessels, thus making them less accessible to viewing. In contrast to the situation in 1995 and 1996, the trends exhibited by the number of interactions paralleled those of the number of vessels operating in 1997. This suggests that, with experience, the vessel operators had become more adept in detecting *R. typus*. With the expansion of the Whale Shark Photo-identification Library (see Chapter 4) and the continued collection of observational data on this species at NMP, it should be possible in the future to determine whether the same sharks are being subjected to repeated tourist interactions.

7.4.2 Personal observations of whale shark/tourist interactions at Ningaloo Marine Park

Number and minimum distance of swimmers and Rhincodon typus

Although a maximum of 16 snorkellers were recorded swimming with a whale shark at any one time, the mean number over the 1995, 1996 and 1997 seasons was 8.9 (Table 7.3). Regulations stipulate that a maximum of ten swimmers are permitted in the water with *R. typus* at any time (Fig. 7.2), although CALM gave permission for

myself to be the eleventh person throughout the study. This explains why the mode in 1995, 1996 and 1997, was 11 (Fig. 7.11). A small but significant reduction in the mean number of swimmers involved in interactions in 1996 and 1997, compared with 1995 indicates that industry operators were attempting to reduce the crowding of each shark.

The mean minimum distance recorded between a snorkeller and *R. typus* per interaction was confidently estimated throughout the duration of the study. In 1995, this distance was 1.5 m, and therefore greater than the 1 m minimum distance stipulated in the Whale Shark Operator Guidelines for that year. Furthermore, industry operators often encouraged tourists to remain further from the shark (*ca* 3 m). This guideline was subsequently amended to 3 m prior to the 1996 season (Fig. 7.2). Although there was a significant increase in the mean minimum distance recorded between swimmers and *R. typus* in 1996 and 1997 relative to 1995, these distances in 1996 and 1997 were still substantially less than stipulated by CALM. This may reflect an inability of these tourists to judge distance underwater. It does, however, indicate that this amendment was successful in encouraging swimmers to remain at a greater distance from *R. typus*. Any further increase to the minimum distance of swimmers from the sharks would likely result in a reduction in the frequency of accidental contact between swimmer and shark (Birtles *et al.*, 1996).

Distance of vessels from Rhincodon typus

When snorkellers were swimming with whale sharks in 1995 and 1996, the mean minimum distance recorded between vessels and *R. typus* was 20.7 and 21.3 m, respectively. This is considerably less than the 30 m required under the CALM Whale Shark Interaction Code (Fig. 7.1). However, the mean minimum vessel distance between whale sharks and vessels throughout each interaction had increased to *ca* 31 m in 1997. The combined results from all three years of the study (1995-1997) indicate that the mean minimum distance kept between vessels and *R. typus,* when tourists were swimming with *R. typus,* was not rigorously adhered to by all industry operators.

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However, this can be partially attributable to adverse weather conditions, including strong winds, waves and swell which made it difficult for vessel operators to maintain the minimum required distance at all times. A significant increase in the mean minimum distance in 1997, compared to 1995 and 1996, indicates that industry operators were becoming more aware of the need to maintain their vessels at a distance from *R. typus*. An increase in the minimum distance permitted by CALM between vessels and *R. typus*, during whale shark/tourist interactions at NMP, may assist industry operators to ensure that vessels never encroach within 30 m of the sharks and thus reduce the potential tourism-industry related injury or avoidance behaviour of whale sharks.

Duration of each interaction between swimmers and Rhincodon typus

The significant reduction in the mean interaction time from 19.3 min in 1995 to 9.5 min in 1997 (Fig. 7.14), indicates that *R. typus* may have become less tolerant to extended interactions with swimmers at NMP. Indeed, throughout the current study, many interactions lasted less than five minutes, usually due to sharks diving. However, after a period with a whale shark, industry operators occasionally 'passed' sharks on to other vessels.

Since the mean minimum distance of both swimmers and vessels from *R. typus* declined during each interaction (Fig. 7.15), a reduction in the time permitted for interactions would reduce the periods when swimmers are particularly close to sharks. This may assist operators and tourists to obey the minimum allowable distances stipulated in the regulations for whale shark ecotourism.

7.4.3 Behaviour of *Rhincodon typus*

While it was possible to record specific behaviours of *R. typus*, *i.e.* dives, porpoises, banks and eye rolls, during interactions at NMP, there was no opportunity for control observations when no swimmers were present. However, the

limited variation in the overall frequency of each of these behaviours in 1995, 1996 and 1997 suggests a base frequency per minute of interaction (Table 7.5), although changes in behaviour of *R. typus* occasionally appeared attributable to close swimmer and/or vessel proximity. Results from acoustic tracking at NMP in 1997 indicate that diving behaviour in *R. typus* is common at times when swimmers are not present (see Chapter 5; Stevens *et al.*, 1998). As diving and porpoising behaviour enable *R. typus* to disengage from a whale shark/tourist interaction at any time, until the natural frequency of these behaviours can be assessed, these behavioural displays during shark/tourist interactions may be interpreted as a response to ecotourism pressure.

Since the skin on the dorsal surface of *R. typus* is extremely thick, banking ensures that this surface is the one exposed to any attack and thus provides some protection from damage. While there appeared to be no 'natural' threat to *R. typus* at NMP, banking was often recorded when swimmers were close (Table 7.8) and 'duck-dived' near the head region of several sharks (Table 7.10). In contrast, a change in behaviour was rarely observed when a snorkeller 'duck-dived' posterior to the first dorsal fin, indicating that individual *R. typus* were less perturbed when 'duck-diving' occurred out of sight of the shark. Swimmers should, therefore, be discouraged from 'duck-diving' near the anterior of *R. typus*.

Although it was not always possible to observe whether *R. typus* exhibited eye-rolling behaviour during each interaction in 1995, 1996 and 1997, it was often observed when snorkellers were close to the shark's head (Table 7.11). *Rhincodon typus* lacks a nictitating membrane (Bass *et al.*, 1975), but has the ability to roll its' eyes within the orbit. This behaviour, which appears to be an indicator of discomfort to the animal, should be avoided by encouraging snorkellers to keep at least the required minimum distance of 3 m from *R. typus* at all times. Further research on *R. typus*, incorporating data from several subsequent seasons, may elucidate whether decreased mean minimum person distance during tourist interactions has a negative impact on this species.

On those occasions when snorkellers were swimming with whale sharks, the frequency of behavioural changes was greatest in the 0 - 4 min time interval in 1995, 1996 and 1997. The fact that the number of occasions when behavioural changes were recorded increased progressively from 56.0% in 1995 to 70.7% in 1997 (Table 7.6), may reflect a reduction in tolerance of *R. typus* towards tourist interactions between those years.

On several occasions, *R. typus* were attracted to the 'bubbling' caused by boat propellers (Fig. 7.17). The bubbles create an area of concentrated micro-eddies, as would the swimming action of swarming krill, a known prey of *R. typus* (see Chapter 3). A concentrated flow of water from a deck hose had a similar effect. The lateral line receptors of sharks are sensitive to water displacement, and this enables them to orient towards and follow a disturbance to the source (Bres, 1993). On many occasions at NMP, *R. typus* actively avoided approaching vessels (G. Kailis, Exmouth Air Charter, Exmouth, pers. comm.). Sharks have a well-developed sense of hearing, can detect sounds up to 100 m (possibly more) from the source, and are initially attracted to both synthesised and natural biological sounds (Myrberg, 1978; Bres, 1993). However, as they are startled and repelled by sudden loud sounds (Myrberg & Nelson, 1991), industry operators at NMP should approach *R. typus* with great caution and keep vessels well clear of each shark.

During periods in 1995 and 1996, when the mean minimum vessel distance throughout each whale shark/tourist interaction at NMP was *ca* 20 m, less than 40% of *R. typus* were recorded as moving slowly (Tables 7.3, 7.8). However, in 1997, when the mean minimum vessel distance per interaction exceeded 30 m, most whale sharks (*ca* 72%) were recorded swimming at a slow pace. *Rhincodon typus* have been reported to swim slowly until the approach of divers and vessels, when they increase swimming speed (Latin & Latin, 1992; Clark & Nelson, 1997). These data suggest that the swimming speed of *R. typus* may be slower when vessels remain further than 30 m from *R. typus*.

Contact between swimmers and Rhincodon typus

Physical contact between swimmers and *R. typus* was not permitted (see Fig. 7.2), and was strongly discouraged by industry personnel prior to each interaction. However, contact was recorded on 23 occasions between 1995 and 1997, with an obvious change in the behaviour of each shark observed in 56.5% of those instances (Table 7.9). A reaction to touch was not unexpected, considering that the surface of all sharks is covered with many sense organs (Mojetta, 1997). *Rhincodon typus* either dived or swam away fast when the caudal fin was touched, although little change in behaviour was recorded when contact was made with the mid-body region (Hass, 1958; Demetrios 1979; Clark, 1992; B. Norman, unpub. data). Clark (1992) and Clark and Nelson (1997) report that *R. typus* retreat when touched and, while contact with the first dorsal fin of *R. typus* had little effect on the behaviour of a shark observed in 1994, a violent swipe of the tail was observed when the second dorsal fin was contacted (J. Stevens, unpub. data). While Clark (1992) suggested that a ban on touching *R. typus* would be impossible or difficult to enforce, commercial tour operators at NMP actively discourage this type of activity, which also carries a substantial fine for swimmers if prosecuted.

Use of SCUBA and flash photography during interactions with Rhincodon typus

The data collected during the current study indicated that *R. typus* changed behaviour when SCUBA was used in it's vicinity (Table 7.13). The use of SCUBA at NMP had previously resulted in the majority of animals veering away or diving deeper to avoid human contact (Clark, 1992; Latin & Latin, 1992; R. Karniewicz, CALM Exmouth, pers. comm.). Nelson (1974) suggests that most sharks are likely to avoid divers, especially when using SCUBA, while noise associated with SCUBA caused rapid departure in schooling hammerhead sharks (Myrberg & Nelson, 1991). Consequently, although SCUBA is permitted during interactions between swimmers and whale sharks at NMP, the use of this equipment should continue to be discouraged.

Since underwater flash photography during interactions at NMP is banned (Fig. 7.2), there was limited opportunity to determine its' effect on the behaviour of

R. typus. However, on one occasion in 1995, *R. typus* reacted with prolonged eye rolling, which appears to indicate that the shark was experiencing discomfort. This would suggest that the ban on the use of this equipment should remain.

Determination of 'natural' behaviour

For most species of shark, very little is known about their behaviour under completely natural conditions (Nelson, 1977). At NMP, *R. typus* would be aware of the presence of swimmers during each whale shark/tourist interaction given that the human body produces bioelectric fields that, presumably, are able to be detected by sharks (Bres, 1993). Further analysis of the behaviour of *R. typus* during ecotourism operations at NMP will be possible when data are available from 'natural' or 'control' situations. This will enable an accurate comparison between 'natural' and 'tourist influenced' behaviour and may be achieved through the use of improved technology, such as separate tracking with tourists absent/present, remote videography etc., together with continued research programs on *R. typus* at NMP and other locations where whale shark tourism is undertaken.

7.4.4 Sharks with body scarring

Injuries to many *R. typus* at NMP appear to have been caused by physical contact with vessels. The combination of a rapid healing rate by injured *R. typus* (see Chapter 4), a normal swimming speed of *ca* 3 km/h (see Chapter 5), and regular sightings of identified sharks over an extended period (see Chapter 5), indicate that the scarring on some of these sharks may have been incurred by contact with vessels within NMP between 1995 and 1997. Several sharks (e.g. shark A-042 - see Chapter 4: Library 1), have healed 'bite-shaped' scars where flesh has been permanently removed, which may have been inflicted by predators when *R. typus* was small. However, with only two recorded accounts of predation on juvenile *R. typus* in the literature (see Chapter 1), it

would seem that influences other than natural predation were responsible for the majority of these scars observed on *R. typus* at NMP.

The mean duration of each interaction between swimmers and *R. typus* exhibiting recent scars from boat contact (Table 7.13), was considerably less than the overall mean interaction time I recorded between 1995 and 1997 (Table 7.4). Indeed, several tour operators suggested in their Whale Shark Operator logbooks that *R. typus* exhibiting recent wounds caused by propellers had appeared calm while swimmers were alongside, but that the sound of an approaching boat caused these sharks then to dive (B. Norman, unpub. data). Given that sharks have the ability to learn rapidly (Myrberg, 1978), the responses exhibited by *R. typus* with recent scarring suggests that these animals are avoiding vessels.

Many *R. typus* at NMP were observed with anti-fouling paint and/or scarring on their dorsal surface resulting from vessel contact (see Chapter 4; Table 7.13). A review of boat speed limits should be undertaken, as *R. typus* swimming at the surface are sometimes extremely difficult to see. Both private and commercial vessel operators should be encouraged to specifically watch for *R. typus* swimming at the surface within NMP.

THE WHALE SHARK INTERACTION CODE
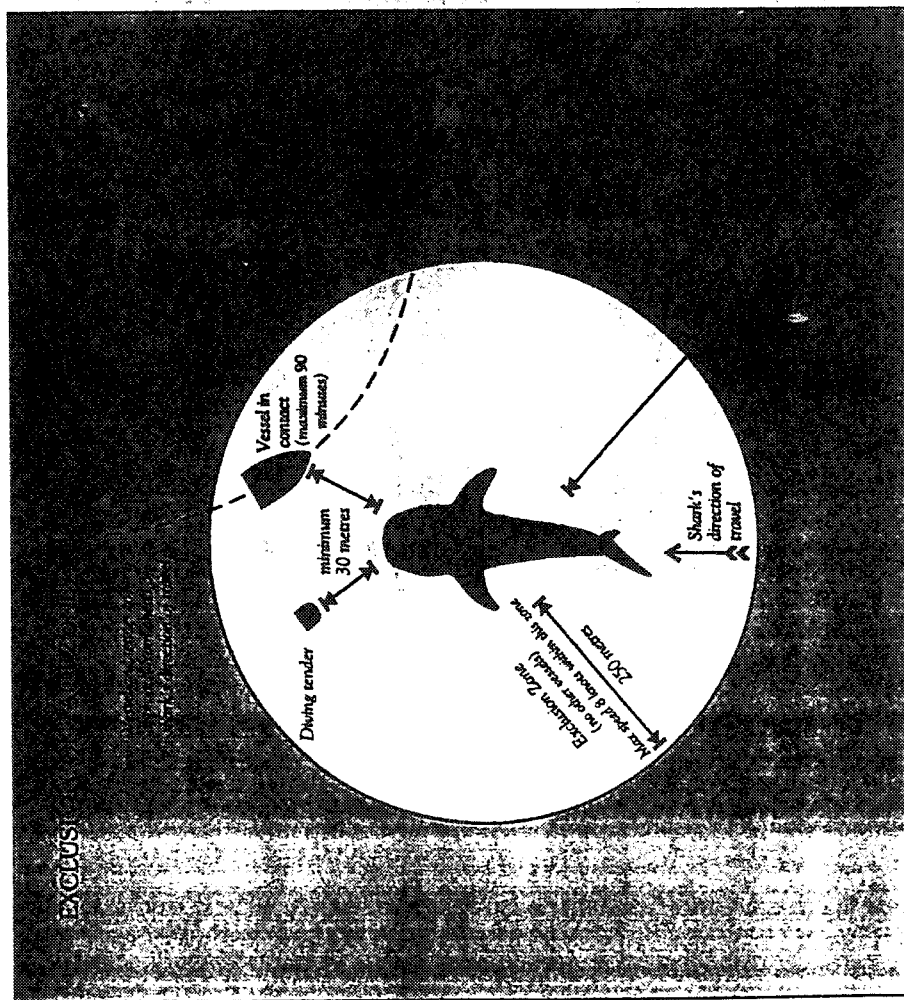
Whale sharks are fully protected under the Wildlife Conservation Act and the CALM Act. To minimise the risk of injury and to prevent the animals from being harmed or disturbed, the following code of conduct has been prepared for commercial tour operators and their passengers.

Contact zone

O An exclusive contact zone of 250 m radius applies around any whale shark.

O Only one vessel at a time may operate within that zone for a maximum time of 90 minutes and at a speed of 8 knots or less.

O The first vessel within that zone is deemed to be 'in contact'. The second vessel to arrive must keep a distance of 250 m from the shark, and any other vessels must be 400 m from the shark.

Figure 7.1 CALM interaction guidelines for tour boat operators (from CALM Whale Shark Operator Logs).
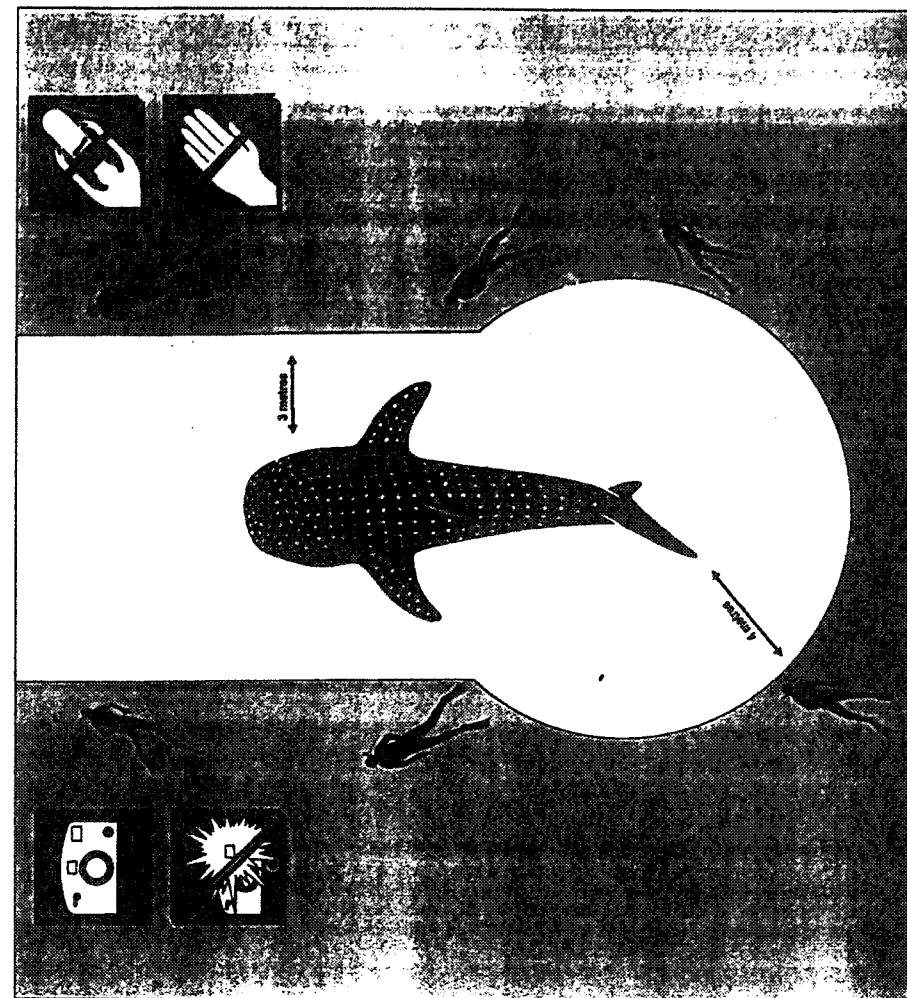
Vessel operators in the contact zone

○ Must not approach closer than 30 m to a shark.

○ Should approach from ahead of the shark's direction of travel when dropping swimmers into the water.

○ Must display flags when swimmers are in the water.

Swimmers in the contact zone

○ Must not attempt to touch or ride on a whale shark, restrict the normal movement or behaviour of the shark, or approach closer than 3 metres from the head or body and 4 metres from the tail.

○ Must not undertake flash photography or use motorised propulsion aids.

○ Are limited to a maximium of 10 people in the water at any one time.

Figure 7.2 CALM interaction guidelines for tourists (from CALM Whale Shark Operator Logs).

Figure 7.3 Photograph showing tourists swimming alongside *Rhincodon typus* with an associated tourist vessel (courtesy Simon Visser).

DATE: _____   BOAT: _____   GPS: _____   CLOUD COVER. _____
                                                                       WIND DIRECTION: _____
                                                                       SEA CONDITIONS: _____

Contact start _____   WATER TEMPERATURE: _____   # Snorkel: _____   TEMPERATURE: _____
TIME   WATER DEPTH: _____

Contact finish _____   VISIBILITY: _____   # Scuba: _____

                                                                                PARASITES: REMORA: _____

SHARK LENGTH: _____   SEX: ____   PROXIMITY OF CLOSEST SHARK: _____   ___ _   SUCKERFISH: _____
                                                                        GOLD TREVALLY: ____
BOAT # ON SHARK (i e 1st etc) _____   SWIMMING DIRECTION: _____   MISC. FISH: ____

TIME	Mean shark depth	min. distance of divers	min. distance of main boat	min. distance of small boat	# eye rolls	# dives	# banks	swim speed	Mean mouth opening	gill flushing	NOTES
0-5											
5-10											
10-15											
15-20											
20-25											
25-30											
30-35											
35-40											
40-45											
45-50											
50-55											
55-60											
60-65											

FILM # :

PHOTO # :

Figure 7.4 Data sheet used by B. Norman when collecting information during each interaction between swimmers and *Rhincodon typus* at Ningaloo Marine Park between 1995 and 1997.

Figure 7.5 Photograph of *Rhincodon typus* displaying a dive behaviour at Ningaloo Marine Park.
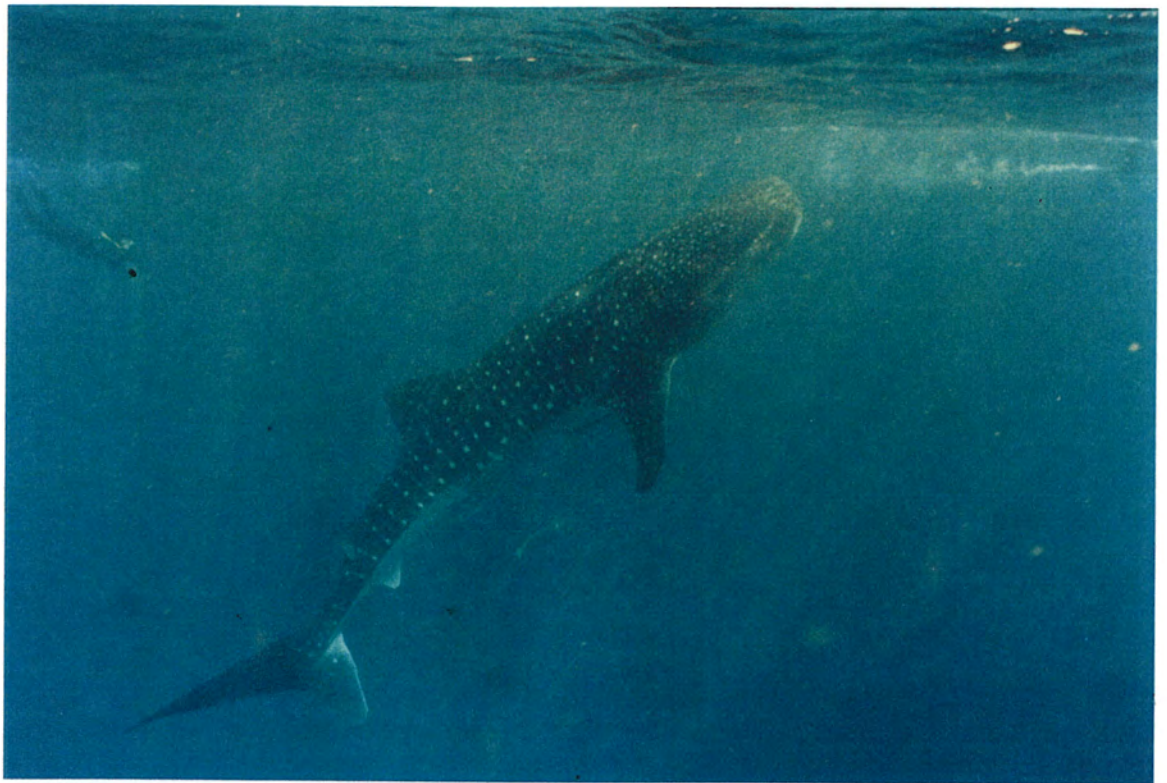
Figure 7.6 Photograph of *Rhincodon typus* displaying a porpoise behaviour at Ningaloo Marine Park.

Figure 7.7 Photograph of *Rhincodon typus* displaying a bank behaviour at Ningaloo
Marine Park.
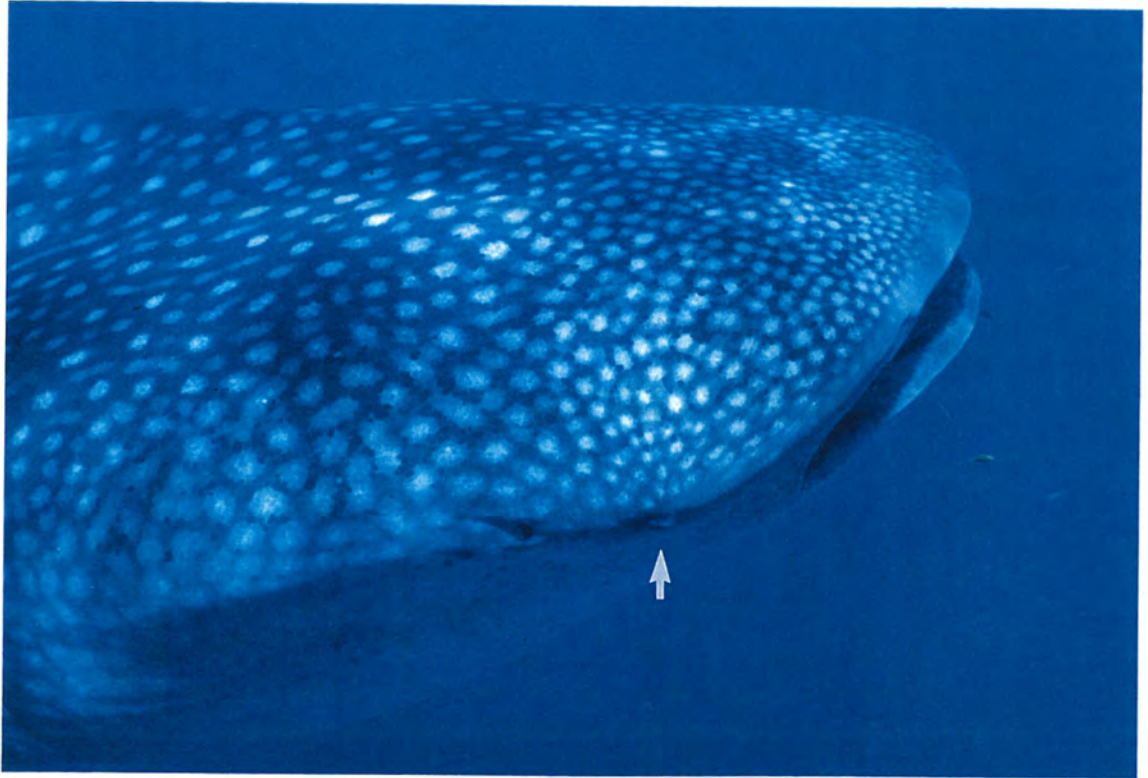
Figure 7.8 Photograph of *Rhincodon typus* displaying eye-roll behaviour at
Ningaloo Marine Park.
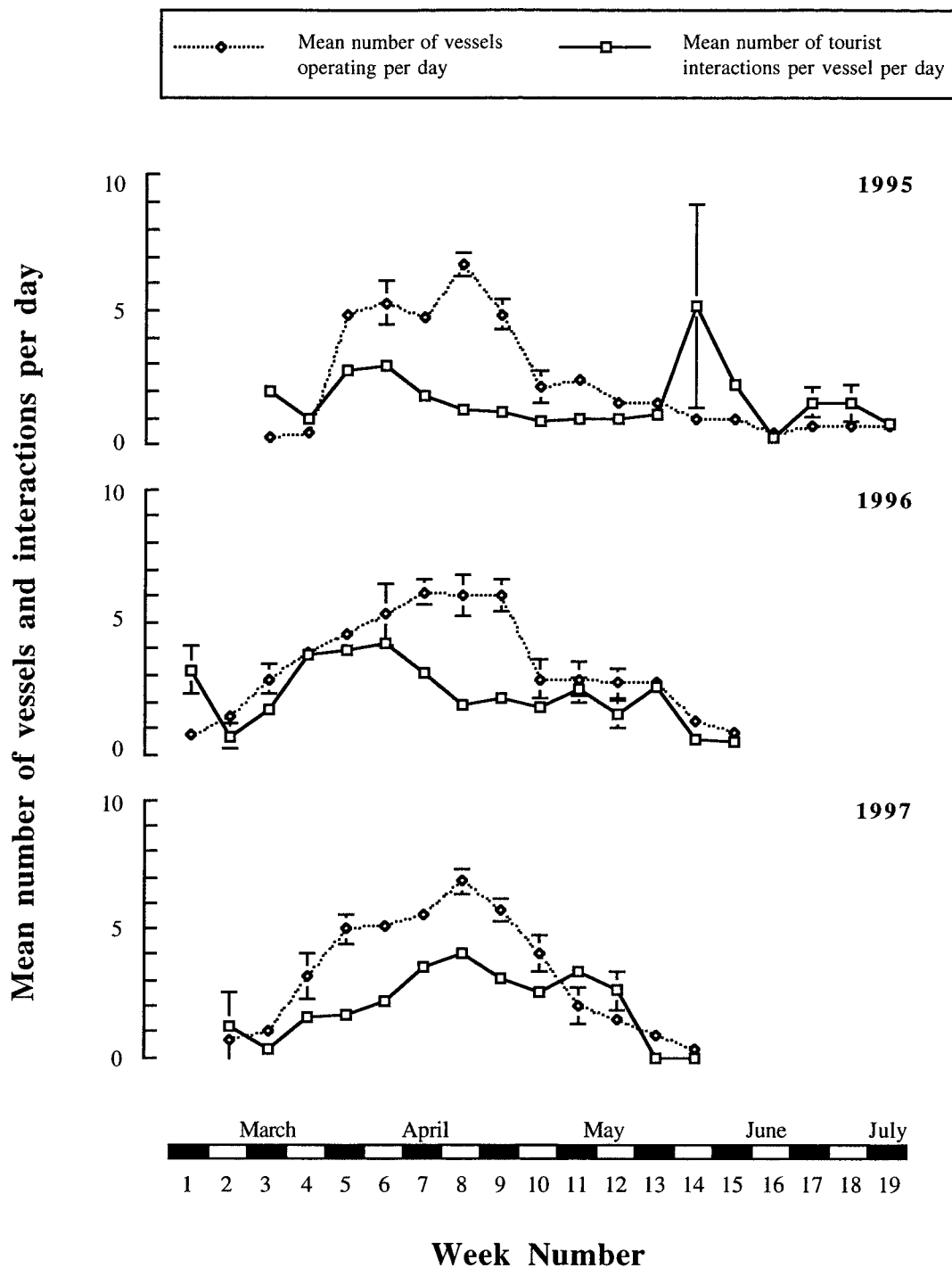
Figure 7.9 Mean number ± 1 S.E. of industry vessels operating per day and of interactions between swimmers and *Rhincodon typus* recorded per day during successive weekly intervals by Industry operators conducting whale shark interaction tours at Ningaloo Marine Park during 1995, 1996 and 1997.
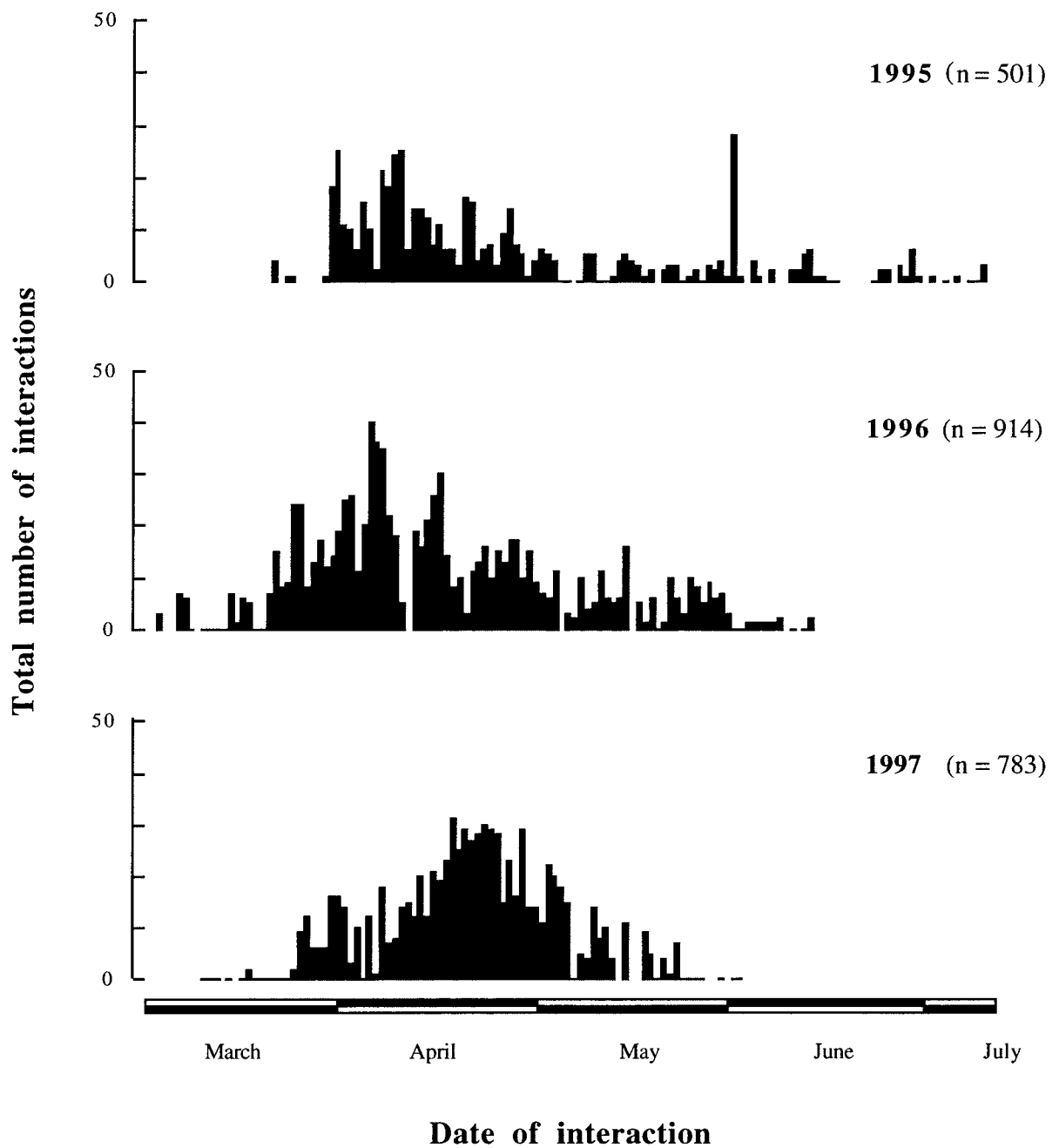
Figure 7.10 Number of occasions when Industry operators recorded swimmers in the water with *Rhincodon typus* at Ningaloo Marine Park throughout the 1995, 1996 and 1997 seasons.
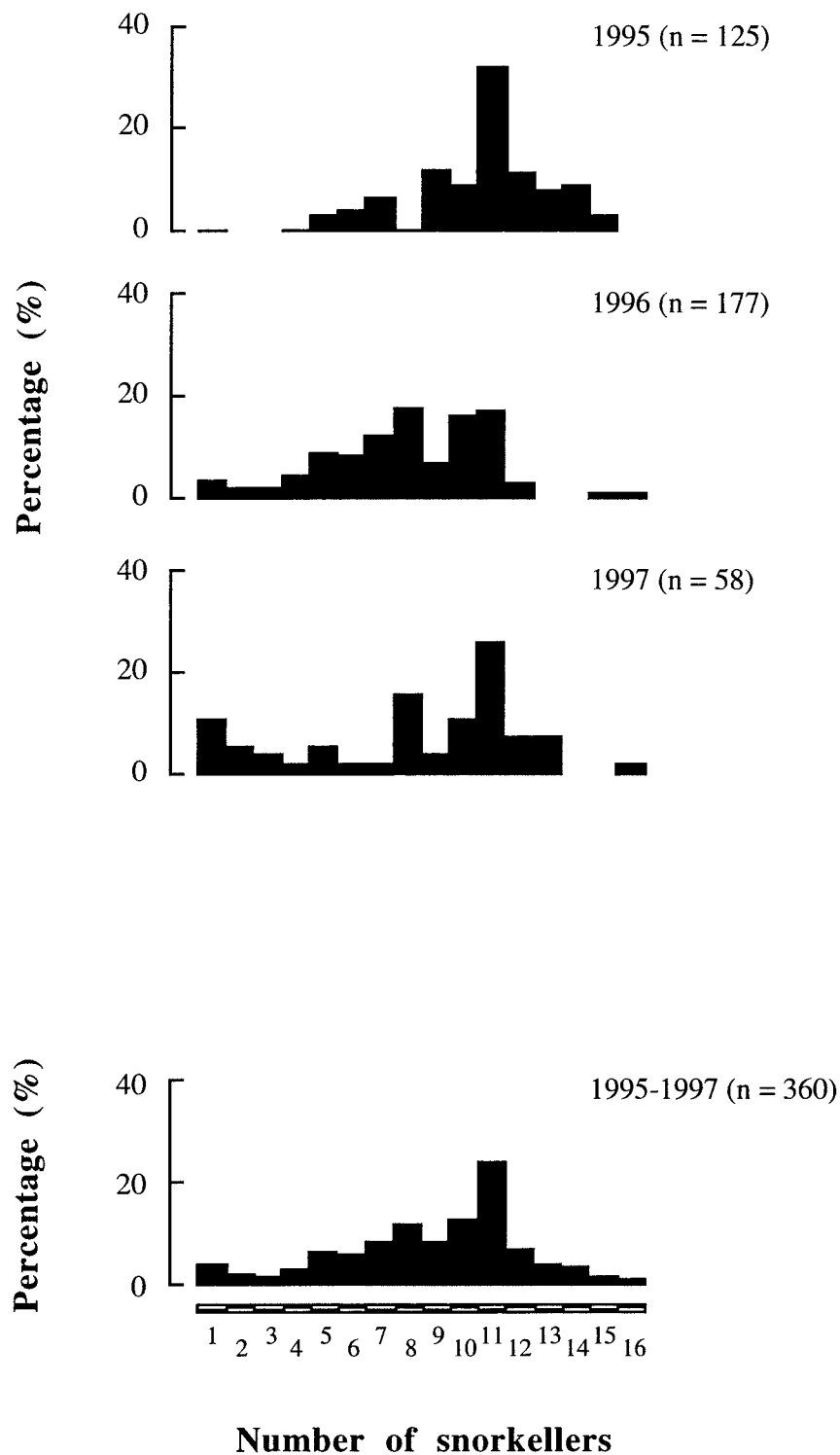
Figure 7.11 The percentage occurrence of different numbers of snorkellers recorded swimming alongside *Rhincodon typus* during each whale shark/tourist interaction at Ningaloo Marine Park. Data were recorded by B. Norman on 360 occasions between 1995 and 1997 and the number of snorkellers includes B. Norman.
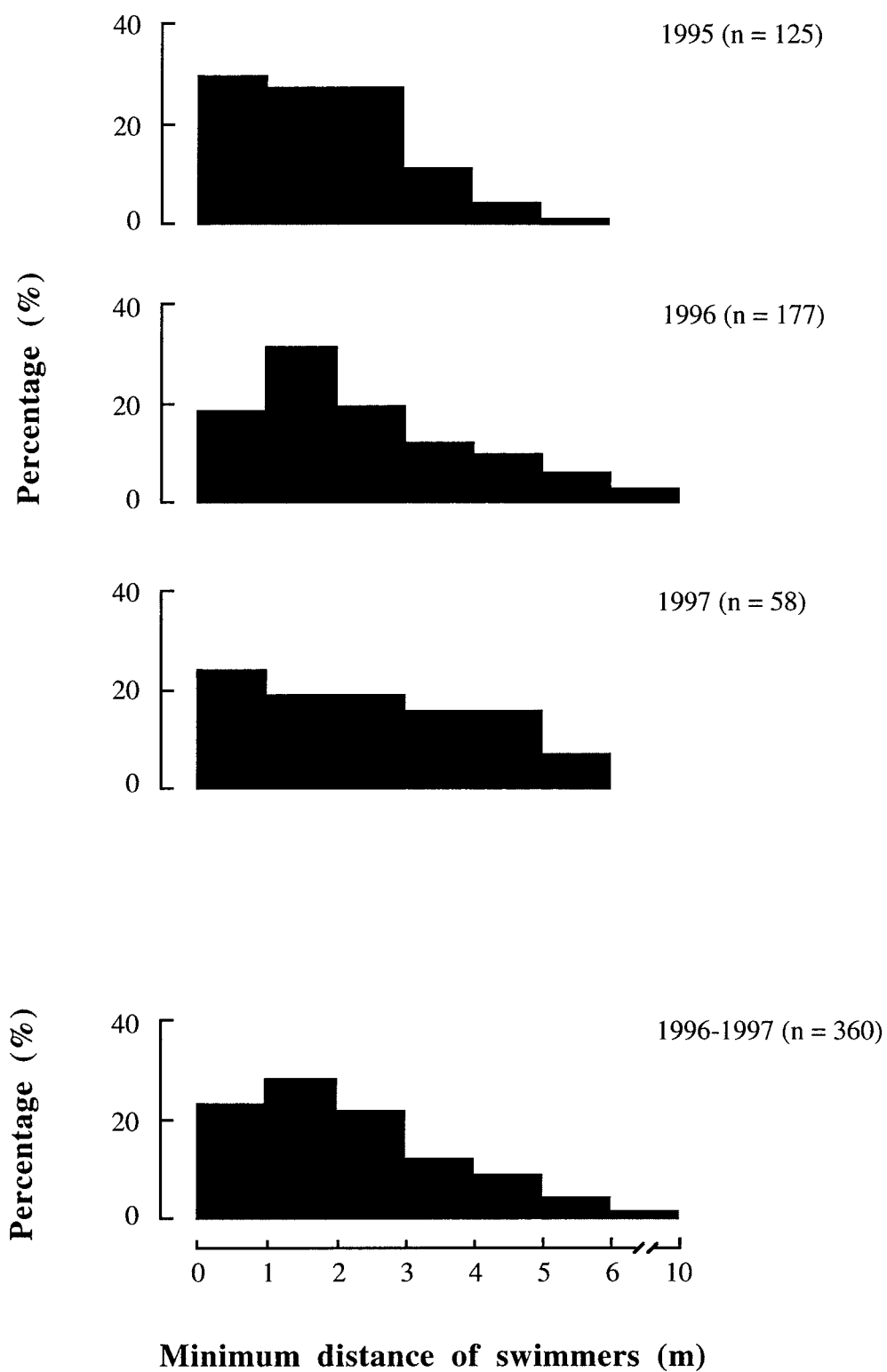
Figure 7.12 The minimum distance between snorkellers and *Rhincodon typus*
recorded by B. Norman during 360 separate whale shark/tourist
interactions at Ningaloo Marine Park between 1995 and 1997,
expressed as a percentage.
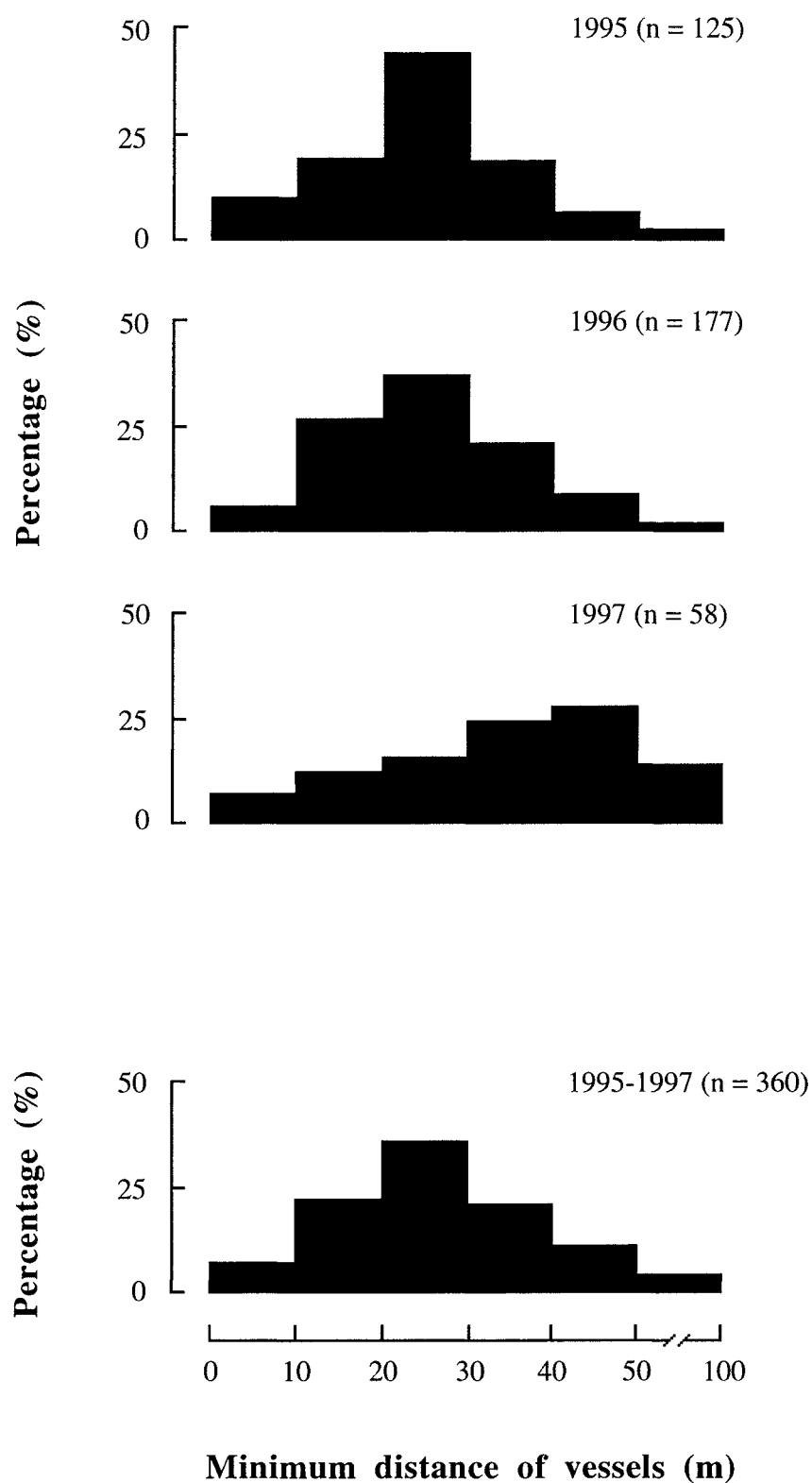
Figure 7.13   The minimum distance between industry vessels and *Rhincodon typus* recorded by B. Norman during 360 separate whale shark/tourist interactions at Ningaloo Marine Park between 1995 and 1997, expressed as a percentage.

40

20

0

1995 (n = 125)

Percentage (%)

40

20

0

1996 (n = 177)

40

20

0

1997 (n = 58)

Percentage (%)

40

20

0

1995-1997 (n = 360)

0 10 20 30 40 50 60

Duration of interaction (min)
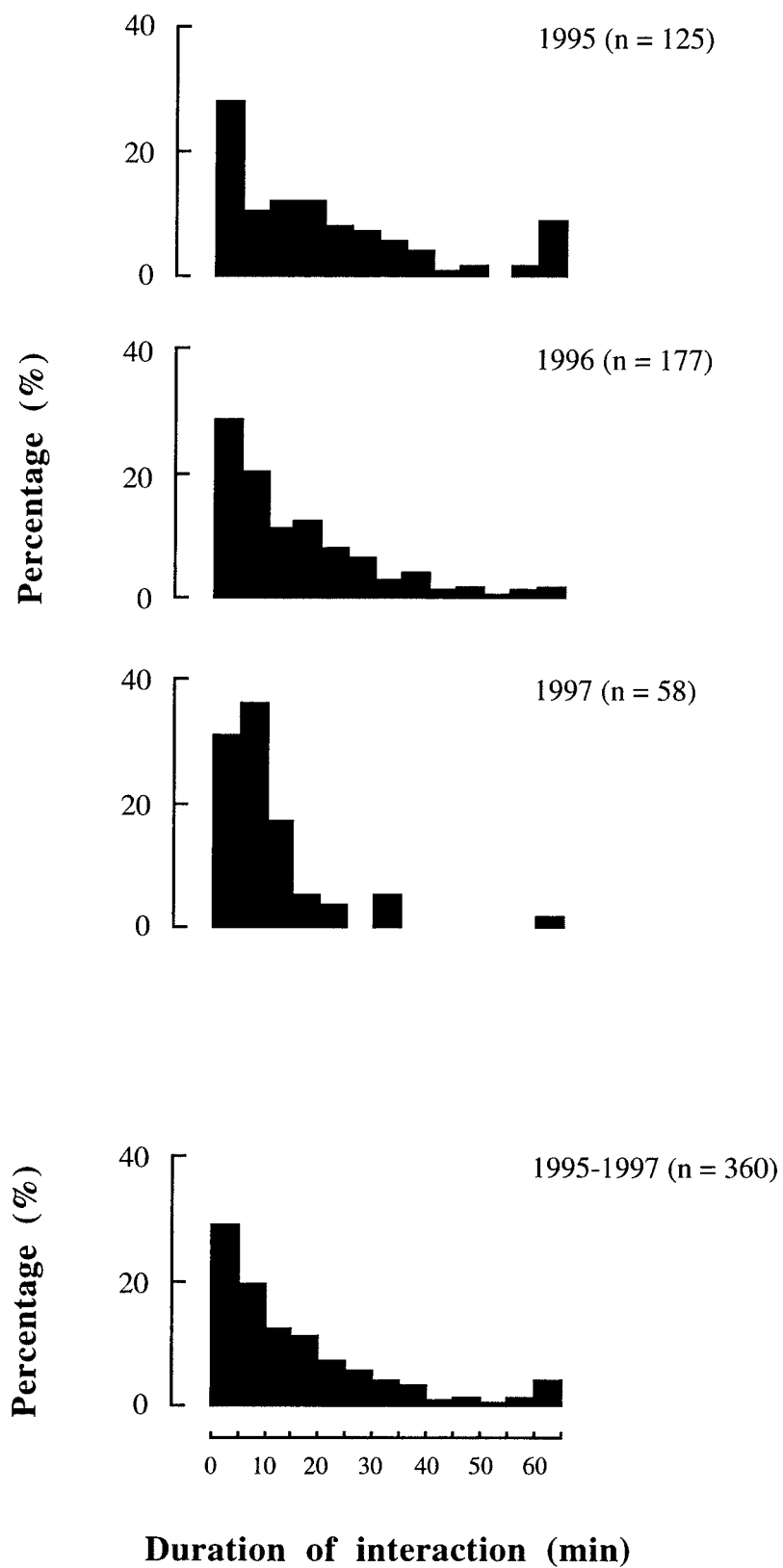
Figure 7.14 The duration of each interaction between *Rhincodon typus* and swimmers recorded by B. Norman on 360 occasions at Ningaloo Marine Park between 1995 and 1997.
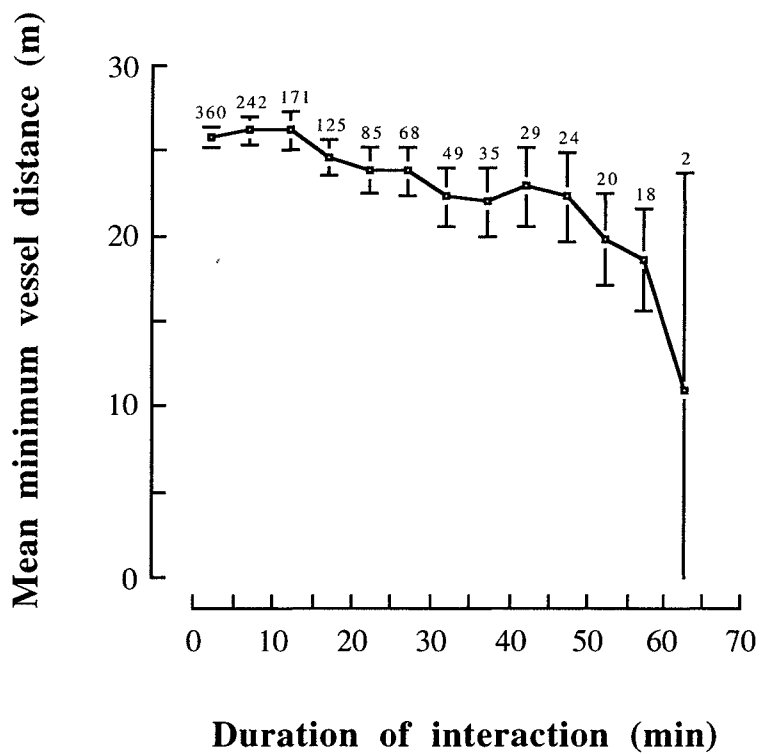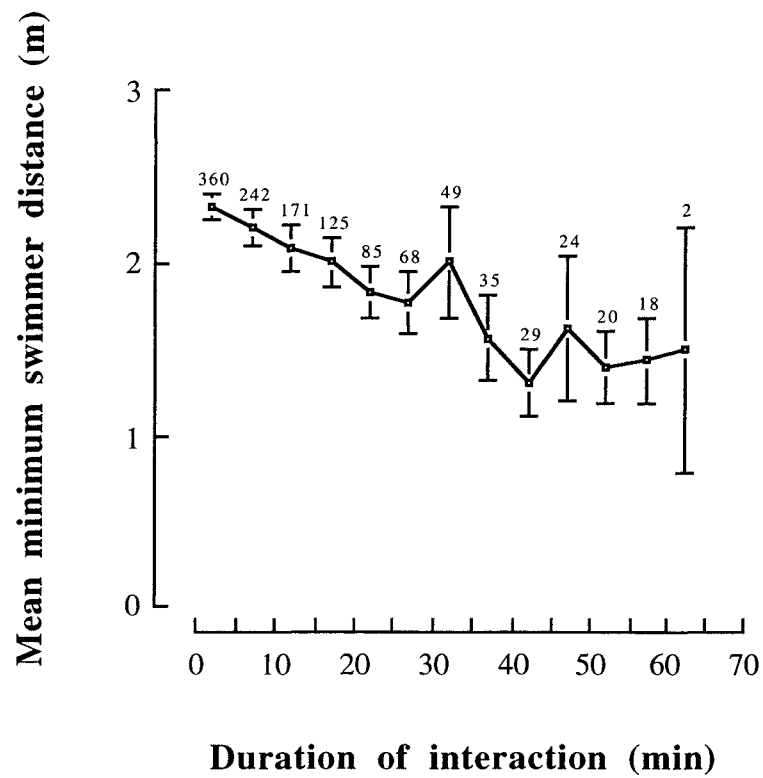
Figure 7.15 The mean minimum distance between *Rhincodon typus* and both
swimmers and vessels ± 1 S.E. were recorded by B. Norman within
each successive five minute interval of whale shark/tourist
interactions at Ningaloo Marine Park between 1995 and 1997.
NB. The number of observations within each time interval is given.
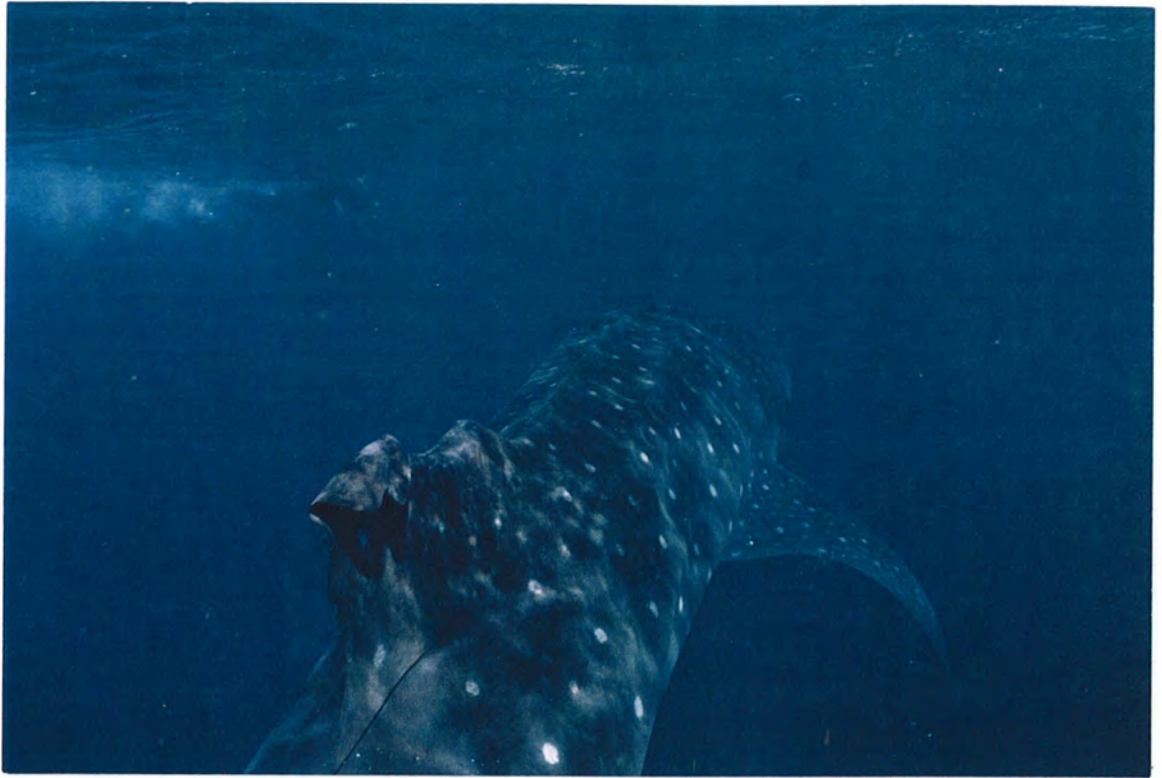
Figure 7.16 Example of obvious trauma exhibited by *Rhincodon typus* within Ningaloo
Marine Park which was likely caused from vessel contact.

Figure 7.17 *Rhincodon typus* actively ingesting exhaust bubbles from vessel
propellers at Ningaloo Marine Park.
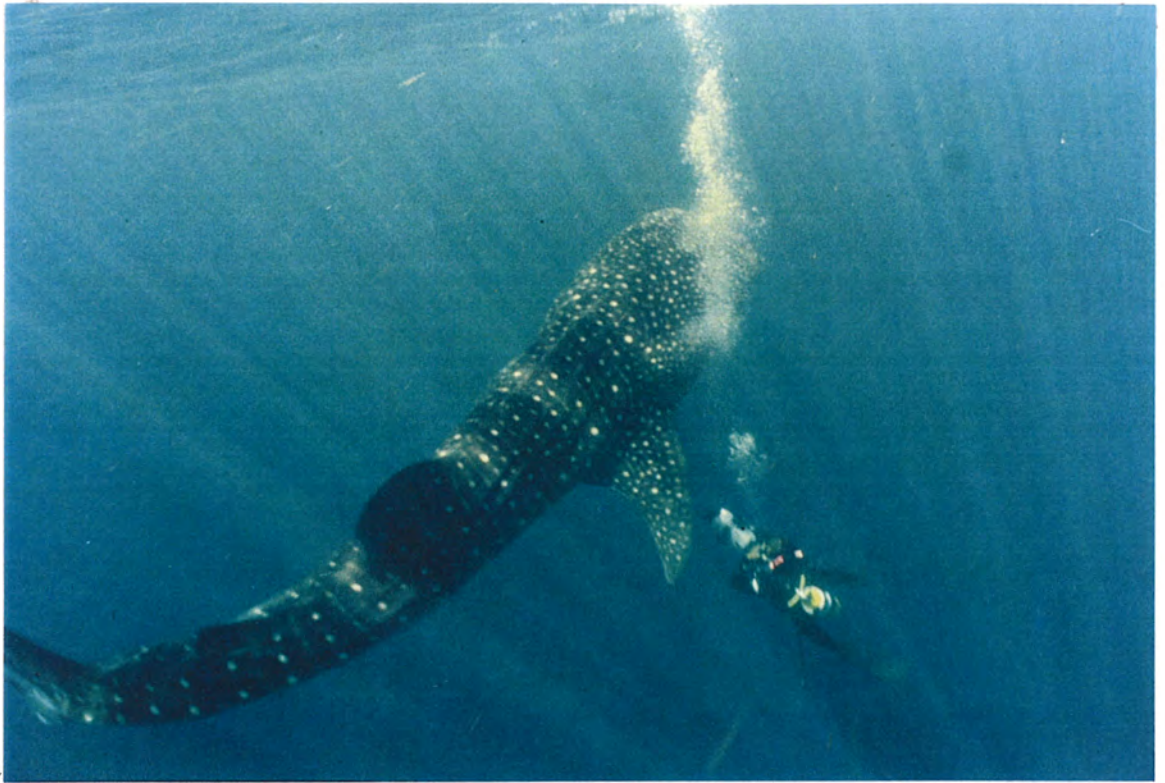
Figure 7.18 Photograph showing the behavioural response displayed by *Rhincodon typus* towards SCUBA bubbles.
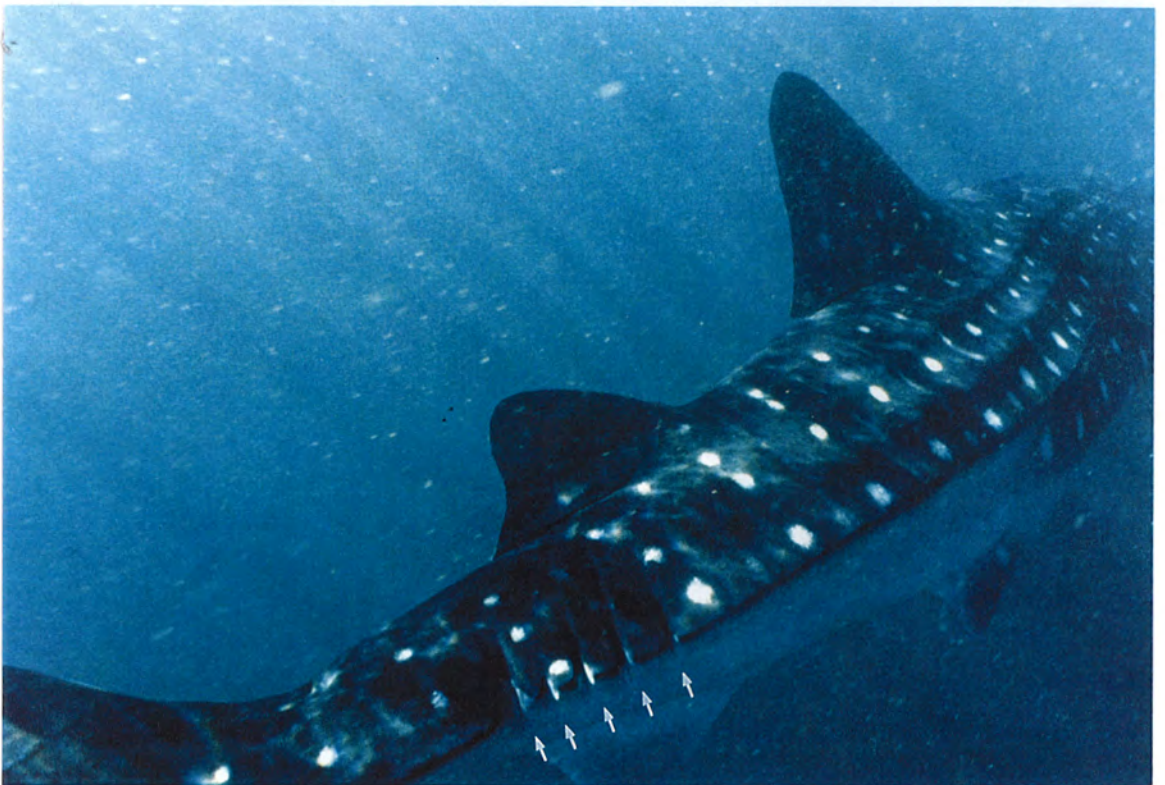
Figure 7.19 Photograph of *Rhincodon* with 'fleshy' gash wounds which appear to have been caused by a boat propeller.
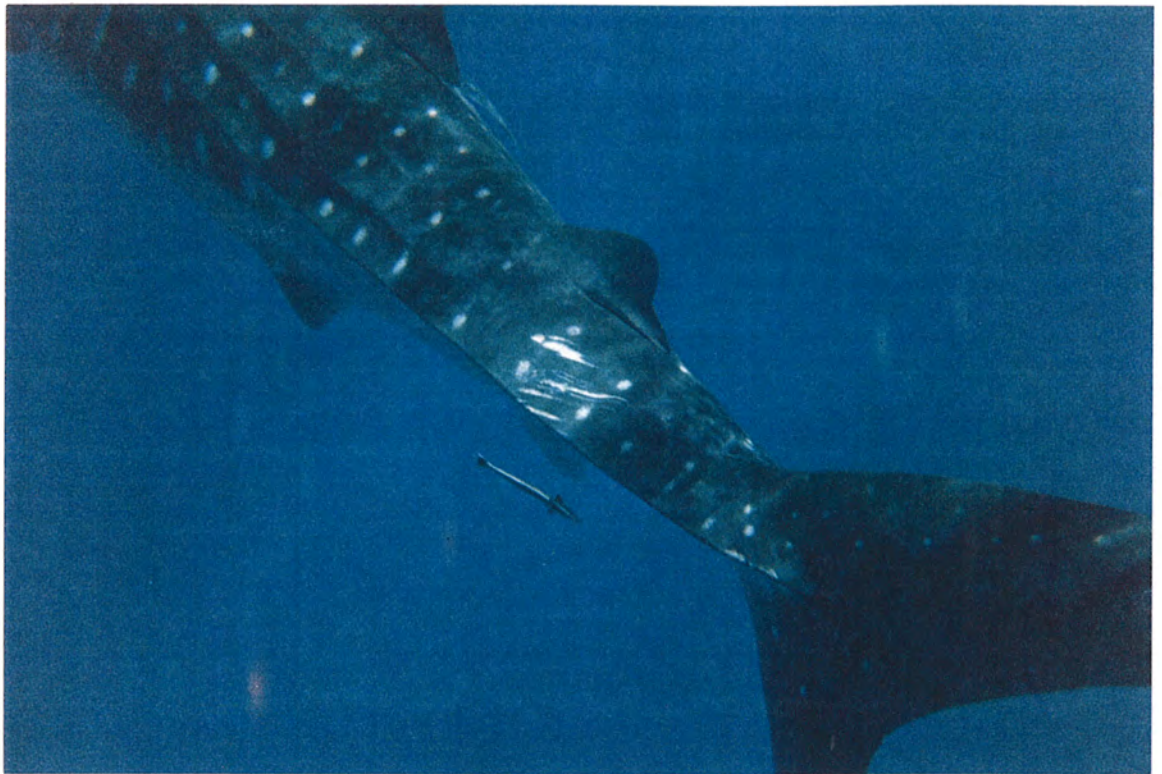
Figure 7.20 Example of a scratch on the skin of *Rhincodon typus* which was probably

the result of the shark rubbing against the hard surface of Ningaloo Reef.

Figure 7.21 Shark A-053 with a paint-like substance over its' body.

Table 7.1 The mean values ± 1 S.E. for the number of vessels operating per day, and the number of occasions when tourists were swimming with *Rhincodon typus* per day, in sequential weeks at Ningaloo Marine Park in 1995, 1996 and 1997.

Week Number	Mean number of vessels operating per day			Mean number of interactions per vessel per day		
	1995	1996	1997	1995	1996	1997
1) Mar 1 - 7	-	0.7 ± 0.39	-	-	3.2 ± 0.89	-
2) Mar 8 - 14	-	1.4 ± 0.40	0.7 ± 0.20	-	0.7 ± 0.45	1.2 ± 1.34
3) Mar 15 - 21	0.3 ± 0.31	2.9 ± 0.55	1.0 ± 0.24	2.0 ± 0.00	1.7 ± 0.43	0.3 ± 0.20
4) Mar 22 - 28	0.4 ± 0.22	3.9 ± 0.28	3.1 ± 0.86	1.0 ± 0.00	3.8 ± 0.41	1.6 ± 0.26
5) Mar 29 - Apr 4	4.9 ± 0.37	4.6 ± 0.40	5.0 ± 0.58	2.8 ± 0.34	4.0 ± 0.31	1.6 ± 0.20
6) Apr 5 - 11	5.3 ± 0.84	5.3 ± 1.15	5.1 ± 0.28	3.0 ± 0.33	4.2 ± 0.39	2.1 ± 0.23
7) Apr 12 - 18	4.7 ± 0.39	6.1 ± 0.44	5.6 ± 0.40	1.8 ± 0.23	3.1 ± 0.31	3.5 ± 0.22
8) Apr 19 - 25	6.7 ± 0.45	6.0 ± 0.78	6.9 ± 0.50	1.3 ± 0.18	1.8 ± 0.14	4.1 ± 0.24
9) Apr 26 - May 2	4.9 ± 0.55	6.0 ± 0.58	5.7 ± 0.45	1.2 ± 0.14	2.1 ± 0.19	3.0 ± 0.29
10) May 3 - 9	2.1 ± 0.60	2.9 ± 0.72	4.0 ± 0.71	0.9 ± 0.26	1.8 ± 0.32	2.5 ± 0.31
11) May 10 - 16	2.4 ± 0.32	2.9 ± 0.68	2.0 ± 0.71	1.0 ± 0.22	2.4 ± 0.48	3.4 ± 0.34
12) May 17 - 23	1.6 ± 0.40	2.7 ± 0.56	1.4 ± 0.32	1.0 ± 0.24	1.5 ± 0.48	2.6 ± 0.74
13) May 24 - 30	1.6 ± 0.32	2.7 ± 0.31	0.9 ± 0.28	1.2 ± 0.37	2.5 ± 0.43	0.0 ± 0.00
14) May 31 - Jun 6	1.0 ± 0.33	1.3 ± 0.20	0.3 ± 0.20	5.1 ± 3.77	0.6 ± 0.19	0.0 ± 0.00
15) Jun 7 - 13	1.0 ± 0.33	0.9 ± 0.28	-	2.3 ± 0.39	0.5 ± 0.37	-
16) Jun 14 - 20	0.4 ± 0.22	-	-	0.3 ± 0.41	-	-
17) Jun 21 - 27	0.7 ± 0.20	-	-	1.6 ± 0.57	-	-
18) Jun 28 - Jul 4	0.7 ± 0.31	-	-	1.6 ± 0.67	-	-
19) Jul 5 - 11	0.7 ± 0.31	-	-	0.8 ± 0.42	-	-
Mean (Year)	2.3 ± 0.38	3.3 ± 0.51	3.2 ± 0.44	1.7 ± 0.50	2.3 ± 0.39	2.0 ± 0.34
Mean (Weeks 5 – 9)	5.3 ± 0.52	5.6 ± 0.67	5.7 ± 0.44	2.0 ± 0.24	3.0 ± 0.27	2.9 ± 0.24

Table 7.2 The number of occasions when swimmers were discharged from tourist industry vessels to swim with *Rhincodon typus* during the 1995, 1996 and 1997 whale shark seasons at Ningaloo Marine Park. Data collected personally are compared with records from Industry operators each year. NB. Mean values are ± 1 S.E.

		Number of vessel days	Tourist Interactions		
			n	Range	Mean per vessel per day
1995	Industry records	276	501	0 - 26	1.8 ± 0.13
	Personal observations	52	125	1 - 7	2.4 ± 0.22
1996	Industry records	353	914	0 - 15	2.6 ± 0.11
	Personal observations	45	177	1 - 13	3.9 ± 0.42
1997	Industry records	297	783	0 - 10	2.6 ± 0.10
	Personal observations	17	58	2 - 6	3.4 ± 0.37
Overall	Industry records	926	2198	0 - 26	2.4 ± 0.07
(1995-1997)	Personal observations	114	360	1 - 13	3.2 ± 0.21

Table 7.3 The number of snorkellers and the minimum distance between swimmers and each *Rhincodon typus*, based on data recorded on 360 occasions when snorkellers were swimming alongside *R. typus* at Ningaloo Marine Park between 1995 and 1997. The values are given as the range and the mean ± 1 S.E.

		Number of snorkellers	Minimum distance of swimmers (m)	Minimum boat distance (m)
1995	Range	1 - 15	0 - 5	0.5 - 50
(n = 125)	Mean	10.5 ± 0.23	1.5 ± 0.09	20.7 ± 0.92
1996	Range	1 - 16	0 - 12	0 - 60
(n = 177)	Mean	8.0 ± 0.21	2.0 ± 0.14	21.3 ± 0.79
1997	Range	1 - 16	0 - 5	5 - 100
(n = 58)	Mean	8.3 ± 0.52	2.1 ± 0.20	31.0 ± 2.23
1995-1997	Range	1 - 16	0 - 12	0 - 100
(n = 360)	Mean	8.9 ± 0.17	1.9 ± 0.08	22.6 ± 0.64

Table 7.4 The duration of each separate interaction between swimmers and *Rhincodon typus* was recorded by B. Norman on 360 occasions when tourists were in the water swimming alongside *R. typus* at Ningaloo Marine Park in 1995, 1996 and 1997. NB. Mean values are ± 1 S.E.

Year	n	Total interaction time (min)	Range (min)	Mean duration of each interaction (min)
1995	125	2410	1 - 65	19.3 ± 1.63
1996	177	2521	1 - 63	14.2 ± 1.02
1997	58	552	1 - 70	9.5 ± 1.44
Overall (1995-1997)	360	5483	1 - 70	15.2 ± 0.82

Table 7.5 Data on the different types of behaviour exhibited by *Rhincodon typus* was recorded by B. Norman on 360 occasions when snorkellers were swimming alongside *R. typus* at Ningaloo Marine Park in 1995, 1996 and 1997.

NB. Mean values are ± 1 S.E.

	1995 (n = 125)	1996 (n = 177)	1997 (n = 58)	**Total** (n = 360)
Mean number of dives/minute of interaction	0.19 ± 0.021	0.24 ± 0.024	0.22 ± 0.029	0.22 ± 0.015
Mean number of porpoises/minute of interaction	0.06 ± 0.154	0.04 ± 0.005	0.05 ± 0.013	0.05 ± 0.006
Mean number of banks/minute of interaction	0.08 ± 0.011	0.07 ± 0.012	0.07 ± 0.020	0.07 ± 0.008
Mean number of eye rolls/minute of interaction	0.02 ± 0.092	0.03 ± 0.014	0.04 ± 0.028	0.03 ± 0.009

Table 7.6 The number and percentage of *Rhincodon typus* displaying 0, 1 or 2 behavioural changes during each of the first four successive 5 min intervals when snorkellers were swimming with *R. typus* at Ningaloo Marine Park in 1995, 1996 and 1997.

Year	Time interval (min)	Number of recorded behaviour changes		
		0 n (%)	1 n (%)	2 n (%)
1995 (n = 125)	0 - 4	55 (44.0)	39 (31.2)	25 (20.0)
	5 - 9	26 (20.8)	39 (31.2)	11 (8.8)
	10 - 14	26 (20.8)	24 (19.2)	12 (9.6)
	15 - 19	18 (14.4)	21 (16.8)	12 (9.6)
1996 (n = 177)	0 - 4	69 (39.0)	79 (44.6)	20 (11.3)
	5 - 9	43 (24.3)	44 (24.9)	22 (12.4)
	10 - 14	38 (21.5)	27 (15.2)	11 (6.2)
	15 - 19	27 (15.2)	17 (9.6)	10 (5.6)
1997 (n = 58)	0 - 4	17 (29.3)	29 (50.0)	9 (15.5)
	5 - 9	10 (17.2)	14 (24.1)	7 (12.1)
	10 - 14	6 (10.3)	8 (13.8)	1 (1.7)
	15 - 19	6 (10.3)	0 (0.0)	1 (1.7)
1995-1997 (n = 360)	0 - 4	141 (39.2)	147 (40.8)	54 (15.0)
	5 - 9	79 (21.9)	97 (26.9)	40 (11.1)
	10 - 14	70 (19.4)	59 (16.4)	24 (6.7)
	15 - 19	51 (14.2)	38 (10.6)	23 (6.4)

Table 7.7 The behavioural responses of *Rhincodon typus* when industry vessels were at different distances from each shark while swimmers were alongside at Ningaloo Marine Park in 1995, 1996 and 1997. NB. Swimmers were in excess of 5 m in each instance.

Date	Shark length (m)	Sex	Distance to shark (m)	Behavioural response
23/3/95	11	m	5	bank & dive
8/4/95	9	m	20-40	several porpoises
11/4/95	5	m	5	bank & dive
27/4/95	6	f	20	dive
1/5/95	4	m	5	bank & turn away
26/6/95	5.5	m	30	dive
26/6/95	7	m	5	porpoise
1/7/95	4.5	m	5	bank & swam away fast
16/3/96	8.5	m	20	dive
2/4/96	11	m	0	bank & dive
2/4/96	6	m	10	eye roll & bank
3/4/96	11	m	5	no reaction
3/4/96	11	m	10	no reaction
12/4/96	7	m	2	bank & dive
14/4/96	6	f	40	dive
28/4/96	10	m	15	dive
28/4/97	4	m	5	bank & dive
30/4/97	6	m	5	no response
30/4/97	6	m	5	no response

Table 7.8 The estimated swimming speed of *Rhincodon typus*, expressed as slow, medium or fast, during interactions at Ningaloo Marine Park between 1995 and 1997.

Swimming speed	Year		
	1995 (n = 125)	1996 (n = 177)	1997 (n = 58)
Slow (%)	38.4	37.8	72.4
Medium (%)	43.2	50.8	27.6
Fast (%)	18.4	11.4	0

Table 7.9 The behavioural responses displayed by *Rhincodon typus* when a swimmer made contact with a shark during an interaction at Ningaloo Marine Park between 1995 and 1997. NB. No reaction was recorded on 43.5% of those occasions.

Date	Shark length (m)	Sex	Behavioural response				
			Dive	Porpoise	Bank	Eye roll	Other
16/4/95	7	m	-	-	-	-	-
23/4/95	8	m	1	-	1	-	-
23/4/95	8	m	1	-	-	-	-
28/4/95	6	m	-	-	-	-	-
14/5/95	4.5	m	-	-	-	-	-
9/6/95	5	m	-	-	-	1	increased swimming speed
26/3/96	5	m	-	1	-	-	-
31/3/96	6	m	-	-	-	-	-
31/3/96	6	m	-	1	1	-	-
1/4/96	6	m	-	1	1	-	-
1/4/96	6	m	-	-	-	-	-
3/4/96	6	m	-	-	-	-	-
3/4/96	11	m	-	-	-	-	-
3/4/96	11	m	-	-	-	-	-
3/4/96	5.5	m	1	-	-	-	-
7/4/96	5.5	m	-	-	-	-	-
12/4/96	7	m	-	-	-	-	-
12/4/96	7	m	-	-	-	-	-
29/4/96	11	m	-	1	1	-	-
26/5/96	9.3	m	1	-	-	-	-
5/5/97	6.5	m	1	-	-	-	-
5/5/97	6.5	m	1	-	-	-	increased swimming speed
28/5/97	5.5	m	1	-	-	-	-

Table 7.10 The behavioural responses displayed by *Rhincodon typus* when a swimmer 'duck-dived' near the head region of the shark during interactions at Ningaloo Marine Park in 1995, 1996 and 1997.

Date	Shark length (m)	Sex	Behavioural response	
			Number of banks	Other
11/4/95	4.5	f	1	-
26/4/95	6.5	f	1	-
27/4/95	6	f	1	-
6/4/96	5.5	m	3	-
1/5/95	8	m	1	-
18/5/95	6.5	f	>5	-
29/5/95	8	m	6	-
3/6/95	8	m	1	dive
3/6/95	5	m	6	-
6/6/95	8	m	1	-
9/7/95	6.5	m	1	-
25/3/96	5.5	m	1	dive
2/4/96	11	m	1	-
6/4/96	5.5	m	3	-
23/4/96	7.5	m	1	-
24/4/96	7	m	1	-
28/4/96	10	m	1	fast swim away
17/4/97	6.5	m	1	-
15/5/97	8	f	10	-
21/5/97	7.5	m	2	-

Table 7.11 Number of eye rolls exhibited by *Rhincodon typus* during whale shark/tourist interactions at Ningaloo Marine Park when swimmers were observed within close proximity of the shark's eye.

Date	Shark length (m)	Sex	Person distance to shark (m)	Number of eye rolls
18/3/95	8	m	0.5	1
22/3/95	7	m	1	1
25/3/95	8	m	0.5-5	>5
17/4/95	6.5	f	0.5-5	>5
30/4/95	6	m	0.3	1
1/5/95	8	m	5	1
26/3/96	8	m	0.5	1
26/3/96	5	m	0	1
27/3/96	6.5	m	1	2
2/4/96	6	m	0.5-3	3
28/4/96	10	m	0.5	3
10/5/96	7.5	m	0.5-2	>5
12/5/96	9.1	m	0.5-3	>5
26/5/96	4.7	m	1-5	>5

Table 7.12 The number and types of behavioural response displayed by *Rhincodon typus* when SCUBA was used during an interaction at Ninagloo Marine Park in 1995 and 1996. NB. No reaction was recorded on one occasion.

Date	Shark length (m)	Sex	Behavioural response			
			Dive	Porpoise	Bank	Other
25/3/95	8	m	-	1	-	-
27/3/95	9	m	1	-	1	-
27/5/95	9	m	-	-	1	swam away fast
31/3/96	6.5	f	1	-	-	-
31/3/96	6	m	-	-	-	-
1/4/96	8	m	1	-	1	-
1/4/96	6	n/a	1	-	-	-
1/4/96	6	m	1	-	1	-
12/4/96	7	m	-	-	-	swam away fast

Table 7.13 Scarring/markings observed on the body of *Rhincodon typus* at Ningaloo Marine Park during interactions which appear to have been caused through contact with a vessel. The duration of each initial and subsequent whale shark/tourist interaction is also given. NB. Those sharks with substantial recent scarring are marked with an asterix (*).

Shark No./date	Length (m)	Sex	Description of scars and/or markings	Interaction No. and duration (min)									
				1	2	3	4	5	6	7	8	9	10
A-001	10	m	upper lobe of caudal fin mostly cut away and healed	28	3	14	-	-	-	-	-	-	-
A-002	8	m	vertical gash on leading edge of upper lobe of caudal fin; top of upper lobe previously truncated	7	7	-	-	-	-	-	-	-	-
A-014	9.5	m	significant recent white scarring on the dorsal surface, and right flank	8	5	-	-	-	-	-	-	-	-
A-016	8	m	large gouges on right flank, posterior to the pectoral fin and ventral to the 1st dorsal fin.	2	8	3	-	-	-	-	-	-	-
A-022	9	m	top half of 1st dorsal had been previously truncated and healed	14	6	2	-	-	-	-	-	-	-
A-024	7.5	m	top of upper lobe of caudal fin truncated; pieces of flesh missing from trailing edges of 1st dorsal, 2nd dorsal, upper lobe of caudal fin	23	9	-	-	-	-	-	-	-	-
A-025	11	m	three separate diagonal white scratches on starboard flank	44	25	-	-	-	-	-	-	-	-
A-026	8	m	white longitudinal scar (*ca* 15cm) on the medial ridge, immediately anterior to the 1st dorsal fin	9	30	11	20	20	-	-	-	-	-
A-029	6	m	blue antifoul on caudal fin	12	-	-	-	-	-	-	-	-	-
A-031	6.5	f	healed gouge behind gill slits on right flank; apical portion of right pectoral fin missing	8	4	28	47	18	23	3	2	15	2
A-041	9	m	deep healed horizontal cut, midway up the leading edge of the upper lobe of the caudal fin	4	39	-	-	-	-	-	-	-	-
3/6/95	5	m	white scratches on dorsal surface of head; apical point of upper lobe of caudal fin missing	29	-	-	-	-	-	-	-	-	-
*3/6/95	8	m	four 'fleshy' vertical gashes (likely resultant from propeller contact) on right flank, immediately anterior to caudal fin	2	2	-	-	-	-	-	-	-	-
25/3/96	8	m	white scar on dorsal surface	7	39	-	-	-	-	-	-	-	-
6/4/96	8	m	white scar on dorsal surface immediately anterior to the 1st dorsal fin.	3	-	-	-	-	-	-	-	-	-
*19/5/96	6	n/a	top half of 1st dorsal fin recently truncated leaving a 'fleshy' margin/edge	1	1	-	-	-	-	-	-	-	-
*22/5/96	7.5	n/a	white scar in front of 1st dorsal fin; four deep fleshy horizontal gashes (likely resultant from propeller contact) on upper lobe of caudal fin	1	-	-	-	-	-	-	-	-	-
27/5/96	7	m	blue antifoul on dorsal surface	45	-	-	-	-	-	-	-	-	-

CHAPTER 8

GENERAL DISCUSSION AND
CONSERVATION RECOMMENDATIONS

Rhincodon typus is widely distributed throughout tropical regions and, although aggregations of this species are not common, relatively large numbers have been sighted at certain times of the year at Ningaloo Marine Park (NMP) since the early 1980s. During the current study, approximately 85% of *R. typus* observed at NMP were male, and these had a mean total length of *ca* 7.3 m. On the basis of clasper morphology, male *R. typus* typically become sexually mature at *ca* 8.6 m (Chapter 3). This would indicate that the majority of *R. typus* observed within NMP were not involved in breeding activities.

A method, using scars and natural patterning, was developed for identifying individual *R. typus,* with more than 50 individuals at NMP being able to be identified using the resultant Whale Shark Photo-identification Library (see Chapter 4: Library 1). There were multiple resightings of 24 of these sharks during the period of the study. Continued use of this library will contribute information relevant to discussions of the population dynamics and migratory patterns of whale sharks and help refine management plans for this species, as has been achieved in the case of zebras (Briand Petersen, 1972).

Rhincodon typus was distributed widely throughout NMP, with the majority of sightings occurring around the middle of each day and usually in shallow water depths close to the reef. There were more *R. typus* observed in the northern region of NMP, where the search effort was greatest, and a greater number of sharks were observed travelling in a northward than southward direction. These data and reports of other sightings suggest that, after leaving the NMP, whale sharks may migrate northwards to the Timor Sea, and northwest to Christmas Island, Indian Ocean (see Chapter 5).

The commercial whale shark watching industry at NMP has been operating since 1993 (Colman, 1997), providing tourists with the opportunity to swim alongside *R. typus*. In 1993, the Western Australian Department of Conservation and Land Management (CALM), in conjunction with whale shark industry operators, formulated a set of management guidelines for the whale shark watching industry within NMP. However, these were constructed without any previous scientific information regarding whale shark behaviour and/or the level of human impact that these sharks can tolerate. Fourteen interaction licences were used between 1995 and 1997, although not all licence holders operated daily in each season.

Industry operators were very successful at locating *R. typus* in 1995, 1996 and 1997 and this thereby facilitated interactions between tourists and whale sharks. The fact that whale sharks did not move rapidly out of the way of swimmers suggests that any 'pressure' from the ecotourism industry was largely tolerated by *R. typus*. The fact that at least one swimmer was occasionally observed within the minimum distance from whale sharks, as laid down by CALM, demonstrates that tourist operators were not always able to ensure that the guidelines for whale shark ecotourism at NMP were adhered to by all participants.

CALM Wildlife Officers on the CALM vessel *Pseudorca 11* were present at NMP between 1995 and 1997 to monitor whale shark licence activities. However, with the potential for 14 licenced, and often widely dispersed vessels throughout NMP being involved in searching for *R. typus,* it was impossible for CALM staff aboard *Pseudorca 11* to monitor all of these vessels and the associated tourism activities. Industry operators must contend sometimes with adverse conditions, including wind, swell etc., which may account for boats sometimes encroaching within the 30 m minimum distance from whale sharks. All vessels except that which is 'in contact' with *R. typus* and *Pseudorca 11,* are required to remain at a minimum of 250 m from the shark during interactions (Appendix 2). However, unless CALM staff were swimming

alongside the sharks, it was not possible to police the minimum distance between swimmers and *R. typus*.

Photographic evidence that some scars had been recently formed on the whale sharks observed at NMP, together with the fact that whale sharks remain within NMP for some time, indicate that individual *R. typus* had been injured by vessels operating within NMP (see Chapters 4, 5, 7). While the CALM whale shark licence stipulates that vessels must move at a speed of 8 knots or less when they are within 250 m of *R. typus* (Appendix 2), there is no speed limit when vessels are outside this zone. Thus, since *R. typus* are difficult to see when they are swimming at the surface, they are particularly prone to damage from boats that are travelling at faster speeds. The restriction of boat speeds at all times for vessels operating within the commercial whale shark watching area at NMP between March and June would improve the ability to sight sharks and thereby reduce the potential for contact between vessel and shark.

Less than 5% of all whale shark/tourist interactions at NMP in 1995, 1996 and 1997 continued up to the 60 min limit permitted by the whale shark operator guidelines (see Chapter 7). However, individual *R. typus* were occasionally subjected to interactions from more than one operator as a result of 'passing' a shark from one vessel to another through industry co-operation. This was especially evident when very few sharks were available for tourist interactions, with several industry vessels forming a queue so that the tourists onboard their vessel would be provided with the opportunity to swim with *R. typus*. There is no maximum limit on the overall duration of the interaction with individual *R. typus*, *i.e.* from tourists on a number of boats and thus, on occasions, a combined interaction time in excess of 150 min was recorded (B. Norman, unpub. data). On any given day, there is, under extreme circumstances, the potential for individual *R. typus* to be subjected to 14 (number of licences) x 10 (number of snorkellers) = 140 individual tourists and 14 (number of licences) x 60 (number of min) = 840 min.

Given that most interactions at NMP lasted for less than 10 min throughout the course of the present study (see Chapter 7), the maximum duration allowed for each individual whale shark/tourist interaction could be set at a much lower level than present, e.g. 20 min as opposed to 60 min. A vessel number and cumulative time limit spent with each individual *R. typus* (e.g. three vessels for 20 min each) would result in a maximum of 60 min interaction time.

If swimmers were dispatched into the water alongside, and at least 50 m ahead of approaching *R. typus*, there would be less chance of inexperienced tourists failing to move out of the path of an oncoming shark. This practice has already been employed during dolphin/swimmer interaction tours at Port Phillip Bay, with a view to reducing the impacts of ecotourism on these animals (Weir *et al.*, 1996). Ideally, if swimmers enter the water behind *R. typus*, there would be no need for the shark to alter course as a consequence of tourism activities.

Birtles *et al.* (1996) report that a questionaire completed by tourists at NMP in 1995 show that most tourists believe that a reduction in the number of swimmers in the water with *R. typus* at any one time would provide an improved 'tourist experience', as crowding was the greatest individual event that detracted from the experience of interacting with the whale sharks. Indeed, over 70% of participants believed that only six or less snorkellers should be swimming with *R. typus* at any one time, as was the practice of one licence holder at NMP during the current study (B. Norman, unpub. data).

The mean number of snorkellers per interaction was greatest in 1995, the year in which the mean minimum distance between snorkellers and *R. typus* was least. A decrease in the mean number of snorkellers per interaction in 1996 and 1997 was accompanied by an increase in the minimum mean distance from swimmers to sharks (see Chapter 7). Although these minimum distances were still less than those stipulated in the Code of Conduct (Appendix 2), the trend towards a greater minimum distance from swimmers in successive years, subsequent to the change within the Code of Conduct,

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presumably reflects an increased effort on behalf of industry operators and CALM to inform tourists of this regulation. Alternatively, a lower number of tourists in the water encouraged swimmers to remain at a greater distance from sharks, as viewing is less restricted. The greater mean minimum distance between swimmers and sharks in 1997 than in 1995 and 1996, suggests that industry operators were abiding more rigorously to the restrictions set out within the Code of Conduct during this third year.

Summary of suggested amendments to the Code of Conduct

1) Commercial vessels should approach each whale shark from either behind, or from a position to the side and well in front of the animal. Vessels should remain at a distance of at least 50 m from *R. typus* at all times. This would ensure that no residual propeller/exhaust bubbles are in the path of the oncoming shark. Since exhaust bubbles from vessels appear to be attractive to *R. typus*, this amendment should reduce the potential for injury caused by vessels and propellers.

2) The speed of all vessels moving within the commercial whale shark watching area at NMP, between March and June, should be restricted to 8 knots at all times.

3) 'Duck-diving' by snorkellers, especially near the anterior region of *R. typus*, should not be permitted as this usually results in an observed behavioural change in these sharks.

4) Since this study provides evidence that whale sharks react negatively to SCUBA bubbles, SCUBA divers should, at no time, be positioned in the path of an oncoming shark, and remain at a minimum distance of 15 m from the shark at all times.

5) Consideration should be given to altering both the minimum distance permitted between snorkellers and whale sharks from 3 to 5 m, and the maximum duration permitted of each whale shark/tourist interaction from 60 to 20 min.

Research and Monitoring

1) Further monitoring and observations of *R. typus* at NMP, and indeed at other international locations, will ensure that a substantial data set on the behaviour of specific individuals under differing tourism and environmental conditions is obtained over an extended time period.

2) The Whale Shark Photo-identification Library should be continued in future years as this will help in estimating the size of the whale shark assemblage at NMP and thereby facilitate the development of management strategies for the ecotourism industry at NMP.

3) The tagging and tracking work initiated by the author in collaboration with CSIRO Marine Research should continue, in order to obtain reliable data on both short and long-term movements of *R. typus*. The results obtained from such studies in 1997 show that tagging has little impact on these sharks (see Chapter 5). Although there was a concern regarding the aesthetics of tagged sharks, it is important for the conservation and management of this species that the patterns of movements of particular individuals within populations are established (Priede & French, 1991).

Global Implications for the Conservation of **Rhincodon typus**

The appearance of *R. typus* at NMP each year provides the opportunity for a continued economically beneficial tourist industry to allow tourists to experience swimming with *R. typus* in their natural environment. An increase in tourist number may lead to undesirable 'pressure' on *R. typus* at NMP (Anderson, 1994). Regular monitoring for any changes in the behaviour and/or numbers of whale sharks will enable suitable changes to the guidelines required for interactions between tourists and sharks. However, because of their potentially extensive long-distance movements through international waters (Helfman *et al.*, 1997; see Chapter 5), management of the whale shark ecotourism industry at NMP alone may not be sufficient to protect these sharks. Few data are currently available on either the short or long term impacts of fisheries that

take *R. typus*, although most shark populations are unable to withstand a relatively small depletion of stocks through fishing mortality (Helfman *et al.*, 1997). *Rhincodon typus* is believed to be at potential risk from fishing activities (Casey *et al.*, 1992) and, given the close proximity of several international whale shark fisheries (see e.g. Silas, 1986; Chen *et al.*, 1997), the future conservation of *R. typus* within Australian (and indeed international) waters will benefit from further research at NMP. This research may provide sufficient information to amend the current status of *R. typus* in the IUCN '*Red Data List of Threatened Animals*' from 'Indeterminate - Data Deficient' to 'Rare' or 'Endangered' and ultimately assist with the global protection for this, the largest of living sharks.

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Appendix 1

Wildlife Conservation Act 1950

from Colman (1997)

WILDLIFE CONSERVATION ACT 1950

WILDLIIFE CONSERVATION (CLOSE SEASON FOR WHALE SHARKS) NOTICE 1996

Made by the Minister under section 14 (2) (a).

Citation

1. This notice may be cited as the *Wildlife Conservation (Close Season for Whale Sharks) Notice 1996*.

Object of this notice

2. The object of this notice is to allow limited interaction between humans and whale sharks in State waters, while protecting whale sharks from disturbance and molestation, by setting out acceptable approach distances, etc., for vessels, swimmers and divers when in proximity to a whale shark, and to prevent some other activities that may disturb whale sharks.

Interpretation

3. (1)   In this notice -

        "**contact vessel**" means a vessel, and any tender vessel accompanying the vessel, within a contact zone,

        "**contact zone**" means the area within a radius of 250 metres of any whale shark that is in State waters;

        "**whale shark**" means the fauna *Rhincodon typus*.

    (2)   It is the responsibility of the person in charge of a vessel to comply with a requirement placed on that vessel by this notice.

Declaration of a close season

4. (1)   Subject to clauses 5 to 14, a close season is declared in respect of whale sharks in all State waters.

    (2)   The close season is for the period commencing on the day on which this notice is published in the *Government Gazette* until the day on which this notice is cancelled or this clause is varied by a notice under section 14 (2) (b) of the Act,

Restriction on number of vessels in or near contact zone

5. (1)   A vessel must not enter a contact zone if another vessel is in the contact zone.

    (2)   If a vessel is in a contact zone and a second vessel is within 400 metres of the relevant whale shark, any other vessels must maintain a distance of at least 400 metres from that whale shark.

Restriction on period in contact zone

6. A contact vessel must not remain in the same contact zone for longer than 90 minutes.

Restriction on vessel speed in contact zone

7. (1) Subject to subclause (2), a contact vessel must not exceed 8 knots in a contact zone.

(2) If, for reasons of safety, a contact vessel must exceed 8 knots in a contact zone, that vessel must leave the contact zone as soon as is practicable.

Proximity of contact vessel to whale shark

8. A contact vessel must at all times maintain a distance of at least 30 metres from the nearest whale shark.

Direction of approach

9. If swimmers or divers are to enter the sea from a contact vessel to view a whale shark, the contact vessel must approach a whale shark from the opposite direction of travel to the whale shark's direction of travel.

Physical contact with whale sharks prohibited

10. Subject to clause 12, a person must not touch or ride on, or attempt to touch or ride on, a whale shark.

Proximity of swimmers or divers to whale shark

11. Subject to clause 12, a person in the sea must at all times maintain a distance of at least:

(a) 3 metres from the head or body of a whale shark, when approaching a whale shark from any direction; and
(b) 4 metres from the tail of a whale shark, when approaching the tail from any direction.

Exception when authorized under the Act

12. Clause 10 and 11 do not apply to a person who is authorized under the Act to make physical contact with a whale shark, if that contact is in accordance with the authorization (eg. *authorized under a scientific licence*).

Motorized swimming or diving aids, and other aids, prohibited

13. (1) A person must not use a submersible motorized or otherwise powered swimming or diving aid in a contact zone.

(2) A person must not use any device capable of towing or carrying a person, that is towed behind a vessel, in a contact zone.

Other taking, etc., of whale sharks prohibited

14. (1)　A person must not capture, disturb, molest or take in any other way, a whale shark unless that person does so in accordance with this notice and the *Wildlife Conservation Act 1950*, or unless it is lawful for that person to do so -

        (a)　under the *Fish Resources Management Act 1994; or*

        (b)　under the *Conservation and Land Management Act 1984.*

   (2)　To the extent that this notice and the *Wildlife Conservation (Fauna of Ningaloo Marine Park) Notice 1992** are inconsistent, this notice prevails.

[Published in Gazette of 17 July 1992 at p. 3388-9]*

P. G. FOSS, Minister for the Environment

Appendix 2

Conservation and Land Management Act 1984 (Section 101)

form Colman (1997)

Code of Conduct 1996
This document has been reviewed for the 1999 - 2003 Licences

Licence Number   «licence»

Expiry Date

SCHEDULE 1

1. The licence holder must abide by the conditions and restrictions as set out in the "General Licence Conditions dated July 1994 as varied from time to time by the Executive Director.

2. The licence holder must prepare, keep and preserve a full record of operations indicating, on a daily basis and in form approved by the Executive Director, details of whale shark sightings and the number of passengers carried during the operation of the licence, and

    (a) make this record available to the Executive Director on request; and

    (b) submit a copy of the record of operations to the Exmouth CALM office, at weekly intervals during the operation of the licence, for the licence activities conducted during the previous week.

3. In consideration for the licence, the licence holder must pay to the Executive Director

    (a) a charge of $15.00 per adult per day and $7.50 per child (under the age of 16) per day for all paying passengers carried during the operation of the licence between 11 March and 9 June (inclusive) each year payable on or before 10 July for each year of the licence period; and

    (b) an annual (non-refundable) deposit on these charges of $750.00 on or before 31 January for each year of the licence period. Note that this deposit will be deducted from the amount payable under Condition 3 (a), and represents the minimum annual licence charge payable.

4. Upon payment of the deposit required under Condition 3 (b), the Executive Director will issue to the licence holder passenger validation tickets for the purposes of Condition 6. At the completion of each whale shark season all unused passenger validation tickets must be returned to the Executive Director on or before 10 July each year The difference between the number of tickets issued and the number of tickets returned will be used to assist calculation of the amount payable under condition 3 (a).

CODE OF CONDUCT - COMMERCIAL WHALE SHARK INTERACTION TOURS (NINGALOO MARINE PARK)

5. The licence holder must ensure that interactions occur during daylight hours only.

6. The licence holder must ensure that each paying passenger is issued a passenger validation ticket appropriate to their age group, to be supplied by the Executive Director, for each day, or part thereof, that the passenger spends on a whaleshark interaction tour conducted by the licence holder, and that each ticket issued is validated as required by the Executive Director.

7. The licence holder must cooperate with the Department of Conservation and Land Management (CALM) in gathering and providing any data which may be required for research and management purposes.

8. The licence holder must comply with all directions issued to him by an officer designated under the CALM Act 1984 as amended.

9. The licence holder is required to make available on request a position on their vessel for any officer designated under the CALM Act 1984 as amended to monitor licence activities.

10. The licence shall be displayed in prominent position on the vessel specified on the licence.

11. The licence holder must ensure that all due care is taken to avoid stressing or injuring whale sharks and interaction activities are to cease immediately any stress or injury is apparent.

12. The licence holder must ensure that activities authorised under the licence are conducted each year of the licence period. If the licence is not used to a reasonable extent, as determined by the Executive Director, the Executive Director may cancel the licence.

13. The licence is not transferable. The licence holder must explain to prospective purchasers of a business operation that involves the operation of the licence that the licence is not transferable, and that the prospective purchaser would be required to make application to the Executive Director to obtain a new licence to continue the licensed activities conducted by the licence holder.

"Licensed vessel" means the vessel nominated on the licence as the vessel to be used by the licence holder to carry out the licensed activities.

"Exclusive contact zone" means all waters within a 250 metre radius of any whale shark.

"Swimmer" includes divers, snorkelers and any other persons in the water within the exclusive contact zone.

EXCLUSIVE CONTACT (EXCLUSION) ZONE

14. Only one licensed vessel is to operate within the exclusive contact zone at any one time. All other vessels are to use boat power as necessary to avoid any encroachment into an exclusive contact zone occupied by another vessel.

15. The first vessel to encroach within an exclusive contact zone will be deemed to be "in contact" with a whale shark, regardless of the position of any spotter aircraft. Other vessels should attempt to locate other sharks, with the exception that the second vessel to arrive at the exclusive contact zone may queue to have access to the shark by maintaining a minimum distance of no less than 250 metres from the contacted shark. All other licensed vessels are to maintain a distance of at least 400 metres from the contacted shark.

16. A licensed vessel may remain "in contact" with a whale shark for a maximum of ninety (90) minutes. Swimmers from the licensed vessel may remain in the water with a shark for a maximum of sixty (60) minutes from the time of first entry into the water.

17. In the event that two (2) or more whale sharks are within a 250 metre radius of each other the limit of one vessel "in contact" still applies until the sharks separate by more than 250 metres, in which case each shark will have its own exclusive contact zone.

18. In the event that two (2) or more whale sharks with swimmers "in contact" from separate vessels close to within 250 metres of each other, skippers must cooperate to ensure the safety of their swimmers and the sharks.

LICENSED VESSELS AND THEIR TENDERS

19. The vessel nominated by the licence holder to be the licensed vessel must not be nominated as the licensed vessel to be used by another licence holder.

20. The licence holder must nominate a principal vessel to be used during the operation of the licence, and may nominate a substitute vessel to be used only in the event that the primary vessel is unavailable. The substitute vessel may be a vessel nominated as the licensed vessel to be used by another licence holder, only where unavailability of the primary vessel is for mechanical reasons.

21. Licensed vessels will be restricted to a maximum of one diving tender in addition to the licensed vessel.

22. Licensed vessels and diving tenders must not approach within thirty (30) metres of a whale shark and shall move at a slow speed (8 knots or less) when within an exclusive contact zone.

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23. Licensed vessels and tenders may only approach whale sharks from ahead of the shark's direction of travel an must drop swimmers into the water no less than thirty (30) metres ahead of the shark.

24. Licensed vessels must clearly display one (1) dive flag (International Code Flag "A") and one "whale shark" flag a design approved by the Executive Director to indicate when swimmers are in the water and must maintain radi contact with other approaching vessels to advise that diving/shark interactions are in progress.

SWIMMERS

Licence holders must ensure that the "in water" activities of swimmers comply with the following:

25. Swimmers must treat all whale sharks with caution and at all times recognise that while they appear to be "gentle giants" they are wild animals that can inflict serious injury if they strike a swimmer with their body, tail or fins.

26. Swimmers must not touch a whale shark under any circumstances and must maintain a minimum distance of a least three (3) metres from the head or body of a shark and four (4) metres from its tail.

27. Swimmers must not attempt to block a whale shark from its chosen direction of movement.

28. Swimmers must not undertake flash photography.

29. The number of swimmers in the water with a whale shark at any one time is limited to a maximum of ten (10).

30. The number of swimmers to be carried by a licensed vessel is limited to a maximum of twenty (20) unless otherwise endorsed on the licence.

31. Swimmers must not use dive scooters or any other motorised propulsion aid.

CAUTION: **Whale sharks are normally gentle but are capable of inflicting injury or death, particularly if harassed or distressed.**

32. The licence will not be automatically renewed upon expiry of the licence period. The licence holder should expect that licence renewal will be subject to a competitive application process, following a full review of licence activities and numbers.

INDEMNITY

33. The Licence Holder hereby indemnifies the Executive Director from and against liability for all actions, suits. demands, costs, losses, damages and expenses (hereinafter called "claims") which may be brought against or made upon the Executive Director or which the Executive Director may pay, sustain, or be put to by reason of damage to property or injury to persons (including death) caused by or arising in any way out of the conduct of the Licence Holder on any lands or waters managed by the Department of Conservation and Land Management ("CALM") or generally as a result of the presence of the Licence Holder, or the Licence Holder's agents or clients on lands or waters managed by CALM and for the purpose of this indemnity the Licence Holder shall at all times during the period of the licence maintain a policy of public liability insurance in the names of the Licence Holder and the Executive Director to the extent of their respective rights and interests for a sum of not less than 5 million dollars ($5,000,000) to cover claims to which this indemnity applies made against the Executive Director or the Licence Holder AND SHALL LODGE WITH THE EXECUTIVE DIRECTOR proof of the insurance policy with the interest of the Executive Director noted thereon and shall on demand by the Executive Director produce evidence of current premiums required under the policy having been paid.

I confirm that I have read and
will comply with the conditions
and restrictions above.

....

....

Licence Holder   Date

WILDLIFE CONSERVATION ACT 1950

WILDLIFE CONSERVATION (CLOSE SEASON FOR WHALE SHARKS) NOTICE 1996

Made by the Minister under section 14 (2) (a).

Citation

1. This notice may be cited as the *Wildlife Conservation (Close Season for Whale Sharks) Notice 1996.*

Object of this notice

2. The object of this notice is to allow limited interaction between humans and whale sharks in State waters, while protecting whale sharks from disturbance and molestation, by setting out acceptable approach distances, etc., for vessels, swimmers and divers when in proximity to a whale shark, and to prevent some other activities that may disturb whale sharks.

Interpretation

3. (1) In this notice—

"contact vessel" means a vessel, and any tender vessel accompanying the vessel, within a contact zone;

"contact zone" means the area within a radius of 250 metres of any whale shark that is in State waters;

"whale shark" means the fauna *Rhincodon typus.*

(2) It is the responsibility of the person in charge of a vessel to comply with a requirement placed on that vessel by this notice.

Declaration of a close season

4. (1) Subject to clauses 5 to 14, a close season is declared in respect of whale sharks in all State waters.

(2) The close season is for the period commencing on the day on which this notice is published in the *Government Gazette* until the day on which this notice is cancelled or this clause is varied by a notice under section 14 (2) (b) of the Act.

Restriction on number of vessels in or near contact zone

5. (1) A vessel must not enter a contact zone if another vessel is in the contact zone.

(2) If a vessel is in a contact zone and a second vessel is within 400 metres of the relevant whale shark, any other vessels must maintain a distance of at least 400 metres from that whale shark.

Restriction on period in contact zone

6. A contact vessel must not remain in the same contact zone for longer than 90 minutes.

Restriction on vessel speed in contact zone

7. (1) Subject to subclause (2), a contact vessel must not exceed 8 knots in a contact zone.

(2) If, for reasons of safety, a contact vessel must exceed 8 knots in a contact zone, that vessel must leave the contact zone as soon as is practicable.

Proximity of contact vessel to whale shark

8. A contact vessel must at all times maintain a distance of at least 30 metres from the nearest whale shark.

Direction of approach

9. If swimmers or divers are to enter the sea from a contact vessel to view a whale shark, the contact vessel must approach a whale shark from the opposite direction of travel to the whale shark's direction of travel.

Physical contact with whale sharks prohibited

10. Subject to clause 12, a person must not touch or ride on, or attempt to touch or ride on, a whale shark.

Proximity of swimmers or divers to whale shark

11. Subject to clause 12, a person in the sea must at all times maintain a distance of at least—

(a) 3 metres from the head or body of a whale shark, when approaching a whale shark from any direction; and

(b) 4 metres from the tail of a whale shark, when approaching the tail from any direction.

Exception when authorized under the Act

12. Clauses 10 and 11 do not apply to a person who is authorized under the Act to make physical contact with a whale shark, if that contact is in accordance with the authorization (*eg. authorized under a scientific licence*).

Motorized swimming or diving aids, and other aids, prohibited

13. (1) A person must not use a submersible motorized or otherwise powered swimming or diving aid in a contact zone.

(2) A person must not use any device capable of towing or carrying a person, that is towed behind a vessel, in a contact zone.

Other taking, etc., of whale sharks prohibited

14. (1) A person must not capture, disturb, molest or take in any other way, a whale shark unless that person does so in accordance with this notice and the *Wildlife Conservation Act 1950*, or unless it is lawful for that person to do so—

(a) under the *Fish Resources Management Act 1994*; or

(b) under the *Conservation and Land Management Act 1984*.

(2) To the extent that this notice and the *Wildlife Conservation (Fauna of Ningaloo Marine Park) Notice 1992** are inconsistent, this notice prevails.

[* *Published in Gazette of 17 July 1992 at p. 3388-9.*]

P. G. FOSS, Minister for the Environment.