Appendix 1

Diversity, abundance and habitat utilisation of sharks and rays.

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1. EXECUTIVE SUMMARY

The main objectives of this project were to investigate the elasmobranch faunal composition of the Ningaloo Marine Park (NMP), determine the distribution and abundance of species, and examine the habitat utilisation, movement patterns and activity space of selected key species. Of interest to management, was whether existing sanctuary zones were effective for elasmobranchs as well as the location and timing of aggregation sites reported for some species.

We carried out snorkel and SCUBA surveys in the lagoon and at the reef edge, and longline surveys outside the reef, over most of the Park in April and June 2007 and August and December 2008. We examined the spatial dynamics of key species using acoustic telemetry and satellite tracking. Acoustic tags were deployed in February 2008, and at other times by students involved in the project, and monitored by 96 listening stations situated on the seabed in three transects across the reef and various arrays at sites of interest as part of the Australian Acoustic Tagging and Monitoring System (AATAMS).

We documented 47 species, mainly from our surveys, but estimate that about 118 species occur in the Park area at certain times. This is an equivalent diversity to the Great Barrier Reef which is about 70 times the area of NMP. Despite an apparent high diversity of elasmobranch species at NMP most species are not easily seen and visual sightings can be unpredictable and low. The diversity and abundance of elasmobranchs was higher in April than December and was generally highest in southern areas of the Park. The most frequently seen elasmobranchs on our visual surveys of the lagoon and reef edge were the Giant Shovelnose ray *G. typus,* the Cowtail Stingray *P. atrus,* the Bluespotted Maskray *N. kuhlii,* the Bluespotted Fantail Ray *T. lymma* and the Blacktip Reef Shark *C. melanopterus.* Aggregations of up to 50 individuals of *G. typus, P. atrus* and *C. melanopterus* occurred in April at Winderabandi and Pelican Point, Point Cloates and Mangrove Bay (all in sanctuary zones). These aggregations resulted in high densities of elasmobranchs at some sites with a maximum of 840 animals/ha recorded on one transect. The dive surveys provided several new records for the Park and documented species range extensions. Of particular importance was the discovery of a new species of maskray which may be endemic to the Park. Longline catch rates outside the reef were highest for the Sandbar Shark *C. plumbeus,* the Milk Shark *R. acutus,* the Tiger Shark *G. cuvier,* the blacktip sharks *C. limbatus/tilstoni* and the Sliteye Shark *L. macrorhinus.* The NMP provides a refuge for *C. plumbeus* which is commercially exploited elsewhere in Western Australia.

Sightings per unit area (SPUA: individuals per 1000 m^2) were higher in sanctuary zones than in non-sanctuary zones for all elasmobranchs combined and for nine out of ten of the most frequently encountered species from lagoon and reef edge dive surveys. Similarly, catch per unit effort (CPUE: individuals per 100 hooks) from longline surveys outside the reef were higher for all elamobranchs combined and for six out of the eight most frequently caught species. Although mangrove habitat is restricted in the NMP, the sand and mangrove habitat (particularly at Mangrove Bay) had the highest sighting rate for elasmobranchs of any of the 11 habitat types. Six species, *C. melanopterus,* the Lemon Shark *N. acutidens, G. typus,* the

Pink Whipray *H. fai, P. atrus* and the Porcupine Ray *U. asperrimus* had their highest sighting rate in the sand and mangrove habitat, highlighting the importance of this habitat type.

The lagoon at Ningaloo appears to function as juvenile habitat and nursery areas for several elasmobranch species including *G. typus, C. melanopterus* and the Grey Reef Shark *C. amblyrhynchos.*

Data from the acoustic arrays shows that the activity space of several shark and ray species is restricted with little exchange between different regions of the Park. Despite the apparent mobility of many of these species they tend to remain within a relatively restricted area lending support to the findings of higher sightings or catch rates from existing sanctuary zones. While bycatch mortality of elasmobranchs from fishing in the NMP is probably low, there may be an indirect effect through capture of their teleost prey species.

Satellite tracking shows that despite a high abundance of preferred prey such as turtles, dugongs and stingrays in NMP some individual large predators (*G. cuvier* and *S. mokarran*) may be only transient visitors to the Park, although other individuals may be more resident. The tracking also demonstrated that some *G. cuvier* move throughout Western Australian waters and as far afield as Indonesia.

We recommend further research and monitoring work is carried out on the elasmobranchs at Ningaloo to build on the protocols and findings established through our project. Many of our findings are preliminary because of poor seasonal coverage as a result of limited resources and the poor weather conditions experienced. Documenting elasmobranch faunal composition through survey work is problematic and time consuming. Visual survey techniques established for teleost fishes will not work well for elasmobranchs because of generally low sighting rates and the behaviour of many of the highly mobile species which may be either wary or inquisitive. We recommend the use of long transects with multiple divers in lagoon habitats which are often of patchy reef and extensive sand flats, combined with shorter more detailed transects for cryptic species on reefal habitat and Baited Underwater Video (BUV) techniques. Public participation should be sought in viewing existing still and video footage of elasmobranchs taken in NMP. While we have been able to demonstrate the general effectiveness of existing sanctuary zones for elasmobranchs, we were not able to do this on an individual sanctuary zone basis because of low sightings rates and the high survey effort required. With a number of species utilising the nearshore, shallow environment, habitat partitioning and micro-habitat use would be a fertile area of future research. On-going use should be made of the NRETA/AATAMS acoustic arrays to further research the spatial dynamics of key species and in particular to examine home ranges with respect to existing sanctuary zone size and mixing rates with adjacent and widely separated zones. We chose to satellite track *G. cuvier* and *S. mokarran* because they are two of the largest predatory sharks at NMP and because their prey includes other iconic megafauna in the Park, notably turtles, dugongs and stingrays. However, possibly because we tagged individuals outside the reef where they may ne more transitory, they did not remain in the Park for long. In future, it would be better (although more difficult) to tag individuals from the lagoon as these may be more resident individuals. We assume that existing bycatch mortality of elasmobranchs by recreational fishers in the Park is low. However, monitoring of catches at boat ramps and angler interviews should be used to confirm or refute this. Education on correct handling and release procedures would also be valuable.

Should further work confirm that the new species of maskray discovered during this project is endemic to the NMP, then its very restricted distribution will necessitate a number of management strategies. Research will be needed to map its distribution and preferred habitat and to establish rough population size. The species may require listing and protective status and will need to be protected by existing (or new) sanctuary zones. Educative materials will be required to publicise its presence and status in the NMP. The record of a Green Sawfish *Pristis zijsron* captured by a recreational fisher at Coral Bay also requires similar management actions. This species is listed on the EPBC Act as Vulnerable, on the IUCN Red List as Critically Endangered, on Appendix 2 of CITES, is totally protected under the Western Australian Fish Resources Management Act and specially protected under the Western Australian Wildlife Conservation Act. On-going education, surveillance and enforcement activities are needed to ensure successful conservation of these species.

1.1 Date

December 2009.

1.2 Project Title and Number

Diversity, abundance and habitat utilisation of sharks and rays. Project 2: Subproject 3.2.1

1.3 Project Leader

John Stevens, CSIRO Marine and Atmospheric Research, Hobart.

1.4 Project Team

Peter Last, William White (CSIRO Marine and Atmospheric Research, Hobart), Rory McAuley (Department of Fisheries, Government of Western Australia, Perth), Mark Meekan (Australian Institute of Marine Science, Perth).

1.5 Dates Covered

January 2007 to December 2009.

2. KEY FINDINGS AND RECOMMENDATIONS

2.1 Objectives and Outcomes – key findings

This project addresses questions explicitly identified in the NRP research priorities under A1.4 'large marine fauna' to characterise shark and ray diversity and abundance in the reserves and support development of management targets for them. It also addresses requirements of the NMP Research and Monitoring Plan to document shark/ray movement patterns and aggregations within the reserve.

Project Objectives:

- Investigate faunal composition and determine the distributions and abundances of species

  Dive (visual census) and longline surveys were used to investigate the faunal composition, distribution and abundance of elasmobranch species in NMP. Forty two species (25 sharks, 17 rays) were documented from the Park (or just outside it). We estimate that about 118 species are present in the NMP at certain times making it an area of high diversity (by comparison the GBR contains about the same number of species but is about 70 times its area). The discrepancy between what we observed and what probably occurs in the Park is due to the survey techniques used and the resources available. Additional techniques such as BUV and shorter more detailed transects searching for cryptic species, as well as greater seasonal coverage and viewing existing images of elasmobranchs taken in the Park would be required to increase the observed faunal count. Success of our dive surveys was also affected by the poor weather (including Cyclone Nicholas) experienced on most fieldtrips.

- Determine habitat requirements of species and identify those habitats critical to potentially vulnerable species

The habitat requirements of about 12 species of elasmobranchs at NMP were documented. Of particular note is that although mangrove areas are limited at NMP, the sand and mangrove habitat (particularly at Mangrove Bay) had the highest sighting rate for elasmobranchs of any of the 11 habitat types. Six species, *C. melanopterus, N. acutidens, G. typus, H. fai, P. atrus* and *U. asperrimus* had their highest sighting rate in the sand and mangrove habitat, highlighting the importance of this habitat type. A new species of maskray that is possibly endemic to the NMP was found on mixed habitat of sand and staghorn coral in <3 m depth; however, its dependence on this habitat type is not known at this stage. Relating sighting rates of individual species to habitat in the lagoon were complicated by many of the individual surveys covering multiple habitat types. Additionally, although we recorded the relative amounts of each habitat on a particular survey, we did not record precisely where each elasmobranch was seen.

- Compare the species composition, abundance and size structure between adjacent management zones

Of particular significance to management is the fact that sightings in the lagoon and at the reef edge of all elasmobranchs combined, and of nine out of the ten most commonly seen species, were higher in sanctuary zones than in non-sanctuary zones. In the offshore surveys, catch rates of all elasmobranchs combined, and of six of the top eight of the most frequently caught species, were also higher in sanctuary than in non-sanctuary zones. Given the mobile nature of many of these species this result may at first sight seem surprising. However, results from the acoustic tracking at NMP, as well as telemetry studies from other areas, have shown most of these species to be relatively site attached. While fishing activities probably have relatively little direct impact at NMP (mortality rates through accidental capture are probably low) there may be an indirect effect through capture of their teleost prey species. We were not able to compare the abundance between adjacent management zones, or to make these comparisons at a finer spatial scale, because of the generally low number of elasmobranchs seen on the surveys. It was also not possible to compare the size structure of species between different management zones for the same reason. However, difference in size structure between fished and non-fished areas may not be expected. Bycatch mortality of elasmobranchs from fishing is likely to be low and size structure between areas is more likely to vary with other factors such as location of nursery areas. However, there were some sites with relatively large aggregations of elasmobranchs, several of which were of neonates, and these were all in sanctuary zones.

- Examine the habitat utilisation, movement patterns and activity space of selected key species

The movement patterns, habitat utilisation and activity space of six key shark and three ray species were examined by acoustic telemetry using the AATMS arrays, and by satellite tagging. *Galeocerdo cuvier* and *S. mokarran* satellite tagged outside the reef did not remain for long in the Ningaloo area but generally moved north to the North West Shelf and Kimberly region. Some sharks did however re-visit the Ningaloo area. One *G. cuvier* tracked for 13 months moved as far north as Sumba Island, Indonesia and as far south as Esperance suggesting mixing of this species population across Western Australia and with Indonesia. By contrast, an acoustically tagged *G. cuvier* remained in the same area around Mangrove Bay for four months, before disappearing and not returning (to date). Limited information on depth behaviour showed *G. cuvier* spent most of their time in relatively shallow water, at times perhaps inside the lagoon, and did not go deeper than 150 m. The individual that ranged from Indonesia to Esperance experienced temperatures from 10–31° C but spent 91% of its time in 18–27° C water. The *S. mokarran* showed a bimodal depth distribution spending most of its time either between the surface and 10 m, or from 50–100 m, and not going deeper than 150 m. This shark experienced temperatures between 21–30° C spending most of its time in 24–27° C water.

- Determine times and sites where certain species aggregate, with particular reference to existing and proposed management zones

Aggregation sites were documented for one shark (*C. melanopterus*) at Pelican Point in April, and two ray (*G. typus* and *P. atrus*) species at Mangrove Bay, Point Cloates, Pelican and

Winderabandi Point, all in sanctuary zones. The *C. melanopterus,* and two of the *G. typus,* aggregations were of neonatal fish suggesting that these may be nursery areas. However, further work is needed to determine the consistency of these aggregation events.

- Identify candidate sites and species for ecotourism development

Aggregation sites for juvenile *C. amlyrhynchos* and *C. melanopterus* occur at Skeleton Beach, Coral Bay, in summer and possibly also at Pelican, Sandy and Winderabandi Point. The Skeleton Beach aggregations were not observed during our April field trip, possibly because of cool weather conditions at the time. Further work is needed to establish the regularity of these aggregations which can usually be viewed by snorkelling. We observed aggregations of *G. typus* at several sites in April some of which could be viewed from the beach as the fish were only in a few centimetres of water. These aggregations may be tidally related (as well as seasonal) and further investigation is required to establish there regularity. Groups of large stingrays were also observed at some sites, such as Mangrove Bay, where they could provide an attraction for snorkelers although both observer safety and disturbance of the rays would need to be considered.

2.2 Implications for Management – Recommendations

- Through cooperation with University of Western Australia, examine existing BUV tapes from NMP for additional elasmobranch records

- Encourage public participation in a project to examine existing still and video footage taken in the NMP for additional elasmobranch records

- Ensure protection of mangrove habitats in NMP as these contain relatively high abundances of elasmobranch species

- On-going use should be made of the NRETA/AATAMS acoustic arrays to further research the spatial dynamics of key species and in particular to examine home ranges with respect to existing sanctuary zone size and mixing rates with adjacent zones.

- Monitor recreational fishers for bycatch of elasmobranchs and produce educational material encouraging correct handling and live release procedures.

- Further research is required to document the distribution, habitat requirements and approximate population size of the newly discovered *Neotrygon* sp.(likely endemic to the Park)

- Produce educational material to inform the public, and recreational fishers in particular, on the presence and protective requirements of *Neotrygon* sp. and of the IUCN and EPBC listed *P. zijsron.*

2.3 Other Benefits

Dive surveys resulted in the discovery of a new species of maskray *Neotrygon* sp. which is possibly endemic to the NMP. If confirmed, the restricted distribution of this species will require careful monitoring and management within the Park. The surveys also provided new records for NMP and extended the southern range of four species: *Orectolobus wardi, Himantura granulata, Taeniurops meyeni* and *Mobula eregoodootenkee.*

Satellite tracking of *G. cuvier* at NMP has demonstrated movement of this species over most of the west and south coast of Western Australia (east to Esperance) and as far afield as Sumba Island, Indonesia. All of the *G. cuvier* tracked for more than two weeks, together with one *S. mokarran,* showed movement away from the NMP, although the *S. mokarran* subsequently revisited the area. By contrast, an acoustically tagged *G. cuvier* monitored by the acoustic array remained in the Mangrove Bay area for four months and was detected regularly in this area. Information on depth behaviour obtained for one *G. cuvier* showed that it spent 80% of its time in <50 m of water while similar information for one *S. mokarran* showed a bimodal depth distribution with this shark spending 41% of its time between 0–10 m and 38% of its time from 50–100 m; it did not go deeper than 150 m. To our knowledge, these are the first depth data obtained for a *S. mokarran.*

2.3.1 Tools, technologies and information for improved ecosystem management

The AATAMS listening station array has, and will continue to provide, information on the spatial dynamics of some of the key elasmobranch species in NMP allowing evaluation of the suitability of current sanctuary zones for these species. Satellite tracking of two of the large predators in NMP has the potential to show their residency periods in the Park and linkages to other areas on the Western Australian coast and outside Australian waters where they may be impacted by fishing. Genetic barcoding of elasmobranch species will help in resolving taxonomic affinities of some of the more problematic groups and assist in identifying any cryptic species. Plots of elasmobranch species abundance from dive and longline surveys, and shark tracks from satellite tagging, will provide interesting educational materials.

2.3.2 Forecasting for natural resource management decisions

Information obtained on home range and activity space for key elasmobranch species from the main acoustic arrays at Mangrove Bay and Coral Bay can be used to predict these parameters for these species in other areas of the Park.

2.3.3 Impacts

2.4 Problems Encountered (if any)

Our project proposal included a number of techniques (detailed below) to address our objectives that were ultimately not used in the study. Some of these methods were omitted due to practical considerations that emerged once the study was started, but the underlying reason in most cases were financial constraints imposed on our original budget and an overspend on the labour component of the project. We attempted to resolve this by using a number of volunteers to assist with the fieldwork and by incorporating student projects into one of the core objectives (spatial dynamics of key species). An original component of our study was habitat mapping. The WFO Collaborative Cluster hyperspectral mapping was intended to provide a broad overview of habitats within the NMP. Selected regions were then to be ground-truthed by visual observations to obtain fine-scale resolution of habitat and to improve maps. However, the hyperspectral mapping did not occur and our habitat mapping was limited to using existing coarse-scale maps provided by the Department of Environment and Conservation (DEC) to guide our selection of habitat types to be sampled, and then recording the proportions of habitat cover we actually observed. Our visual census techniques intended to incorporate Baited Underwater Video (BUV) but this was not carried out due to financial and labour constraints. This technique has been used in another project examining demersal fish distributions in the NMP and it may be possible to examine existing footage for elasmobranch occurrences in the future (Ben Fitzpatrick, University of Western Australia, personal communication). As part of a suite of techniques to investigate the spatial dynamics of key species we initially planned to incorporate active acoustic tracking and conventional tagging. However, these were subsequently dropped both because of logistic and labour constraints and also to minimise interference with the species.

One of the project objectives was to compare the species composition, abundance and size structure of elasmobranchs between adjacent management zones (within the same reef and lagoonal habitats) that are either open or closed to recreational fishing. While we were able to compare the overall elasmobranch abundance, and that of key species, between sanctuary zones and non-sanctuary zones it was not possible to examine this on a smaller spatial scale because of the low sightings rates and feasibility of sampling sufficient sites.

We had also hoped to accumulate anecdotal information from local stakeholders (i.e. recreational and commercial fishers, diving operators, etc) to gain an historical picture of community structure of elasmobranchs in the Park which would have helped in addressing the question (number 3 in the NRP February 2006 workshops) of how current abundances compare to historical ‘natural’ abundances. However, again because of time and labour constraints this was not possible.

Visual census techniques for elasmobranchs using divers are problematic and there is no current methodology that is successful for all species. Many of the more cryptic species (such as *Hemiscyllium* spp) would not have been observed without detailed examination of the habitat. Species such as *T. obesus* are primarily nocturnal and remain resting in caves and under ledges during the day. Swimming transects works reasonably well for more sedentary species such as stingrays, but may disturb and miss more active and wary species. The low number of encounters on our average transects, even given multiple divers and long swim times, was also a problem. Surveying mobile and inquisitive species such as *C. amblyrhynchos* is also notoriously difficult. These sharks may appear immediately divers enter the water, and then rapidly retreat out of visibility range, or they may remain just beyond the limits of visibility. Baiting techniques which attract them make it difficult to estimate natural densities. *Carcharhinus cautus* provides a good example of the dive surveys missing a species. This shark was commonly caught in the Mangrove Bay area during fishing operations to obtain species for acoustic tagging.

We had mixed success with the results from the satellite tagging. Four tags never transmitted after deployment and two more only transmitted for 11–14 days. The reason for this is unknown but may be due to mortality due to the capture process or the fish not coming to the surface, although this would seem unlikely given results from other tags on these species in our study and other programs. All fish for tagging were captured from a research vessel, handled carefully and appeared to be in good condition.

Bad weather caused problems on all our dive surveys with high winds and rain causing poor visibility and limiting small boat access to a number of sites. Fieldwork to address the May 2008 milestones was originally planned for February 18–28 2008. However, due to severe Cyclone Nicholas that passed close to Exmouth and Coral Bay the trip had to be shortened to February 21–28. Because of the curtailed trip and the poor diving conditions created by the cyclone the fish visual census work (milestone 11) and the associated habitat mapping validation (milestone 10) had to be cancelled. This was re-scheduled and carried out in December 2008.

3. RESEARCH CHAPTER(S)

3.1 Introduction

Ningaloo Marine Park (NMP) extends for 260 km from Amherst Point south of Coral Bay, north to Bundegi Reef in the Exmouth Gulf (21°40’S to 23°34’S). It is one of the largest fringing reefs in the world; the reef crest is as close as 100 m off the coast in some locations and as far as 4 km offshore in others. The Park was declared in May 1987 and covers about 2635 km^2 of State and 2435 km^2 of Commonwealth waters. The Park protects a diverse range of environments, flora and fauna through a series of multi-use management and sanctuary zones. The State component includes habitats from the shorelines, lagoon, reef and the waters extending approximately 3 nm out to sea from the edge of the reef. The major habitats of the Commonwealth component are the waters and seabed of the continental shelf and slope which extend 3–9 nm seaward from the State boundaries. In 2004, the Park boundaries were extended and a revised management plan was released in 2005 operating under the Environmental Protection and Biodiversity Act (EPBC) and providing for it to be managed as an IUCN Category Reserve. Ningaloo Marine Park is part of the National Representative System of Marine Protected Areas (NRSMPA).

Human usage of the NMP includes snorkeling, diving, recreational and commercial fishing, shipping transport and oil exploration. Recreational fishing is a major activity in the Park and has been increasing in recent years. A survey by the Western Australia Fisheries Department estimated that fishing effort in both Commonwealth and State waters of NMP from private boats was about 45,000 angler days per year at the end of the 1990s. The area is also a key tourist destination with recorded visits to the Marine Park and the adjoining Cape Range National Park currently exceeding 80,000 per year (Department of the Environment and Heritage, 2002). The management plan process highlighted deficiencies in the information required to assess the adequacy and effectiveness of the marine park zoning and to address the potential impact of increased recreational use and tourism development on the marine park.

The Park is estimated to contain about 500 species of fish and while it is well known for its seasonal aggregations of Whale Sharks *Rhincodon typus* and Manta Rays *Manta birostris* the chondrichthyan biodiversity of the Park has not been specifically recorded. Last and Stevens (2009) provide the most comprehensive listing of chondrichthyan fishes in Australian waters and, based on their information, about 118 species occur (or are likely to occur) in the Park. Of these, about 25 species mostly occur in water deeper than 200 m and of the 93 species mostly found in <200m, 59 are sharks and 34 are rays. Most sharks and rays are predators at or near the top of food webs and some may be keystone species in marine ecosystems. Because of their conservative K-selected life-history strategies they are vulnerable to human-induced sources of mortality, such as fishing, and can serve as indicator species for the health of ecosystems. Ningaloo Marine Park has possibly the largest and most diverse shark and ray fauna found anywhere on the Australian coastline but the habitat requirements and distributions of most of these species are poorly known. Some of the megafauna (i.e. *R. typus* and *M. birostris*) are already economically important to a seasonal ecotourism industry at Ningaloo. However, several other large species (i.e. large stingrays Dasyatidae, reef sharks Carcharhinidae, wedgefishes Rhynchobatidae and shovelnose rays Rhinobatidae) have the charismatic characteristics to make them equally important at other times of the year.

This research project aims to characterise the diversity, abundance and spatial dynamics of sharks and rays within different habitats and zones in the NMP to provide a baseline for developing management strategies and assessing ecotourism potential for these species. It will identify critical habitat and aggregation sites and examine habitat utilisation through movement patterns and activity space. This will allow assessment of the adequacy and representativeness of zoning and development of management targets for sharks and rays. This aligns directly with specified priorities of the Ningaloo Research Program under A1.4 ‘Large marine fauna biodiversity assessments’ and requirements of the Ningaloo Marine Park Research and Monitoring Plan under sharks and rays.

3.2 Materials and Methods

3.2.1 Species composition

Lagoon and reef edge surveys

Snorkel and SCUBA underwater visual surveys were conducted as part of four field trips to Ningaloo in April and June 2007 and August and December 2008. The June and August surveys were restricted to the reef edge on SCUBA, while the April and December surveys were mainly on snorkel and in the lagoon. While the original intention was to provide coverage through the different seasons, poor weather conditions coincided with most of the planned fieldwork (including Cyclone Nicholas) resulting in re-scheduling of some trips.

In the majority of underwater surveys between one and four swimmers were spaced out in parallel, their distance apart based on water visibility, and swam in one direction, usually with the current. The start and finish positions were recorded by GPS, as well as the start and finish times, visibility and depth, enabling a swept area to be calculated. Any elasmobranchs observed were recorded on a datasheet (see Table 1) immediately after returning to the surface. In some cases, when GPS positions were not available, the distance swum was estimated or calculated from relationships developed between swim duration and distance for a given number of observers. Sites were chosen to cover major habitat types and different management zones (sanctuary versus non-sanctuary) based on maps provided by DEC, while covering as much of the NMP as possible. Where feasible, each survey was performed on a uniform habitat, but in some cases the habitat was mixed. The different habitat types encountered on a dive were expressed as a percentage of the overall cover. In the lagoon, we mainly operated as two teams working from aluminium dinghys allowing a greater coverage of the Marine Park. A few surveys were conducted from a boat over shallow water when conditions were calm, or from the shore. When multiple divers conducted a survey, the species observed were discussed immediately after leaving the water to reduce the possibility of double counting. A total length for sharks, wedgefish and shovelnose rays (or disc width for all other rays) was estimated for each individual observed and recorded on the datasheet next to the relevant species.

Table 1. Data sheet for recording elasmobranch species on the dive surveys.

CMAR UVC Datasheet	Date:	Time:	Diver:

Site:	Lat/Long:	Habitat:	Vis:	Depth:

Orectolobidae		**Sphyrnidae**	
Euc. dasypogon		Sph. mokarran	
Ore. hutchinsi			
Hemiscyllidae			
Chilo. punctatum			
Hemi. ocellatum		**Rhinobatidae**	
Hemi. trispeculare		Rhino. typus	
Stegostomatidae		**Rhynchobatidae**	
Stego. fasciatum		Rhyn. australiae	
Ginglymostom.			
Neb. ferrugineus		**Dasyatidae**	
		Das. kuhlii	
		Das. leylandi	
Hemigaleidae		Him. fai	
Hem. australiensis		Him. uarnak	
		Him. undulata	
		Past. sephen	
Carcharhinidae		Taen. lymma	
Car. albimargin.		Taen. meyeni	
Car. amblyrhynchos		Uro. asperrimus	
Car. brevipinna			
Car. cautus			
Car. limbatus			
Car. melanopterus			
Gal. cuvier		**Myliobatidae**	
Neg. acutidens		Aeto. narinari	
Rhizo. acutus			
Tria. obesus		**Mobulidae**	
		Manta	

Sand:	Reef:	Rubble:	Bommies:	Seagrass:	Mangrove:	Algae:

Notes:____.

Weather was a major factor governing which sites and habitats could be surveyed. Tides and launching sites also influenced the shallower sites and the channel access to the outer reef.

Survey data were entered into a spreadsheet every night and any issues or queries about any particular survey were discussed with personnel who undertook that survey. The area swept was calculated as follows:

Area swept =Distance swum*number observers*visibility

The sightings of each species were expressed as the number of individuals per unit area of 100 m^2 (SPUA).

Offshore surveys
Longline fishing was used to survey elasmobranchs outside the reef and was carried out from the Western Australia Fishery Department vessel RV ‘Naturaliste’. Longlines comprised 1 km of 12 mm diameter mainline with (usually) 50 hooks. Snoods were 8–10 m apart and each snood was 2 m long and had an 11/0 or 12/0 J hook baited with mullet. About 250 hooks were set per day, as between one and five separate lines. Lines were generally set for periods of between 2.4 h and 5.2 h (mean of 3.6 h) over the dawn period but 10 lines (set over 2 days) were set at dusk and retrieved at dawn the following day (mean soak time of 15.2 h). Elasmobranchs that came up alive (the majority) were landed on deck by means of a cradle, identified, measured, sexed, tagged and released. Tags were either Jumbo Rototags inserted in the dorsal fin, or occasionally dart tags inserted in the musculature where tagging was carried out with the fish still in the water. Genetic samples from a representative selection of each species were taken from muscle biopsies or fin clips. Catch per unit effort (CPUE) was expressed a number of individuals caught per 100 hooks.

Comparison with historic research data
The Western Australian Department of Fisheries has conducted longline research cruises with RV ‘Naturaliste’ throughout NMP and beyond since November 2001. Although these cruises primarily targeted Sandbar Sharks, *Carcharhinus plumbeus,* for tagging and biological research, the fishing gear, bait, soak time and other aspects of fishing behaviour were largely the same as those used during the current project. It was therefore considered of interest to compare the contemporary survey data with the historic time series of longline data from the same area to examine whether there have been detectable changes in catch rates or catch composition over time. Three exploratory pelagic (i.e. drifting) sets that were conducted in May 2002 and September 2003 were excluded from these analyses as the gear configuration, water depths, locations and soak times were markedly different to the remaining sets.

Data analysis
The number of shark sightings (dive surveys) and catch rates (longline surveys) were compared between sanctuary and non-sanctuary zones with a one-way Analysis of Variance (ANOVA). Data were firstly fourth-root transformed to meet the assumption of homogeneity of variances and deal with the large number of zeros. A one-way ANOVA was also used to test for differences in shark occurrence between sanctuary and non-sanctuary zones for each species separately. For six species, data were firstly fourth-root transformed to meet the assumptions of homogeneity of variances. For the remaining species no transformation could overcome this problem and the non-parametric Mann-Whitney U test was used.

3.2.2 Spatial dynamics

Acoustics
Elasmobranchs were tagged with acoustic tags and subsequently monitored with acoustic receivers (Vemco VR2, VR2W and VR3) moored on the seabed that constitute the Ningaloo

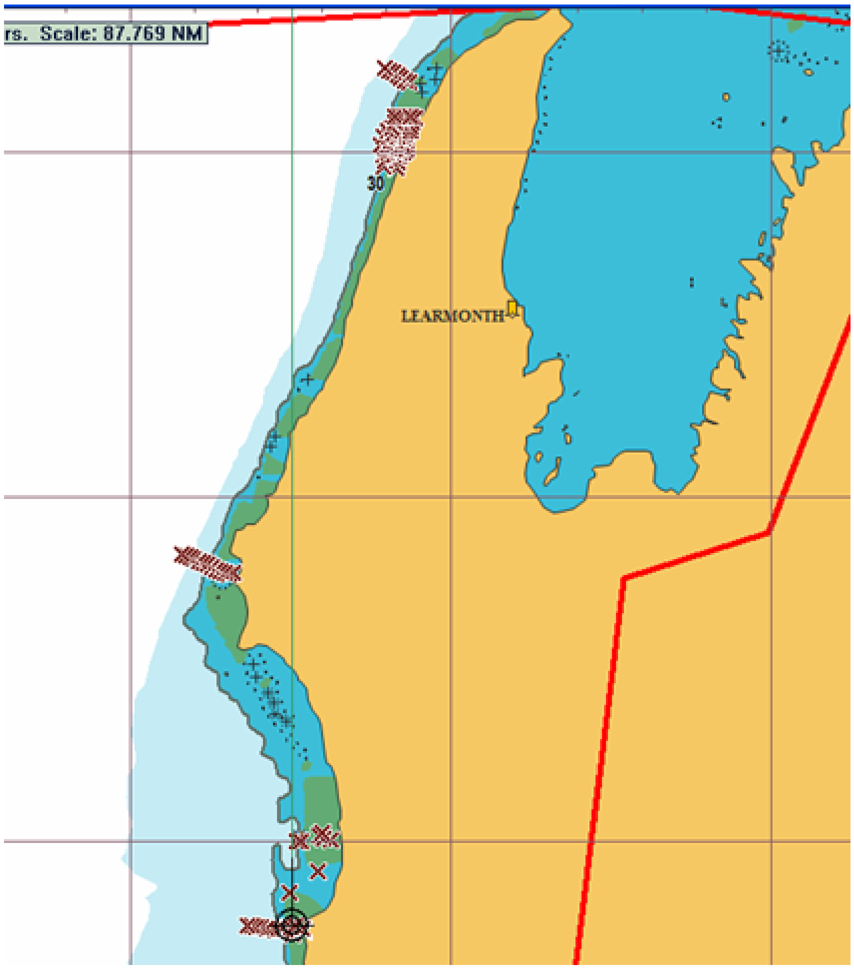
Reef Ecosystem Tracking Array (NRETA). This array is part of the nationwide network of marine acoustic monitoring, the Australian Acoustic Tagging and Monitoring System (AATAMS) A total of 96 acoustic receivers are deployed at Ningaloo Reef between Coral Bay and Tantabiddi. These are deployed as three curtains (Tantabiddi, Norwegian Bay, Coral Bay), three arrays (Mangrove Bay, Coral Bay, Stanley Pool), and three points of interest (Coral Bay) (Fig. 1). Arrays were deployed in November and December 2007, whereas curtains were deployed in February 2008. The Tantabiddi curtain comprises 7 receivers (10–96 m), the Norwegian Bay curtain 13 receivers (95–160 m) and the Coral Bay curtain 12 receivers (7–66 m). The array at Mangrove Bay consists of 50 receivers (1–47 m) and the Coral Bay array consists of 14 receivers (2–34 m). VR2 and VR2W receivers have been deployed on concrete filled tyres in shallow water (<25m) near the reef, or star pickets hammered into the sand, while in deeper waters (>25–200 m) the units have been deployed on moorings lines with an acoustic release anchored by 120 kg steel weights.

The acoustic tags were Vemco V16s and V13s that were 35–62 mm long. Most tags were surgically implanted in the peritoneal cavity. The skin around the surgical site was sterilised with Betadine spray. A small incision (1.5 cm long) was made in the ventral region forward of the cloaca in both sharks and rays. The tag was sterilised in Savlon and pushed through the incision which was then closed by 4–6 dissolving sutures. Some tags were coated in a paraffin and beeswax mixture in an effort to prevent transmitter rejection. Forceps and needle holders were sterilised between surgeries by submerging then in alcohol. Once the wound was closed it was sprayed with Betadine. A mass dependent dose of Engemycine (Oxytetracycline 100 $mgml^{-1}$) was administered intramuscularly via a 1 ml syringe and 26 gauge needle. The entire surgical procedure from capture to release took approximately 15 minutes. Some larger rays were tagged externally with V16s using a Hawaiian sling or modified speargun. The sex, total length (for sharks and shovelnose rays) or disc width (for stingrays) was recorded and a genetic sample taken from a fin clip.

Elasmobranchs for acoustic tagging were caught by a variety of methods. Fishing was carried out both from the shore and from aluminium dinghies mainly in the vicinity of Mangrove Bay where there was a large array of listening stations in place. Sharks and rays were caught using gillnets, longlines, handlines, rod and line and dipnets.

Gillnets were 25–50 m long, 2 m drop and had a stretched mesh size of 10 cm. They were set from the shore and any fish were removed as soon as they were seen to hit the net. Longlines were anchored at both ends and comprised 100 m of mainline with 10 hooks baited with mullet. Sets were of about 1 h duration. Longlines were deployed from a 5 m aluminium vessel. Fishing with handlines and rod and line was carried out both from the shore and from dinghies. Dipnetting was carried out in shallow water to capture rays that could be approached close enough.

Figure 1. Ningaloo Marine Park acoustic array (red crosses are receivers).



Satellite tagging
Two types of platform transmitter terminals (PTTs) were used, Wildlife Computers (Redmond, USA) smart position or temperature transmitting tag (SPOT4 or SPOT5) and SPLASH tags. SPOT tags provide ARGOS locations together with water temperature reported as time-at-temperature histograms in user defined bins. SPLASH tags provide ARGOS locations together with depth and temperature reported as time-at-depth and temperature histograms in user defined bins. Depth is recorded down to 980 m (resolution = 0.5 m; accuracy ± 1 m 0–100 m, 1% 100–1000 m), temperature is measured from –40° C to +60° C, with a resolution of 0.2°C and accuracy of ± 1°C. Tags were attached by two 5 mm diameter bolts which passed through the first dorsal fin and were secured on the other side by two washers and nuts. Tags were secured so that the antenna extended out of the water when the fin broke the surface. Transmissions were detected and processed by the ARGOS data collection and location system The accuracy of

ARGOS position estimates is coded by location class (LC) 3, 2, 1, 0, A or B, with LC3 being the most reliable with a root mean square error of <150 m. The other numeric LC codes decline in reliability and can be within several kilometres of true (ARGOS, 2008). Sharks were caught by longline and, depending on size, either landed on deck for tag attachment or held in a sling at the stern of the vessel while the tag was attached.

3.3 Results

3.3.1 Sites sampled

Lagoon and reef edge
A total of 137 sites were surveyed between Vlaming Head on the northeast of the Cape to Gnaraloo in the southern part of the Marine Park (Table 2 and Figs 2 and 3). The individual surveys undertaken at each location by habitat type are shown in Table 2. Of these surveys, 89 were in sanctuary zones and 48 in non-sanctuary zones.

Offshore
A total of 111 longline sets were made between Three Mile Camp towards the southern extremity of the Marine Park, to northeast of the Muiron Islands outside the northern limits of the Park; the distribution of these sets are shown in Fig. 4. Of these 111 sets, 17 were in sanctuary zones and 94 in non-sanctuary zones.

Historic data
Catch composition and catch rate data from the current project were compared to those from 150 longline sets conducted in the same area between 13th November 2001 and 28th August 2006. The locations of these sets are illustrated in Fig. 5 and other details are summarised in Table 3. Three quarters of historic sets (n=113) were conducted in spring and summer months prior to 2004. Fewer hooks per set were made in this early time series (mean of 48) relative to the current project surveys (mean of 59). Set depths were also generally deeper (mean depth=146 m) than during the current survey (mean depth=75 m) due to targeting of *C. plumbeus* further offshore.

Figure 2 Map showing sites surveyed in the Ningaloo Marine Park.

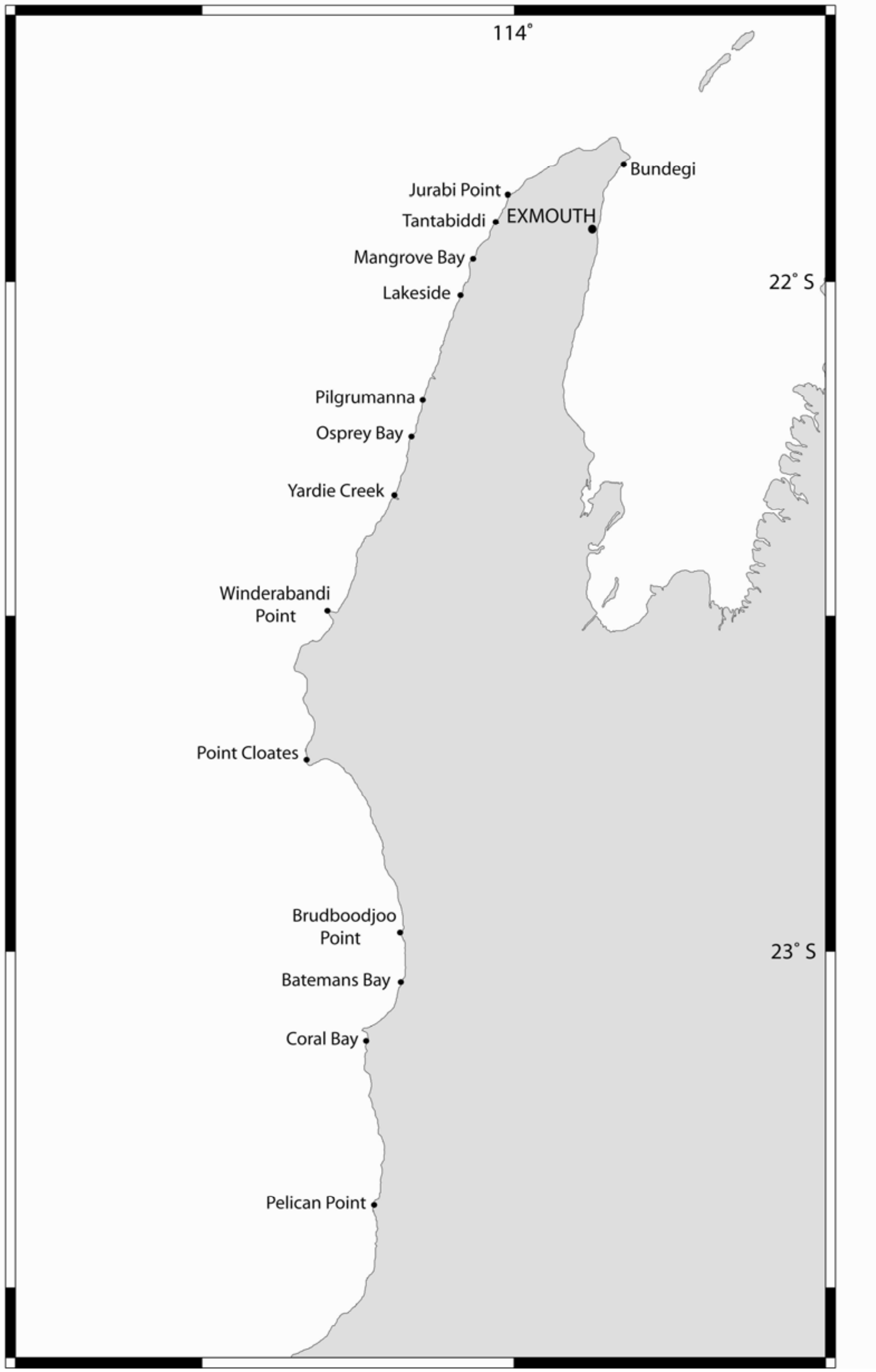


Figure 3. All dive survey sites. Red = April 2007, blue = December 2008, yellow = reef edge (June 2008 and August 2008). Hatched areas are sanctuary zones.

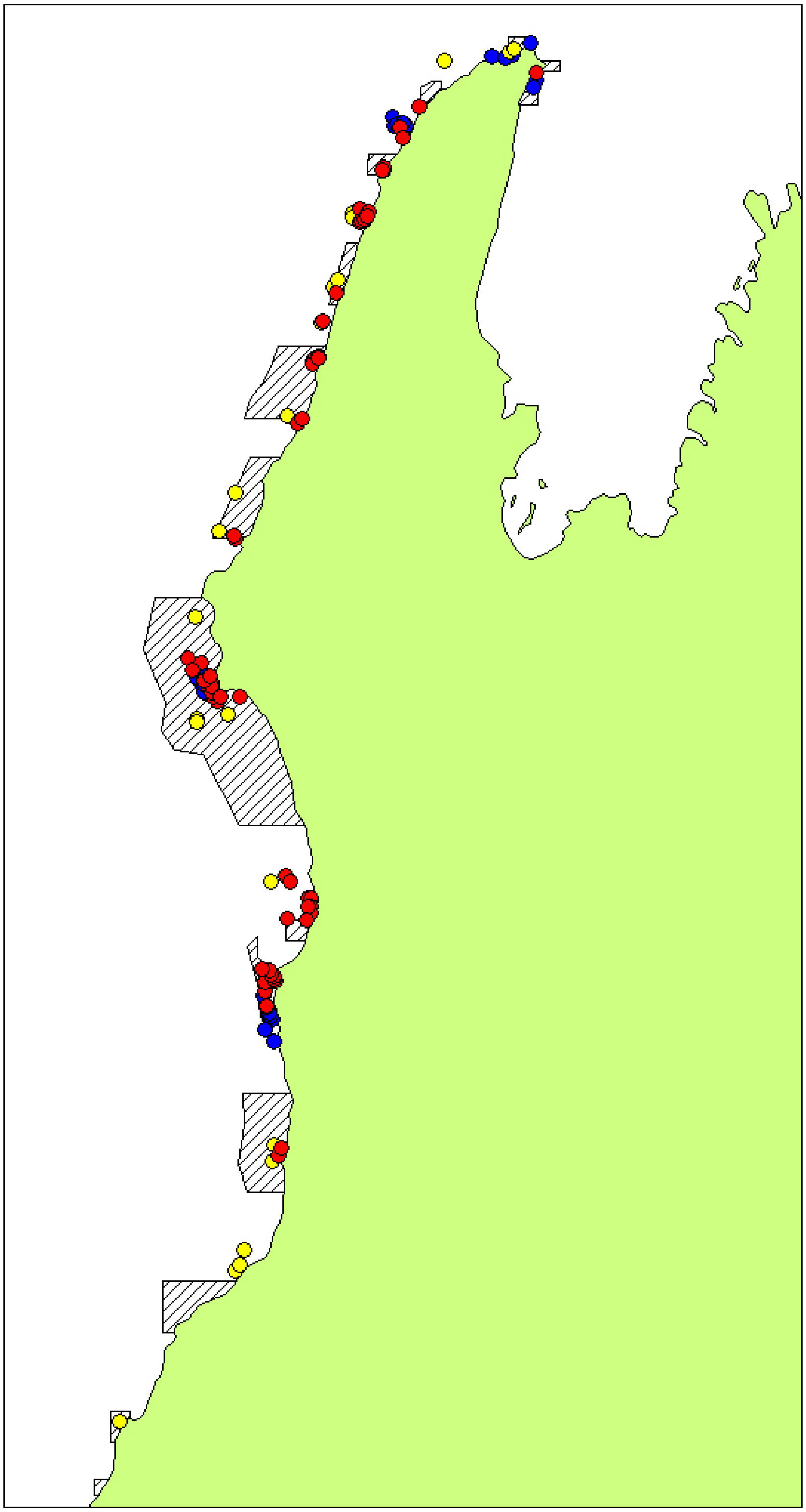


Figure 4. All RV 'Naturaliste' longline sets. Hatched areas are sanctuary zones.

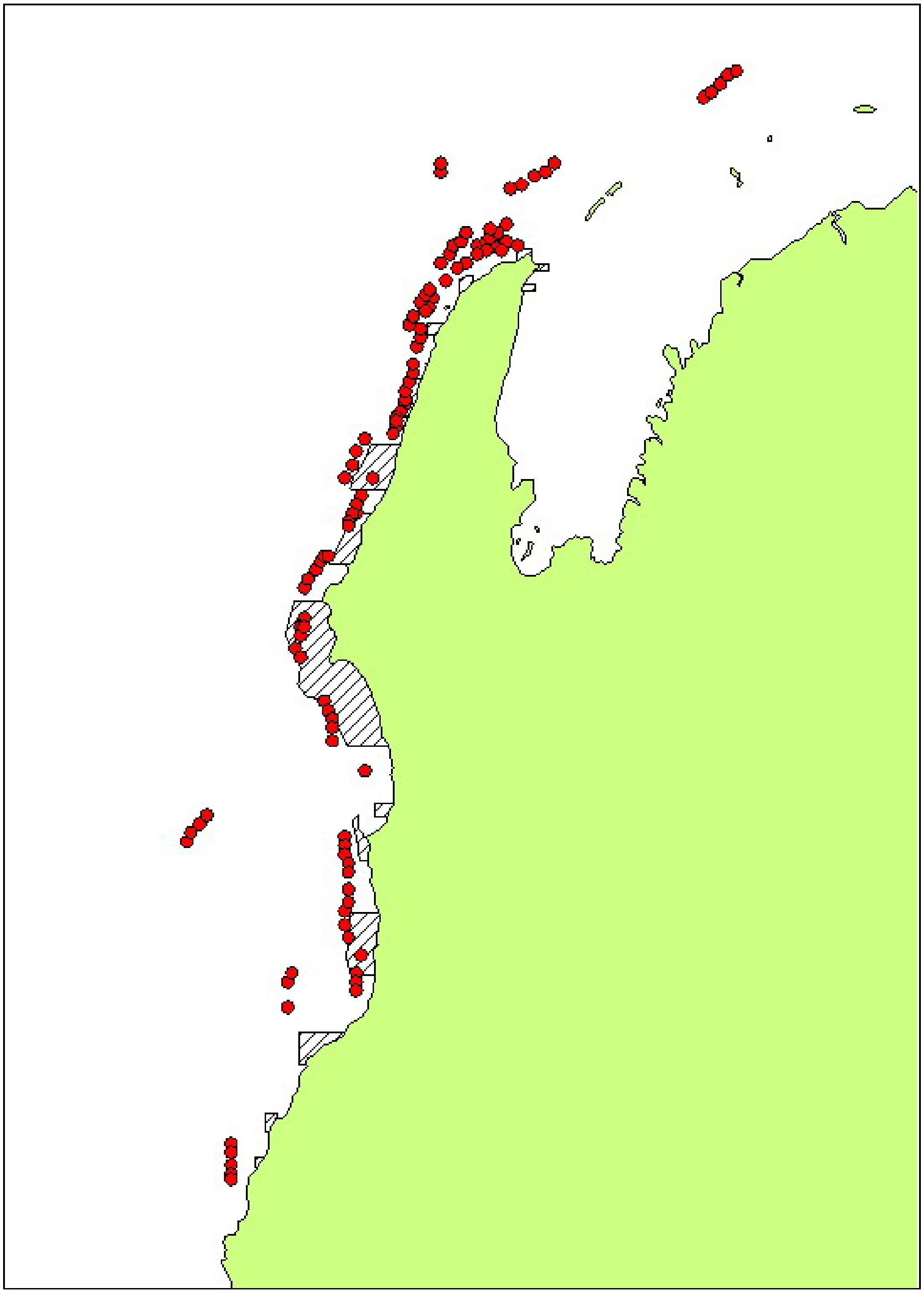


Figure 5. Locations of historic RV 'Naturaliste' longline shots in (a) November 2001: (b) May–June and September 2002; (c) September 2003; (d) April and May–June 2004; (e) June–July 2005 and (f) August–September 2006. Three pelagic shots excluded from analyses are circled in red.

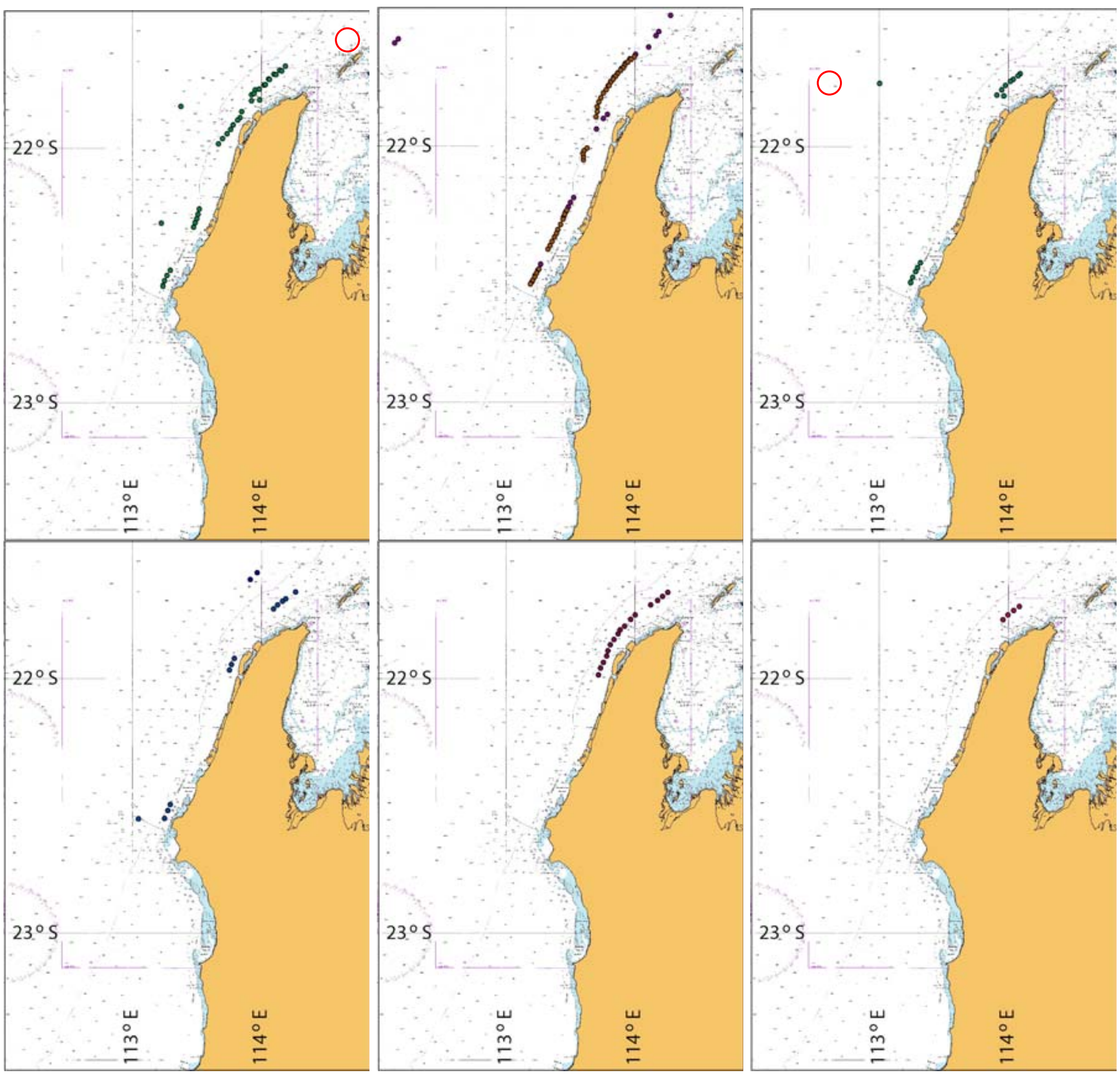


Table 2. Number of sites surveyed by major habitat type* at each of the main regions in Ningaloo Marine Park. * habitat type represents 60% or more of the site.

Location	Sand	Shallow reef	Deep reef	Algae	Seagrass	Mangrove	Variable	**TOTAL**
Vlaming Head							1	**1**
Bundegi		1					2	**3**
Lighthouse Bay		2	3				2	**7**
Jurabi Point		1	3					**4**
Tantabiddi	1	4					2	**7**
Mangrove Bay	3							**3**
Lakeside	5	3					2	**10**
Pilgrumanna			2					**2**
Mandu			2				1	**3**
Osprey Bay	4	3	1				1	**9**
Yardie Creek				1		1		**2**
Winderabandi Pt	3		2					**5**
Point Cloates	16	4	2	1	1		5	**29**
Black Rock			3					**3**
Brudboodjoo Pt	5		1				2	**8**
Batemans Bay	1	2						**3**
Coral Bay	22	6					1	**29**
Pelican Point	4		2					**6**
Amherst Point			3					**3**
Gnaraloo			1					**1**
TOTAL	**64**	**26**	**24**	**2**	**1**	**1**	**19**	**138**

Table 3. Details of historic RV 'Naturaliste' longline sets.

Trip start			**Depth (m)**		
month	**No. Shots**	**No. Hooks**	**Min**	**Max**	**Mean**
Nov 01	34	1381	73	195	97.1
May 02	25	1191	75	393	191.0
Sep 02	40	1605	97	203	188.7
Sep 03	14	1204	98	434	126.8
Apr 04	5	585	287	410	360.6
May 04	12	843	71	208	95.5
June 05	16	966	72	100	88.3
Aug 06	4	252	95	103	99.5

3.3.2 Species composition

A complete checklist of elasmobranch species recorded in the NMP during dive and longline surveys, acoustic tagging fieldwork and from other sources is shown in Appendix 1, Table 1.1.

Lagoon and reef edge surveys

A total of 27 species of elasmobranchs, 10 sharks and 17 rays, were identified from the visual surveys carried out in the lagoon and reef edge. In total, the Giant Shovelnose Ray *Glaucostegus typus* comprised 26.4% (170 individuals) of the sightings all of which were recorded in the April survey. This species was observed in large aggregations over sand in very shallow water with 160 individuals seen at 4 sites, Mangrove Bay, Pelican Point, Starfish Bay (Point Cloates) and Winderabandi Point. At Winderabandi Point, 50 individuals, mostly small juveniles of 40–100 cm TL, were seen lying around a sand spit in only a few cm of water. The Cowtail Stingray *Pastinachus atrus* represented 13.2 % of sightings and was mainly encountered on the April survey (Table 4); 26 individuals were seen at one site on sand habitat (Winderabandi Point). The Bluespotted Maskray *Neotrygon kuhlii* represented between 8.1 and 17.2 % of the elasmobranchs seen on all surveys, including the reef edge. This species was usually seen over sandy substrates but often close to reef areas. On the reef edge surveys, as might be expected, the Grey Reef Shark *Carcharhinus amblyrhynchos* was the most frequently seen elasmobranch (30.2 %) with the Whitetip Reef Shark *Triaenodon obesus* comprising 9.3% of the elasmobranchs seen. The Blacktip Reef Shark *Carcharhinus melanopterus* and the Bluespotted Fantail Ray *Taeniura lymma* were relatively common on both lagoon surveys but *C. melanopterus* was not seen, and *T. lymma* only rarely, on the reef edge surveys. Both the Reticulate Whipray *Himantura uarnak* and the Pink Whipray *Himantura fai* were more commonly encountered on the April 2007 survey (Table 4). Although numbers were generally low, the Blotched Fantail Ray *Taeniurops meyeni* was more frequently seen in the deeper reef edge surveys. Of particular importance was a new species of maskray *Neotrygon* sp. recorded during the surveys. This ray, which was observed at three sites at Coral Bay, was found on sand habitat adjacent to staghorn and plate coral in less than 3 m depth. Two individuals were captured and subjected to detailed morphological, meristic and genetic analysis. The new species is similar to the Bluespotted Maskray *Neotrygon kuhlii* but differs from it in having a vivid colour pattern dominated by orange markings and pale bluish white spots rather than obvious blue spots on the dorsal surface. It also has more protrusible eyes which clearly separates it from another co-occurring maskray, *Neotrygon leylandi*. *Neotrygon* sp. appears to be endemic to the Ningaloo area as it does not seem to occur to the north or south of the region. This is partly due to suitable habitat, but it also seems that another morphologically similar new *Neotrygon* species takes its place further south at Shark Bay in very shallow waters.

Offshore surveys

Longline catches from surveys outside the reef on the RV 'Naturaliste' were dominated by *Carcharhinus plumbeus* which comprised from 52.8–67.2% of the elasmobranchs caught on all three cruises. Other frequently caught species were the Milk Shark *Rhizoprionodon acutus,* Tiger Shark *Galeocerdo cuvier,* Sliteye Shark *Loxodon macrorhinus*, the blacktip sharks *Carcharhinus limbatus* and *C. tilstoni* (not differentiated in the catches) and the Spot-tail Shark *C. sorrah* (Table 5). Overall, 20 species of elasmobranchs were caught; 18 sharks and 2 rays.

Table 4. Species composition of elasmobranchs observed from dive surveys. April and December surveys were mostly in the lagoon; reef edge surveys were in June 2007 and August 2008.

	April 2007		Reef edge		December 2008		TOTAL	
	Number	%	Number	%	Number	%	Number	%
E. dasypogon	0	0	1	1.2	0	0	1	0.2
O. wardi	1	0.2	0	0	0	0	1	0.2
S. fasciatum	2	0.4	0	0	1	1.0	3	0.5
N. ferrugineus	6	1.3	0	0	3	3.0	9	1.4
C. amblyrhynchos	9	2.0	26	30.2	4	4.0	39	6.1
C. limbatus	0	0	1	1.2	0	0	1	0.2
C. melanopterus	30	6.6	0	0	17	17.2	47	7.3
C. obscurus	0	0	1	1.2	0	0	1	0.2
N. acutidens	7	1.5	0	0	0	0	7	1.1
T. obesus	11	2.4	8	9.3	9	9.1	28	4.4
unid. carcharhinid	1	0.2	1	1.2	0	0	2	0.3
unid. shark	2	0.4	0	0	0	0	2	0.3
R. australiae	4	0.9	0	0	0	0	4	0.6
G. typus	170	37.1	0	0	0	0	170	26.4
H. fai	19	4.1	2	2.3	0	0	21	3.3
H. granulata	1	0.2	0	0	2	2.0	3	0.5
H. jenkinsii	0	0	1	1.2	1	1.0	2	0.3
H. uarnak	31	6.8	1	1.2	4	4.0	36	5.6
N. kuhlii	37	8.1	13	15.1	17	17.2	67	10.4
N. leylandi	2	0.4			1	1.0	3	0.5
N. sp.	0	0	0	0	5	5.1	5	0.8
P. atrus	77	16.8	5	5.8	3	3.0	85	13.2
T. lymma	26	5.7	2	2.3	24	24.2	52	8.1
T. meyeni	1	0.2	10	11.6	2	2.0	13	2.0
U. asperrimus	9	2.0	0	0	5	5.1	14	2.2
A. narinari	8	1.7	9	10.5	1	1.0	18	2.8
M. birostris	4	0.9	0	0	0	0	4	0.6
M. eregoodootenke	0	0	1	1.2	0	0	1	0.2
M. thurstoni	0	0	4	4.7	0	0	4	0.6
TOTAL	**458**		**86**		**99**		**643**	

Historic data

Twenty seven species (or higher taxa) were identified from historic longline data (Table 6), including eleven species of sharks that were not recorded in the current study. These were: Bronze Whaler *Carcharhinus brachyurus* (however, the identification of this species may be dubious), Blue Shark *Prionace glauca*, Grey Nurse Shark *Carcharias taurus*, Gulper Shark *Centrophorus acus*, Lemon Shark *Negaprion acutidens*, Spinner Shark *Carcharhinus brevipinna*, Sicklefin Houndshark *Hemitriakis falcata*, Western Spotted Gummy Shark *Mustelus stevensi*, Australian Sharpnose Shark *Rhizoprionodon taylori*, Gulf Wobbegong *Orectolobus halei* and an unidentified species of dogfish *Squalus* sp. Five of the species observed during the current study were absent from the historic data: the Pelagic Thresher *Alopias pelagicus*, Pigeye Shark *Carcharhinus amboinensis*, Whitecheek Shark *Carcharhinus dussumieri*, Blotched Fantail Ray *Taeniurops meyeni* and Whitespotted Guitarfish *Rhynchobatus australiae*, however it is likely

that the latter two species were previously caught and recorded under the generic taxon "unidentified batoid" (McAuley, Department of Fisheries, Perth, pers. comm.).
As with the current project, the historic target species *C. plumbeus* dominated catches from all previous trips except in April 2004 when three of the five sets were in depths greater than 400 m, where *C. plumbeus* is uncommon, and in June–July 2005 when a below average *C. plumbeus* CPUE coincided with an unusually high CPUE of *R. acutus* (see section 3.3.3). In contrast, *C. limbatus/tilstoni* and *G. cuvier* were caught in noticeably lower quantities and less frequently prior to 2007 (when the current study began). Although *R. acutus* and *C. sorrah* were important components of the overall historic catch, they were also caught less consistently in previous years'.

Table 5. Species composition of elasmobranchs observed from RV 'Naturaliste' longline surveys.

	June-July 2007		August 2008		May-June 2009		TOTAL	
	Number	%	Number	%	Number	%	Number	%
H. nakamurai	2	1.1	0	0	0	0	2	0.3
N. ferrugineus	6	3.3	3	1.6	0	0	9	1.5
A. pelagicus	1	0.6	0	0	0	0	1	0.2
C. albimarginatus	3	1.7	9	4.8	5	2.3	17	2.9
C. altimus	4	2.2	0	0	0	0	4	0.7
C. amblyrhynchos	5	2.8	16	8.6	0	0	21	3.6
C. amboinensis	1	0.6	0	0	0	0	1	0.2
C. dussumieri	0	0	0	0	1	0.5	1	0.2
C. limbatus/tilstoni	6	3.3	2	1.1	21	9.8	29	5.0
C. plumbeus	95	52.8	125	67.2	115	53.5	335	57.7
C. obscurus	7	3.9	3	1.6	0	0	10	1.7
C. sorrah	6	3.3	2	1.1	16	7.4	24	4.1
G. cuvier	22	12.2	12	6.5	1	0.5	35	6.0
L. macrorhinus	8	4.4	9	4.8	11	5.1	28	4.8
R. acutus	5	2.8	2	1.1	36	16.7	43	7.4
S. lewini	2	1.1	0	0	3	1.4	5	0.9
S. mokarran	0	0	3	1.6	2	0.9	5	0.9
unid. shark	0	0	0	0	3	1.4	3	0.5
R. australiae	5	2.8	0	0	1	0.5	6	1.0
T. meyeni	1	0.6	0	0	0	0	1	0.2
Unid. dasyatid	1	0.6	0	0	0	0	1	0.2
TOTAL	**180**		**186**		**215**		**581**	

3.3.3 Abundance

Lagoon and reef edge
The highest abundance (SPUA as number/1000 m^2) of elasmobranchs was observed on the April survey (0.219 SPUA) and the lowest on the December surveys (0.042 SPUA) (Table 7). The April data were influenced by the large number of *G. typus* recorded at four sites (160 individuals); if these fish were removed from the analysis then the data for April were reduced to 0.143 SPUA. The SPUA data for all elasmobranchs combined by site for the different dive surveys are shown in Appendix 3, Fig. 3.1. As noted above, the high SPUA values in April are

Table 6. Species composition of elasmobranchs observed during historic RV 'Naturaliste' longline sets.

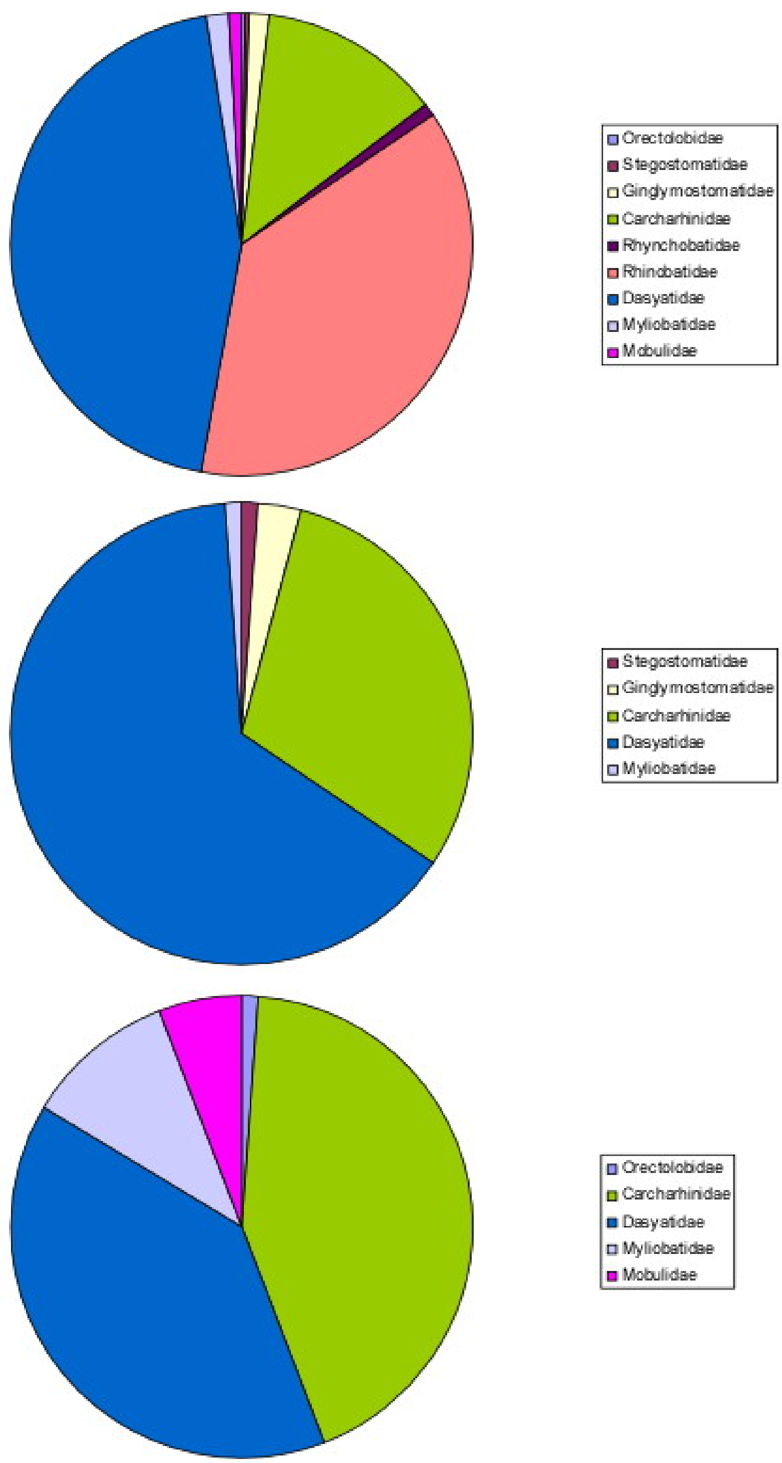
	November 01		May–June 02		September 02		September 03		April 04		May–June 04		June–July 05		August–Sept. 06	
Species	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	Percent	Number	%
C. altimus	0	0.0	1	0.5	0	0.0	0	0.0	2	12.5	4	8.5	0	0.0	0	0.0
C. limbatus/tilstoni	2	1.2	1	0.5	2	0.8	0	0.0	0	0.0	1	2.1	10	9.1	1	4.3
C. obscurus	5	3.0	2	1.0	14	5.8	1	2.6	1	6.3	1	2.1	0	0.0	0	0.0
H. nakamurai	0	0.0	0	0.0	0	0.0	3	7.9	1	6.3	0	0.0	0	0.0	0	0.0
C. brachyurus	0	0.0	0	0.0	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
P. glauca	1	0.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
C. taurus	1	0.6	1	0.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
C. amblyrhynchos	0	0.0	0	0.0	0	0.0	1	2.6	0	0.0	0	0.0	0	0.0	0	0.0
C. acus	0	0.0	0	0.0	0	0.0	0	0.0	4	25.0	3	6.4	0	0.0	0	0.0
S. mokarran	0	0.0	0	0.0	0	0.0	1	2.6	0	0.0	0	0.0	0	0.0	1	4.3
S. lewini	5	3.0	10	5.1	69	28.6	0	0.0	3	18.8	0	0.0	2	1.8	2	8.7
N. acutidens	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	2.1	0	0.0	0	0.0
C. brevipinna	0	0.0	0	0.0	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
R. acutus	6	3.6	1	0.5	0	0.0	2	5.3	0	0.0	6	12.8	43	39.1	7	30.4
Unid. Squalid	0	0.0	1	0.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
L. macrorhinus	3	1.8	1	0.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
H. falcata	1	0.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
C. sorrah	15	8.9	0	0.0	0	0.0	3	7.9	0	0.0	1	2.1	10	9.1	2	8.7
Unid. batoid	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	2.1	0	0.0	0	0.0
C. albimarginatus	5	3.0	2	1.0	2	0.8	2	5.3	0	0.0	0	0.0	0	0.0	0	0.0
R. taylori	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	7	6.4	0	0.0
G. cuvier	3	1.8	3	1.5	3	1.2	0	0.0	2	12.5	0	0.0	1	0.9	1	4.3
C. plumbeus	121	72.0	172	87.3	145	60.2	25	65.8	2	12.5	28	59.6	37	33.6	9	39.1
N. ferrugineus	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	2.1	0	0.0	0	0.0
O. halei	0	0.0	1	0.5	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
M. stevensi	0	0.0	1	0.5	3	1.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Unid. Shark	0	0.0	0	0.0	0	0.0	0	0.0	1	6.3	0	0.0	0	0.0	0	0.0

influenced by the large aggregations of *G. typus* at Winderabandi Point and Mangrove Bay, and *C. melanopterus* at Pelican Point. As would be expected, the abundances of individual species (Table 7) basically reflected the species composition data in Table 4 with *G. typus* and *P. atrus* being the most frequently sighted rays and *C. amblyrhynchos* and *C. melanopterus* the most frequently sighted sharks. The relative abundance of elasmobranchs on the April, December and reef edge surveys is shown in Fig. 6.

Table 7. Number of elasmobranchs observed per 1000 m^2. April and December surveys were mostly in the lagoon; reef edge surveys were in June 2007 and August 2008. Figures in parentheses are areas in km^2.

Species	April 2007 (2.089)	Reef edge (0.925)	December 2008 (2.340)	TOTAL (5.354)
E. dasypogon	0	0.001	0	0
O. wardi	0	0	0	0
S. fasciatum	0.001	0	0	0.001
N. ferrugineus	0.003	0	0.001	0.002
C. amblyrhynchos	0.004	0.028	0.002	0.007
C. limbatus	0	0.001	0	0
C. melanopterus	0.014	0	0.007	0.009
C. obscurus	0	0.001	0	0
N. acutidens	0.003	0	0	0.001
T. obesus	0.005	0.009	0.004	0.005
unid. carcharhinid	0	0.001	0	0
unid. shark	0.001	0	0	0
R. australiae	0.002	0	0	0.001
G. typus	0.081	0	0	0.032
H. fai	0.009	0.002	0	0.004
H. granulata	0	0	0.001	0.001
H. jenkinsii	0	0.001	0	0
H. uarnak	0.015	0.001	0.002	0.007
N. kuhlii	0.018	0.014	0.007	0.013
N. leylandi	0.001	0	0	0.001
N. sp.	0	0	0.002	0.001
P. atrus	0.037	0.005	0.001	0.016
T. lymma	0.012	0.002	0.010	0.010
T. meyeni	0	0.011	0.001	0.002
U. asperrimus	0.004	0	0.002	0.003
A. narinari	0.004	0.010	0	0.003
M. birostris	0.002	0	0	0.001
M. eregoodootenke	0	0.001	0	0
M. thurstoni	0	0.004	0	0.001
TOTAL	**0.219**	**0.093**	**0.042**	**0.120**

Figure 6. Relative abundance of elasmobranch families from dive surveys. Top = April 2007, middle = December 2008, bottom = reef edge (June 2007 and August 2008).



The abundance of the nine most commonly recorded species is shown by site in Appendix 3, Figs 3.2–3.10. *Carcharhinus amblyrhynchos* was most abundant between Pilgrumanna and Coral Bay with the highest SPUA of 1.9 at Asho's Pass Coral Bay (Fig. 3.2). The April survey recorded the highest abundance of *C. melanopterus* (SPUA 28.0) due to an aggregation at Pelican Point; this species was also encountered at relatively high abundance at Point Cloates (Fig. 3.3). *Triaenodon obesus* was encountered over the length of the Park (Fig. 3.4) with highest abundance recorded at North West Cape and Osprey Bay (SPUA 1.0). Of the batoids, the aggregations of *G. typus* at Winderabandi and Pelican Point (Fig. 3.5) have already been noted while abundance was highest for *H. fai* at Mangrove Bay and Brudboodjoo Point (Fig. 3.6), *H. uarnak* (Fig. 3.7) at Winderabandi and Brudboodjoo Point and *P. atrus* (Fig. 3.9) at Mangrove Bay and Winderabandi Point. *Neotrygon kuhlii* was most abundant between Coral Bay (highest SPUA 0.36 at Maud's Channel) and Lakeside (Fig. 3.8) and *T. lymma* abundance was highest at Skeleton Bay (Coral Bay) and Lakeside (Fig. 3.10).

Of the 138 sites, 90 were in sanctuary zones and 48 were in non-sanctuary zones. The total sightings of elasmobranchs in the sanctuary zones was higher (SPUA = 0.164) than in non-sanctuary zones (SPUA = 0.048). The sanctuary data were influenced by four sites with very high SPUA (84.000, 26.000, 5.972 and 1.944), due to aggregations of *G. typus, C. melanopterus* and *P. atrus.* When these data were removed from the analysis, the sanctuary SPUA was reduced to 0.097. However, even with all data included these differences were not significant (one-way ANOVA: $F_{(1, 134)} = 1.1174$, $p = 0.2924$). When the individual species were compared, the abundance of nine of the top ten species was higher in sanctuary zones than in non-sanctuary zones. For *T. lymma,* the abundance was the same in both zones (Table 8).

Table 8. Abundance (SPUA) of the 10 most frequently encountered species on dive surveys, and of all elasmobranchs combined, inside and outside of sanctuary zones.

Species	Sanctuary	Non-sanctuary
C. amblyrhynchos	0.009	0.004
C. melanopterus	0.013	0.002
T. obesus	0.007	0.002
G. typus	0.051	0
H. fai	0.005	0.001
H. uarnak	0.009	0.003
N. kuhlii	0.015	0.009
P. atrus	0.024	0.003
T. lymma	0.009	0.009
T. meyeni	0.004	0.001
TOTAL	**0.164**	**0.048**

When the individual species were compared, the abundance of nine of the top ten species was higher in sanctuary zones than in non-sanctuary zones. For *T. lymma,* the abundance was the same in both zones (Table 8). The assumptions for individual ANOVA tests were met for six species none of which showed significant differences between sanctuary and non-sanctuary zones: *N. kuhlii* (p = 0.9461); *T. lymma* (p = 0.9880); *C. amblyrhynchos* (p = 0.2070); *T. meyeni* (p = 0.2278); *H. uarnak* (p = 0.3420); *H. fai* (p = 0.1661). For the remaining species, a non-parametric Mann-Whitney U test showed significant differences for *G. typus* (p = 0.0483) but not for *C. melanopterus* (p = 0.4270), *T. obesus* (p = 0.3062) or *P. atrus* (p = 0.2562). An ANOSIM test also found no significant differences in the species composition between sanctuary and non-sanctuary zones (ANOSIM, Global R = 0, p = 0.44).

We attempted to examine the survey data by habitat type but this was complicated by many of the dives covering multiple habitats, small sample sizes for some habitats and a lack of precision in recording exactly where individual elasmobranchs were seen on the surveys (see Methods section). Based on the habitats recorded, the data for the April and December lagoon surveys were separated into 11 habitat types (Table 9); single habitats (i.e. sand or reef) were those comprised of 80% or more of that habitat while mixed habitats (i.e. sand and reef, seagrass and reef etc) were those comprised of <80% but 20% or more of that habitat type. Mangrove habitats were those adjacent to mangroves irrespective of the percentage cover recorded. Table 9 shows that of the more abundant species in the lagoon, *G. typus, P. atrus* and *H uarnak* were only seen on sand habitats, *T. obesus* were only seen on reef habitats and *C. amblyrhynchos, C. melanopterus, H. fai, N. kuhlii, T. lymma, T meyeni* and *U. asperrimus* on sand and reef habitats. The percentage cover for habitat types in the reef edge surveys was not recorded; however, this general habitat type was dominated by *C. amblyrhynchos, N. kuhlii, T. meyeni* and *A. narinari*

The depths of the individual dive surveys in the lagoon ranged from 0.2–9.5 m (mean 2.9 m, n = 112) and on the reef edge from 6.5–29.0 m (mean 15.7 m, n = 25). The very shallow areas of the lagoon were dominated by batoids, mainly *G. typus, P. atrus* and *H. uarnak,* although one aggregation of juvenile *C. melanopterus* was also encountered in very shallow water. The deeper reef edge habitat was, as noted above, dominated by *C. amblyrhynchos.* Other than these generalisations, there appeared to be little relationship of species abundance with depth (Fig. 7). The abundance data contained a few very high values due to aggregations of species at some sites. If these values are retained when examining the relationship with depth, the remaining data points are compressed towards zero with little discrimination visible. In Fig. 7, three data points were removed from the plot of all elasmobranchs (SPUA values of 84.0, 26.0 and 6.0) and one from the *C. amblyrhynchos* data (SPUA of 1.9).

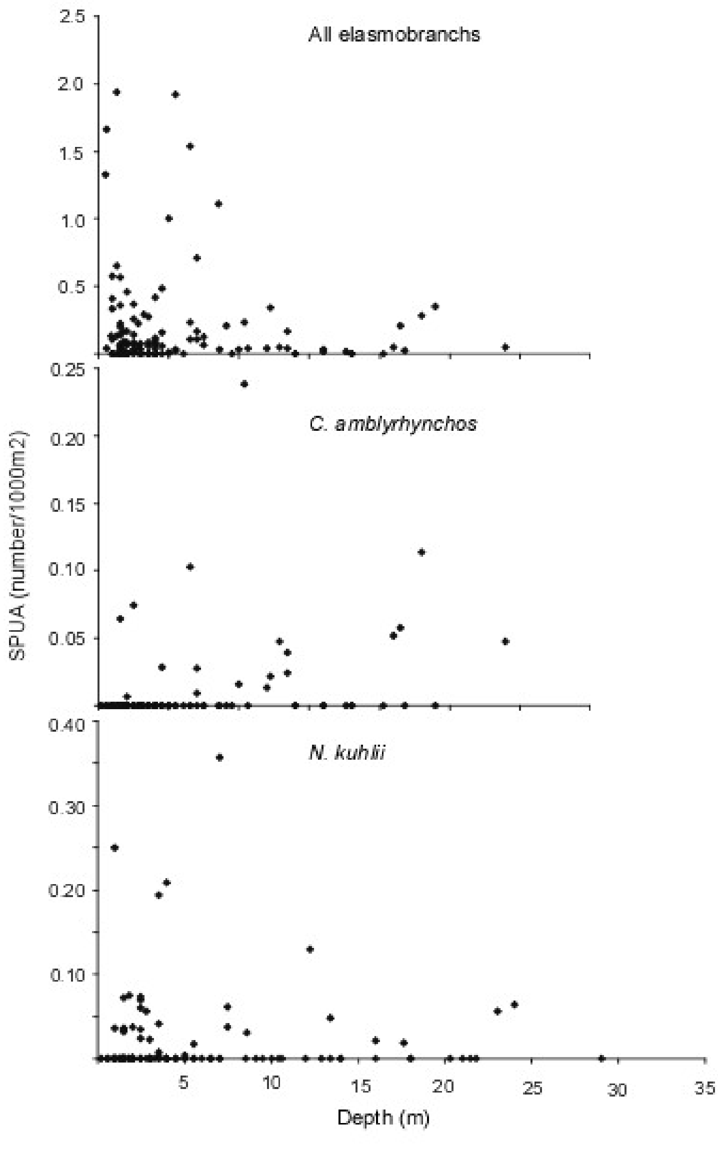
Table 9. Number of elasmobranchs observed per 1000 m^2 by habitat type in the lagoon.

Species	Sand	Reef	Algae	Sand & reef	Seagrass & reef	Reef & algae	Sand & algae	Reef, seagrass & sand	Sand, reef & algae	Sand, reef & mangroves	Sand & mangroves
E. dasypogon	0	0	0	0	0	0	0	0	0	0	0
O. wardi	0.001	0	0	0	0	0	0	0	0	0	0
S. fasciatum	0.001	0	0	0.001	0	0	0	0	0	0	0
N. ferrugineus	0	0.004	0	0.005	0	0	0	0	0	0	0
C. amblyrhynchos	0.001	0.013	0	0.002	0	0.002	0	0.028	0	0	0
C. limbatus	0	0	0	0	0	0	0	0	0	0	0
C. melanopterus	0.012	0.005	0	0.007	0	0	0.011		0.023	0	0.091
C. obscurus	0	0	0	0	0	0	0	0	0	0	0
N. acutidens	0.001	0	0	0	0	0	0		0	0	0.078
T. obesus	0	0.009	0	0	0	0	0	0	0	0	0
unid. carcharhinid	0	0	0	0.001	0	0	0	0	0	0	0
unid. shark	0	0	0	0.001	0	0	0	0	0	0	0
R. australiae	0.003	0	0	0	0	0	0	0	0	0	0
G. typus	0.104	0	0	0	0	0	0		0	0	0.481
H. fai	0.005	0.002	0	0.003	0	0	0		0	0	0.078
H. granulata	0	0	0	0.001	0	0	0		0.002	0	0
H. jenkinsii	0	0	0	0.001	0	0	0	0	0	0	0
H. uarnak	0.019	0	0	0.006	0	0	0	0	0	0	0
N. kuhlii	0.005	0.014	0	0.019	0	0.002	0.021		0.012	0	0
N. leylandi	0	0	0	0.001	0	0	0	0	0	0	0
N. sp.	0.002	0	0	0.001	0	0	0	0	0	0	0
P. atrus	0.030	0	0	0.011	0	0	0		0	0	0.338
T. lymma	0.005	0.004	0	0.022	0	0	0.032		0.005	0	0
T. meyeni	0.001	0.002	0	0	0	0	0	0.028	0	0	0
U. asperrimus	0.002	0.004	0	0.002	0	0.005	0		0	0	0.052
A. narinari	0.005		0.045	0.001	0	0	0	0	0	0	0
M. birostris	0		0	0.003	0	0	0	0	0	0	0
M. eregoodootenke	0		0	0	0	0	0	0	0	0	0
M. thurstoni	0		0	0	0	0	0	0	0	0	0
TOTAL	0.196	0.056	0.045	0.100		0.010	0.064	0.056	0.042	0	1.117
Area (km^2.)	1.282	0.553	0.022	1.452	0.002	0.419	0.094	0.036	0.431	0.007	0.077
n	39	14	2	38	1	4	3	1	6	1	3

Offshore

The CPUE of all elasmobranchs from the RV 'Naturaliste' longline surveys varied from 7.19 in June/July 2007 to 12.14 individuals per 100 hooks in May/June 2009. *Carcharhinus plumbeus* dominated the catches with an overall CPUE of 5.13 with the next most frequently caught species being *R. acutus* (0.66), *G. cuvier* (0.54) and *L. macrorhinus* (0.43) (Table 10). *Galeocerdo cuvier* catches were much lower in May/June 2009 (0.06) than in 2007 and 2008 while *R. acutus* were highest in the 2009 cruise (2.03) (Table 10).

Figure 7. Relationship between abundance and depth for all elasmobranchs, *C. amblyrhynchos* and *N. kuhlii* from dive surveys (some high data points have been removed – see text for details).



The CPUE of all elasmobranchs combined, and of the four most commonly caught species, by site and cruise survey are shown in Figs 8–12. In 2007, total CPUE was highest off Pelican Point and Lakeside, in 2008 highest catch rates were off Pelican Point, Yardie Creek and North West Cape and in 2009 catch rates were highest in the region from Yardie Creek to Osprey Bay (Fig. 8). *Carcharhinus plumbeus* CPUE (Fig. 9) was highest off North West Cape, Mangrove Bay and Pelican Point in 2007 and off Yardie Creek in both 2008 and 2009. Catch rates for *G. cuvier* were highest in 2007 in the Pelican Point region (Fig. 10). *Loxodon macrorhinus* CPUE was highest from the southern limits of the Point Cloates sanctuary zone to Yardie Creek in 2008, and off Lakeside in 2009; this species was not caught south of Brudboodjoo Point (Fig. 11). *Rhizoprionodon acutus* was only caught off North West Cape and Pelican Point in 2007, only off Pelican Point in 2008 and only to the north of Point Cloates in 2009 with highest catch rates to the northeast of the Muiron Islands outside the limits of the Park (Fig. 12).

Table 10. Catch per unit effort of elasmobranchs from RV 'Naturaliste' longline surveys. CPUE is number of individuals per 100 hooks; figures in parentheses are number of hooks.

Species	June/July 2007 (2504)	August 2008 (2249)	May/June 2009 (1771)	TOTAL (6524)
H. nakamurai	0.08	0	0	0.03
N. ferrugineus	0.24	0.13	0	0.14
A. pelagicus	0.04	0	0	0.02
C. albimarginatus	0.12	0.40	0.28	0.26
C. altimus	0.16	0	0	0.06
C. amblyrhynchos	0.20	0.71	0	0.32
C. amboinensis	0.04	0	0	0.02
C. dussumieri	0	0	0.06	0.02
C. limbatus/tilstoni	0.24	0.09	1.19	0.44
C. plumbeus	3.79	5.56	6.49	5.13
C. obscurus	0.28	0.13	0	0.15
C. sorrah	0.24	0.09	0.90	0.37
G. cuvier	0.88	0.53	0.06	0.54
L. macrorhinus	0.32	0.40	0.62	0.43
R. acutus	0.20	0.09	2.03	0.66
S. lewini	0.08	0	0.17	0.08
S. mokarran	0	0.13	0.11	0.08
unid. shark	0.00	0	0.17	0.05
R. australiae	0.20	0	0.06	0.09
T. meyeni	0.04	0	0	0.02
Unid. dasyatid	0.04	0	0	0.02
TOTAL	**7.19**	**8.27**	**12.14**	**8.91**

The CPUE of four additional, less frequently caught, species are shown in Appendix 3, Figs 3.11–3.14. Of these, catches of *C. albimarginatus* (Fig. 3.11) were mainly from the Point Cloates to Yardie Creek area while catches of *C. amblyrhynchos* (Fig. 3.12) ranged from Pelican Point to North West Cape. The highest CPUE for both these species was recorded off Point Cloates. Blacktips *C. limbatus/C. tilstoni* (these species were not separated) were not caught in the southern sector of the Park being taken from Point Cloates to North West Cape and northeast of the Muiron Islands, outside the Park, where the highest catch rates were made (Fig. 3.13). However a blacktip shark was sighted during a dive survey south of the Park off Gnarloo station in August 2008. A similar pattern was found for *C. sorrah* which, apart from one individual caught off Brudboodjoo Point, was only caught from Lakeside to North West Cape and northeast of the Muiron Islands, with these last two locations having the highest CPUE (Fig. 3.14).

Table 11. Abundance (CPUE) of the 8 most frequently encountered species on the 2008 longline survey, and of all elasmobranchs combined, inside and outside of sanctuary zones.

Species	Sanctuary	Non-sanctuary
C. albimarginatus	0.72	0.19
C. amblyrhynchos	1.72	0.32
C. limbatus/tilstoni	0.29	0
C. plumbeus	6.58	5.10
C. sorrah	0	0.13
G. cuvier	0.72	0.45
L. macrorhinus	0.43	0.39
R. acutus	0	0.13
TOTAL	**10.73**	**7.16**

Only the 2008 cruise contained a sufficient number of longline stations inside and outside of sanctuary zones. In 2007, only three stations were in sanctuary zones and in 2009 most stations were further offshore and none were in sanctuary zones. Of the 45 stations in 2008, 14 were in sanctuary zones and 31 in non-sanctuary zones. The mean combined elasmobranch CPUE was 10.7 from the 14 stations in sanctuary zones compared to a mean CPUE of 7.1 for the 31 stations outside of sanctuary zones. However, these differences were not significant (one-way ANOVA: $F_{(1, 45)} = 2.56328$, $p = 0.1167$). When the catch rates of the top eight species in the 2008 catch data were examined (Table 11), only *C. sorrah* and *R. acutus* had lower catch rates in sanctuary zones. Due to the small sample sizes, no statistical test was applied.

Figure 8. *Combined elasmobranch* CPUE from RV 'Naturaliste'surveys. Hatched areas are sanctuary zones.

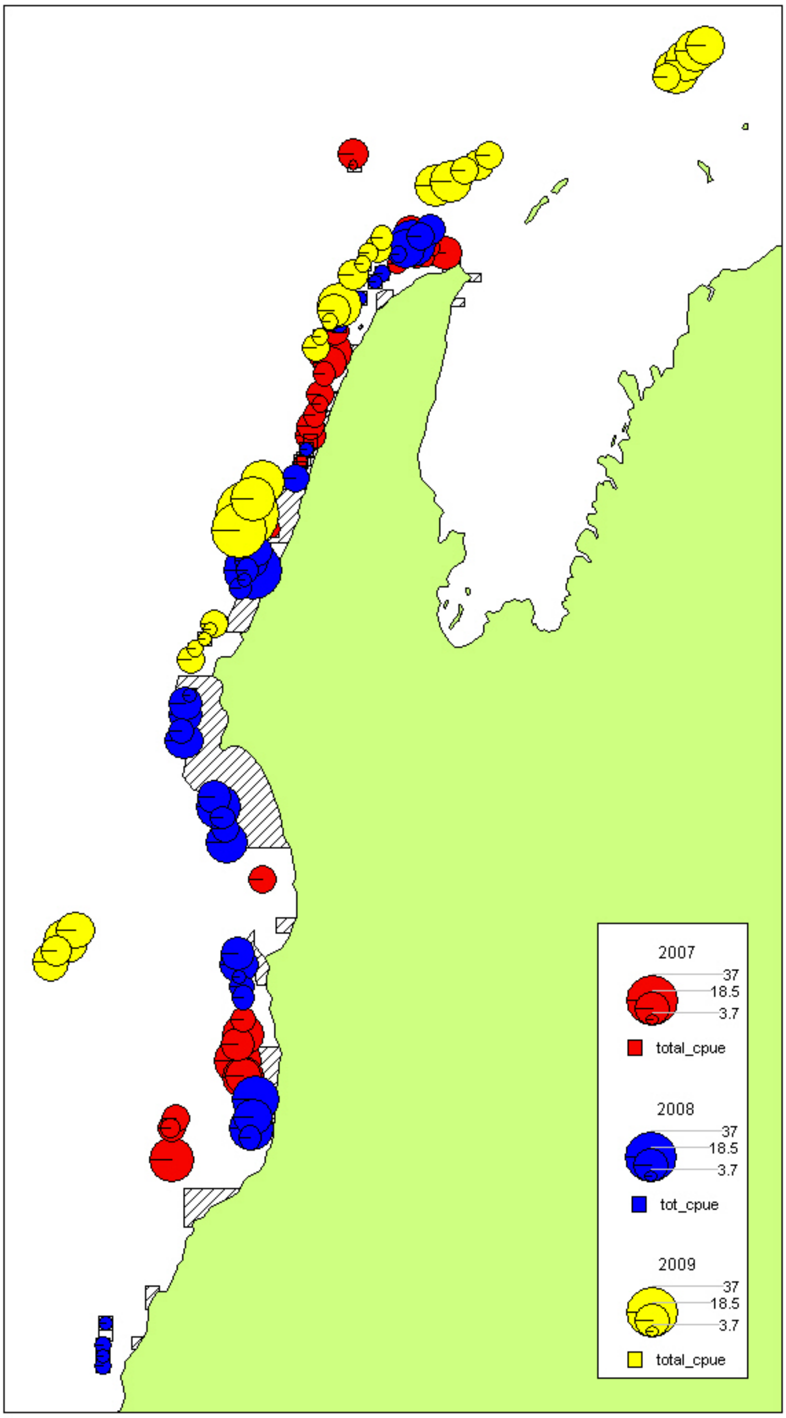


Figure 9. *Carcharhinus plumbeus* CPUE from RV 'Naturaliste' surveys. Hatched areas are sanctuary zones.

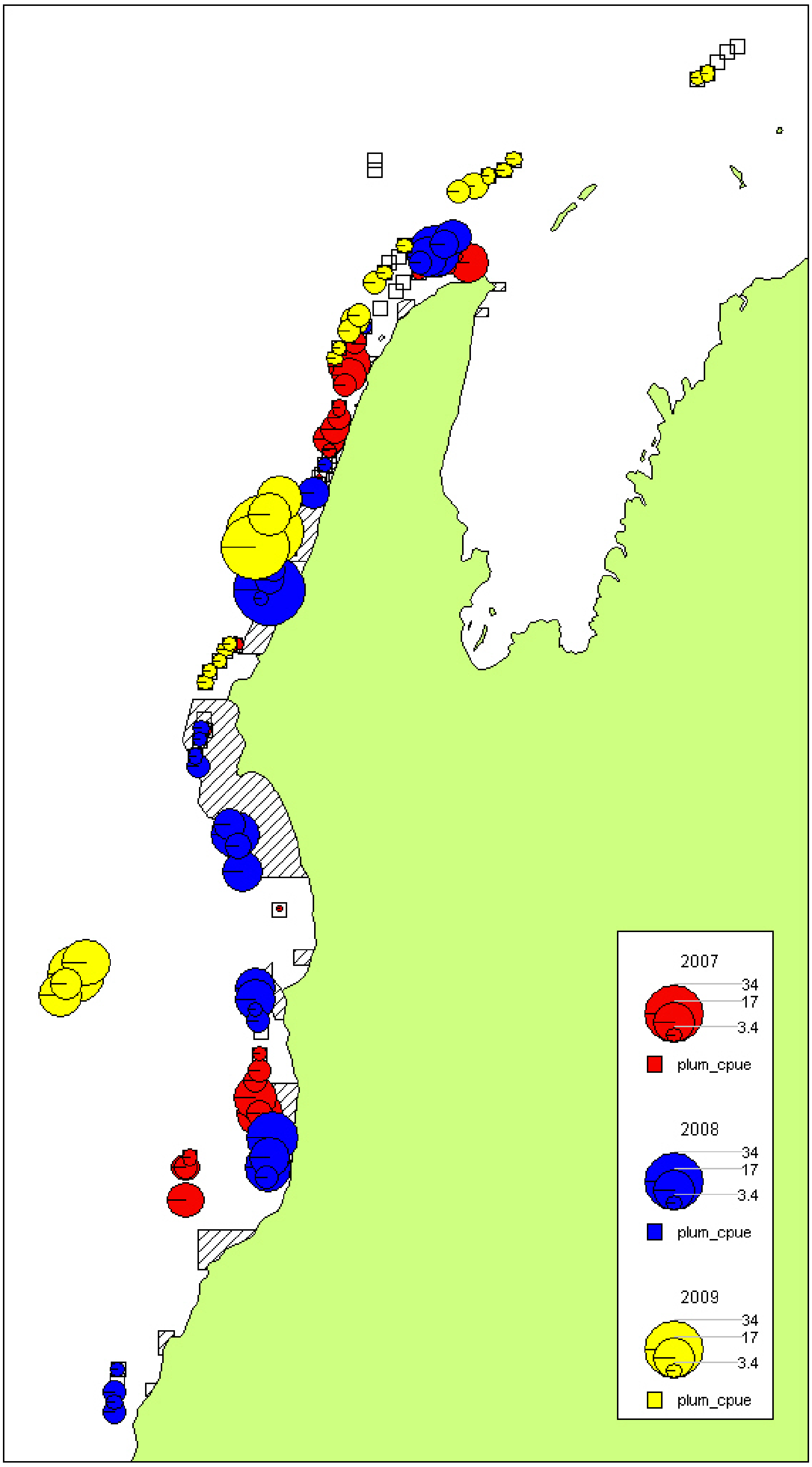


Figure 10. *Galeocerdo cuvier* CPUE from RV 'Naturaliste' surveys. Hatched areas are sanctuary zones.

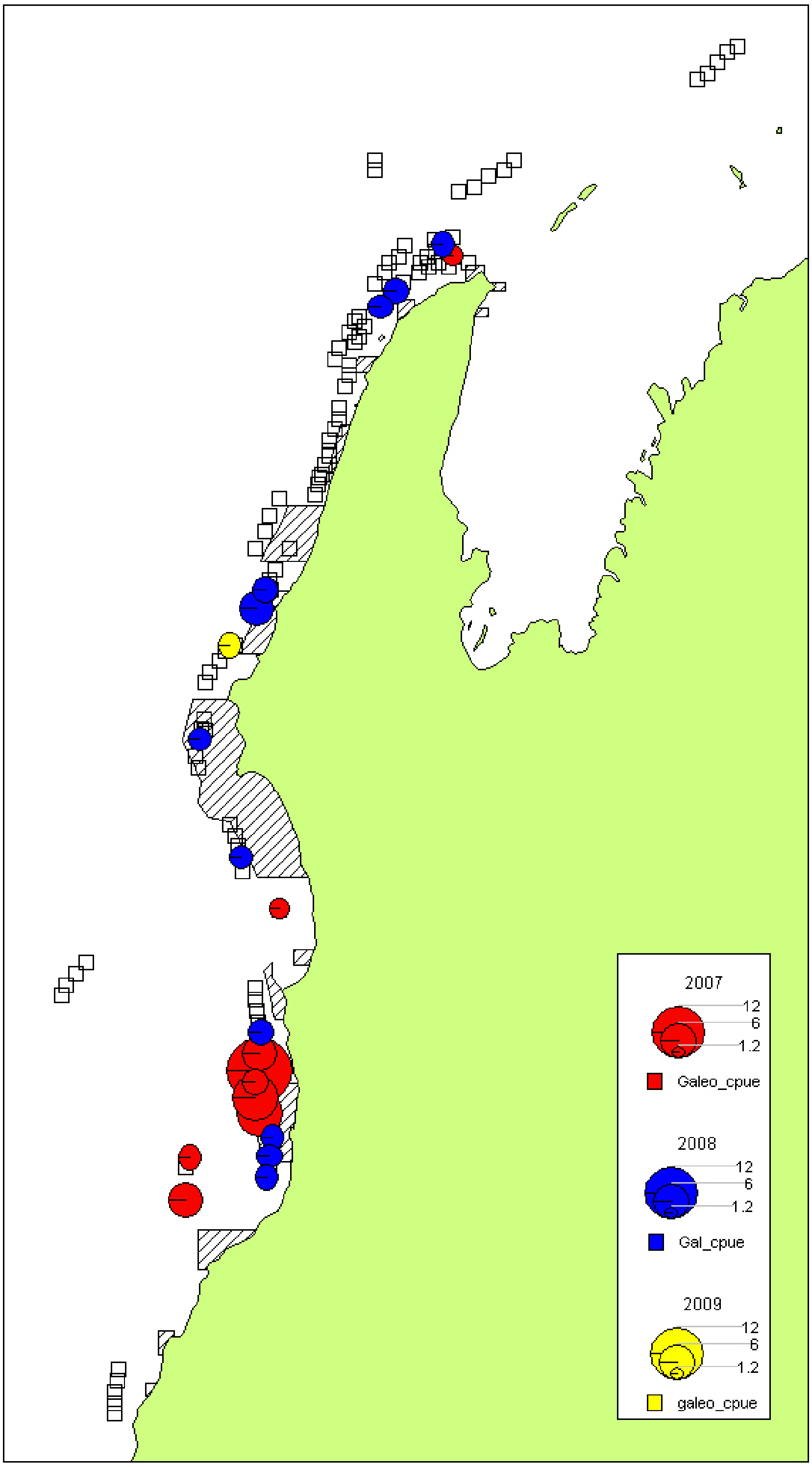


Figure 11. *Loxodon macrorhinus* CPUE from RV 'Naturaliste'surveys. Hatched areas are sanctuary zones.

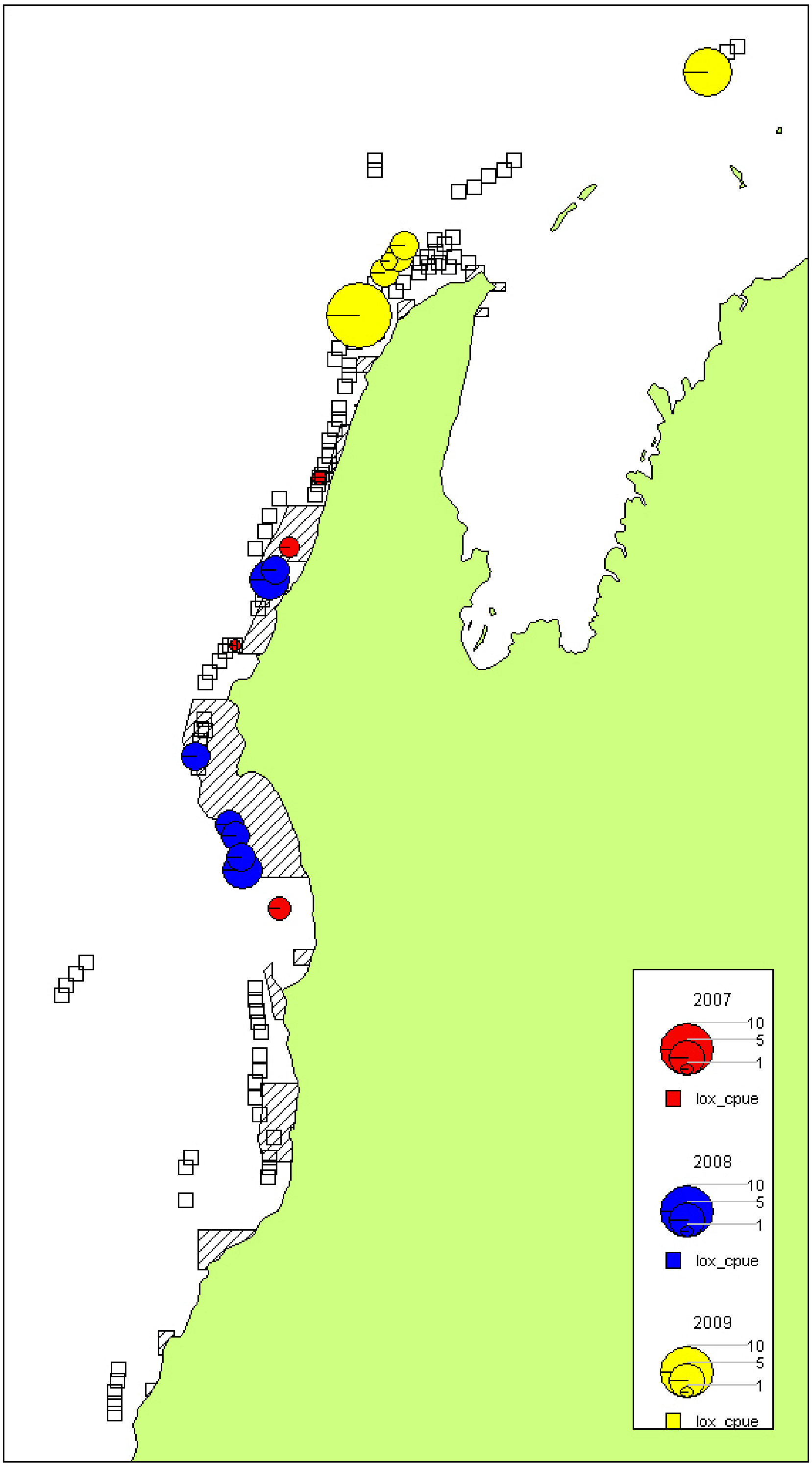
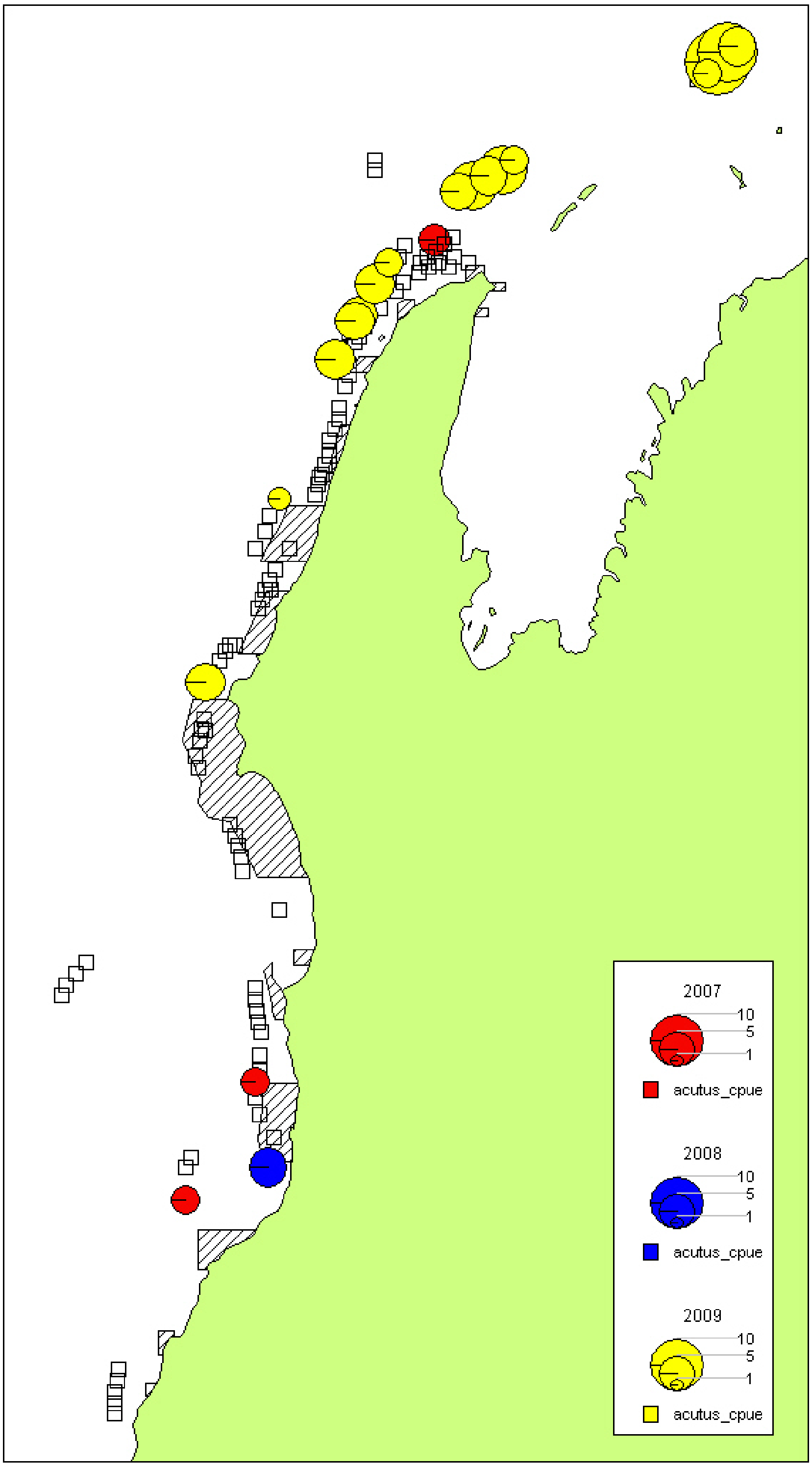


Figure 12. *Rhizoprionodon acutus* CPUE from RV 'Naturaliste' surveys. Hatched areas are sanctuary zones.



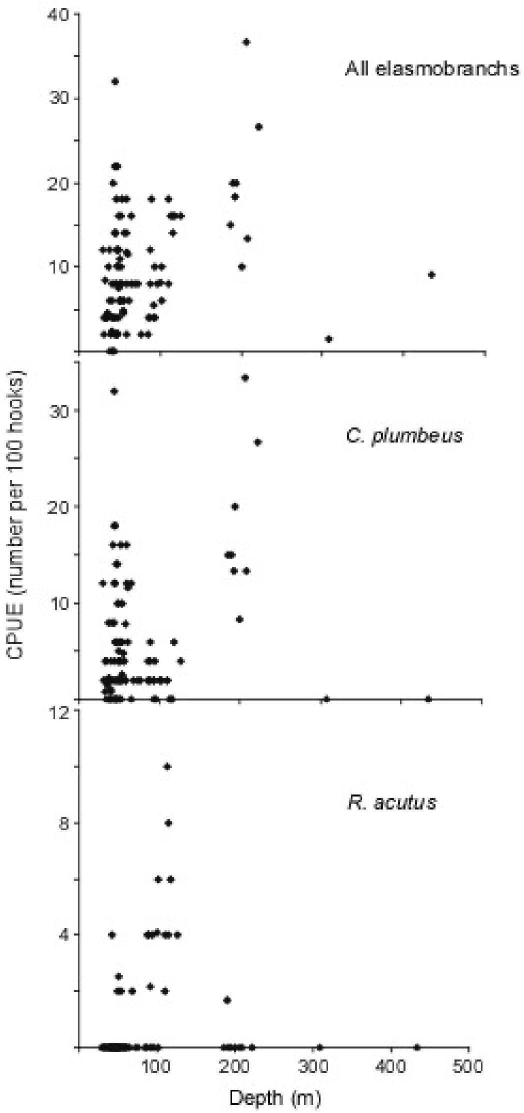
For *C. amblyrhynchos,* the only species encountered in sufficient numbers in both longline and dive surveys, mean CPUE in sanctuary zones was 1.7 compared to a mean of 0.3 outside sanctuary zones.

When the catch data were separated into three depth zones, the catch rate of elasmobranchs increased with depth (Table 12) and this trend was reflected in the catch of *C. tilstoni/C. limbatus, C. sorrah* and *R. acutus* while *C. amblyrhynchos* and *G. cuvier* showed a decreasing CPUE with increasing depth zone. Catch rates of *C. plumbeus* were also highest in the deepest zone. However, when the individual catch data for the two most abundant species, and for the total catch, were plotted against depth no obvious trend was apparent (Fig. 13).

Table 12. Catch per unit effort by depth zone for the most frequently caught elasmobranchs from RV 'Naturaliste'longline surveys. CPUE is number of individuals per 100 hooks; figures in parentheses are number of hooks.

Species	<50 m (3160)	50-100 m (2302)	>100 m (1062)
C. amblyrhynchos	0.54	0.22	0
C. limbatus/tilstoni	0.13	0.39	1.51
C. plumbeus	4.46	4.26	9.04
C. sorrah	0.19	0.39	0.85
G. cuvier	0.82	0.39	0
L. macrorhinus	0.29	0.70	0.38
R. acutus	0.10	0.74	2.17
TOTAL	**7.25**	**8.21**	**15.35**

Figure 13. Relationship between abundance and depth for all elasmobranchs, *C. plumbeus* and *R. acutus* from longline surveys.



Historic data

Prior to 2007, the combined CPUE of all elasmobranchs varied from 2.74 in April 2004 to 16.54 individuals per 100 hooks in May/June 2002. Combined CPUE was generally highest but more variable prior to 2004 (the period for which most historic data are available, Fig. 14a). However, given the variability of individual species' catch rates within the combined rates, as well as differences in set depths, locations and habitats fished between trips, it is probably invalid to attribute any significance to this observation.

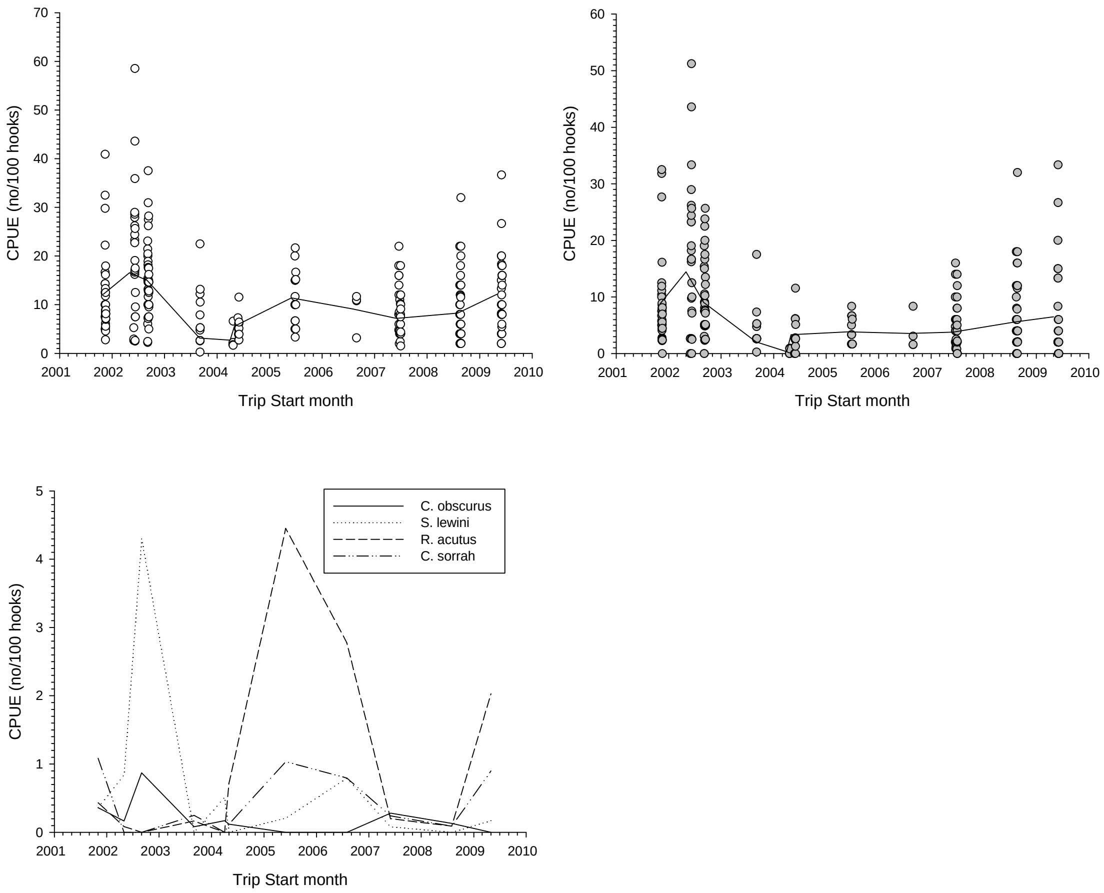
The target species, *Carcharhinus plumbeus* dominated historic catches with a CPUE of up to 14.44 in May/June 2002 and 6.71 over all eight trips prior to 2007. The next most frequently caught species were *S. lewini* (overall CPUE of 1.13), *R. acutus* (0.81), *C. sorrah* (0.39) and *C. obscurus* (0.30) (Tables 13 and Fig.14c). *Galeocerdo cuvier* catch rates were generally much lower and catches less consistent in the historical data than observed during the current project.

The overall catch rate of *C. plumbeus* declined from 8.4 sharks per 100 hooks prior to 2004 (10.9 sharks per 100 hooks over the first 3 trips) to 5.13 during the current study (Fig. 14b). The maximum observed catch rates of *C. plumbeus* also declined from 51.2 animals per 100 hooks in June 2002 to 33.3 sharks per 100 hooks between 2007 and 2009. Similarly, high catch rate shots (comprising at least 20 sharks per 100 hooks) were also notably lower during the current study (n=3) than before 2004 (n=15) and the lower 95^{th} percentile of sandbar shark CPUE declined from 5.3 sharks per 100 hooks prior to 2004 to 4.0 sharks per 100 hooks during the current study. In other words, prior to 2004, 95% of shots realised catch rates of at least 5.3 sandbar sharks per 100 hooks, compared to 4.0 per 100 hooks sharks during the current project. Conversely, the number of shots in which no sandbar sharks were caught increased from 10 to 17 between these periods (only five shots contained no sandbar sharks during the first two RV 'Naturaliste' trips). However, as preliminary Generalised Linear Model (GLM) analysis of these data suggested that depth, season and year had a significant influence on *C. plumbeus* CPUE (by number), any apparent trends in these data should be treated with caution.

Table 13. Historic elasmobranch catch rates (no/100 hooks) from RV 'Naturaliste' trips between November 2001 and August–September 2006.

	CPUE (no/100 hooks)								
Species	November 01	May–June 02	September 02	September 03	April 04	May–June 04	June–July 05	August–Sept. 06	Total
C. altimus	0.00	0.08	0.00	0.00	0.34	0.47	0.00	0.00	0.09
C. limbatus/tilstoni	0.14	0.08	0.12	0.00	0.00	0.12	1.04	0.40	0.21
C. obscurus	0.36	0.17	0.87	0.08	0.17	0.12	0.00	0.00	0.30
H. nakamurai	0.00	0.00	0.00	0.25	0.17	0.00	0.00	0.00	0.05
C. brachyurus	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.01
P. glauca	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
C. taurus	0.07	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.02
C. amblyrhynchos	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.01
C. acus	0.00	0.00	0.00	0.00	0.68	0.36	0.00	0.00	0.09
S. mokarran	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.40	0.02
S. lewini	0.36	0.84	4.30	0.00	0.51	0.00	0.21	0.79	1.13
N. acutidens	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.01
C. brevipinna	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.01
R. acutus	0.43	0.08	0.00	0.17	0.00	0.71	4.45	2.78	0.81
Unid. Squalid	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.01
L. macrorhinus	0.22	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.05
H. falcata	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
C. sorrah	1.09	0.00	0.00	0.25	0.00	0.12	1.04	0.79	0.39
Unid. dasyatid	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.01
C. albimarginatus	0.36	0.17	0.12	0.17	0.00	0.00	0.00	0.00	0.14
R. taylori	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.09
G. cuvier	0.22	0.25	0.19	0.00	0.34	0.00	0.10	0.40	0.16
C. plumbeus	8.76	14.44	9.03	2.08	0.34	3.32	3.83	3.57	6.71
N. ferrugineus	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.01
O. halei	0.00	0.08	0.06	0.00	0.00	0.00	0.00	0.00	0.02
M. stevensi	0.00	0.08	0.19	0.00	0.00	0.00	0.00	0.00	0.05
Unid. Shark	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.01
All spp.	12.17	16.54	15.02	3.16	2.74	5.58	11.39	9.13	10.46

Figure 14. CPUE of (a) all elasmobranchs, (b) *C. plumbeus* and (c) the four next most 'abundant' species caught during RV 'Naturaliste' trips 2001–2009. Circles are the CPUE of individual shots and lines indicate the total trip CPUE.



3.3.4 Size structure

Lagoon and reef edge

Size-frequency data for the more commonly observed species from all sites combined are shown in Appendix 2, Fig. 2.1. The size range of species less commonly seen on the dive surveys are given in Appendix 2, Table 2.1. Because of the generally low numbers of elasmobranchs seen at each site, the data were insufficient to examine possible differences in size structure between sites, or between sanctuary and non-sanctuary zones. However, there were some sites with relatively large aggregations of elasmobranchs and these were all in sanctuary zones. At Pelican Point in April 2007, a group of 14 *C. melanopterus* were seen together close to the shore in very shallow water. These fish were all estimated to be about 35 cm TL (see the large mode in Fig. 2.1b) and would be neonates. No *C. melanopterus* of this size were seen in the December 2008 survey. Aggregations of between 28 and 50 *G. typus* were recorded at four sites (Table 13) in very shallow water over sand or muddy sand. Of these, 55 individuals were estimated at 40–45 cm, 46 at 65–75 cm, 59 at 85–140, 47 at 160–165 and one each at 200 and 250 cm. Of 40 *P. atrus* seen at three sites, 26 were about 75 cm (Table 13). The overall size distributions of *G. typus* and *P. atrus* are shown in Figs 2.1d and h. *Glaucostegus typus* is born at 38–40 cm, matures at 150–180 and reaches at least 270 cm TL. *Pastinachus atrus* attains about 200 cm and is born at about 18 cm DW; size at maturity is unknown (Last and Stevens 2009).

Carcharhinus amblyrhynchos observed on the reef edge surveys (n = 25) were all between 100–160 cm TL while of those seen in the lagoon 41.6% (n = 12) were less than 100 cm. There did not appear to be much difference in sizes of *T. obesus, N. kuhlii* or *T. lymma* seen on the different surveys (Table 14).

Table 13. Size structure of *G. typus* and *P. atrus* at sites where they were aggregated

Site	Sanctuary zone	Species	Number	Estimated size (cm)
Pelican Point	Yes	*G. typus*	20	65 TL
			8	100
Wnderabandi Point	Yes	*G. typus*	25	40
			25	100
Point Cloates	Yes	*G. typus*	35	165
			10	120
Mangrove Bay		*G. typus*	30	45
			6	85–120
			1	250
Pelican Point	Yes	*P. atrus*	26	75 DW
Wnderabandi Point	Yes	*P. atrus*	8	130
			2	160
			1	140
			1	90
Point Cloates	Yes	*P. atrus*	10	160
			1	200

Table 14. Size range, mean size and sample sizes for some of the more commonly observed species on dive surveys. TL (cm) for shark, DW (cm) for rays.

Species	April 2007	Reef edge	December 2008
T. obesus	100–140 (114.5) n=10	90–160 (121.3) n=8	110–200 (135.6) n=9
N. kuhlii	20–40 (33.4) n=36	20–50 (33.1) n=13	30–40 (33.8) n=17
T. lymma	20–40 (30.4) n=26		20–35 (25.5) n=24

Offshore

The length-frequency data for *C. plumbeus,* the most commonly caught species on the longline surveys, are shown separately for the three cruises and split by sex in Fig. 15. Catches of this species ranged in size from 70–161 cm FL. In 2007, the female size distribution was unimodal with the peak mode at 145–150 cm (Fig. 15a) while in the succeeding two years the distribution was bimodal. In 2008, the peak modes were at 125–130 and 150–155 cm (Fig. 15b) while in 2009 they were at 110–115 and 145–150 cm (Fig. 15c). Males were smaller than females and were between 110–155 cm in 2007 and 2008, but a larger distribution of sizes was caught in 2009 (70–155 cm). Females predominated in the catch in 2007 and 2009, while the sexes were caught in about equal numbers in 2008 (Fig. 15c).

Figure 15. Length-frequencies for *C. plumbeus* from RV ‘Naturaliste’ longline surveys (a) June–July 2007 (b) August 2008 (c) May–June 2009. Females above, males below.

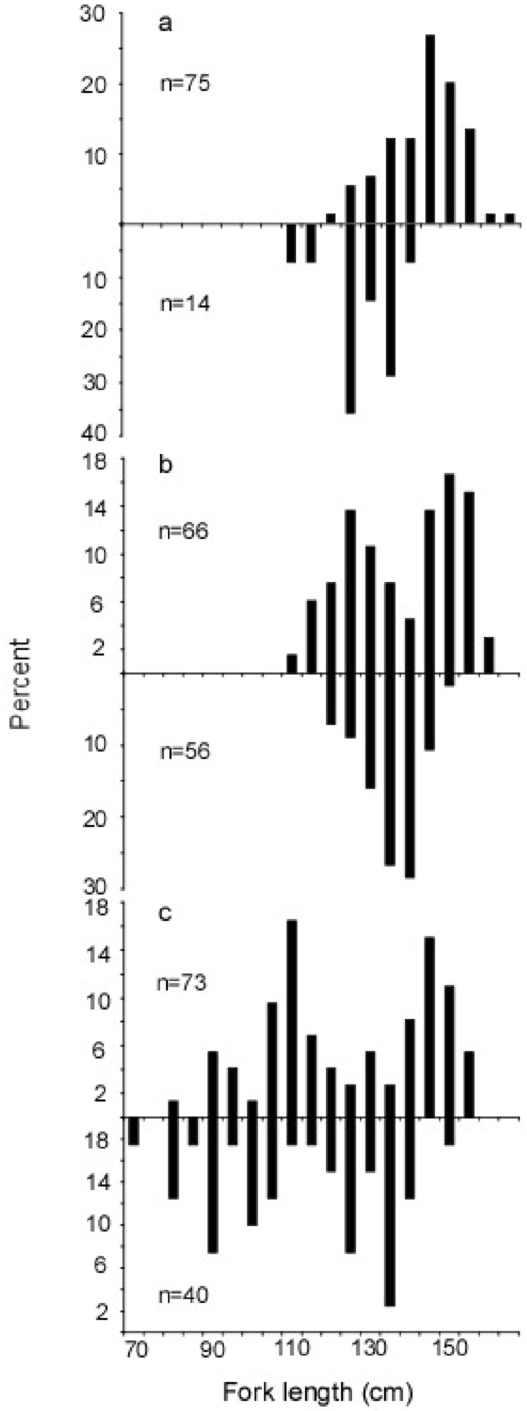
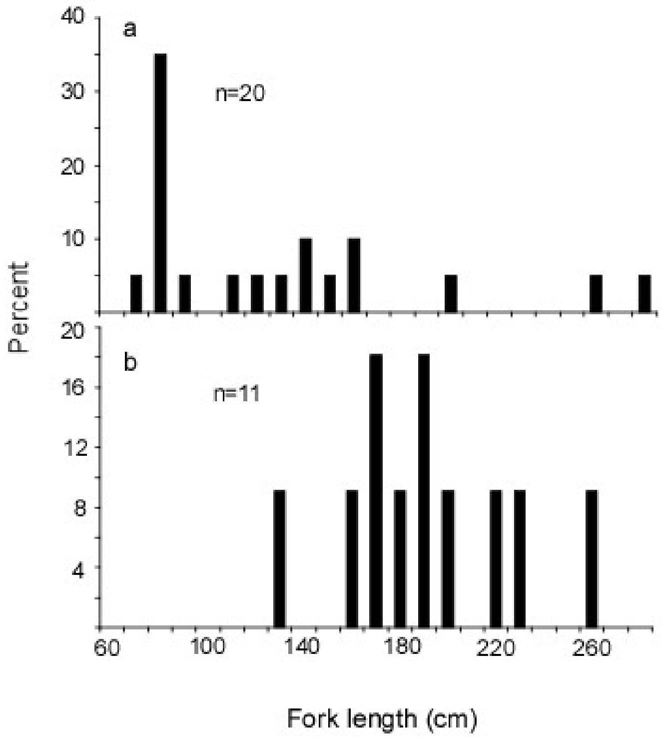


Figure 16. Length-frequencies for *G. cuvier* from RV 'Naturaliste' longline surveys (a) June–July 2007 (b) August 2008



Galeocerdo cuvier was not caught in sufficient numbers to split the size data by sex (Fig. 16). Only one individual (122 cm female) was caught on the 2009 cruise. Individuals ranged in size from a 69 cm male to a 276 cm FL female. The 2007 catches contained several small fish with a mode at 80–90 cm. The 2008 catch was dominated by females (10 females, 2 males) while the sexes were about equal in 2007 (11 females, 9 males).

The size-distributions of other species caught on the longlines in smaller numbers are shown in Figs17 and 18 and Table 15. *Carcharhinus limbatus* and *C. tilstoni* are currently only separable by genetics and meristics and as this was not carried out these two species were not discrimated in the catch. About equal numbers of each sex were caught for *C. albimarginatus* and *C. sorrah* while males dominated the catch of *C. amblyrhynchos* (19:1) and *C. tilstoni/limbatus* (17:1) and females dominated the catch of *L. macrorhinus* (20:5) and *R. acutus* ((26:4).

Figure 17. Length-frequencies from R.V 'Naturaliste' longline surveys (a) *C. amblyrhynchos* (b) *C. albimarginatus* (d) *C. tilstoni/limbatus*

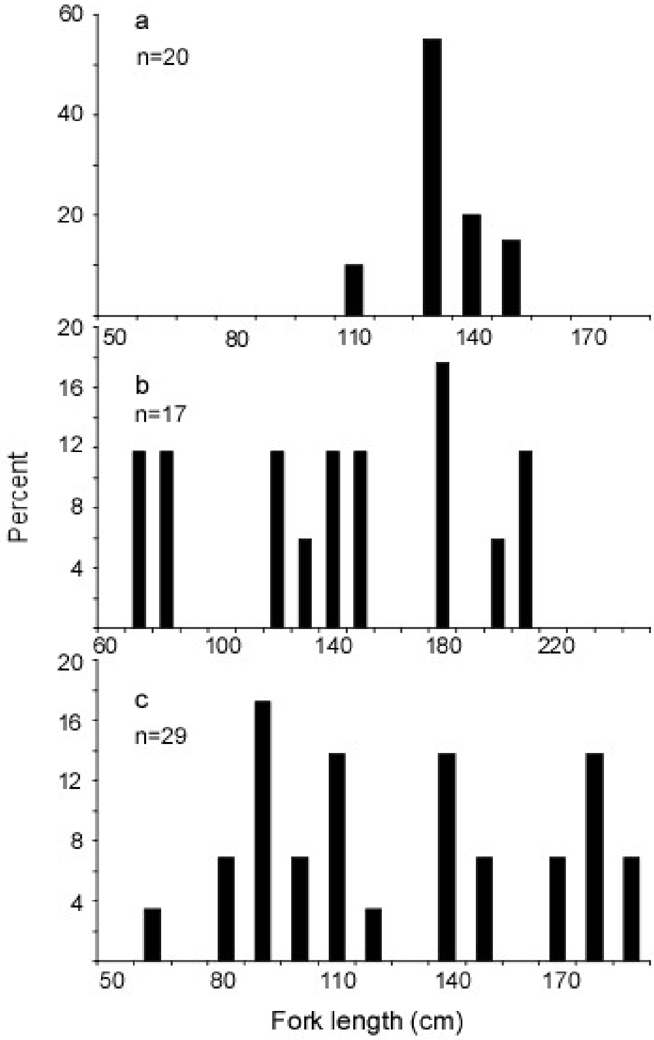


Figure 18. Length-frequencies from R.V 'Naturaliste' longline surveys (a) *C. sorrah* (b) *L. macrorhinus* (c) *R. acutus*

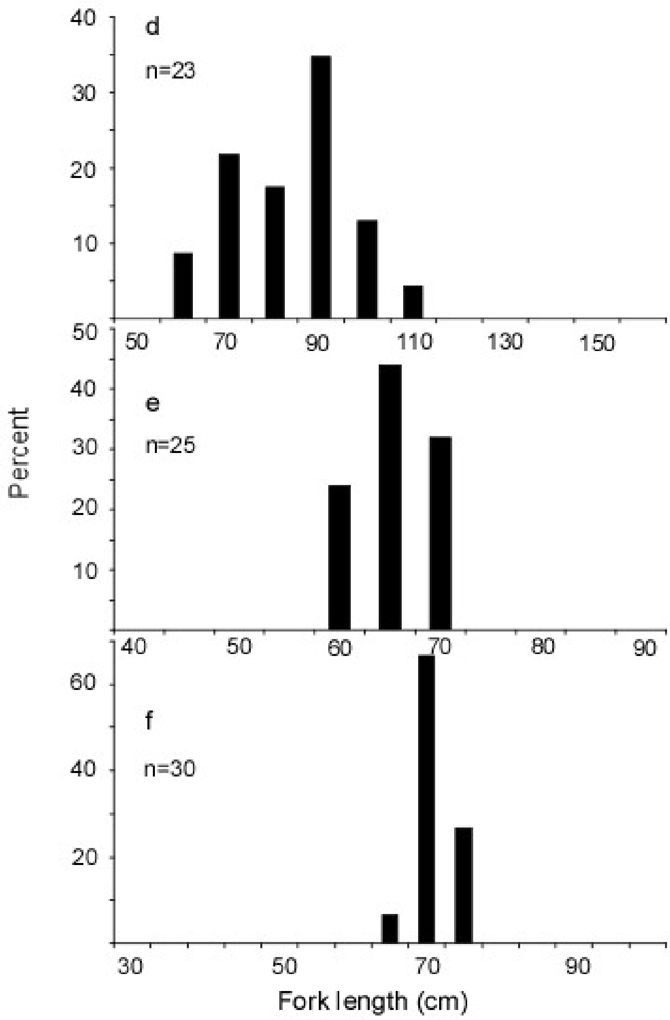


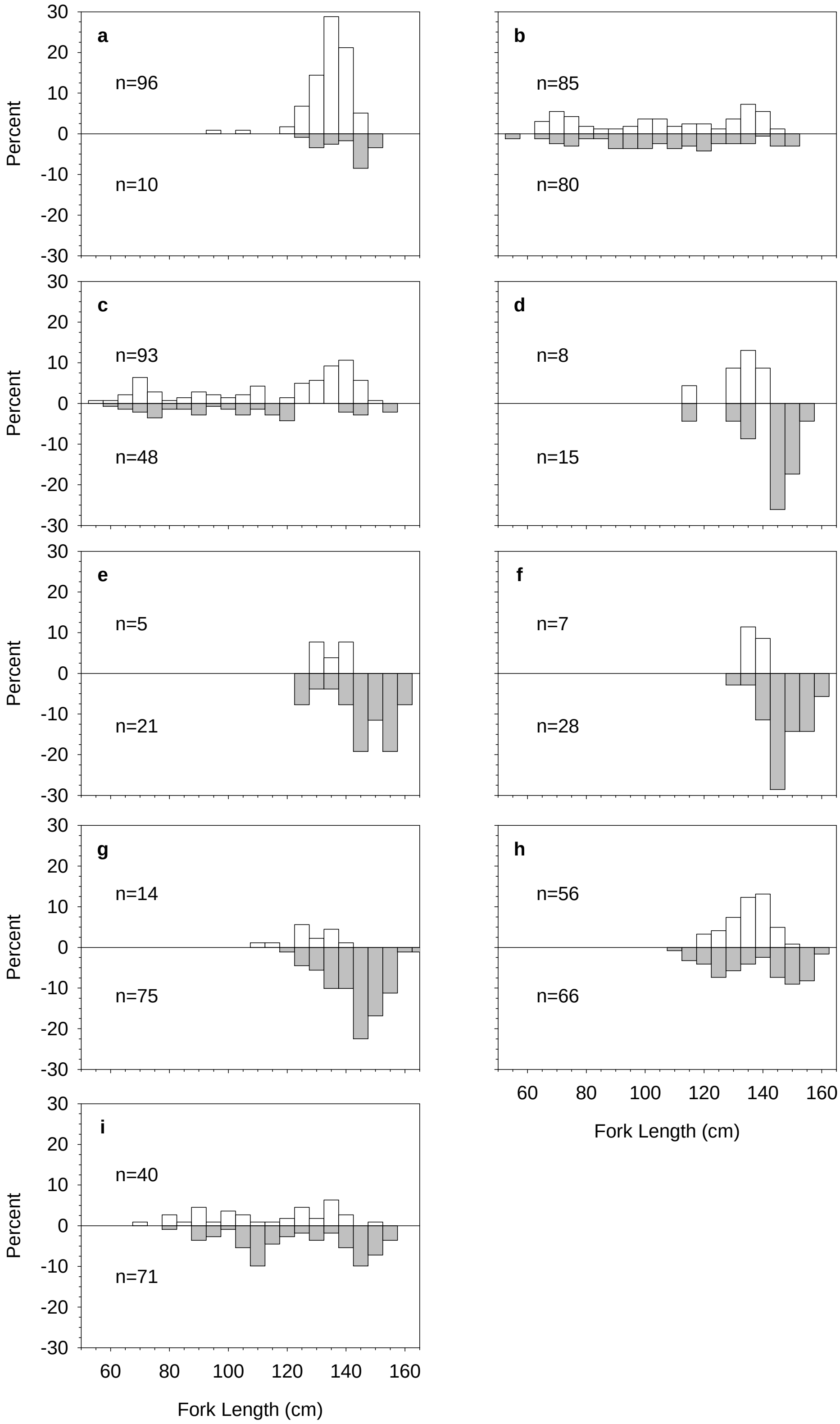
Table 15. Length range and sex of minor species caught by longlining from RV 'Naturaliste'. Fork lengths except for *N. ferrugineus* and *R. australiae* which are TL.

Species	Length range	Males	Females	Total
H. nakamurai	76–82	2	0	2
N. ferrugineus	220–297	6	0	8
A. pelagicus	125	0	1	1
C. altimus	124–193	2	1	3
C. amboinensis	171	1	0	1
C. dussumieri	65	1	0	1
C. obscurus	205–275	1	7	10
S. lewini	128–190	2	2	4
S. mokarran	146–235	2	2	5
R. australiae	190–250	0	4	5

Historic data

Catches of *C. plumbeus* were significantly biased in favour of males prior to 2004 and towards females in subsequent trips (χ^2, df=1, P<0.05; Fig. 19). Apart from catches in April 2004 and August 2006 that were too small to reliably analyse, the only trips for which catches did not significantly vary from a 1:1 sex ratio were: May–June 2002 (χ^2, df=1, P<0.76), September 2003 (χ^2, df=1, P<0.21) and August 2008 (χ^2, df=1, P<0.42). However, no clear trends were observed in the size composition data for *C. plumbeus* catches and the size frequencies of their catches has varied considerably between trips (Fig. 19). Based on the lengths at maturity reported by McAuley et al., 2007 (FL_{50}>136 for females and FL_{50}>127 for males), adult-sized *C. plumbeus* accounted for more than two thirds of catches in November 2001, September 2003, May–June 2004, June–July 2005, June–July 2007 and August 2009. Omitting the small samples obtained from the April 2004 and August 2006 trips, the distribution of (5cm FL) size classes was relatively uniform in catches from the other three trips.

Figure 19. Length and sex composition of historic RV 'Naturaliste' *C. plumbeus* catches in (a) November 2001; (b) May–June 2002; (c) September 2002; (d) September 2003; (e) May–June 2004 and (f) June–July 2005. Current project data are also displayed in the same format for visual comparison (h–i).



3.3.5 Spatial dynamics

Acoustics
A total of 56 acoustic tags were deployed on six species of sharks and three species of rays in the Ningaloo Marine Park in February 2008 (Table 16). The smallest fish tagged was a 38.4 cm DW *P. atrus* and the largest was a 396 cm TL *G. cuvier.*

The 57 elasmobranchs caught comprised:

- 11 Nervous Sharks (*Carcharhinus cautus*)
- 10 Giant Shovelnose Rays (*Glaucostegus typus*)
- 9 Blacktip Reef Sharks (*Carcharhinus melanopterus*)
- 9 Grey Reef Sharks (*Carcharhinus amblyrhynchos*)
- 8 Cowtail Stingrays (*Pastinachus atrus*)
- 4 Porcupine Rays (*Urogymnus asperrimus*)
- 4 Lemon Sharks (*Negaprion acutidens*)
- 1 Tiger Shark (*Galeocerdo cuvier*)
- 1 Whitetip Reef Shark (*Triaenodon obesus*)

Table 16. Acoustic tags deployed on elasmobranchs in the Ningaloo Marine Park in February 2008.

Species	Date	Size	Sex	Serial No.	Position
P. atrus	22/02/08	384	M	1045407	Mangrove Bay
P. atrus	23/02/08	434	F	1046102	Mangrove Bay
P. atrus	23/02/08	458	F	1046092	Mangrove Bay
P. atrus	23/02/08	398	M	1046118	Mangrove Bay
P. atrus	23/02/08	c. 550	F	1046103	Mangrove Bay
P. atrus	24/02/08	490	M	1046104	Mangrove Bay
P. atrus	27/02/08	797	F	1045398	Mangrove Bay
P. atrus	28/02/08	810	M	1045408	Mangrove Bay
N. acutidens	22/02/08	820	F	1045395	Mangrove Bay
N. acutidens	22/02/08	810	M	1045393	Mangrove Bay
N. acutidens	22/02/08	770	F	1045392	Mangrove Bay
N. acutidens	23/02/08	730	M	1046115	Mangrove Bay
C. cautus	22/02/08	770	F	1045394	Mangrove Bay
C. cautus	23/02/08	740	M	1046117	Mangrove Bay
C. cautus	23/02/08	749	F	1046116	Mangrove Bay
C. cautus	23/02/08	798	F	1046119	Mangrove Bay
C. cautus	24/02/08	1099	F	1046021	Mangrove Bay
C. cautus	24/02/08	1079	F	1046022	Mangrove Bay
C. cautus	24/02/08	1143	F	1046020	Mangrove Bay
C. cautus	26/02/08	1170	F	1046005	Mangrove Bay
C. cautus	26/02/08	1100	F	1046002	Mangrove Bay
C. cautus	26/02/08	905	F	1046004	Mangrove Bay
C. cautus	26/02/08	1045	F	1046006	Mangrove Bay
G. typus	23/02/08	852	F	1046112	Mangrove Bay
G. typus	23/02/08	1191	M	1046111	Mangrove Bay
G. typus	23/02/08	862	M	1046113	Mangrove Bay
G. typus	24/02/08	978	M	1046090	Mangrove Bay
G. typus	26/02/08	2300	F	1046003	Mangrove Bay
G. typus	26/02/08	1050	M	1046097	Mangrove Bay
G. typus	26/02/08	1403	M	1046099	Mangrove Bay
G. typus	27/02/08	880	M	1045403	Mangrove Bay

G. typus	27/02/08	2250	F	1046096	Mangrove Bay
G. typus	27/02/08	1820	F	1046093	Mangrove Bay
C. melanopterus	23/02/08	901	F	1046091	Mangrove Bay
C. melanopterus	25/02/08	1340	F	1046008	21°98' S, 113°91' E
C. melanopterus	26/02/08	640	M	1046098	Mangrove Bay
C. melanopterus	26/02/08	1300	F	1046023	21°99' S, 113°91' E
C. melanopterus	26/02/08	1240	M	1046010	21°99' S, 113°91' E
C. melanopterus	27/02/08	1000	F	1046094	
C. melanopterus	27/02/08	1340	F	1046001	21°94' S, 113 92' E
C. melanopterus	27/02/08	1210	F	1046007	21°94' S, 113 92' E
C. melanopterus	28/02/08	780	M	1046095	
U. asperrimus	23/02/08	537	F	1046101	Mangrove Bay
U. asperrimus	24/02/08	550	M	1046114	Mangrove Bay
U. asperrimus	24/02/08	745	M	1046110	Mangrove Bay
U. asperrimus	24/02/08	585	M	1046100	Mangrove Bay
C. amblyrhynchos	23/02/08	1500	F	1046019	South Passage
C. amblyrhynchos	23/02/08	1680	F	1046017	South Passage
C. amblyrhynchos	24/02/08	1460	F	1046018	South Passage
C. amblyrhynchos	24/02/08	970	F	1046105	South Passage
C. amblyrhynchos	25/02/08	1760	F	1046016	21°98' S, 113°91' E
C. amblyrhynchos	26/02/08	1610	F	1046009	21°94' S, 113°92' E
C. amblyrhynchos	26/02/08	948	F	1045402	21°94' S, 113°92' E
C. amblyrhynchos	26/02/08	1520	F	1045399	21°94' S, 113°92' E
C. amblyrhynchos	26/02/08	1600	F	1045400	21°94' S, 113°92' E
G. cuvier	26/02/08	3960	F	1046024	22°00' S, 113°91' E
T. obesus	27/02/08	1130	F	Dead	21°96' S, 113°91' E

An additional 9 *C. amblyrhynchos,* 32 *C. melanopterus,* 6 *N. acutidens* and 2 *T. obesus* were acoustically tagged at Skeleton Bay (Coral Bay), some as early as the end of 2007, as part of a student PhD study (Conrad Speed, Charles Darwin University). The total number of sharks acoustically tagged at Ningaloo up until June 2009 is shown in Table 17 and Appendix 4, Table 4.1.

Table 17. Total number of sharks tagged at Ningaloo up until June 2009.

Species	Size class	Mangrove Bay	Skeleton Bay	Grand total
C. amblyrhynchos	<100	2		2
	>100	7	9	16
Total		**9**	**9**	**18**
C. cautus	<100	5		5
	>100	6		6
Total		**11**		**11**
C. melanopterus	<100	3	2	5
	>100	6	30	36
Total		**9**	**32**	**41**
G. cuvier	>100	1		1
Total		**1**		**1**
N. acutidens	<100	4	1	5
	>100		5	5
Total		**4**	**6**	**10**
T. obesus	>100		2	2
Total			**2**	**2**
Grand total		**34**	**49**	**83**

An additional 38 rays comprising 8 species were tagged in November/December 2008 and August/September 2009 (Table 18) as part of another student PhD project (Florencia Cerutti, Charles Darwin University).

Table 18. Acoustic tags deployed on rays in the Ningaloo Marine Park in November/December 2008 and August/September 2009. (Size is DW except for *G. typus* and *R. australiae*).

Species	Sex	Size	Tag ID Code	Tag type	Date	Locality
Nov/Dec 08						
G. typus	F	72 TL	53408	v13	22/11/08	Mangrove Bay
H. uarnak	M	46	53399	v13	12/11/08	Coral Bay
H. uarnak	F	45	8343	v13	12/11/08	Coral Bay
H. uarnak	M	76	53410	v13	23/11/08	Mangrove Bay
H. uarnak	M	40	53411	v13	28/11/08	Coral Bay
H. fai	M	74	53412	v13	02/12/08	Mangrove Bay
P. atrus	F	40.5	53398	v13	12/11/08	Coral Bay
P. atrus	F	35	53400	v13	12/11/08	Coral Bay
P. atrus	M	54	53405	v13	16/11/08	Mangrove Bay
P. atrus	F	50	53401	v13	19/11/08	Mangrove Bay
P. atrus	M	59	53403	v13	19/11/08	Mangrove Bay
P. atrus	M	88	53383	v16	20/11/08	Mangrove Bay
P. atrus	M	84	53407	v13	20/11/08	Mangrove Bay
P. atrus	M	76	53409	v13	23/11/08	Mangrove Bay
P. atrus	F	76	53384	v16	6/12/08	Mangrove Bay
T. lymma	F	29	53404	v13	15/11/08	Mangrove Bay
T. lymma	M	28	53406	v13	15/11/08	Mangrove Bay
Aug/Sept 09						
H. jenkensii	F	90	60955	v16	31/08/09	Mangrove Bay
H. jenkensii	M	90	60959	v16	31/08/09	Mangrove Bay
H. jenkensii	M	90	60956	v16	31/08/09	Mangrove Bay
H. jenkensii	M	100	60960	v16	31/08/09	Mangrove Bay
H. fai	F	150	60961	v16	04/09/09	Mangrove Bay
H. fai	F	120	60966	v16	04/09/09	Mangrove Bay
H. fai	M	150	60963	v16	04/09/09	Mangrove Bay
H. uarnak	M	100	60949	v16	21/08/09	Stanley's Pool
H. uarnak	M	100	60954	v16P	27/08/09	Mangrove Bay
H. uarnak	F	77	14513	v16P	28/08/09	Mangrove Bay
H. uarnak	M	100	60956	v16P	03/09/09	Mangrove Bay
P. atrus	F	100	60950	v16	21/08/09	Stanley's Pool
P. atrus	F	100	60951	v13	21/08/09	Stanley's Pool
P. atrus	M	100	60952	v16	27/08/09	Mangrove Bay
P. atrus	M	150	60953	v16	27/08/09	Mangrove Bay
P. atrus	F	80	14515	v16P	02/09/09	Mangrove Bay
P. atrus	M	100	60962	v16	03/09/09	Mangrove Bay
P. atrus	M	110	14511	v16P	03/09/09	Mangrove Bay
R. australiae	?	150 TL	14512	v16P	30/08/09	Mangrove Bay
T. lymma	F	31	60974	v16	25/08/09	Mangrove Bay
U. asperrimus	F	100	60984	v16	27/08/09	Mangrove Bay

Table 19. Total number of rays tagged at Ningaloo up until September 2009.

Species	Mangrove Bay	Skeleton Bay	Stanley's Pool	**Total**	Sizes (cm)	Juveniles	Adults
P. atrus	20	2	2	24	35–150 DW	18	6
H. cf *fai*	7	0	0	7	90–150 DW	0	7
H. uarnak	4	3	1	8	45–120 DW	5	3
H. fai	1	0	0	1	74 TL	1	0
G. typus	11	0	0	11	72 TL	9	2
R. australiae	1	0	0	1	150 TL	0	1
T. lymma	3	0	0	3	28–31 DW	0	3
U. asperrimus	5	0	0	5	100 DW	4	1
Total	52	5	3	**60**		37	23

Table 20. Total number of sharks still being detected at Ningaloo in 2009.

Species	**Mangrove Bay**	**Skeleton Bay**	**Total**
C. amblyrhynchos	2	9	11
C. cautus	4		4
C. melanopterus	5	23	28
G. cuvier	0		0
N. acutidens	2	5	7
T. obesus		2	2
Total	**13**	**39**	**52**

The total number of rays tagged at Ningaloo Reef up until September 2009 is shown in Table 19.

From the end of 2007 through to May 2009, a total of 83 sharks of 6 species have been monitored with acoustic telemetry in the Ningaloo region. Thirty four of these individuals were tagged at Mangrove Bay, and the remaining 49 were tagged at Skeleton Bay (Table 20). Of the 83 sharks tagged, 52 are still being detected in 2009; 13 of the 34 tagged at Mangrove Bay (38.2%) and 39 of the 49 individuals tagged at Skeleton Bay (79.6%) (Table 20). For *C. amblyrhynchos,* only 22.2% of individuals are still being detected in 2009 while at Skeleton Bay all tagged individuals are still being detected (Table 20). More than 430,000 detections of sharks have been recorded by the Ningaloo Reef Ecosystem Tracking Array (NRETA) during this study (Table 4.1). Only two tagged sharks have never (to date) been detected by NRETA, both of these were *C. melanopterus*.

Sharks were detected consistently by most of the stations within Mangrove Bay, although some stations recorded particularly high numbers of detections such as MB14A, MB23A and MB24B, which are situated close to shore (Fig. 20). High detections by these stations of juvenile *N. acutidens, C. cautus and C. melanopterus* may be due to this area acting as a communal nursery ground for several elasmobranch species. Approximately 30% of tagged sharks provided > 5,000 detections (Fig.21). Eleven of the thirteen individuals that have been detected in 2009 have been consistently detected in the array (Fig. 22). Percentage detection rates by species were similar for *C. cautus*, *C. amblyrhynchos*, and *C. melanopterus* (Fig 23).

Figure 20. Total detections of sharks by station at Mangrove Bay

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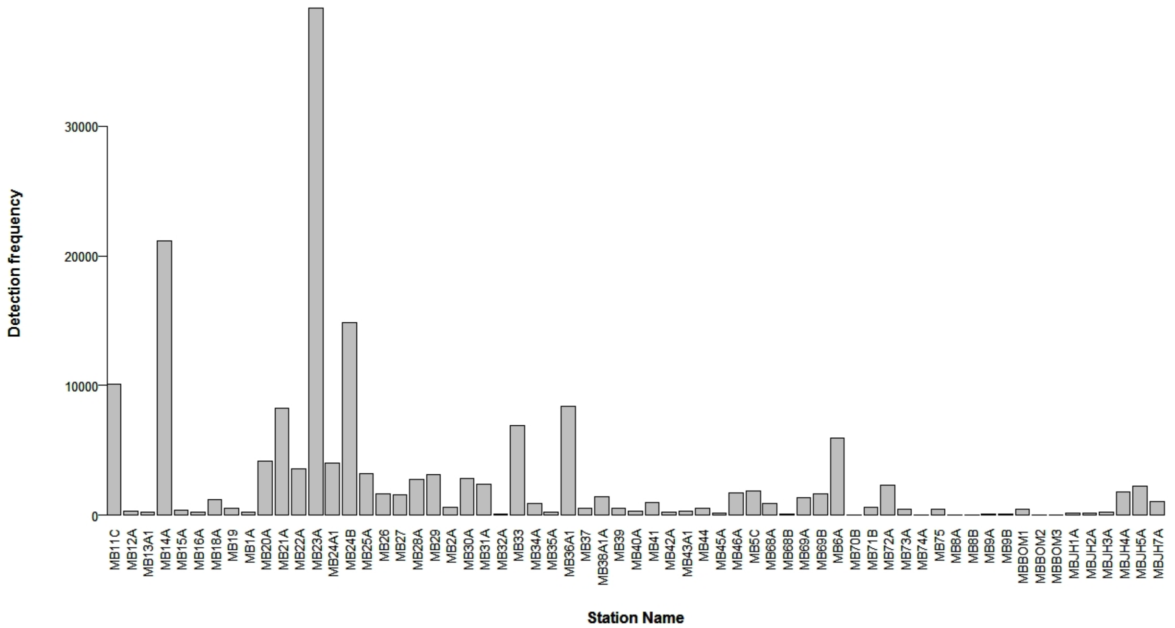


Fewer detections were recorded for *N. acutidens* with only three of the five individuals regularly detected; the other two were detected < 60 times. Only one *G. cuvier* was tagged and this individual was recorded regularly for about five months, but has not been detected since.

Figure 21. Total detections of sharks by tag number at Mangrove Bay

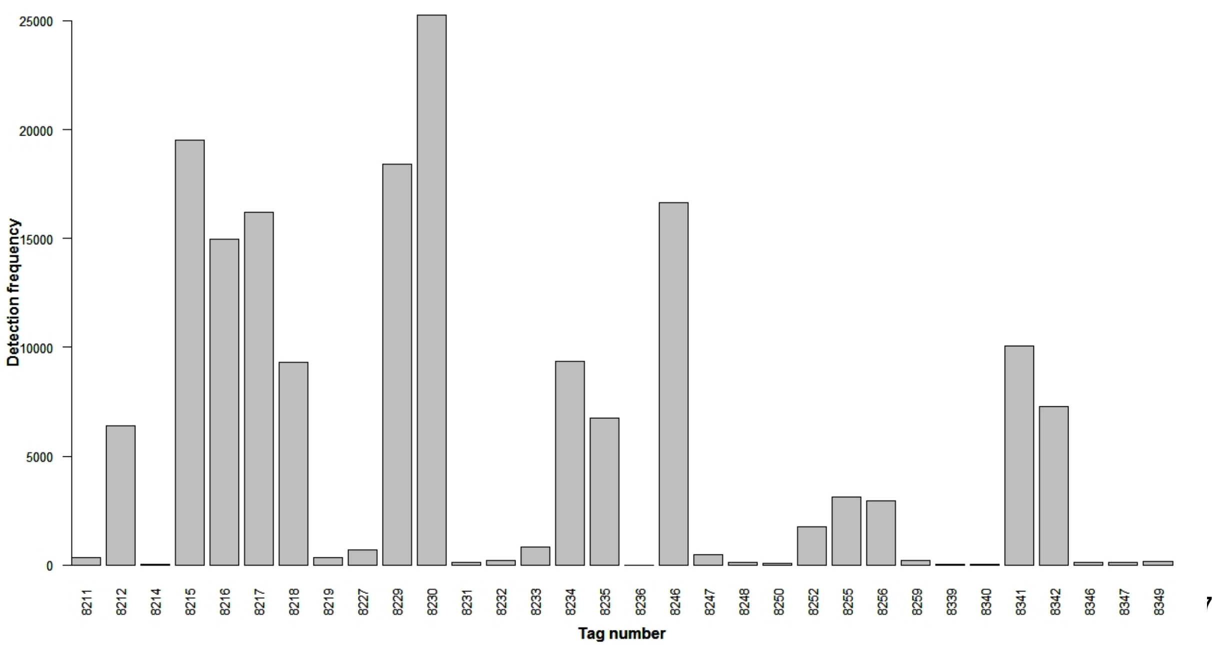


Figure 22. Total detections of sharks over time by tag number at Mangrove Bay

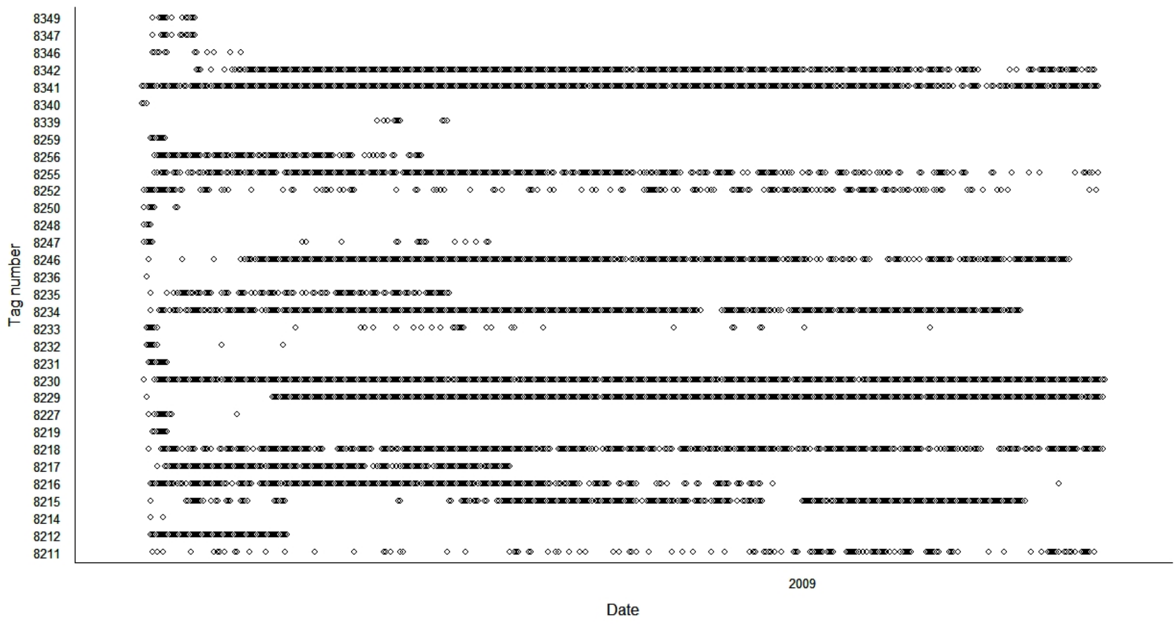
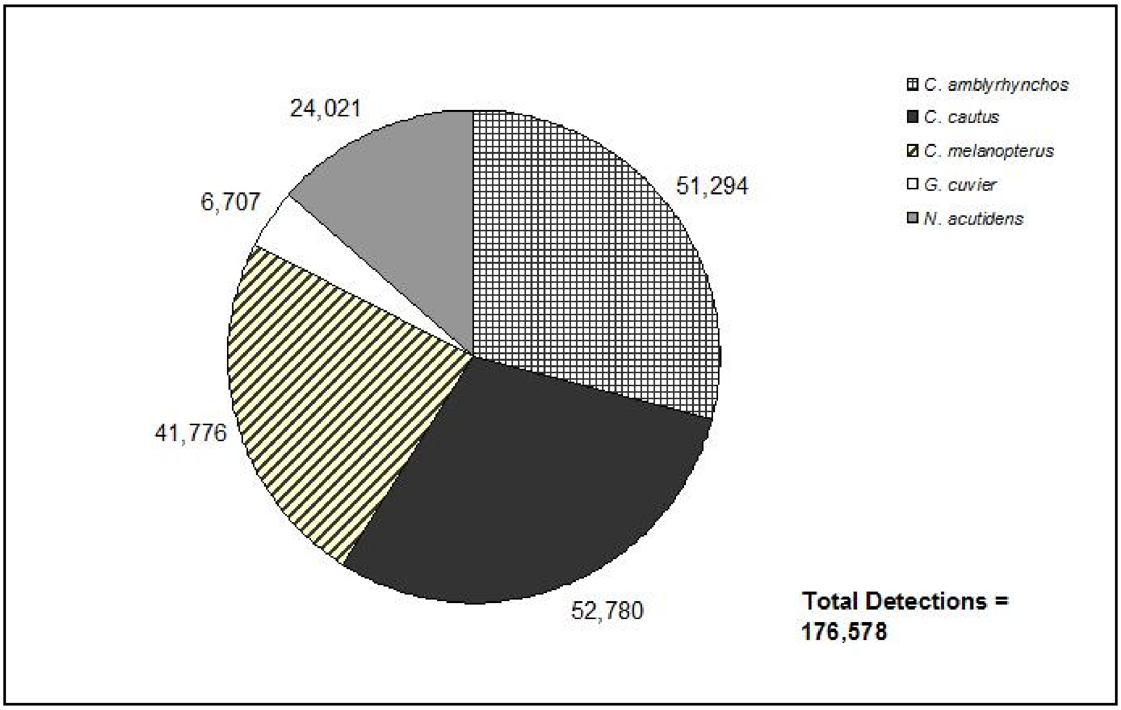


Figure 23. Percentage detection rates of shark species at Mangrove Bay



Negaprion acutidens was primarily detected near one receiver (MB23A), which is situated inside the sand spit of Mangrove Bay (Fig. 24). The density of both numbers of detections (Fig. 25a) and number of individuals (Fig. 25b) were consequently highest in this area.

Figure 24. Total detections of *Negaprion acutidens* by station at Mangrove Bay.

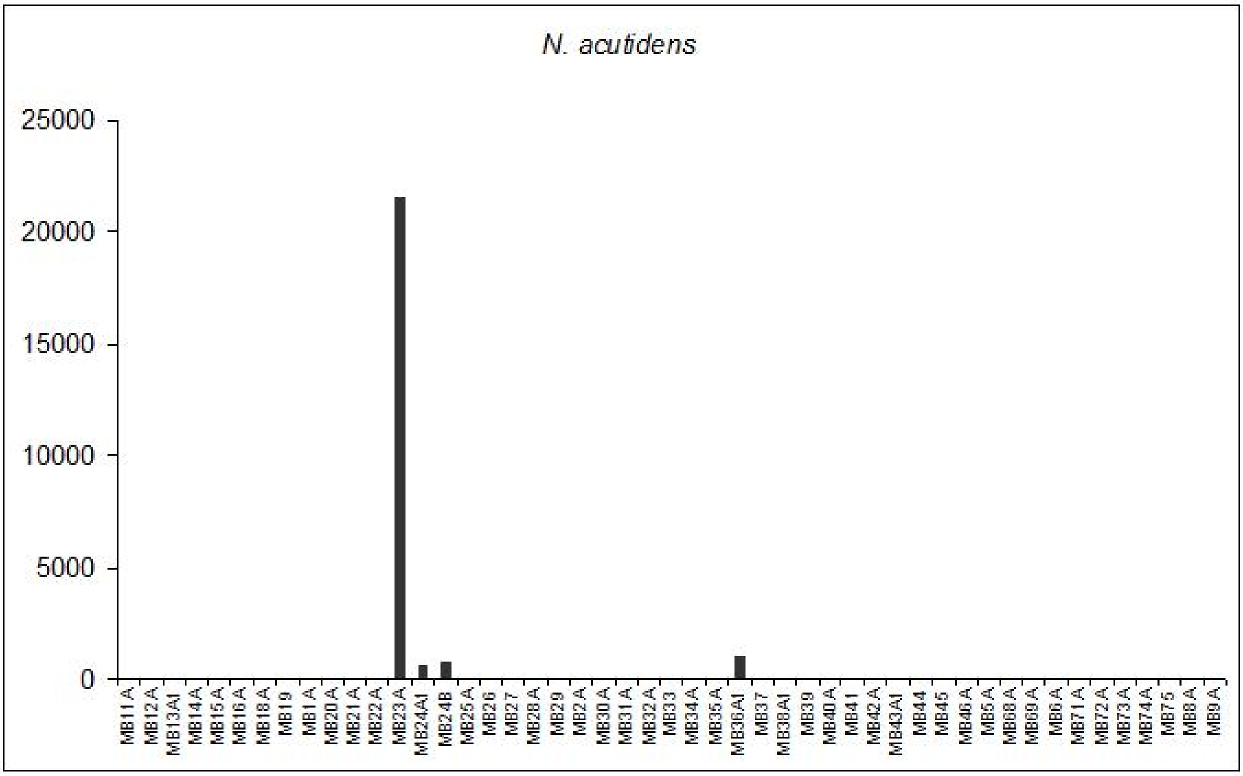
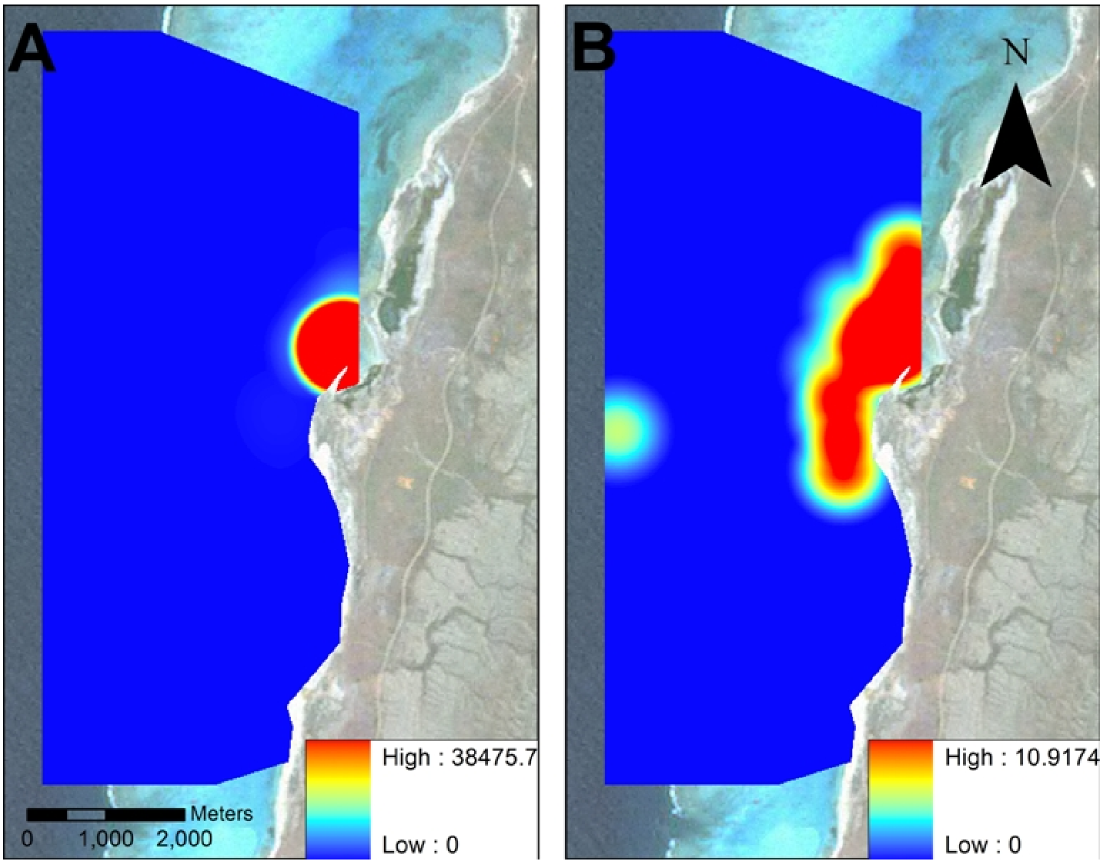


Figure 25 (A) Density of total detection of *N. acutidens* per km^2 and (B) Density of individuals per km^2 at Mangrove Bay.



Carcharhinus amblyrhynchos were intermittently detected along the outer reef crest and inside the channel by receivers MB11A, MB14A and MB6A (Fig. 26). These individuals were captured on long lines outside the reef. Although the density of detections was greatest around the entrance of the channel at Mangrove Bay (Fig. 27a), density of individuals (Fig. 27b) was also high within the lagoon; few detections were recorded inshore.

Figure 26. Total detections of *C. amblyrhynchos* by station at Mangrove Bay.

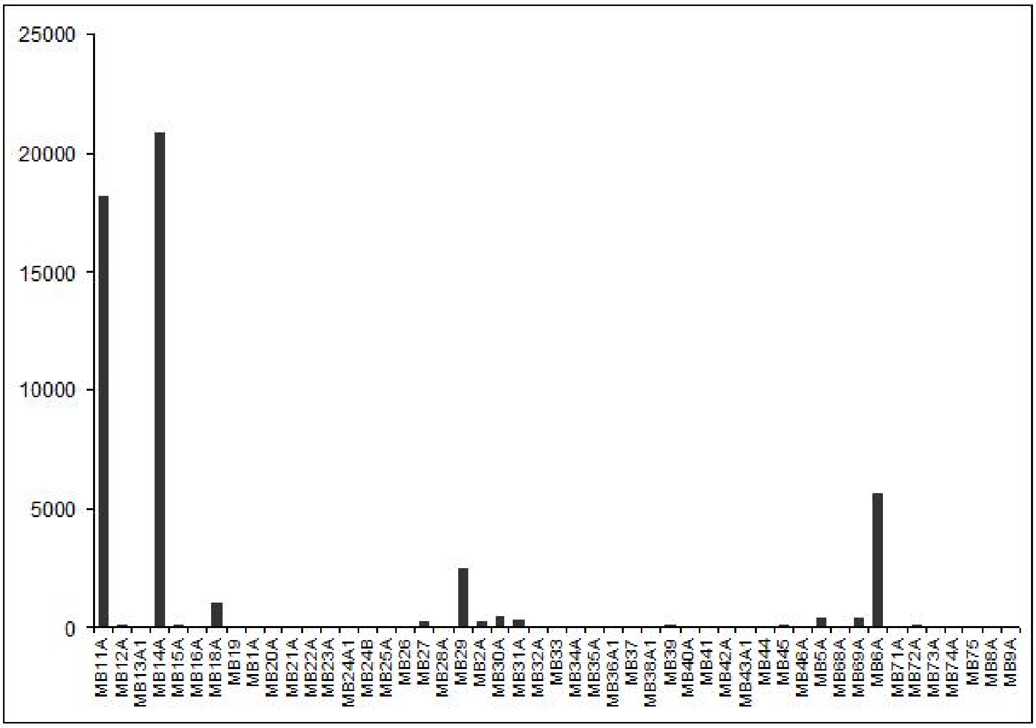
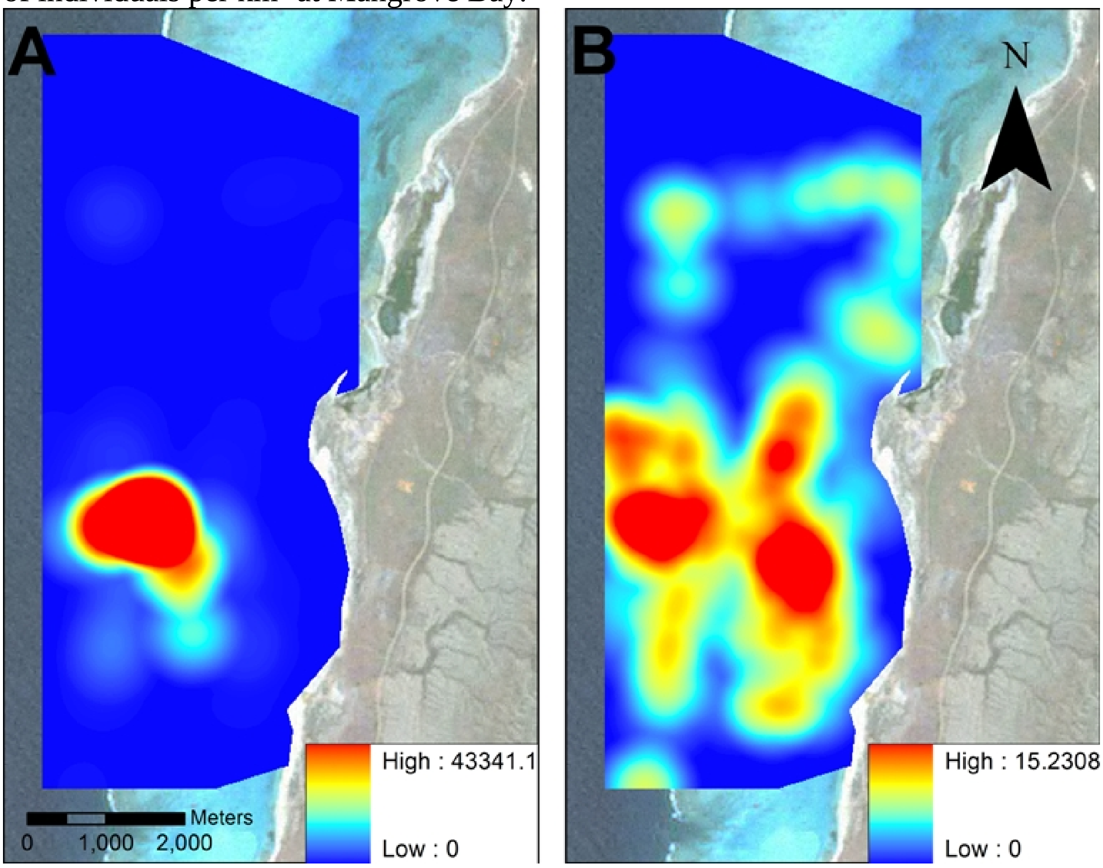


Figure 27 (A) Density of total detection of *C. amblyrhynchos* per km^2 and (B) Density of individuals per km^2 at Mangrove Bay.



Carcharhinus cautus detections were predominantly within the region immediately adjacent to the mangroves, particularly at MB23A, MB24B, and MB33 (Fig. 28) with few detections recorded outside this area. Detection and individual densities were spatially similar, with only a few individuals ranging outside of the area adjacent to the mangroves (Fig. 29a and b).

Figure 28. Total detections of *Carcharhinus cautus* by station at Mangrove Bay.

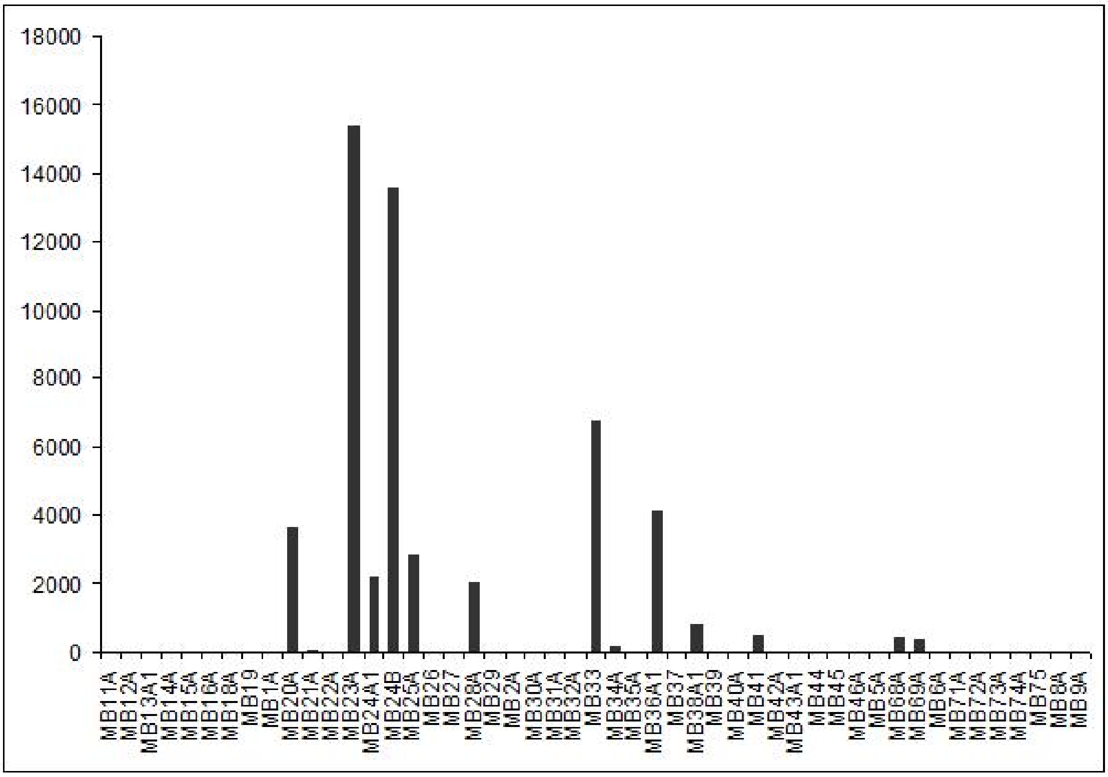
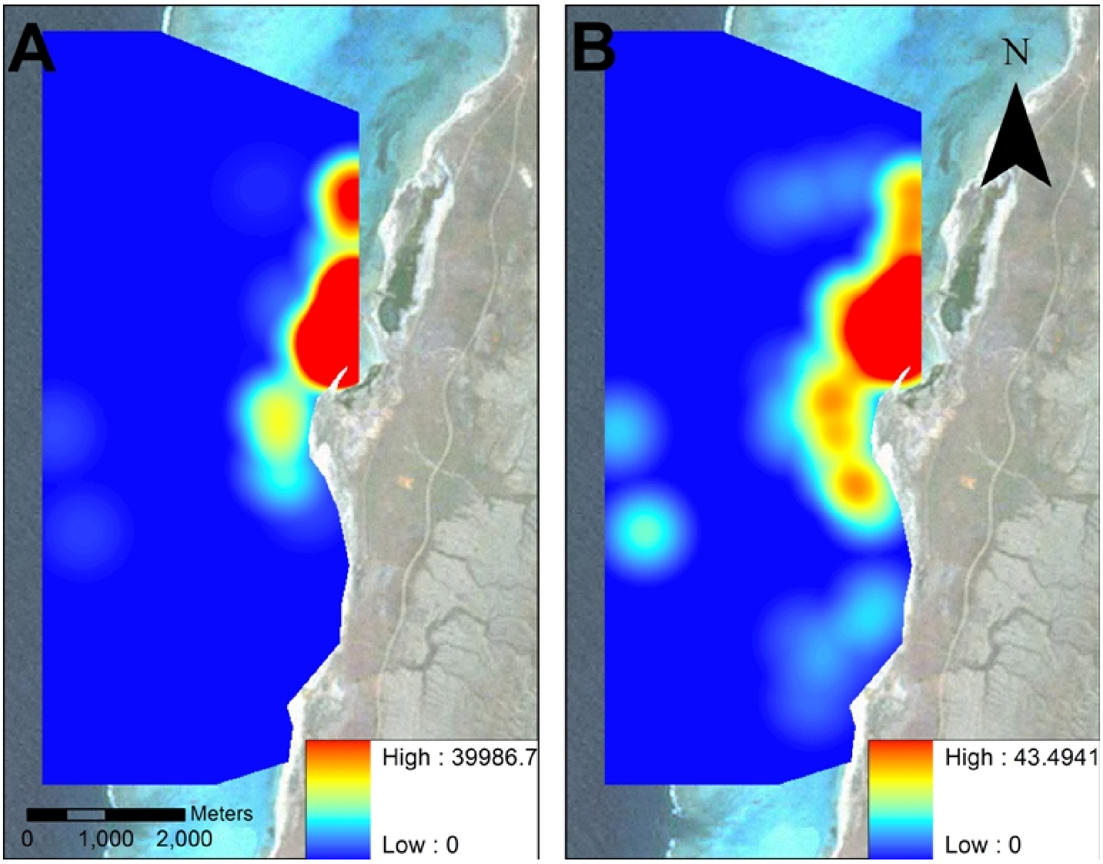


Figure 29 (A) Density of total detection of *C. cautus* per km^2 and (B) Density of individuals per km^2 at Mangrove Bay.



Carcharhinus melanopterus was detected at a wide range of receivers within Mangrove Bay (Fig. 30). There were detection hot spots both inside and around the spit and in the channel (Fig. 31a). The density of individuals is relatively high throughout a large portion of the area monitored in Mangrove Bay, with the highest density being recorded inshore (Fig. 31b).

Figure 30. Total detections of *Carcharhinus melanopterus* by station at Mangrove Bay.

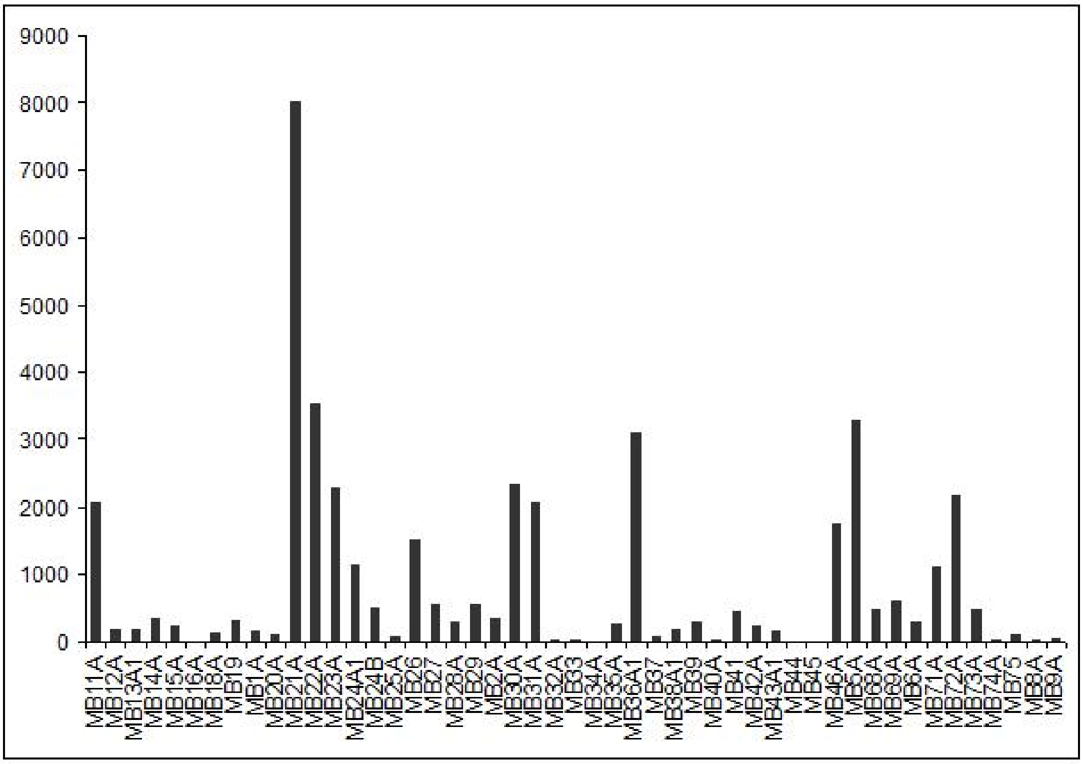
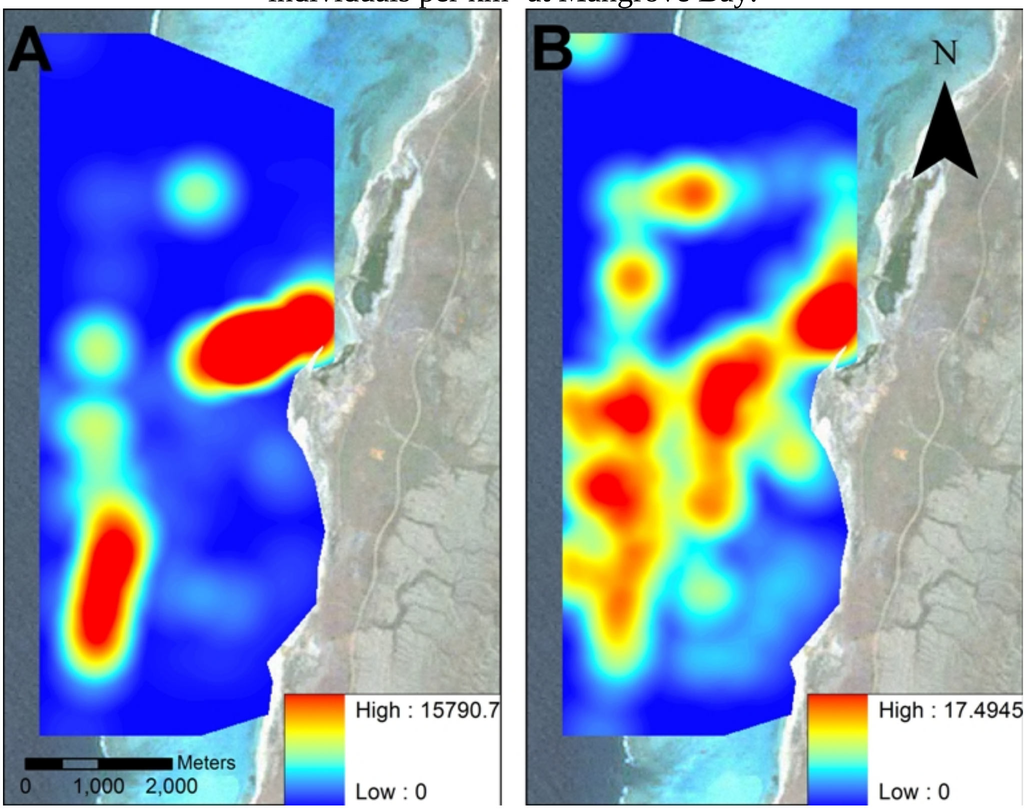


Figure 31 (A) Density of total detection of *C. melanopterus* per km^2 and (B) Density of individuals per km^2 at Mangrove Bay.



The one *Galeocerdo cuvier* tagged to date was monitored for approximately five months within the Mangrove Bay area. During this period it was detected on most receivers within the array (Figs 32 and 33).

Figure 32. Total detections of *Galeocerdo cuvier* by station at Mangrove Bay.

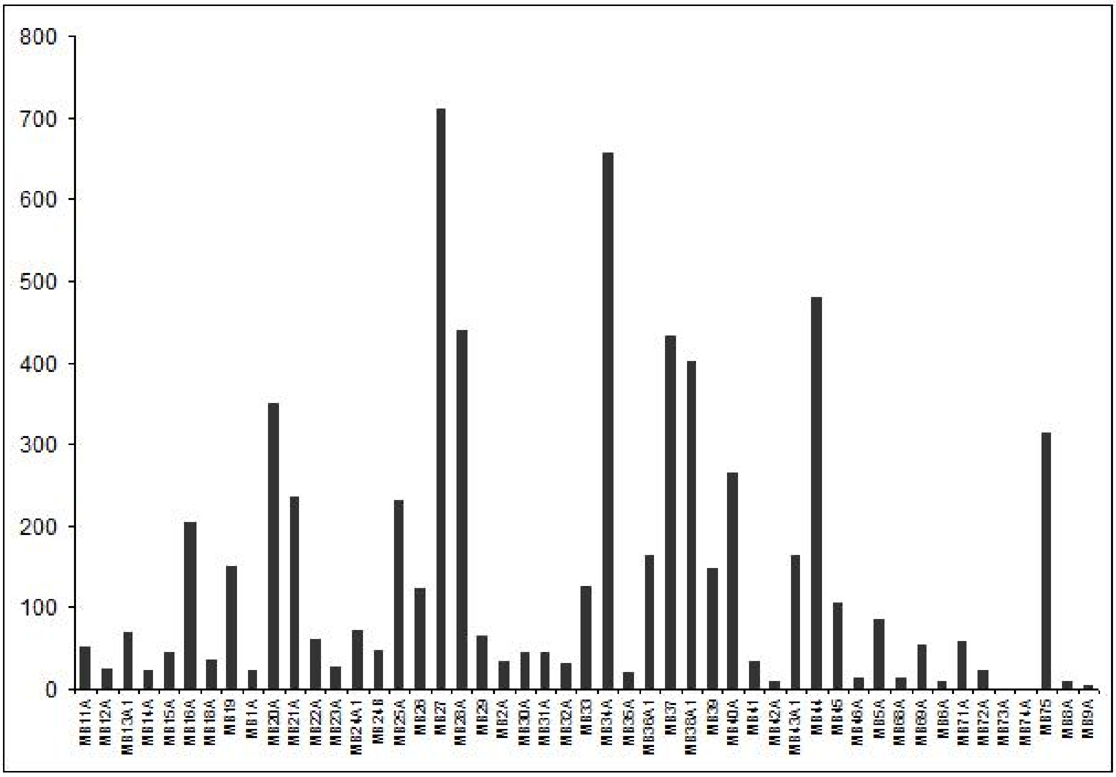
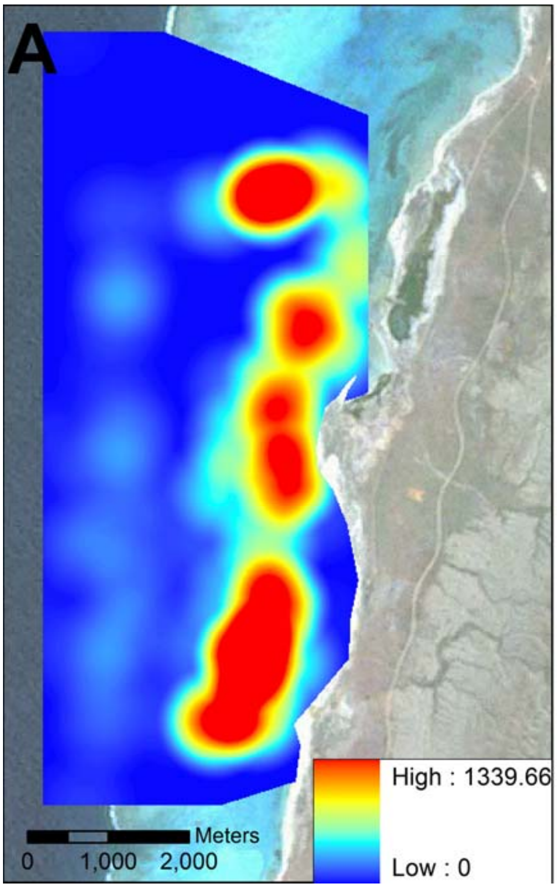


Figure 33 Density of total detection of *G. cuvier* per km^2 at Mangrove Bay



Data from the Coral Bay array (Fig. 34). are currently available for the period from November 2007 to May 2009 The greatest number of detections have been received in the Skeleton Bay portion of the array (Skully inner, Skully mid 1, Skully mid 2, Skully South and Skully North) (Fig. 35). The station Asho's CS is a cleaning station for *C. amblyrhynchos* and there have been a high number of detections from this species at that station. All sharks that have been tagged in Coral Bay have been detected, with some individuals having up to 65,000 detections (Fig. 36). Approximately 80% of individuals were still being detected by the array at the last download in May 2009 (Fig. 37).

Figure 34. Acoustic array at Coral Bay, Ningaloo Reef.

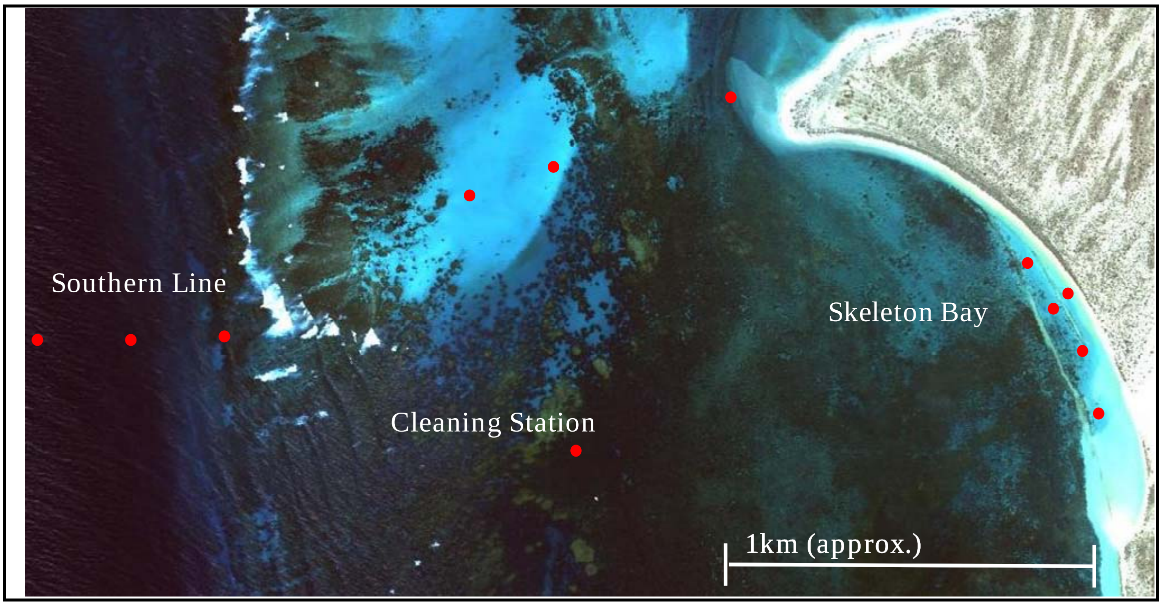
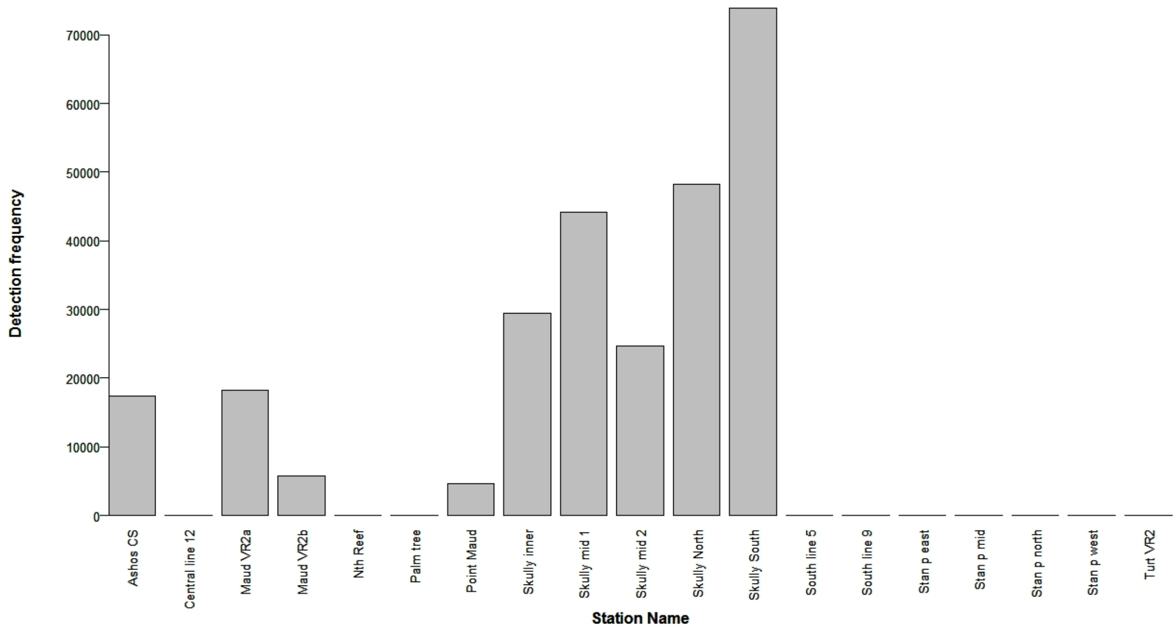


Figure 35. Total detections of sharks by stations in Coral Bay array.



Over the first year of monitoring, distinct detection patterns were observed for three adult female *C. melanopterus*, one juvenile *C. melanopterus*, and one adult female *C. amblyrhynchos* (Fig. 38). All sharks demonstrated an approximate 24 hr cycle of visiting Skeleton Bay, which was around 1500 h WA daylight savings time (1800 h

GMT). The juvenile *C. melanopterus* was detected almost exclusively by the Skeleton Bay receivers and also had a second peak in detections at around 0700 h WA daylight savings time (2200 h GMT).

Figure 36. Total detections of sharks by tag number at Coral Bay.

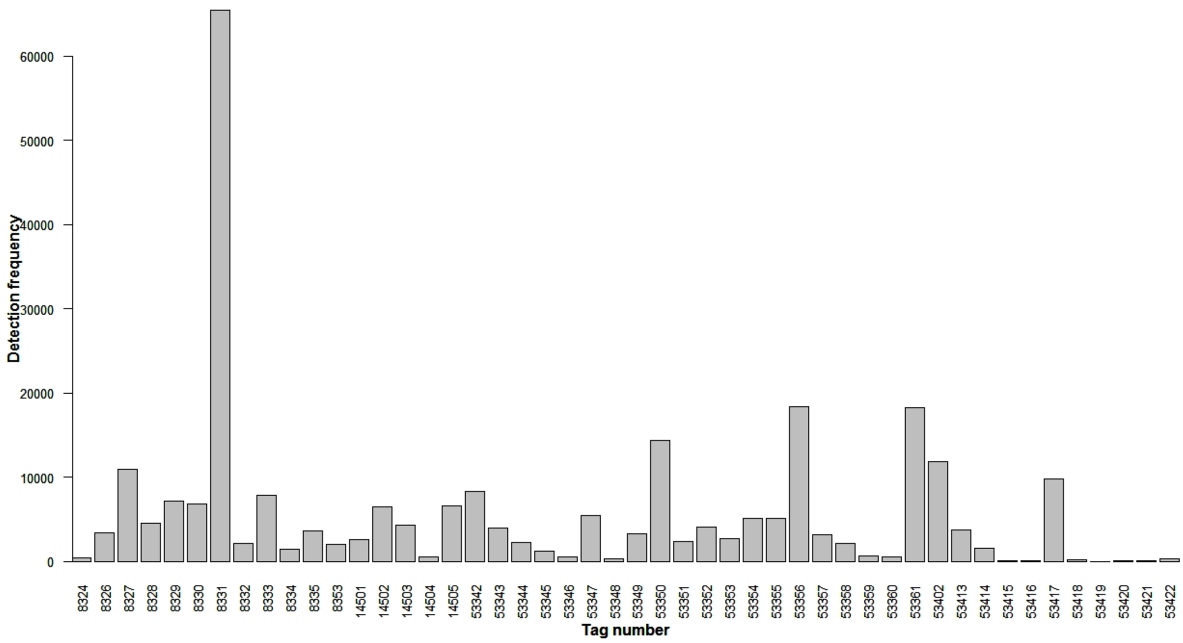


Figure 37. Total detections of sharks over time by tag number at Coral Bay.

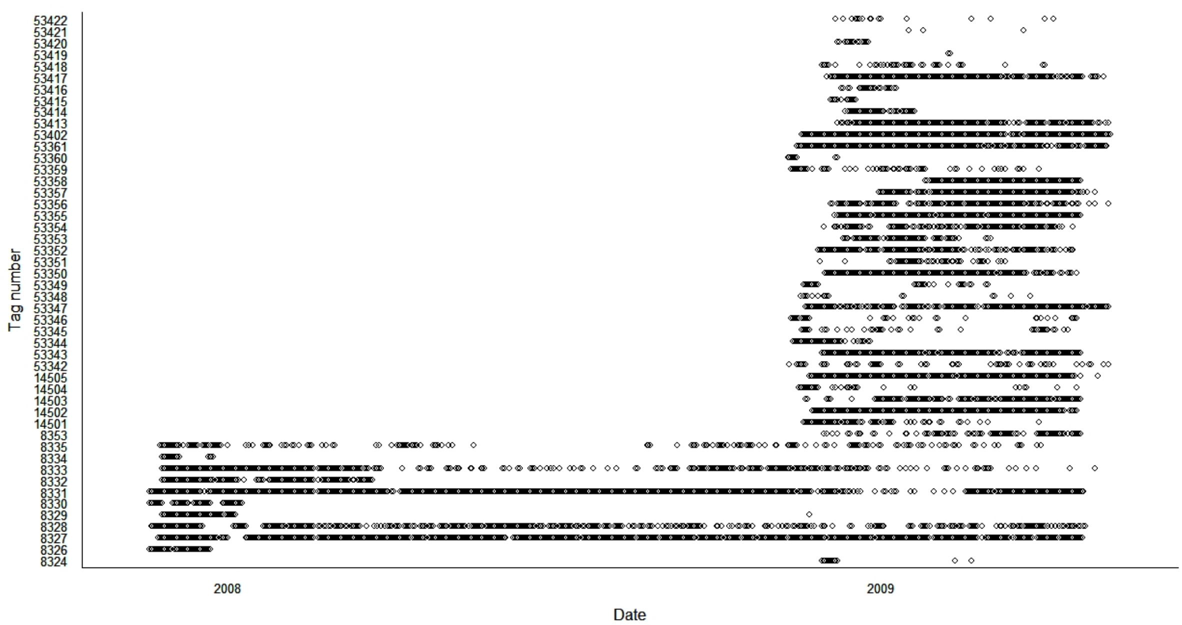
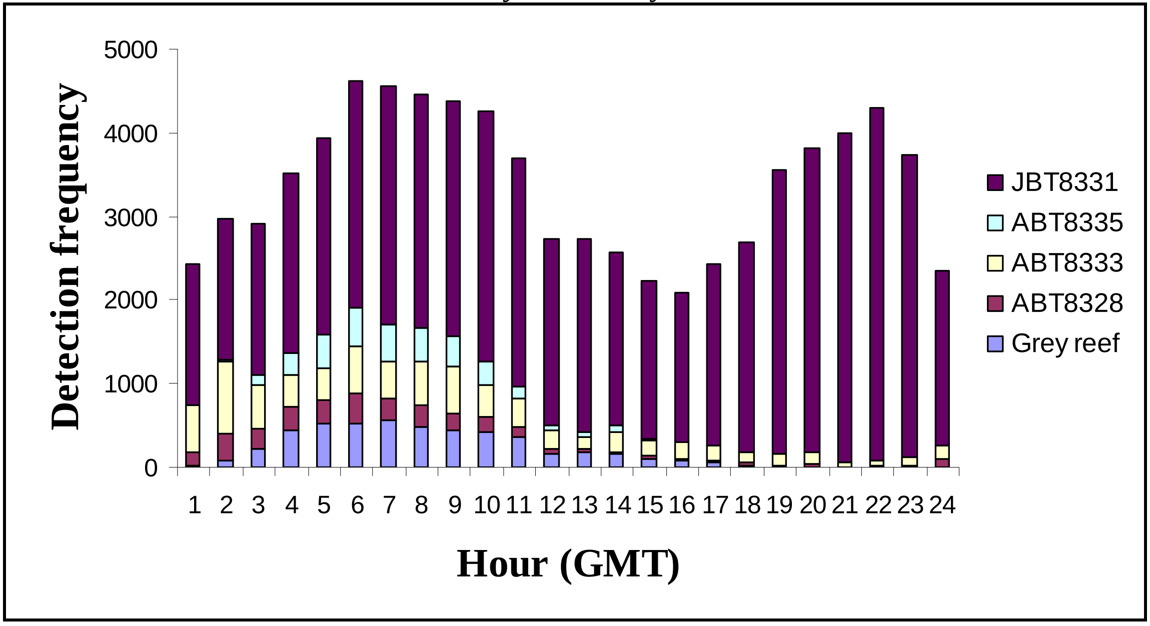


Figure 38. Detections by hour of five sharks monitored for the first year in Skeleton Bay, Coral Bay.



Of the 22 rays tagged in February, 18 were detected (81%); 63% of *P. atrus,* 70% of *G. typus* and 100% of *U. asperrimus* were detected for longer than one month. Sixteen of the rays tagged in February 2008 (5 *P. atrus,* 7 *G. typus,* and 4 *U. asperrimus*) and three tagged in November/December 2008 (2 *T. lymma* and 1 *H. uarnak*) were detected for more than a month and their data were used in this report (Table 21).

Table 21. Rays detected for more than one month after tagging

Species	Sex	DW	ID code	Date tagged	Last detection	Total detections	No. of VR2's detecting
P. atrus	F	45.8	8253	23/02/08	27/09/08	10072	6
P. atrus	F	55	8264	23/02/08	01/08/08	4801	16
P. atrus	M	49	8265	24/02/08	18/05/08	850	13
P. atrus	M	38.4	8354	22/02/08	16/11/08	428	22
P. atrus	M	81	8355	28/02/08	21/05/09	5976	4
G. typus	F	230 TL	8213	26/02/08	10/03/08	173	6
G. typus	M	119.1 TL	8242	23/02/08	04/04/08	119	11
G. typus	F	85.2 TL	8243	23/02/08	26/04/09	3842	14
G. typus	M	97.8 TL	8251	24/02/08	10/09/08	4391	8
G. typus	F	182 TL	8254	27/02/08	20/03/08	636	22
G. typus	M	105 TL	8258	26/02/08	15/07/08	170	8
G. typus	M	140.3 TL	8360	26/02/08	19/05/09	40	9
U. asperrimus	M	74.5	8241	24/02/08	10/02/09	9305	5
U. asperrimus	M	55	8245	24/02/08	08/05/09	16192	8
U. asperrimus	M	58.5	8261	24/02/08	22/02/09	5796	14
U. asperrimus	F	53.7	8262	23/02/08	03/08/08	9960	12
T. lymma	F	29	53404	15/11/08	06/01/09	68	5
T. lymma	M	28	53406	15/11/08	20/05/09	1648	4

H. uarnak	M	76	53410	23/11/08	21/05/09	2436	4

The number of detection records from each ray at each listening station in Mangrove Bay was collated and used to determine the degree of site-fidelity and a measure of minimum "dispersal" range during February and November/December 2008. For each individual, a "primary site" and "neighbouring sites" (sites with the most detection records) were designated and then plotted and mapped by species (Fig. 39–44).

Figure 39. *Pastinachus atrus* detections within the acoustic listening station array at Mangrove Bay. Receivers with detections are shown in yellow and brown. Primary site (PS) and neighbouring sites (NS1 and NS2) with the total percentage of detections are shown in brown. Limits of the sanctuary zone denoted by squares.

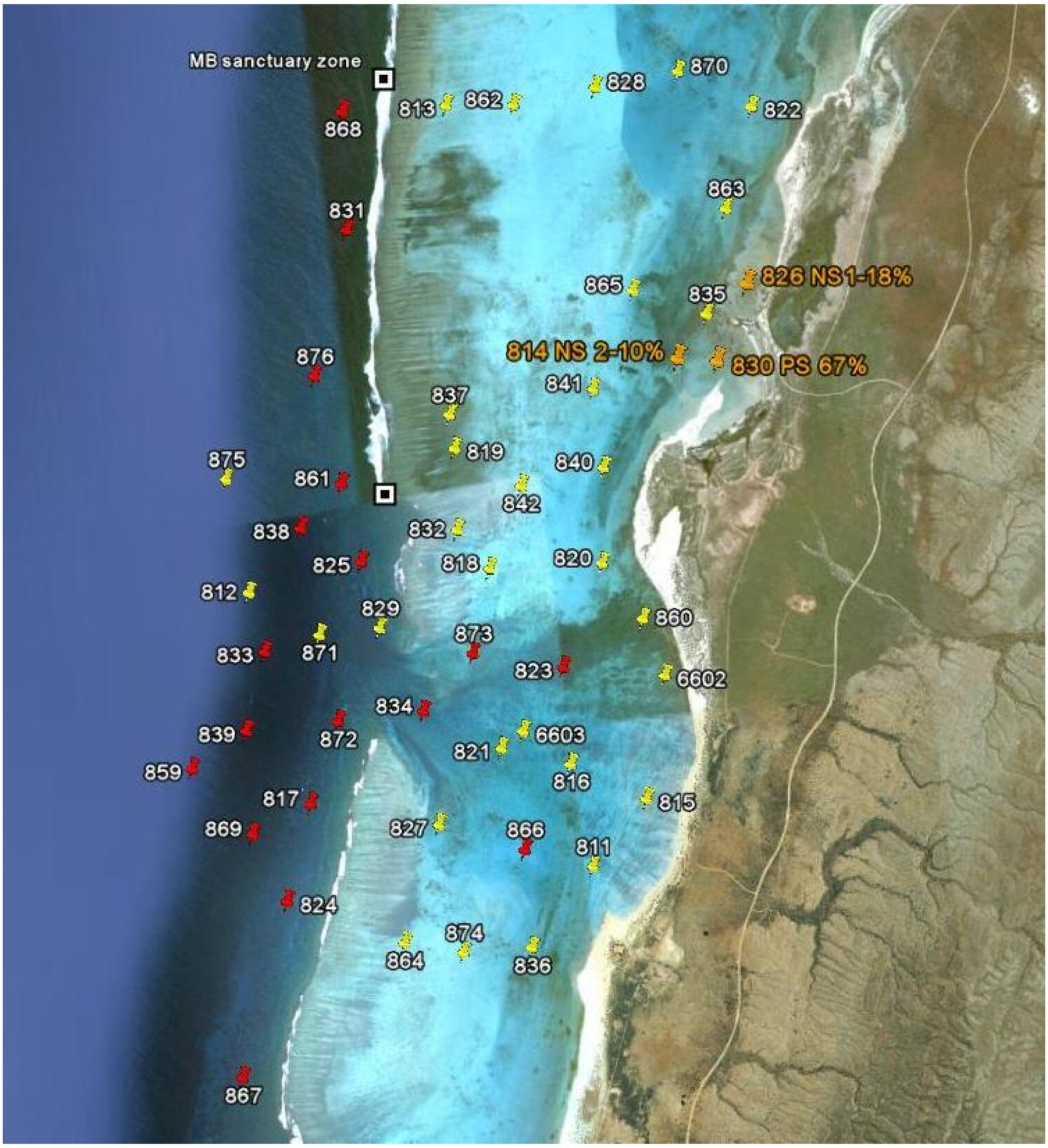


Figure 40. *Glaucostegus typus* detections within the acoustic listening station array at Mangrove Bay. Receivers with detections are shown in yellow and brown. Primary site (PS) and neighbouring sites (NS1 and NS2) with the total percentage of detections are shown in brown. Limits of the sanctuary zone denoted by squares.

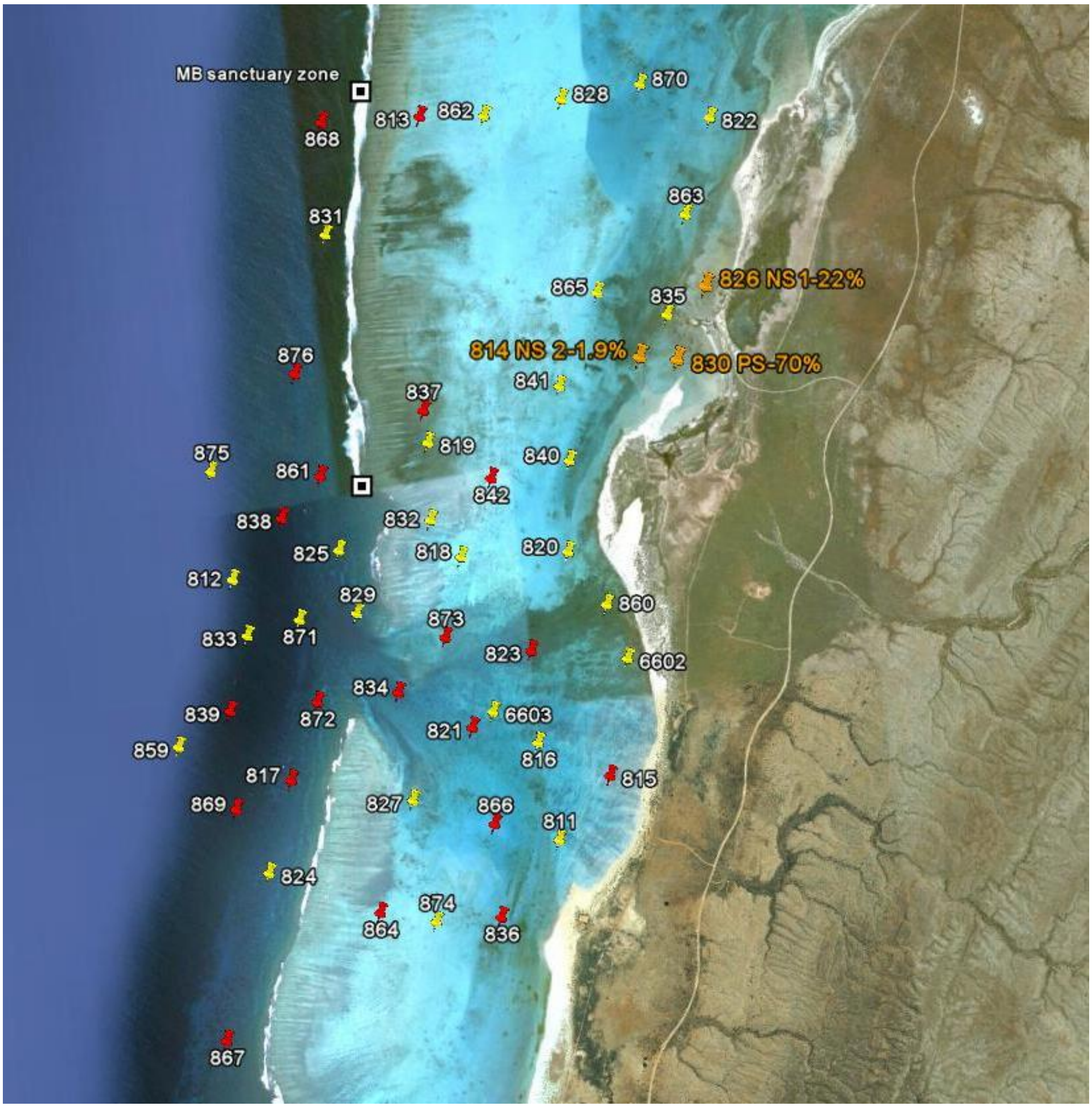


Figure 41. Detections (a) in the Mangrove Bay area and (b) at Stanley's Pool, South reef and Palm tree stations of the largest tagged male *G. typus* (ID code 8360).

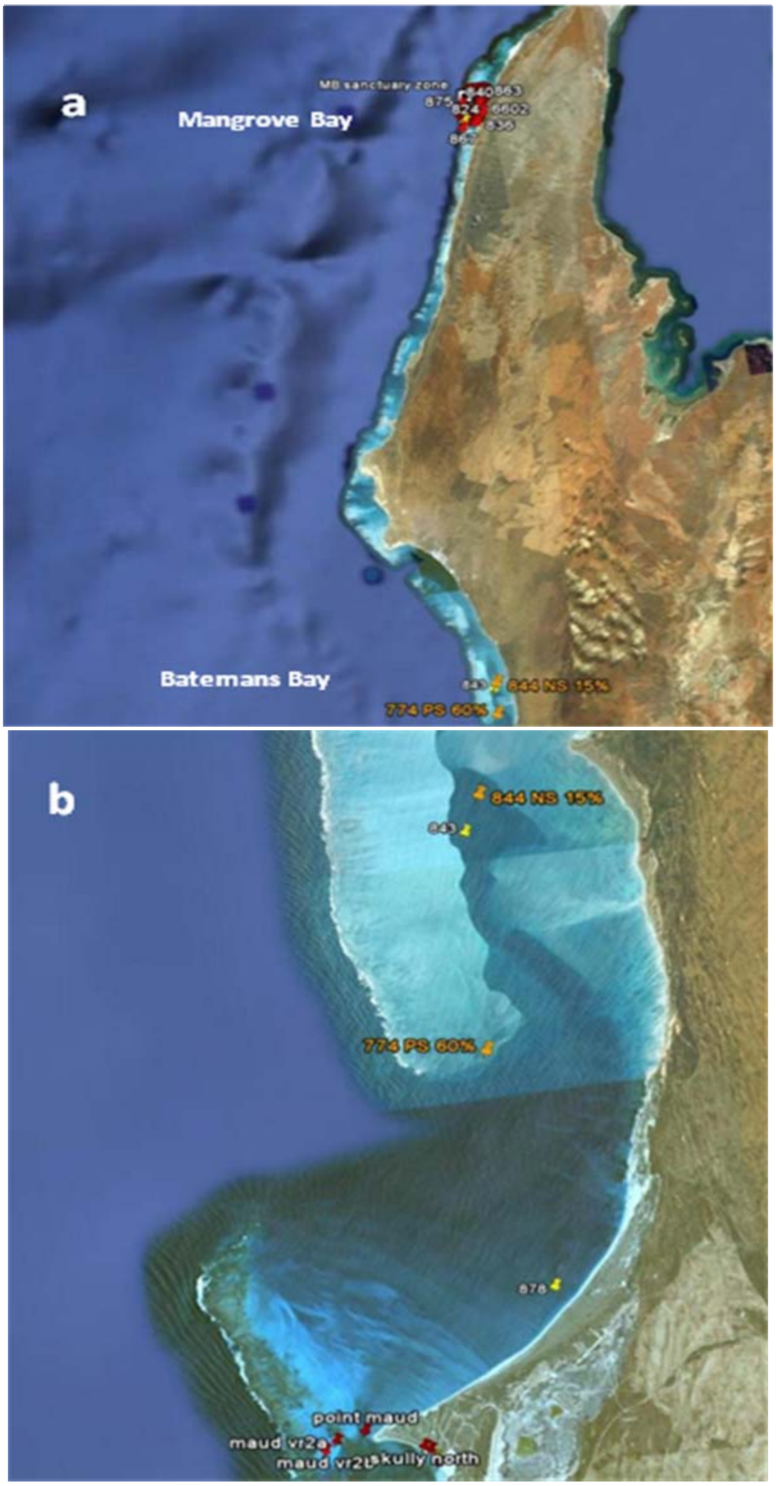


Figure 42. *Urogymnus asperrimus* detections within the acoustic listening station array at Mangrove Bay. Receivers with detections are shown in yellow and brown. Primary site (PS) and neighbouring sites (NS1 and NS2) with the total percentage of detections are shown in brown. Limits of the sanctuary zone denoted by squares.

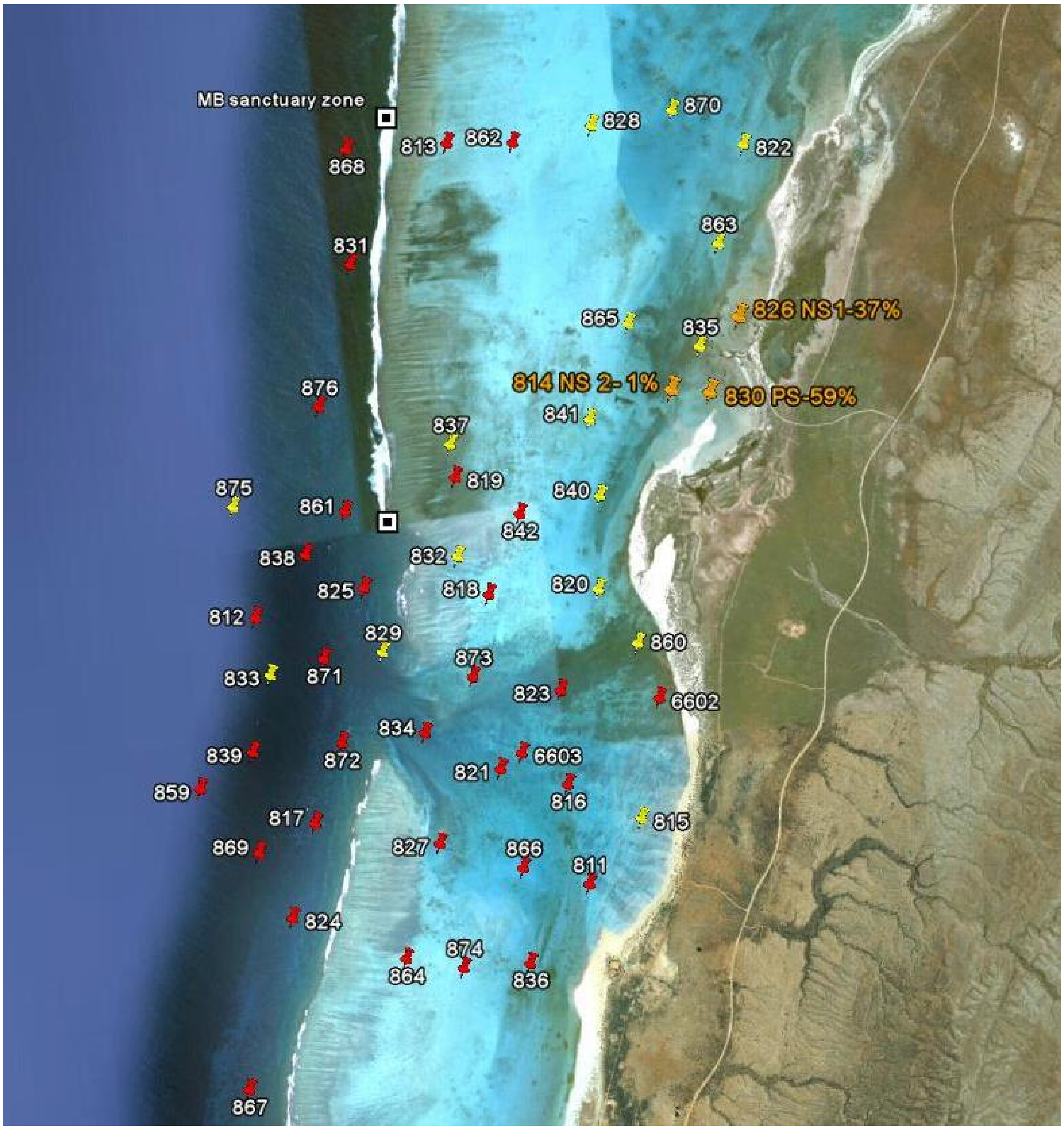


Figure 43. *Taeniura lymma* detections within the acoustic listening station array at Mangrove Bay. Receivers with detections are shown in yellow and brown. Primary site (PS) and neighbouring sites (NS1 and NS2) with the total percentage of detections are shown in brown. Limits of the sanctuary zone denoted by squares.

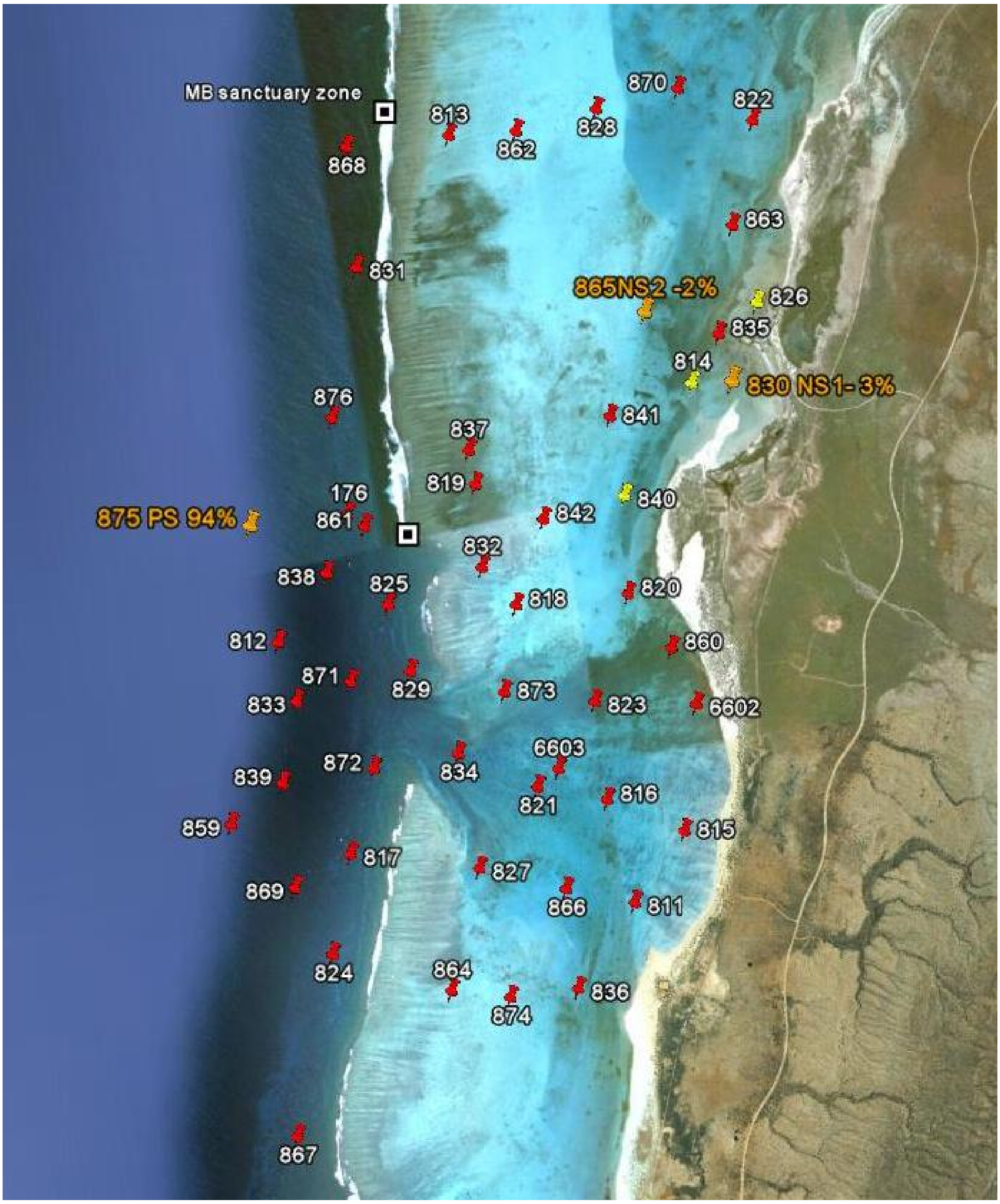
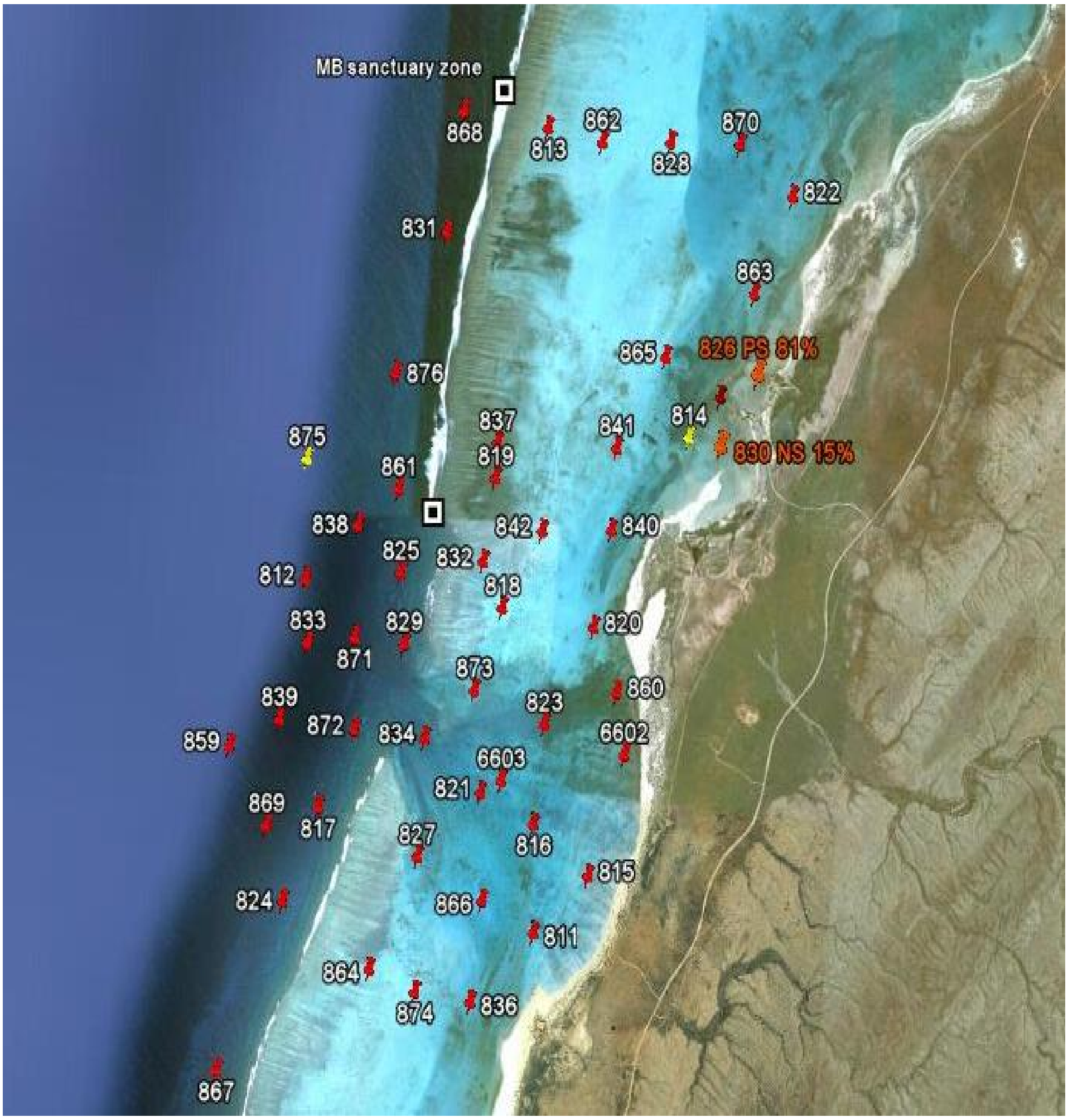


Figure 44. *Himantura uarnak* detections within the acoustic listening station array at Mangrove Bay. Receivers with detections are shown in yellow and brown. Primary site (PS) and neighbouring sites (NS1 and NS2) with the total percentage of detections are shown in brown. Limits of the sanctuary zone denoted by squares.



The number of days each ray was recorded within the array was used to calculate the minimum percentage of days it was present within primary and neighbouring sites (Fig. 45). The minimum dispersal range for each ray along the area of the Mangrove Bay listening station array was estimated by measuring the distance between the peripheries of the detection ranges of the two furthest receivers with detections (Table 22). The number of detections recorded for each ray during diurnal and nocturnal periods was collated to examine diel patterns of activity at primary and neighbouring sites (Fig. 46). The mean detection density (number of detections recorded at the receiver/number of days the receiver was functioning in the water) accumulated in all the listening stations that detected each ray was used to identify the receivers with the highest activity (Fig. 47). Total detections by month (Fig. 48) show seasonal patterns of use of this area over 16 months for the three species of ray tagged in February 2008.

Table 22. Minimum dispersal range (MDR) and total number of receivers detecting three species of ray at Ningaloo Reef. MB = Mangrove Bay, NR = Ningaloo Reef.

Species	MDR (mean)	No. of receivers detecting
P. atrus	4.9 km	32
	4 km within MB	
G. typus	127 km along NR	33
U. asperrimus	4.5 km	18

Figure 45. Proportion of days with detections out of all the days that receivers were functioning (% detection days) for (a) *P. atrus* (b) *G. typus* (c*) U. asperrimus* (d) *H. uarnak* and *T. lymma* at Mangrove Bay. % detection days rays were detected at their "primary site" and up to two "neighbouring sites" combined.

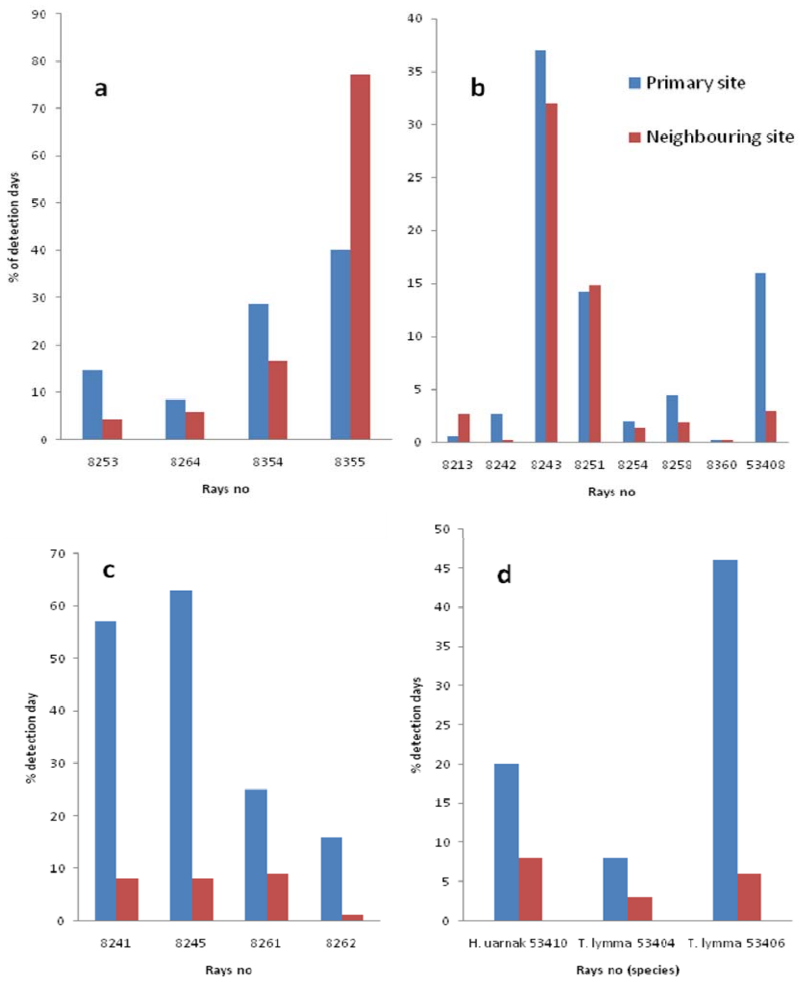


Figure 46. Relative proportions of daytime/nightime detections recorded at primary sites (left) and neighbouring sites (right) for (a, b) *P. atrus* (c, d) *G. typus* (e, f) *U. asperrimus* and (g, h) *T. lymma.*

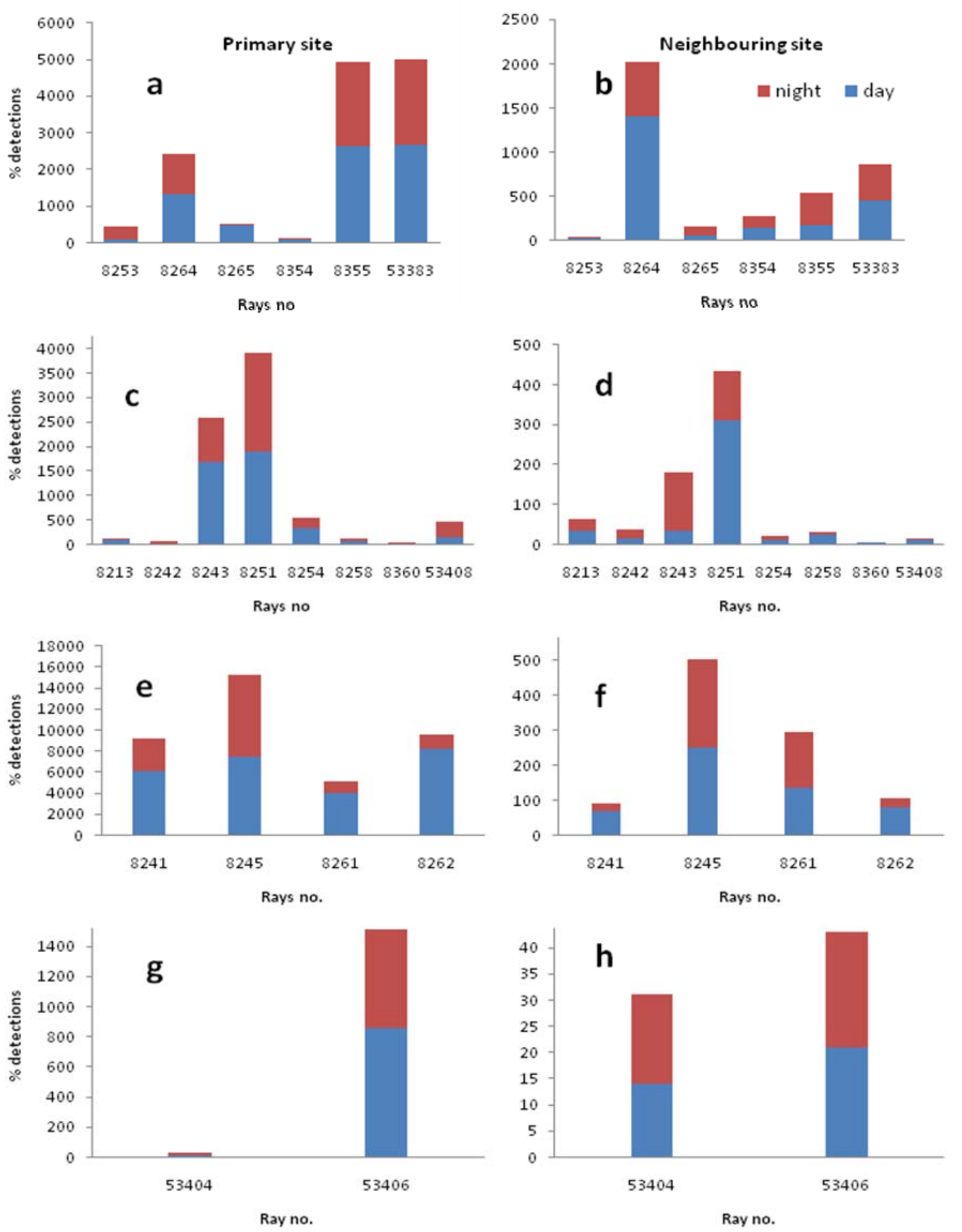


Figure 47. Mean detection density (number of detections recorded at the receiver/number of days the receiver was functioning) of receivers detecting at Mangrove Bay. Shaded area indicates the receivers located inside the Mangrove Bay sanctuary zone for (a) *P. atrus* (b) *G. typus* and (c) *U. asperrimus.*

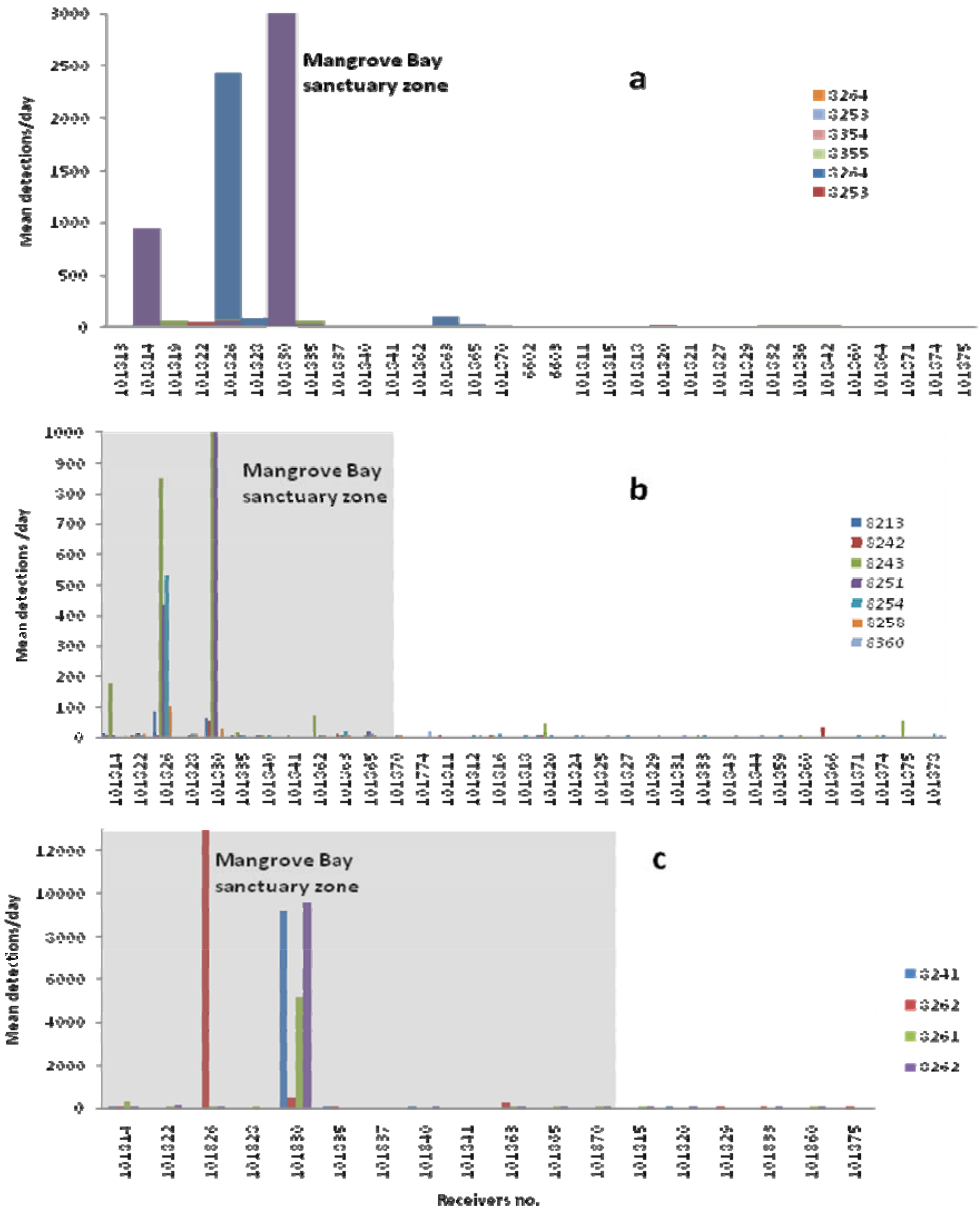
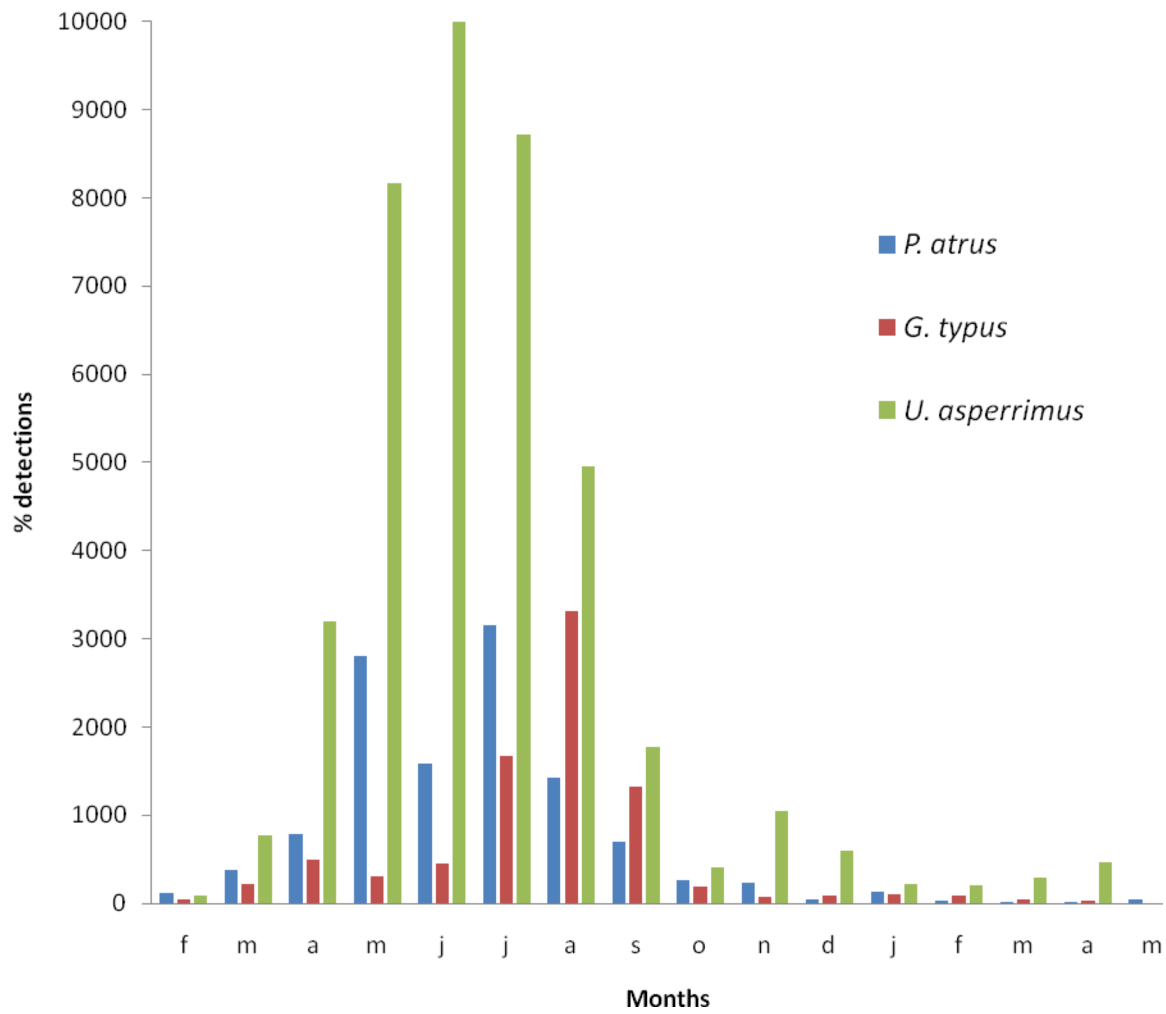


Figure 48. Percentage of all detections by month for three species of rays tagged in February 2008 (data from Feb '08 until May '09).



Satellite tagging

Eight *G. cuvier* and two *S. mokarran* were tagged during the project with Wildlife Computers SPOT or SPLASH tags. Details of these deployments are shown in Table 23.

Of the four *G. cuvier* tagged in 2007, tag 62343 transmitted for two weeks and tag 62346 transmitted for 11 days after which neither tag was heard from again (Figs 49 and 50). Tag 62343 remained in the tagging area for the 14 days that it transmitted and this shark did not go deeper than 150 m. It spent 26% of its time from the surface to 5 m and 80% of its time in less than 50 m of water (Fig. 51) which suggests it was at times in the lagoon; its closest reported position to the coast was 2.4 km. No transmissions from the other two tags (62347 and 62344) were received post-tagging.

Table 23. Details of satellite tagged sharks from RV 'Naturaliste' cruises. * on 3 October

Tag type	PTT	Date	Species	FL (cm)	Sex	Transmission period (days)
SPOT	62346	20/06/07	*G. cuvier*	145	F	11
SPOT	62347	20/06/07	*G. cuvier*	155	F	0
SPLASH	62344	21/06/07	*G. cuvier*	252	F	0
SPLASH	62343	21/06/07	*G. cuvier*	276	F	14
SPOT	83858	17/08/08	*G. cuvier*	179	F	136
SPOT	83857	19/08/08	*G. cuvier*	214	F	69
SPOT	83859	19/08/08	*G. cuvier*	222	F	411*
SPLASH	78362	20/08/08	*G. cuvier*	254	F	0
SPLASH	78363	20/08/08	*S. mokarran*	218	F	165
SPOT	93303	04/06/09	*S. mokarran*	205	M	0

Of the tags deployed in 2008, one of the tiger sharks (SPLASH 78362) was not heard from after tagging but the other four tags all transmitted successfully. SPOT tag 83857 moved north to the Rowley Shoals and was last heard from on 26 October (Fig. 52). SPOT tag 83858 moved north to the Eighty Mile Beach area of the North West Shelf and was last heard from on 30 December, although its last position was reported on 28 November (Fig. 53). The remaining tiger shark, SPOT tag 83859, is currently (03/01/10) still transmitting 16 months after tagging. This shark initially moved north to the Kimberley and then offshore to just south of Sumba Island in Indonesia in mid-October. It then returned south and travelled back past Ningaloo and was off Perth in early February 2009. It then rounded Cape Leeuwin arriving off Esperance on the south coast in early May 2009. Tag 83859 then turned around and travelled back to Ningaloo probably arriving in August 2009 about one year after it was tagged there. However, at this time although the tag was transmitting regularly it was giving very few positions so the exact timing is uncertain. In September 2009, as it did in September 2008, it started heading north and on the 29th was just north of the Monte Bello Islands (Fig. 54). This shark experienced temperatures between 10 and 31° C but spent 91% of its time in 18–27° C water (Fig. 55). Temperatures experienced by the other four *G. cuvier* are shown in Fig. 56; modal temperature for all these fish was 23–25° C with a range of 17–29° C. The *S. mokarran* (SPLASH tag 78363) moved north to the northern end of the Eighty Mile Beach area before returning south and last transmitting from near Coral Bay on 1 February 2009 (Fig. 57). The *S. mokarran* showed a bimodal depth distribution spending 41% of its time between 0–10 m and 38% of its time from 50–100 m, and not going deeper than 150 m (Fig. 58). This shark experienced temperatures between 21–30° C spending 69% of its time in 24–27° C water (Fig. 58).

One *S. mokarran* was tagged in 2009, however, this shark was not detected after tagging.

Figure 49. *Galeocerdo cuvier* tagged 21/06/07 (SPLASH 62343)

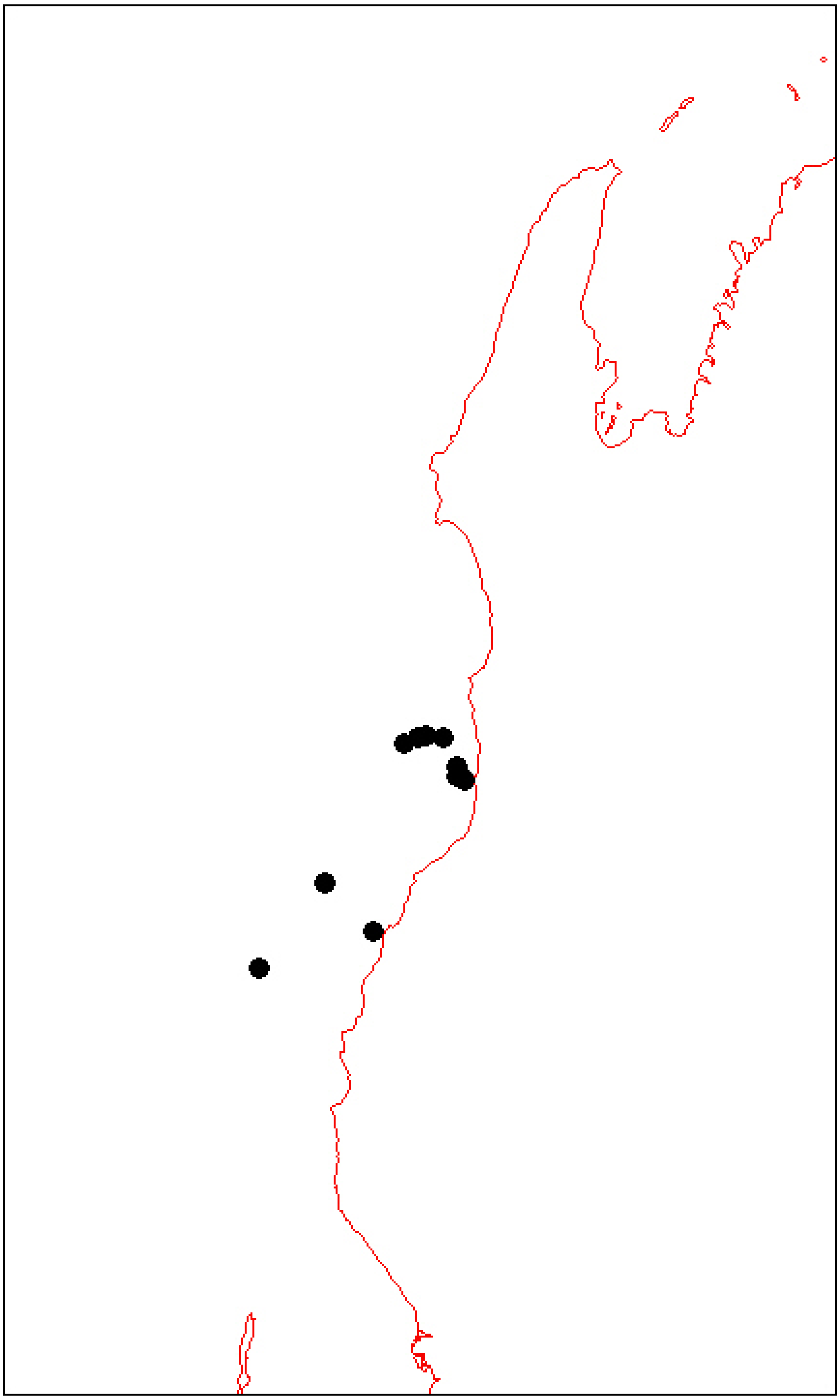


Figure 50. *Galeocerdo cuvier* tagged 20/06/07 (SPOT 62346)

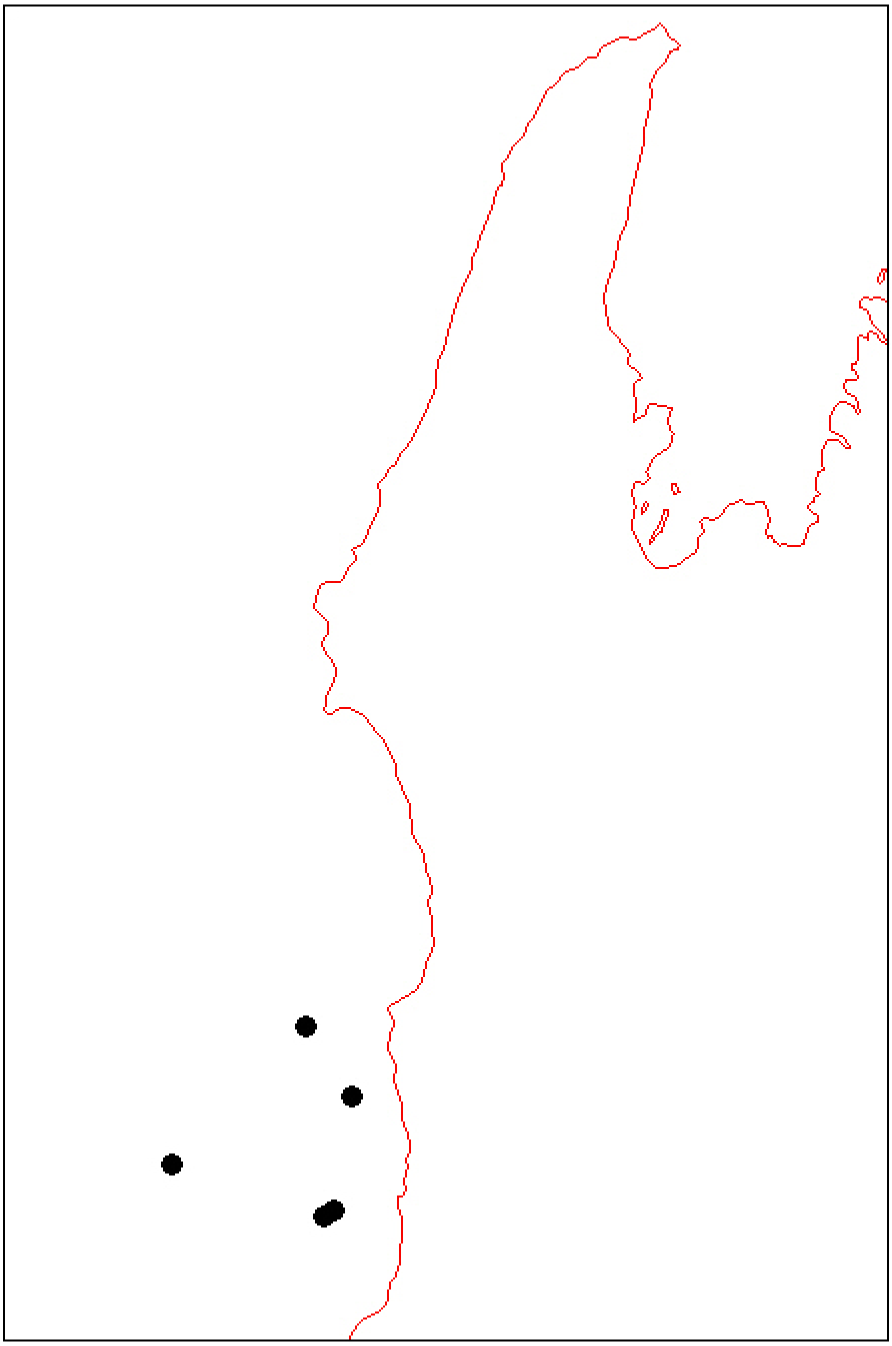


Figure. 51. Time-at-depth for *G. cuvier* (SPLASH 62343)

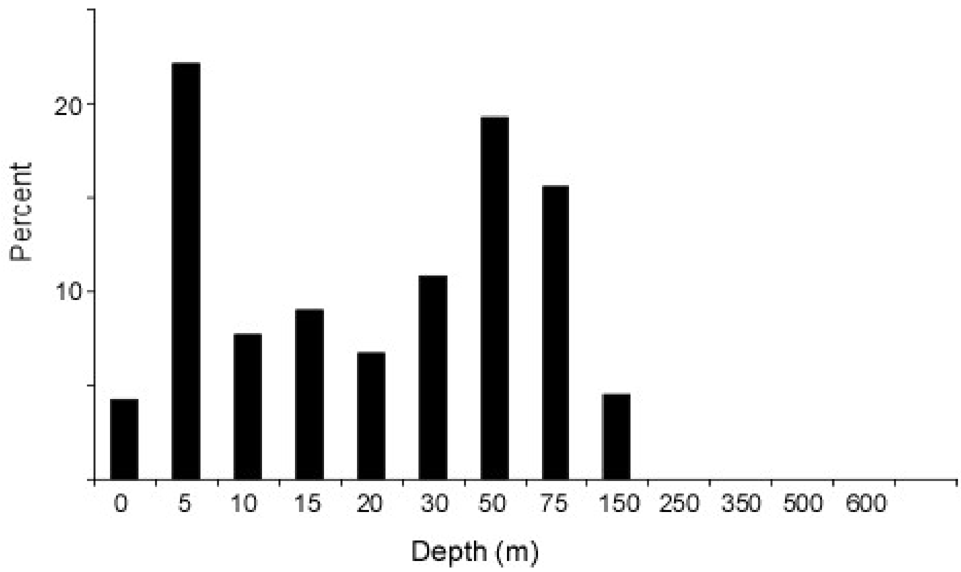


Figure 52. *Galeocerdo cuvier* tagged 19/08/08 (SPOT 83857)

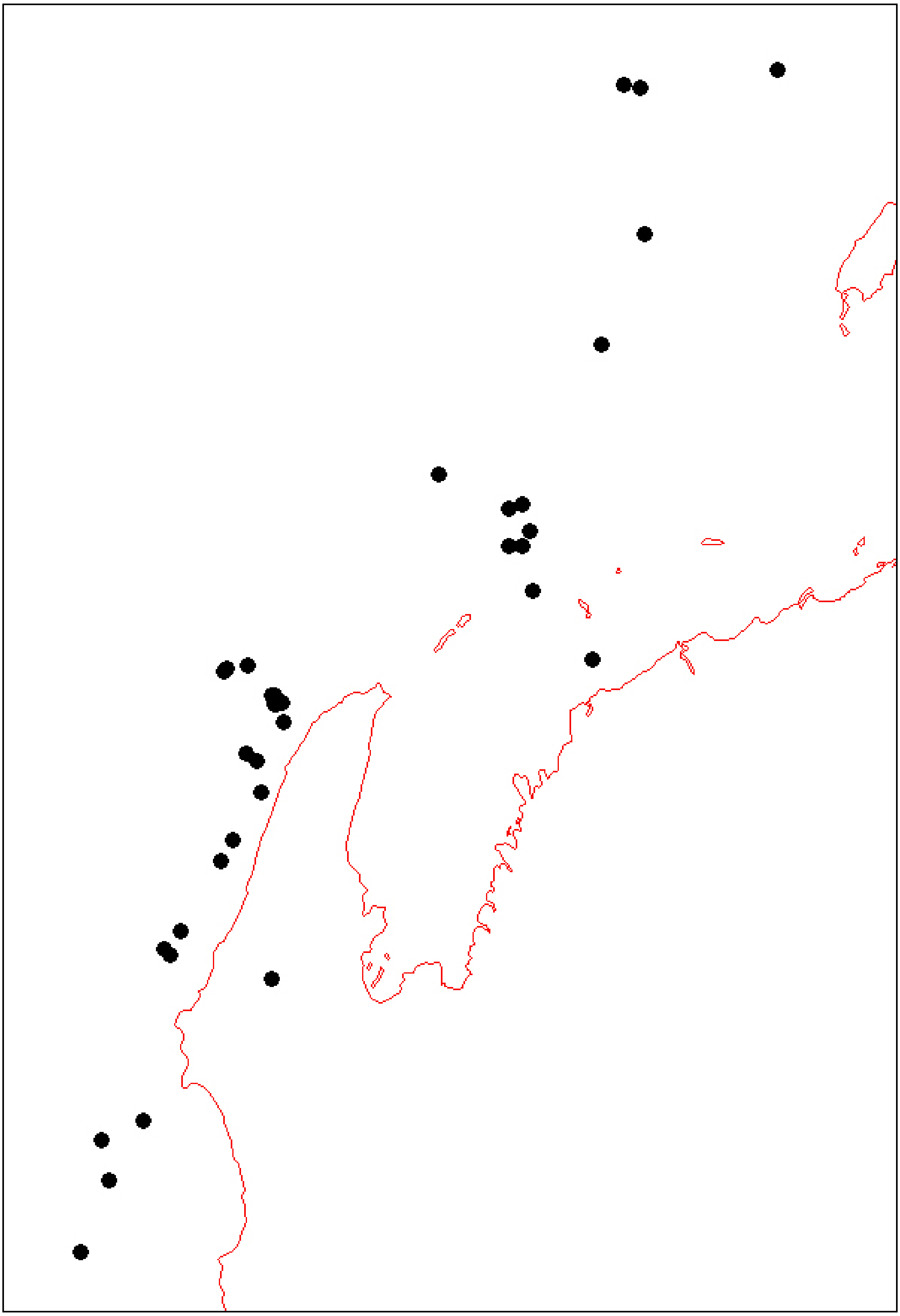


Figure 53. *Galeocerdo cuvier* tagged 17/08/08 (SPOT 83858)

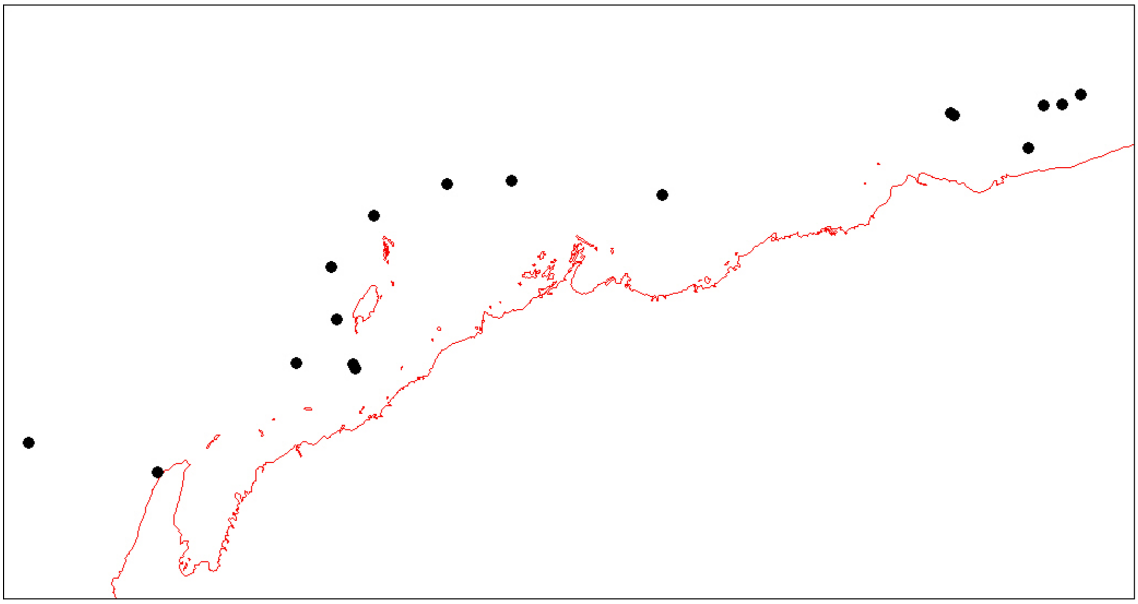


Figure 54. *Galeocerdo cuvier* tagged 19/08/08 (SPOT 83859). Yellow is 19/08/08 to 13/10/08, turquoise is 19/10/08 to 05/05/09 and black is 11/05/09 to 03/10/09.

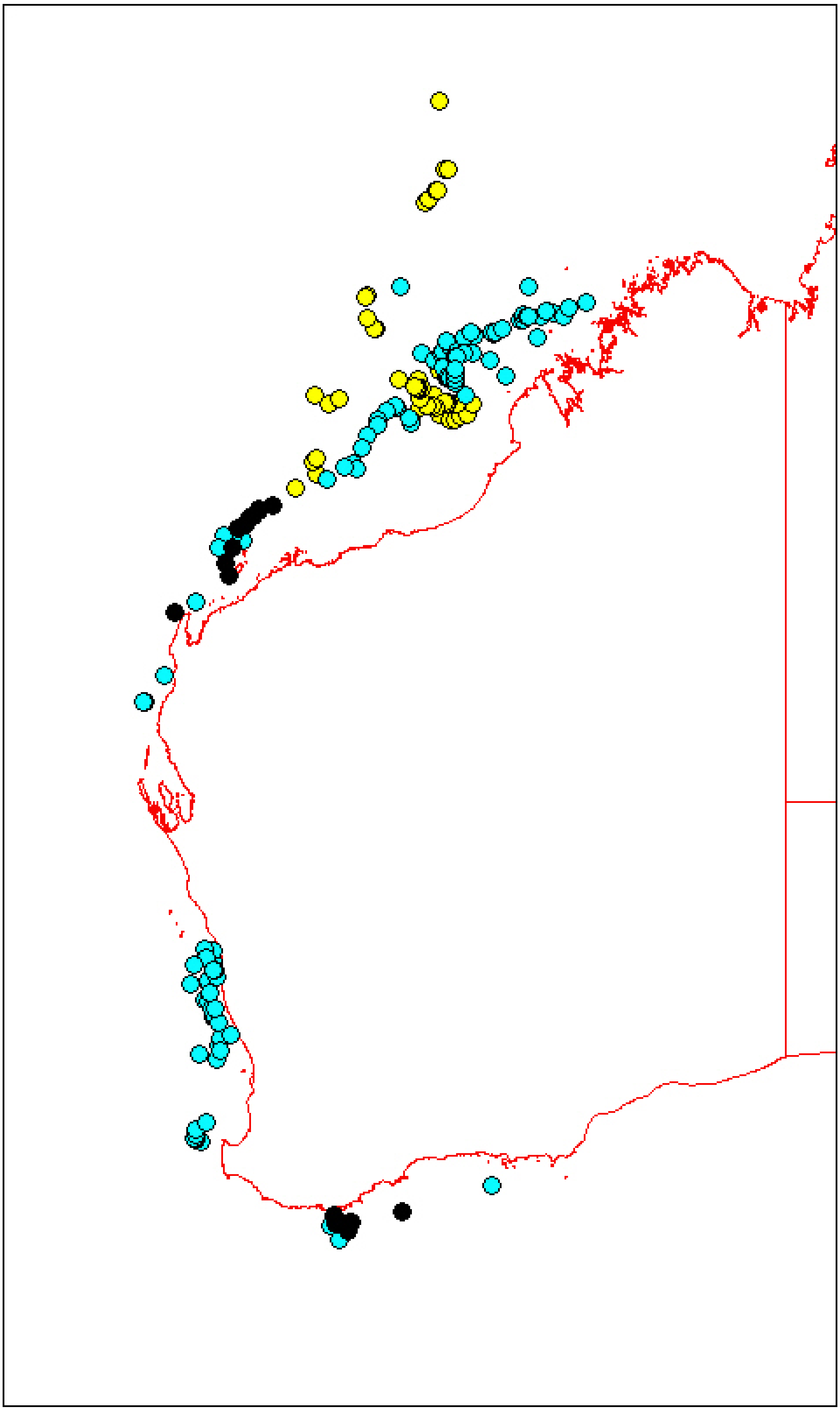


Figure 55. Time-at-temperature for *G. cuvier* (SPOT 83859)

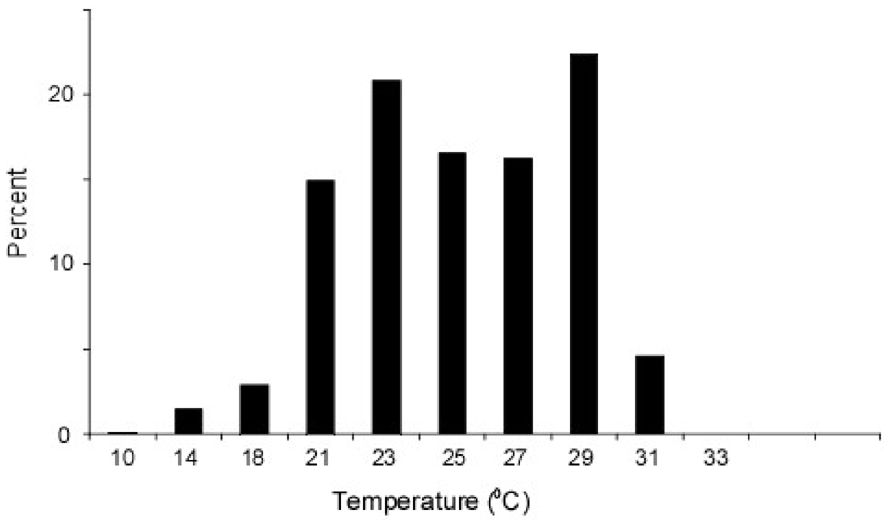


Figure 56. Time-at-temperature for *G. cuvier* (SPOTS62346, 62343, 83858 and 83857)

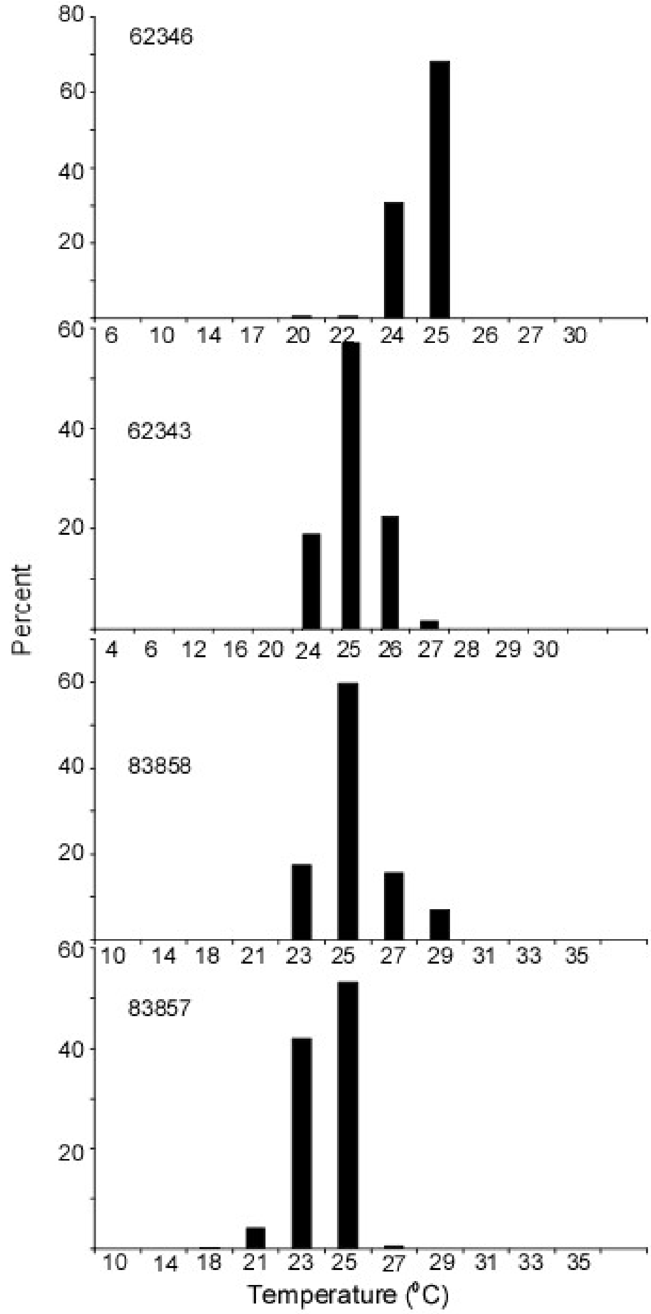


Figure 57. *Sphyrna mokarran* tagged 20/08/08 (SPLASH 78363)

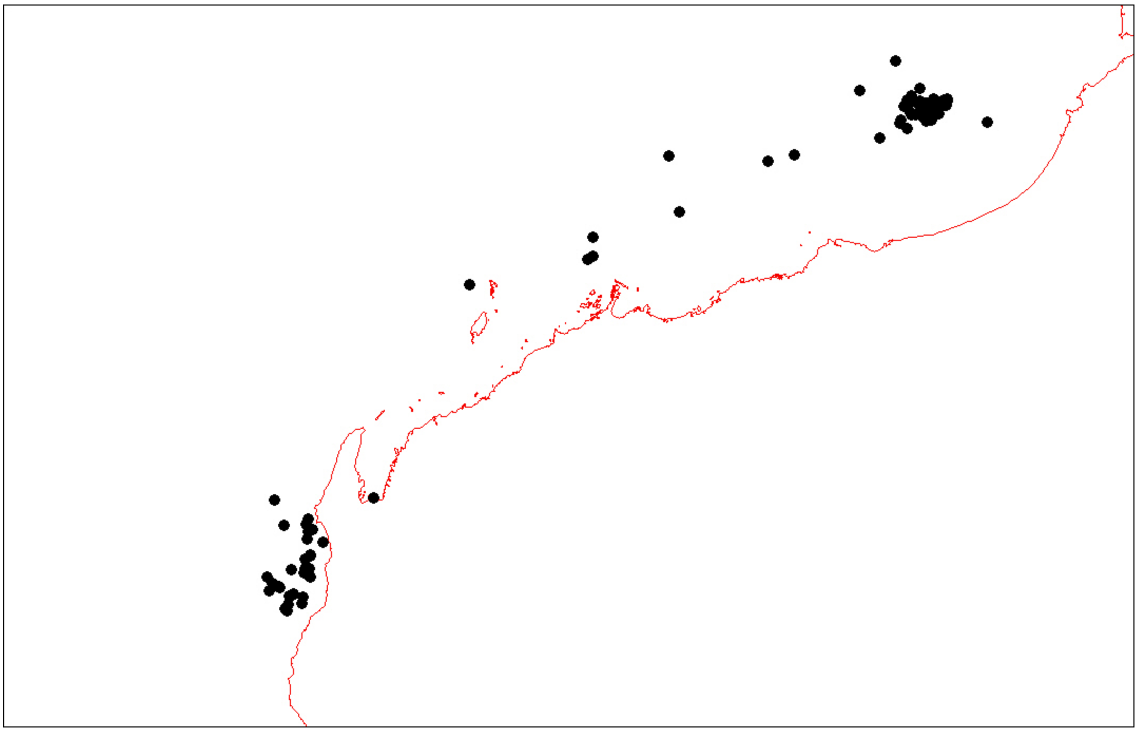
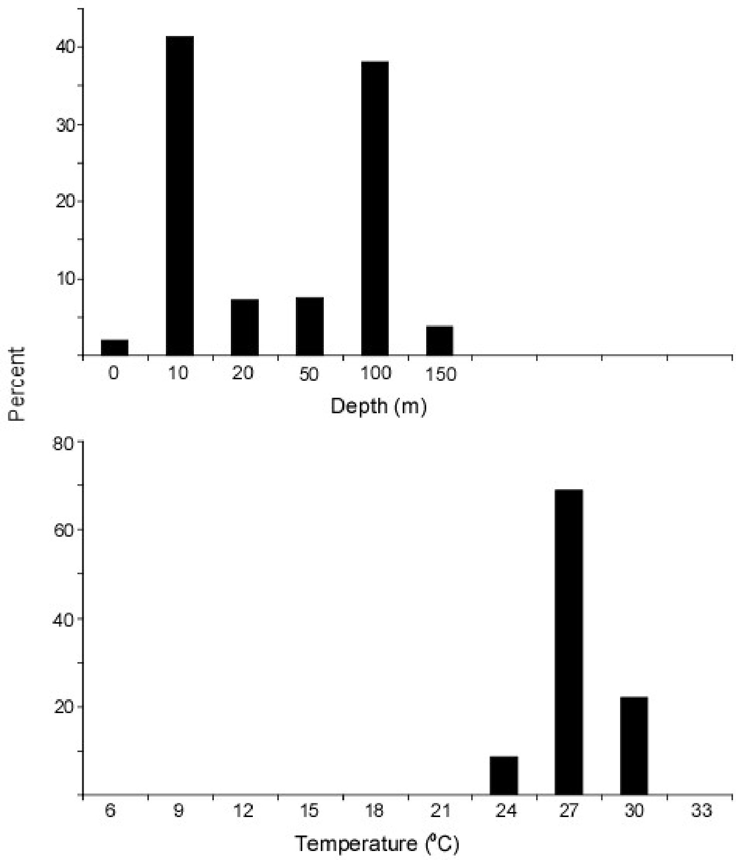


Figure 58. Time-at-depth and time-at-temperature for *S. mokarran* (SPLASH 78363)



3.4 Discussion

3.4.1 Species composition

Twenty seven species (10 sharks, 17 rays) were identified from the dive surveys and 22 species (17 sharks, 2 rays) from the longline surveys outside the reef. The elasmobranch checklist for NMP provided in Appendix 1 comprises 47 species (30 sharks, 17 rays). This includes ten species records obtained from other sources which we were able to validate. An additional two species (*H. nakamurai* and *A. pelagicus*) were caught just outside the Park boundaries.

This is an under-estimate (by about 60%) of the number of elasmobranch species occurring in this area. Based on what we know of elasmobranch distributions in Australia (Last and Stevens 2009), we would expect about 118 species to be present in the NMP at certain times. Of these, about 25 species occur mainly in water deeper than 200 m and of the remaining 93 species, 59 are sharks and 34 are rays. In the Coral Bay region in the southern part of NMP, the 200 m isobath is about 44 km off the coast while in the central section (Yardie to Osprey area) it is about 10 km off the coast. This discrepancy in species numbers is due to the practical constraints limiting the number of sampling techniques we could employ, and to limitations of the diving methods we used. Many of the more cryptic species would not have been observed without detailed examination of the habitat. Species such as *T. obesus* are primarily nocturnal and remain resting in caves and under ledges during the day. It was hoped to use Baited Remote Underwater Video (BRUV) techniques but this was not possible due to cost and labour constraints. This technique has been used in another project examining demersal fish distributions in the NMP and it may be possible to examine existing footage for elasmobranch occurrences in the future (Ben Fitzpatrick, University of Western Australia, personal communication). Dive surveys of elasmobranchs are problematic and there is no current methodology that is successful for all species. Swimming transects works reasonably well for more sedentary species such as stingrays, but may disturb and miss more active and wary species. The low number of encounters on our average transects, even given multiple divers and long swim times, was also a problem. Vaudo and Heithaus (2009) surveyed shallow sandflat habitats in Shark Bay from a boat travelling at 5–6 km/h using 1.5 km belt transects when Beaufort wind conditions were <2. However, our time at Ningaloo was much more limited and conditions on our sampling trips would rarely have allowed this approach. Surveying mobile and inquisitive species such as *C. amblyrhynchos* is also notoriously difficult. These sharks may appear immediately divers enter the water, and then rapidly retreat out of visibility range, or they may remain just beyond the limits of visibility. Baiting techniques which attract them make it difficult to estimate natural densities. *Carcharhinus cautus* provides a good example of the dive surveys missing a species. This shark was commonly caught in the Mangrove Bay area during fishing operations to obtain species for acoustic tagging. Given the amounts of recreational diving and fishing in the NMP, interviews and examining existing photographs and video footage would be another excellent source of information in the Park. It was hoped to do this, but again financial and practical constraints ultimately prevented it. Museum records would also provide another source of species records for the area.

The 47 species we recorded from NMP compares to 30 species of elasmobranchs recorded in a checklist of fishes of the Capricorn-Bunker Group at the southern end of the Great Barrier Reef (GBR) (Russel 1983). Based on current knowledge, we would estimate that about 118 species occur (or are likely to occur) in the NMP. Of these, about 25 species mostly occur in water deeper than 200 m and of the 93 species mostly found in < 200m, 59 are sharks and 34 are rays. Similarly, we estimate that about 123 species occur in GBR waters of which 27 occur mainly deeper than 200 m and 96 species (59 sharks, 37 rays) occur in <200 m (Last and Stevens, 2009). However, the NMP is only about 260 km long with an area of 5000 km^2 compared to the GBR which is about 2000 km long with an area of 345,000 km^2. Vaudo and Heithauss (2009) recorded 21 species (9 sharks, 12 batoids) from 10 families from sand flat habitats in Shark Bay, WA. Together with the records of White and Potter (2004) from unvegetated, seagrass and mangrove habitats in the same area, 28 species from 13 families have been recorded from the western coast of Shark Bay’s eastern gulf from the shoreline to the seagrass beds at depths of about 3 m. This compares to the 30 species from 10 families recorded from the shallow lagoonal habitats at Ningaloo.

Vaudo and Heithaus (2009) found a greater species composition (10 more species) on the sand flats of Shark Bay during the ‘warm’ (September–May) compared to the ‘cold’ (June–August) period. We could not make this comparison because we only sampled the lagoon habitats during April and December, and our June–August sampling was restricted to the reef edge habitat. However, our ‘cold’ season reef edge sampling recorded 15 species compared to 16 species in the December ‘warm’ season. Our April sampling recorded 20 species. As noted by Vaudo and Heithaus (2009), Shark Bay is near the southern limits of a number of elasmobranch species which are more likely to be influenced by the cooler temperatures experienced there as compared to Ningaloo.

Information obtained in this project has extended the known range of a number of elasmobranch species. More importantly, it has documented a new species of maskray that may be endemic to the NMP.

3.4.2 Abundance and size structure

The measures of abundance used in this study were sightings per unit area (SPUA: number per 1000 m^2) for the dive surveys and catch per unit effort (CPUE: number per 100 hooks) for the longline surveys. While both these metrics can be subject to a number of biases, the standardised surveys we used should provide a relative measure of species encounter rates.

Logistic constraints meant that we were not able to sample seasonally in any meaningful way. Longline surveys, while covering three years, were all carried out between May 31 and August 24 and reef edge SCUBA dives covered two years but only between 18 June and 23 August. Lagoon snorkel surveys spanned two years and two seasons, 16–26 April and 4–12 December. Abundance of elasmobranchs in the lagoon was much higher in April 2007 (0.219 SPUA) than December 2008 (0.042 SPUA). The combined reef edge SPUA was 0.093 but being carried out on SCUBA is not strictly comparable to the lagoon snorkel surveys. The highest longline CPUE was in 2009 (12.1), compared to 8.3 in 2008 and 7.2 in 2007. Although these rates were somewhat lower than those observed during the first three years of RV 'Naturaliste' longline research trips, given the number of different species represented in catches, as well as subtle differences in depths and habitats fished between trips, it is thought unlikely that these changes represent actual changes in the general abundance of elasmobranchs over the nine years for which data are available. Nevertheless, McAuley (2009) and Heupel and McAuley (2007) have reported declines in the abundance of *C. plumbeus, G. cuvier* and *Sphyrna* species throughout northern Western Australia over a similar timeframe. Given the prevalence of *C. plumbeus* in RV 'Naturaliste' longline catches and previously high catch rates of *S. lewini*, it is possible that declines in these species' abundance contributed to the overall decline in elasmobranch CPUE between the early and late 2000s. However, the higher catch rates of *G. cuvier* obtained during the current project is inconsistent with the declining trend reported by commercial longline fishers between 1998 and 2006 (Heupel and McAuley, 2007). It is possible that the higher catch rates of *G. cuvier* in the current project could be a result of lines being set closer to Ningaloo Reef than they were in previous years.

Large aggregations of *G. typus, C. melanopterus* and *P. atrus* contributed to the higher April dive sightings. However, the April SPUA was still higher when these aggregations were removed from the data. The *G. typus* aggregations comprised mainly juveniles including a large number of 40–45 cm TL fish that would be newly born. Size at birth for this species is 38–40 cm TL (Last and Stevens, 2009), but the birth season in Australia is unknown. *Glaucostegus typus* was by far the most numerous elasmobranch encountered on the April survey (170 individuals) but none were seen in December or on the reef edge surveys. These aggregations may be tidally induced with most seen in water of only a few cm depth around sand spits. This species was also the dominant elasmobranch observed on the sandflats at Shark Bay by Vaudo and Heithaus (2009) where it was mainly sighted singly, although occasionally in groups. The *C. melanopterus* aggregation comprised fish of about 35 cm TL observed in shallow water close to a sandy beach. This species is born at about 50 cm TL in November in other areas of northern Australia (Lyle, 1987), although size at birth is about 35 cm TL in the Marshall Islands (Last and Stevens, 2009). The aggregation we saw was clearly of neonates although they seem small (even allowing for errors in the estimated size) compared to the birth size recorded by Lyle (1987) and do not support a November parturition period. No *C. melanopterus* of this size were seen in our December survey. Juvenile reef shark aggregations have also been reported at Skeleton Beach (Coral Bay), Winderabandi Point and Sandy Point. Both Vaudo and Heithaus (2009) and White and Potter (2004) concluded that nearshore, shallow waters in Shark Bay served as juvenile habitat and nursery grounds for a number of elasmobranch species. *Pastinachus atrus* was also much more numerous in April (SPUA 0.037) than in December (SPUA 0.001) in our study; the aggregations of this species were of larger individuals and were probably related to feeding. *Himantura fai* and *H. uarnak* were both more abundant in April in the lagoon than in December (Table 7) which may be due to seasonal factors. *Pastinachus atrus*, *H. fai, H uarnak* and *A. narinari* were also prominent species observed on the sandflats at Shark Bay by Vaudo and Heithaus (2009). *Himantura fai* was the only species regularly seen in groups at Shark Bay by these authors. Offshore, notable differences in catch rates in our study were evident for *G. cuvier* (much lower in 2009, see Table 10) and *R. acutus* (much higher in 2009, see Table 10).

The highest sighting rates of elasmobranchs (all species combined) on the dive surveys were generally between Point Cloates and Pelican Point, together with Mangrove Bay and North West Cape (Fig. 3.1). The coral reef associated *T. lymma* and *N. kuhlii* were most abundant at Coral Bay and Lakeside. However, during ray tagging trips *T. lymma* was noted to be abundant on rocky areas at Mangrove Bay in November 2008 (but not in September 2009) and it was also common on sandy areas of Skully Bay (Florencia Cerutti, Charles Darwin University, personal communication). Highest abundance of the stingrays *H. fai, H. uarnak* and *P. atrus* was at Mangrove Bay, Brudboodjoo Point or Winderabandi and large aggregations of *R. typus* were encountered at Winderabandi and Pelican Point. Of the reef sharks, *C. amblyrhynchos* was most abundant at Point Cloates and Coral Bay, *C. melanopterus* at Point Cloates and Pelican Point and *T. obesus* at North West Cape and Osprey. With some exceptions (i.e. *T. obesus*), there was a tendency for sites with highest abundance to be in southern areas of the Park (Figs 3.2–3.10). Maximum elasmobranch density recorded on any of the transects was 840 animals/ha, which compares to a maximum of 29.3 animals/ha reported by Vaudo and Heithaus (2009) for sandflats at Shark Bay.

Outside the reef, catch rates of *C. sorrah, C. limbatus/tilstoni, L. macrorhinus* and *R. acutus* were all highest in the northern sector of the NMP and outside the northern limits of the Park. Of these species, only *R. acutus* was caught south of Brudboodjoo Point. Catch rates of *C. albimarginatus* were highest from Point Cloates to the Yardie Creek area and of *C. amblyrhynchos* from Point Cloates, agreeing with the sightings from the dive surveys. Catch rates of the most frequently caught species, *C. plumbeus,* were highest from the Yardie Creek area while those of *G. cuvier* were highest from the Pelican Point region.

Relating sighting rates of individual species to habitat in the lagoon were complicated by many of the individual surveys covering multiple habitat types. Additionally, although we recorded the relative amounts of each habitat on a particular survey, we did not record precisely where each elasmobranch was seen. For example, a site transect may have covered sand, reef and algal habitats in the proportion of 60, 20 and 20% respectively. However, it was not recorded whether elasmobranchs seen on the transect occurred on the sand, reef or algal component. Consequently, the data in Table 9 was split into 11 habitat and combinations of habitat types, depending on the proportions of each (see methodology). Most habitat types contained combinations of sand and reef. Of the sharks, *T. obesus* was seen only on reef which is not surprising as this species mainly hides under coral ledges and in reef caves during the day (the period our dives were limited to), foraging more widely at night. *Negaprion acutidens* was seen only on sand or close to mangrove areas. *Carcharhinus amblyrhynchos* had highest sightings rates on reef habitats or on multiple habitat types containing reef while *C. melanopterus* was seen most frequently on sand or sand containing habitat types. *Carcharhinus amblyrhynchos*, *C. melanopterus* and *T. obesus* are three of the most common sharks associated with coral reefs in the Indo–Pacific region (Last and Stevens 2009). Sand or sand containing habitat types had the highest sightings rates for several batoids, notably *R. australiae, G. typus, H. uarnak* and *P. atrus* while *N. kuhlii* and *T. lymma* had high sightings rates on both sand and reef habitats. Of particular note is that although mangrove areas are limited at NMP, the sand and mangrove habitat (particularly at Mangrove Bay) had the highest sighting rate for elasmobranchs of any of the 11 habitat types. Six species, *C. melanopterus, N. acutidens, G. typus, H. fai, P. atrus* and *U. asperrimus* had their highest sighting rate in the sand and mangrove habitat, highlighting the importance of this habitat type. The reef edge habitat was dominated, as might be expected, by sightings of *C. amblyrhynchos,* and to a lesser extent by *N. kuhlii, T. meyeni, A. narinari* and *T. obesus.*

There was no clear relationship between sightings of individual species and depth in the dive surveys other than that *C. amblyrhynchos* and *T. meyeni* were seen more frequently in the deeper reef edge habitat while the species sighted most frequently in the very shallow lagoon waters were the batoids *G. typus, P. atrus* and *H. uarnak*. In other areas, juvenile *C. amblyrhynchos* occur in shallower water than the adults (Stevens1984) and, although not seen on either of our surveys, juvenile aggregations of this species have been recorded seasonally from certain sites at NMP (Ref). In areas where *C. melanopterus* is absent, *C. amblyrhynchos* adults may also occur on shallow reef flats (Last and Stevens 2009). Outside the reef, catch rates of *C. amblyrhynchos* and *G. cuvier* showed a decrease in catch rate with increasing depth zone. *Carcharhinus amblyrhynchos* is a reef-associated shark so this may be expected, while *G. cuvier,* which also enters the lagoon, is known to prey on turtles and dugongs that are associated with the reef habitat. Catch rates of *C. limbatus/C. tilstoni, C. sorrah* and *R. acutus* increased with increasing depth zone. All of these species do occur in shallow water in other areas (Last and Stevens, 2009). However, none of them are really reef-associated sharks and so there higher catch rates in somewhat deeper water at NMP may be more related to being found away from the reef environment.

Of particular significance to management is the fact that sightings in the lagoon and at the reef edge of all elasmobranchs combined, and of nine out of the ten most commonly seen species, were higher in sanctuary zones than in non-sanctuary zones. In the offshore surveys catch rates of all elasmobranchs combined, and of six of the top eight of the most frequently caught species, were also higher in sanctuary zones than outside them. While these differences were only statistically significant for one species (*G. typus* sightings), this was probably due to the relatively small sample sizes. Given the mobile nature of many of these species this result may at first sight seem surprising. However, results from the acoustic tracking at NMP, as well as telemetry studies from other areas, have shown several of these species (and juveniles of most of the species) to be relatively site-attached. While fishing activities probably have relatively little direct impact at NMP (mortality rates through accidental capture are probably low) there may be an indirect effect through capture of their teleost prey species.

3.4.3 Spatial dynamics

Acoustics

The passive telemetry approach used at Ningaloo has proved to be very successful for elasmobranchs with more than 430,000 detections recorded to date. Of the 83 sharks tagged with acoustic transmitters, only two have not (so far) been detected. This suggests that the majority of individuals have not been unduly affected by capture, or by the surgery to inplant the transmitters. Some 21–24 months after tagging, about 38% of Mangrove Bay and 80% of Skeleton Bay sharks are still being detected. At this stage, the lower current detection rate at Mangrove Bay is difficult to explain.

In Mangrove Bay, *N. acutidens* was mostly detected by one receiver that is inside the sand spit and close to shore. All tagged individuals of this species were juveniles which appear to have a limited home range. A similar situation has been observed for *N. acutidens* at Aldabra Atoll (Stevens, 1984) and for the other species of lemon shark *N. brevirostris* (Gruber *et al.* 1988; Morrissey and Gruber, 1993; Wetherbee *et al.*, 2007). It is likely that the current sanctuary zones are effectively protecting juveniles. However, larger individuals undoubtedly range further and tagging of adults would be necessary to determine if current sanctuary zones are providing them with any protection.

Carcharhinus amblyrhynchos were mainly detected along the outer reef crest and inside the channel at Mangrove Bay. These individuals were captured on longlines outside the reef, and the intermittent detections are probably due to a relatively large home range which is known elsewhere for this species (Nelson and Johnson 1980; McKibben and Nelson, 1986). Interestingly, even thought the density of detections was greatest around the entrance of the channel the density of individuals was also high within the lagoon, suggesting that this complex reef habitat may be an important foraging area for this species. Few detections were recorded close inshore, which may indicate low levels of predation by *C. amblyrhynchos* in this habitat. Due to the relatively large home range of this species current sanctuary zones probably only provide adequate protection for juveniles which have more restricted movements (Stevens, 1984).

At Mangrove Bay, detections of *Carcharhinus cautus* were mainly adjacent to the mangroves. This species appears to have a very restricted home range, with few detections being recorded outside of this area. Detection and individual densities were spatially similar, with only a few individuals ranging outside of the area adjacent to the mangroves. This species appears to have limited movements and may spent its complete life-cycle within inshore mangrove habitats (White and Potter, 2004). The Mangrove Bay sanctuary zone is likely to effectively protect this species.

Carcharhinus melanopterus was detected by numerous receivers within Mangrove Bay. Both adults and juveniles were tagged inside and outside the lagoon, which may explain the detection hot spots both inside and around the spit and in the channel. The density of individuals is relatively high throughout a large portion of the area monitored in Mangrove Bay, with the highest density recorded inshore. At Coral Bay, one juvenile *C. melanopterus* had more restricted movements than the tagged adults; it was almost exclusively detected at Skeleton Bay suggesting this may be a nursery area. Current sanctuary zones are likely to protect the more spatially resticted juveniles, but adults have larger home ranges that will not be fully protected by current sanctuary zones. For example, of the individuals tagged at Skeleton Bay one was subsequently detected 135 km to the north at Mangrove Bay and another was captured by a recreational fisher 80 km south of Coral Bay outside the Marine Park.

The one *G. cuvier* tagged at Mangrove Bay remained in the area for about five months and was detected by most receivers in the array during this period. Subsequently detections ceased and this shark has not been heard from again. As demonstrated by the satellite tagging results, individuals tagged at Ningaloo may range widely along the Western Australian coast only periodically re-visiting the area (see next section). Current sanctuary zones would only offer temporary protection for this species.

All three species of rays tagged in February 2008 had more detections between April and September 2008. Primary and neighbour sites, as well as percentages of time spent in each site, show slight differences among the three species tagged. However, the three listening stations closest to Mangrove Bay (101814, 101830, 101826) had the greatest number of detections and detection days and this area, located within the Mangrove Bay sanctuary zone (MBSZ), is considered the centre of activity for *P. atrus, G. typus* and *U. asperrimus*. Detections occurred throughout the 24 h period, but were generally more numerous during the day suggesting greater daytime activity.

Only two adults of *T .lymma* were tagged, both in November 2008. The female showed site-fidelity within the shallows of Mangrove Bay having a dispersal range of 2 km while the male showed movement outside of the reef where its primary site was located.

Dispersion ranges varied among species with *U. asperrimus* displaying a very small range and mostly using the northern area of the array, which falls within the Mangrove Bay sanctuary zone. *Pastinachus atrus* showed activity throughout the array, mainly inside the lagoon. *Glaucostegus typus* also showed activity throughout the array but mainly in the northern sector and outside of the reef. *Himantura uarnak* and the male *T. lymma* moved in and out of the sanctuary zone and lagoon; however, larger numbers of animals tagged over a greater period of time are necessary to better describe patterns in these species.

The largest tagged male of *G. typu*s was detected in one of the southern arrays located approximately 130 km south of Mangrove Bay ("North Reef, Stanley's Pool west, Stanley's Pool north and Palm tree" Fig.41). Two of these stations were considered the primary site for this individual. Most of the tagged *G. typus* were adults which may explain their larger dispersion range and the higher usage of stations outside the reef when compared with the species where only juveniles were caught (*P. atrus, U. asperrimus* and *H. uarnak.*

Adult male *G. typus* and *T. lymma* showed a larger dispersal range and had centres of activity outside of the Mangrove Bay sanctuary zone which contrasted with the more restricted range of adult females. This may support the hypothesis of female site-fidelity and male biased dispersal in mature rays. However, these observations are based on very limited data at this stage.

The centres of activity of juvenile *P. atrus, G. typus, U. asperrimus* and *H. uarnak* tagged at Mangrove Bay were contained within the sanctuary zone. However, some movements of juveniles out of the sanctuary zone does occur. Adults of some of the ray species are more wide-ranging and their primary sites are located outside the sanctuary zone.

Satellite tagging

We chose to tag *G. cuvier* and *S. mokarran* because of their large size and likely trophic impacts on other megafauna in the NMP. *Sphyrna mokarran* is a known predator of large stingrays (Compagno, 1984; Strong, 1990) and has been observed in very shallow lagoon waters almost certainly chasing this prey. *Galeocerdo cuvier* is a known predator of turtles and dugongs (Compagno 1984; Heithaus 2001), both of which are abundant at NMP; these sharks are also frequently seen in shallow lagoon waters. We had hoped to tag more *S. mokarran* but catch rates of this species were low and those caught were often in poor condition.

We had mixed success with the results from the satellite tagging. Four tags (three on *G. cuvier* and one on *S. mokarran*) never transmitted after deployment. Transmission times for the remaining six tags ranged from 11–411 days providing a total of 806 transmission days with an average of 134 days. Heithaus *et al.* (2007) achieved transmission periods ranging from 12–99 days (n = 5) for *G. cuvier* and noted that the duration of useful tag life was shorter than that on more pelagic salmon *Lamna ditropis* and blue sharks *Prionace glauca* (Weng *et al.,* 2005). Hays *et al.* (2007) investigated the reasons why Argos satellite tags on marine animals stop transmitting. They suggested that failure of the salt-water switch was the most common cause of transmission loss and that this was most likely due to biofouling. Wilson *et al.* (2006) also thought biofouling was a likely cause of transmission failure, along with malfunction due to repeated contraction and expansion of pressure housings due to deep-diving behavioural cycles. Heithaus *et al.* (2007) dismissed battery failure as a reason for signal loss because of the low number of transmissions from *G. cuvier* they tagged and also thought biofouling of the saltwater switch to be the most likely cause.

Mortality resulting from capture and tagging stress might also be a factor in why tags fail to transmit. Sharks tagged in this study were captured from a research vessel. They were either held in a sling at water level for tagging if large, or landed on deck using the sling if relatively small; only sharks considered to be in good condition were tagged. Moyes *et al.* (2006) attempted to predict the survival of large pelagic fish, mainly *P. glauca,* by combining blood chemistry analysis with a PAT tagging approach. The fish were caught from research vessels using commercial longline fishing techniques and gear. Their analyses suggest that sharks landed in an apparently healthy condition are likely to survive long-term if released. Campana *et al.* (2009) came to a similar conclusion for sharks released in good condition.

Two of the *G. cuvier* moved north after tagging, as did the one *S. mokarran* which then returned to the Coral Bay area after about six months. The remaining *G. cuvier,* still transmitting after 390 days, provided an excellent track. This shark (tag 83859) moved north from Ningaloo travelling via the Kimberley to south of Sumba Island, Indonesia. It then returned south going past Ningaloo and Perth, rounding Cape Naturaliste and heading east as far as Esperance before retracing its path to Ningaloo. As it had done after tagging 12 months earlier, it is again moving north. None of the tracking data provided evidence of either species remaining in the vicinity of NMP for any length of time. However, another *G. cuvier* tagged acoustically outside the reef from Mangrove Bay, remained in the area for about five months Tag 83859 demonstrated that some individuals mix throughout Western Australian waters and also move as far away as Indonesia. Of five *G. cuvier* tagged at Shark Bay, WA, three remained within the Shark Bay region throughout the transmission period of their tags (<67 days). A fourth shark travelled about 400 km north before returning towards Shark Bay. Two of these sharks moved into waters over 800 m deep before returning to shallow coastal waters. One shark apparently moved to an area off the southeast coast of South Africa, although only two poor uplinks were received from this shark. *Galeocerdo cuvier* tagged at Raine Island, Queensland mostly remained in the vicinity of the island, with periodic excursions into deep water, up to a year after tagging; two sharks travelled around Cape York to the eastern Gulf of Carpentaria (Richard Fitzpatrick, Digital Dimensions, personal communication). In Hawaii, acoustically tracked *G. cuvier* were wide-ranging, swimming between islands and patrolling up to 100 km of coastline. Visits to specific sites were typically brief unpredictable and separated by absences of weeks, months or years (Meyer et al. 2009). These authors hypothesised that this was a strategy to surprise prey that otherwise become wary and difficult to catch.

Unfortunately, few depth data were available from the *G. cuvier* tagged at Ningaloo. Tag 62343 that remained in the tagging area south of Coral Bay for its 14 day transmission time spent 80% of its time in <50 m of water and 26% of its time in the top 5 m (Fig. 56); it did not go deeper than 150 m. Together with its position, this suggests that it was at times inside the lagoon. When the temperature data from this tag was compared to those from tags 62346, 83857 and 83858 it was very similar (Fig. 56) with none of these fish experiencing temperatures <14° C (and then only briefly) suggesting very little time was spent below 150–200 m depths. Tag 83859 that moved as far north as Indonesia and as far south as Esperance, experienced temperatures from 10–31° C but spent 91% of its time in 18–27° C water. The *S. mokarran* showed a bimodal depth distribution spending most of its time either between the surface and 10 m, or from 50–100 m, and not going deeper than 150 m. This shark experienced temperatures between 21–30° C spending most of its time in 24–27° C water.

3.5 Acknowledgements

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Darwin University, Darwin) analysed the data and provided much of the write-up on the shark and ray acoustic tracking sections. Russ Bradford (CSIRO Marine and Atmospheric Research, Hobart) helped with software and satellite data, Adam Barnett (University of Tasmania, Hobart) assisted with statistical analysis and Jonathan Ruppert (Charles Darwin University, Darwin) helped with the density plots in section 3.3.5. We thank the Australian Acoustic Tagging and Monitoring System (AATAMS), Sydney, for Charlie Huveneers participation in the field and the Master and crew of the RV 'Naturaliste'. We are grateful to Mike Sugden for acting as Dive Master on the April 2007 and December 2008 field trips. The research was undertaken under permit number SF6104, WA Fisheries permit 2007–30–32, and ethics approvals A07035 (Charles Darwin University ethics committee) and DPIW 7/2007–08. Funding was provided by WAMSI, CSIRO Marine and Atmospheric Research and the Wealth from Oceans Flagship Program and the Department of Fisheries, Government of Western Australia.

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3.7 Appendices

3.7.1 Appendix 1

Table 1.1. Checklist of Ningaloo chondrichthyans

Orectolobidae		
Eucrossorhinus dasypogon (Bleeker, 1867)	Tasselled Wobbegong	Diving
Orectolobus wardi Whitley, 1939	Northern Wobbegong	Diving
Ginglymostomatidae		
Nebrius ferrugineus (Lesson, 1831)	Tawny Shark	Diving, longline
Stegostomatidae		
Stegostoma fasciatum (Hermann, 1783)	Zebra Shark	Diving
Carcharhinidae		
Carcharhinus albimarginatus (Rüppell, 1837)	Silvertip Shark	Longline
Carcharhinus amblyrhynchos (Bleeker, 1856)	Grey Reef Shark	Diving, longline, acoustics
Carcharhinus amboinensis (Müller & Henle, 1839)	Pigeye Shark	Longline
Carcharhinus cautus (Whitley, 1945)	Nervous Shark	Acoustics
Carcharhinus limbatus/tilstoni (Müller & Henle, 1839)/(Whitley, 1950)	Blacktip Shark	Diving, longline
Carcharhinus melanopterus (Quoy & Gaimard, 1824)	Blacktip Reef Shark	Diving, acoustics
Carcharhinus obscurus (Lesueur, 1818)	Dusky Shark	Diving ?, longline
Carcharhinus plumbeus (Nardo, 1827)	Sandbar Shark	Longline
Carcharhinus sorrah (Müller & Henle, 1839)	Spot-tail Shark	Longline
Galeocerdo cuvier (Péron & Lesueur, 1822)	Tiger Shark	Longline, acoustics
Loxodon macrorhinus Müller & Henle, 1839	Sliteye Shark	Longline
Negaprion acutidens (Rüppell, 1837)	Lemon Shark	Diving, acoustics
Rhizoprionodon acutus (Rüppell, 1837)	Milk Shark	Longline
Triaenodon obesus (Rüppell, 1837)	Whitetip Reef Shark	Diving, longline, acoustics
Sphyrnidae		
Sphyrna lewini (Griffith & Smith, 1834)	Scalloped Hammerhead	Longline
Spyrna mokarran (Rüppell, 1837)	Great Hammerhead	Longline
Pristidae		
Pristis zijsron Bleeker, 1851	Green Sawfish	Angler
Rhynchobatidae		
Rhynchobatus australiae Whitley, 1939	Whitespotted Guitar Fish	Diving, longline
Rhinobatidae		
Glaucostegus typus (Bennett, 1830)	Giant Shovelnose Ray	Diving, acoustics
Dasyatidae		
Himantura fai Jordan & Seale, 1906	Pink Whipray	Diving
Himantura granulata (Macleay, 1883)	Mangrove Whipray	Diving
Himantura jenkinsii (Annandale, 1909)	Jenkins' Whipray	Diving
Himantura uarnak (Forsskål, 1775)	Reticulate Whipray	Diving
Neotrygon kuhlii (Müller & Henle, 1841)	Bluespotted Maskray	Diving
Neotrygon sp. (Last, 1987)	Ningaloo Maskray	Diving

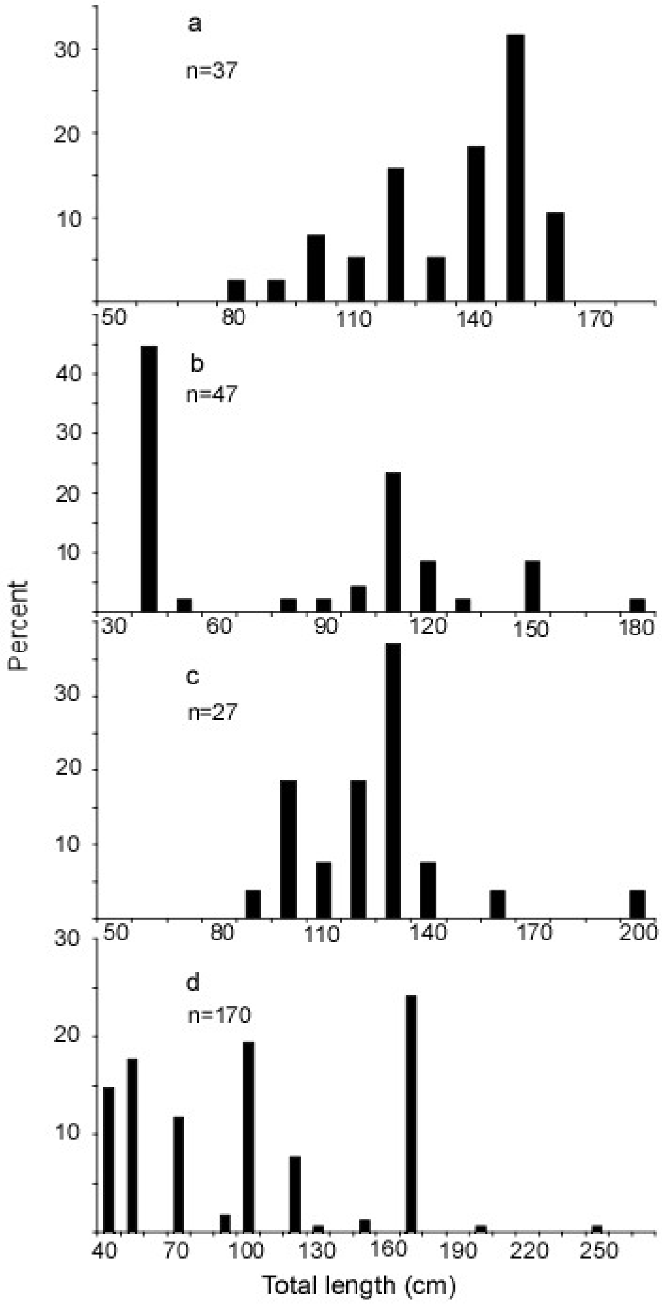
Pastinachus atrus (Macleay, 1883)	Cowtail Stingray	Diving, acoustics
Taeniura lymma (Forsskål, 1775)	Bluespotted Fantail Ray	Diving
Taeniurops meyeni (Müller & Henle, 1841)	Blotched Fantail Ray	Diving, longline
Urogymnus asperrimus (Bloch & Schneider, 1801)	Porcupine Ray	Diving, acoustics
Myliobatidae		
Aetobatus narinari (Euphrasen, 1790)	Whitespotted Eagle Ray	Diving
Mobulidae		
Manta birostris (Walbaum, 1792)	Manta Ray	Diving
Mobula eregoodootenkee (Bleeker, 1859)	Pygmy Devilray	Diving
Mobula thurstoni (Lloyd, 1908)	Bentfin Devilray	Diving

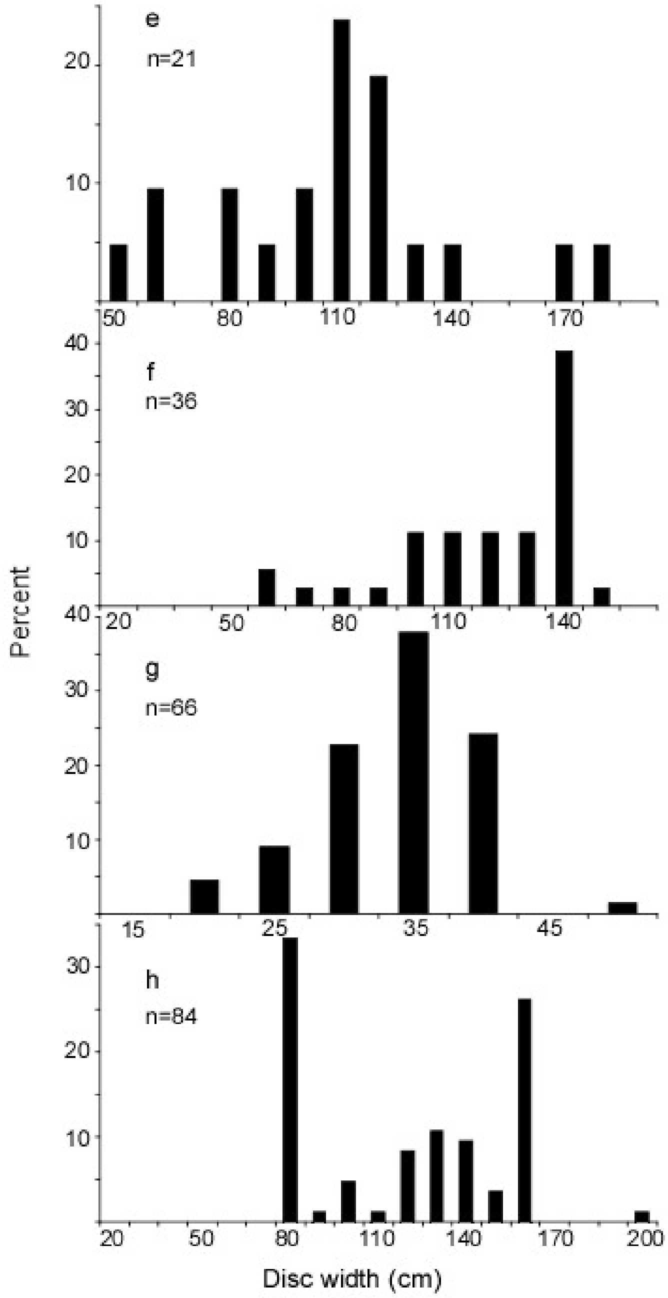
OTHER VALIDATED RECORDS

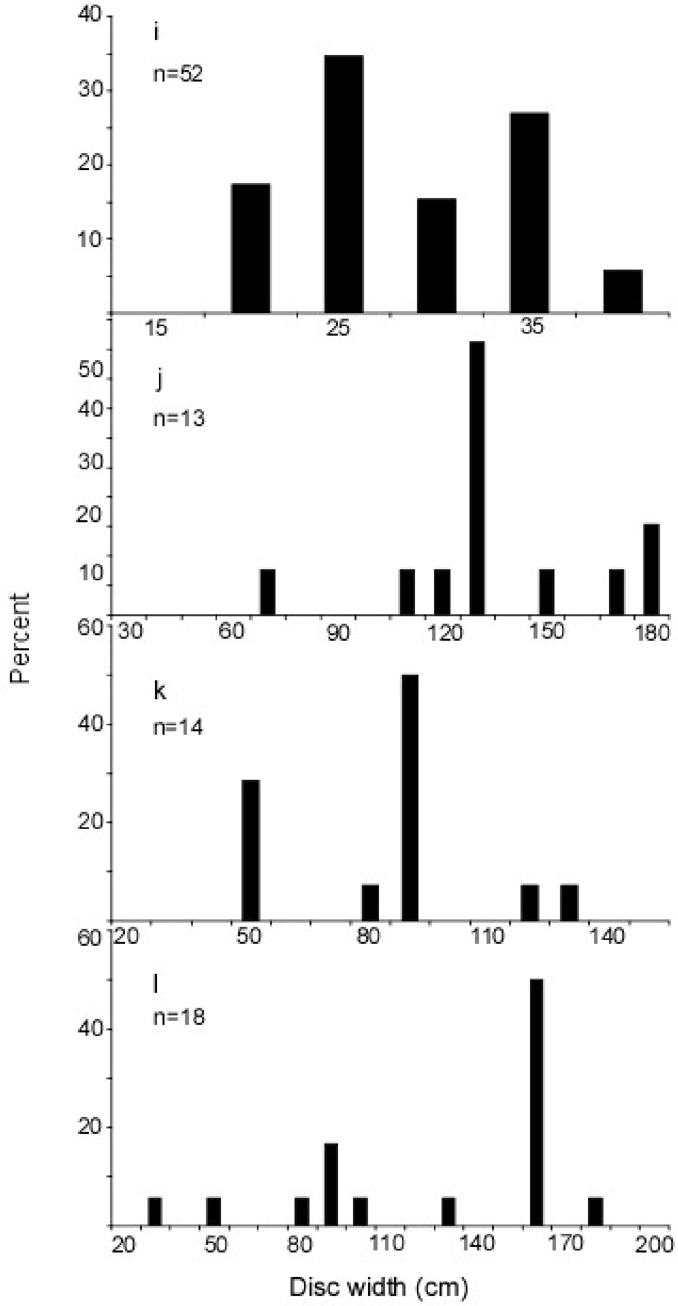
Centrophoridae		
Centrophorus acus Garman, 1906	Gulper Shark	Longline
Orectolobidae		
Orectolobus halei Whitley, 1940	Gulf Wobbergong	Longline
Rhincodontidae		
Rhincodon typus Smith, 1828	Whale Shark	Observation
Odontaspididae		
Carcharias taurus Rafinesque, 1810	Grey Nurse Shark	Photo (Piercam)
Lamnidae		
Carcharodon carcharias (Linnaeus, 1758)	White Shark	Observation
Triakidae		
Mustelus stevensi White & Last, 2008	Western Spotted Gummy Shark	Longline
Hemitriakis falcata Compagno & Stevens, 1993)	Sicklefin Houndshark	
Carcharhinidae		Longline
Carcharhinus brevipinna (Muller & Henle, 1839)	Spinner Shark	Longline
Hypnidae		
Hypnos monopterygius (Shaw, 1795)	Coffin Ray	

3.7.2 Appendix 2

Figure 2.1. Size distributions of elasmobranch species observed on dive surveys (a) *C. amblyrhynchos* (b) *C. melanopterus* (c) *T. obesus* (d) *G. typus* (e) *H. fai* (f) *H. uarnak* (g) *N. kuhlii* (h) *P. atrus* (i) *T. lymma* (j) *T. meyeni* (k) *U. asperrimus* (l) *A. narinari*




e
n=21
f
n=36
g
n=66
h
n=84
Percent
Disc width (cm)



i
n=52
j
n=13
k
n=14
l
n=18
Percent
Disc width (cm)

Table 2.1. Size range of minor species observed during dive surveys. Sharks and *R. australiae* are estimated TL, all other rays are estimated DW.

Species	Size range (cm)	Total
E. dasypogon	120	1
O. wardi	50	1
S. fasciatum	160–180	3
N. ferrugineus	90–250	9
C. limbatus	150	1
C. obscurus	220	1
N. acutidens	80–190	7
unid. carcharhinid	200	2
unid. shark	40–50	2
R. australiae	160–220	4
H. granulata	90–120	3
H. jenkinsii	110–120	2
N. leylandi	25–35	3
N. sp.	20–40	5
M. birostris	300–400	4
M. eregoodootenkee	130	1
M. thurstoni	120–140	4

3.7.3 Appendix 3.

Figure 3.1. All elasmobranchs SPUA. Hatched areas are sanctuary zones.

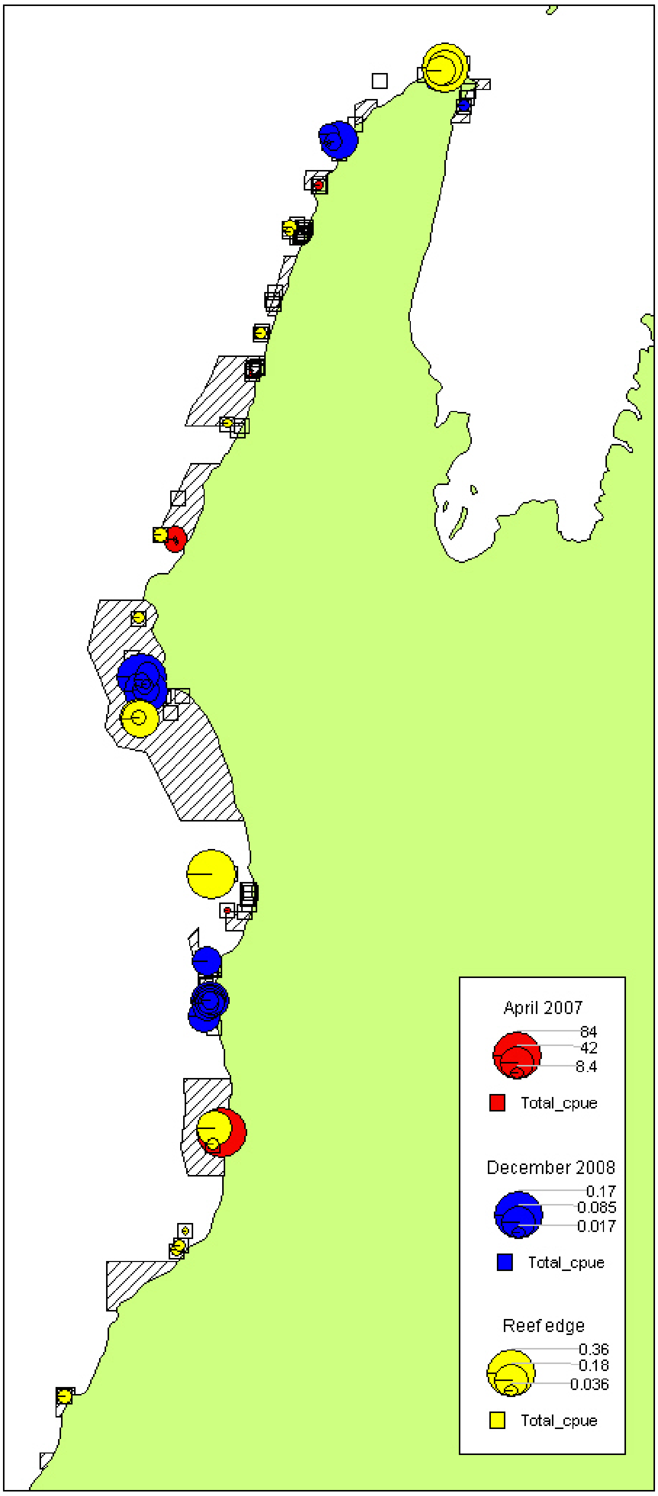


Figure 3.2. *Carcharhinus amblyrhynchos* SPUA. Hatched areas are sanctuary zones.

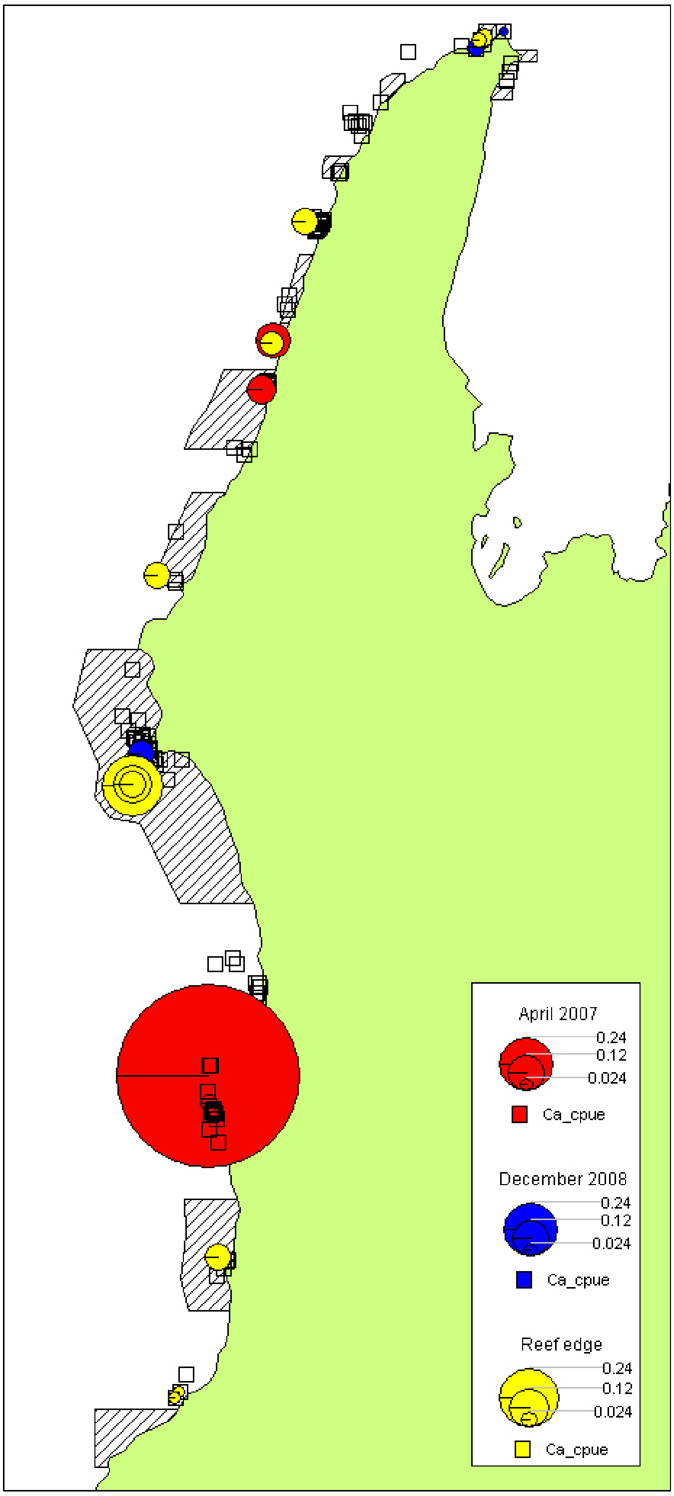


Figure 3.3. *Carcharhinus melanopterus* SPUA. Hatched areas are sanctuary zones.

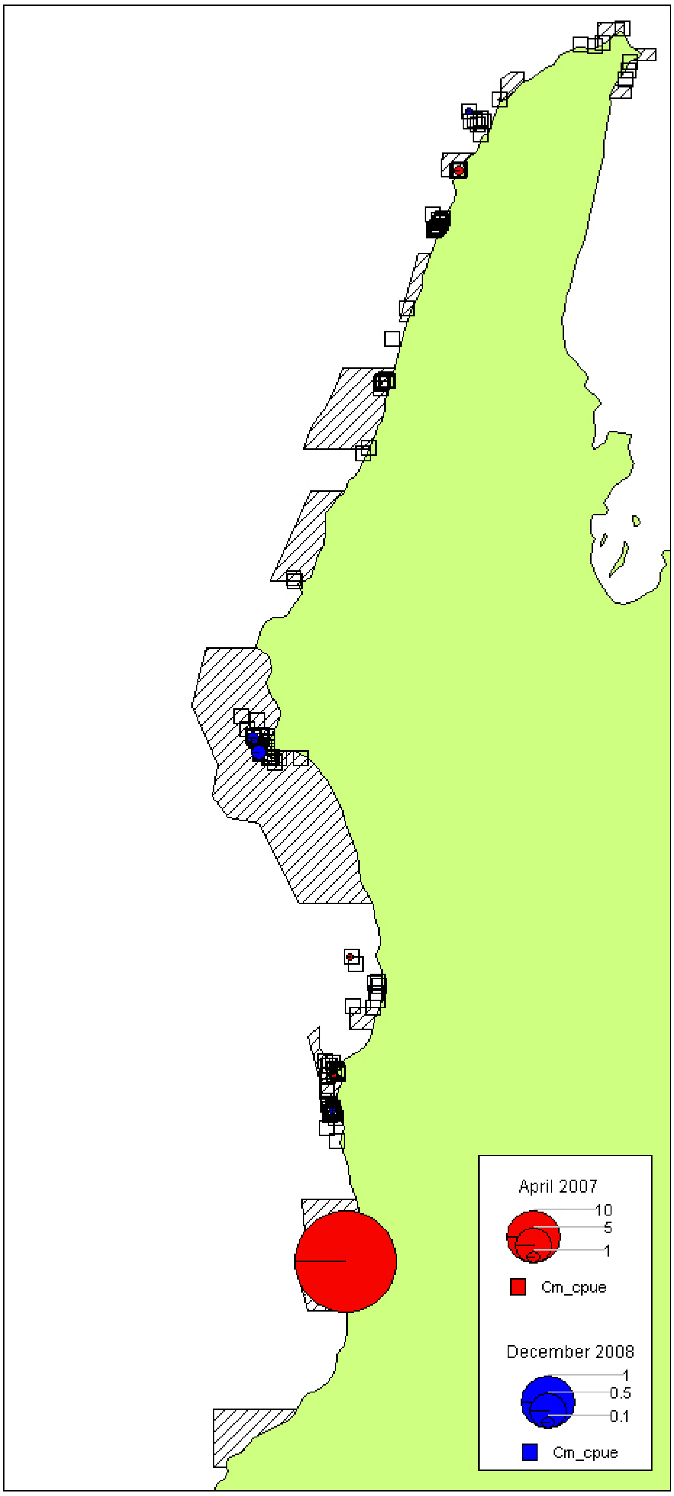


Figure 3.4. *Triaenodon obesus* SPUA. Hatched areas are sanctuary zones.

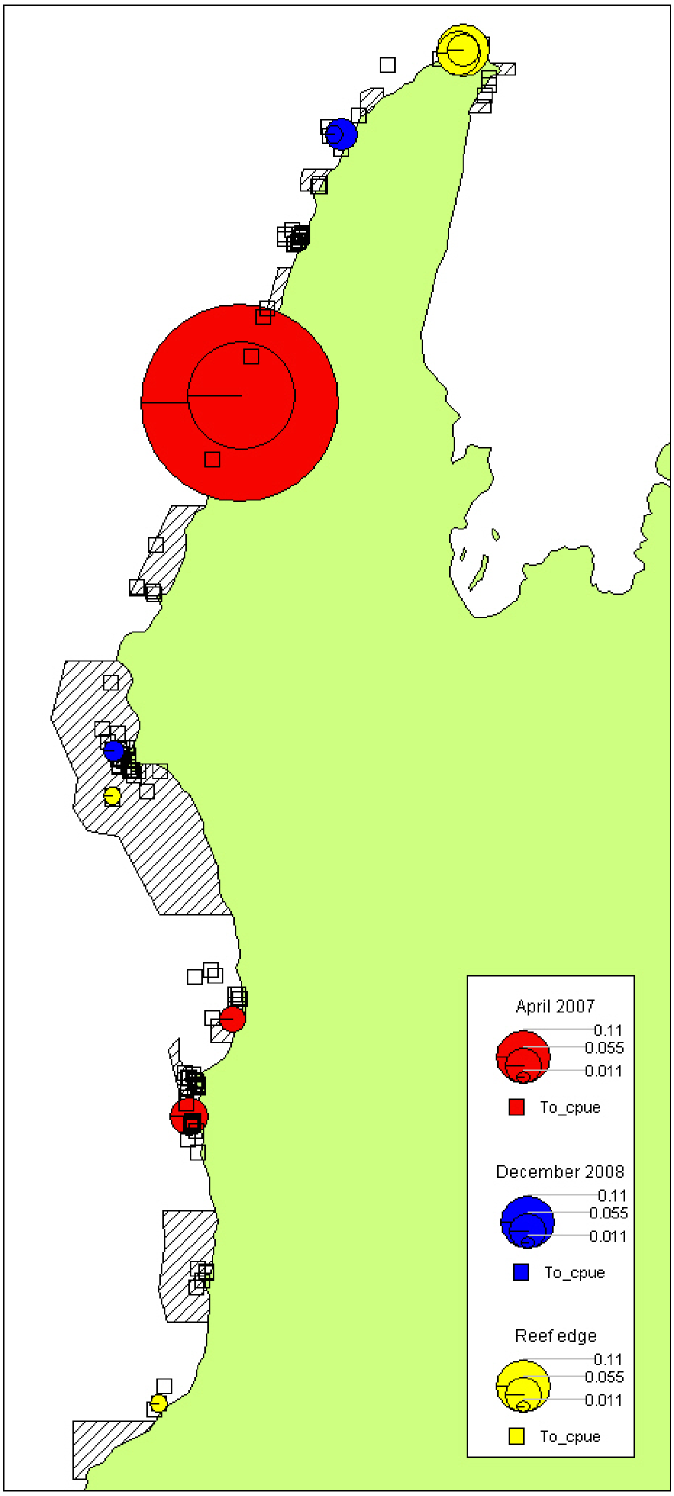


Figure 3.5. *Glaucostegus typus* SPUA. Hatched areas are sanctuary zones.

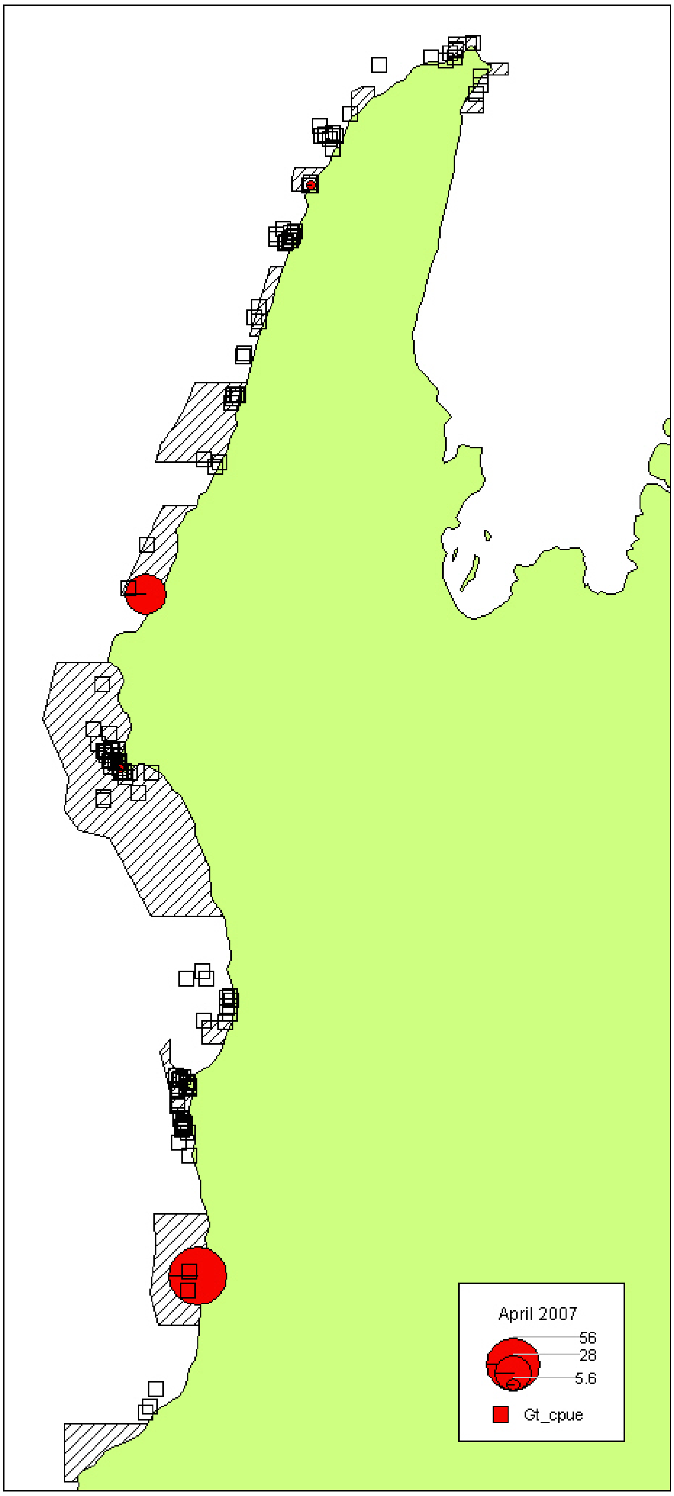


Figure 3.6. *Himantura fai* SPUA. Hatched areas are sanctuary zones.

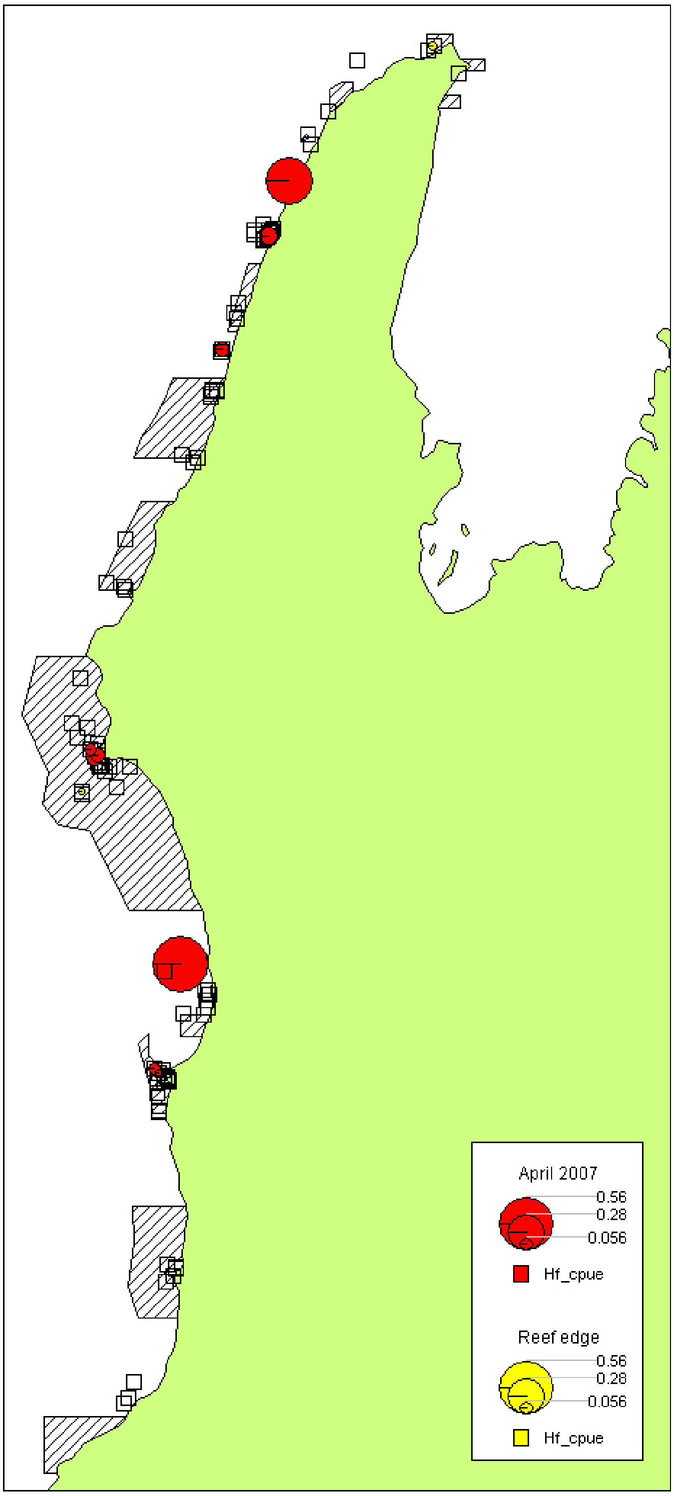


Figure 3.7. *Himantura uarnak typus* SPUA. Hatched areas are sanctuary zones.

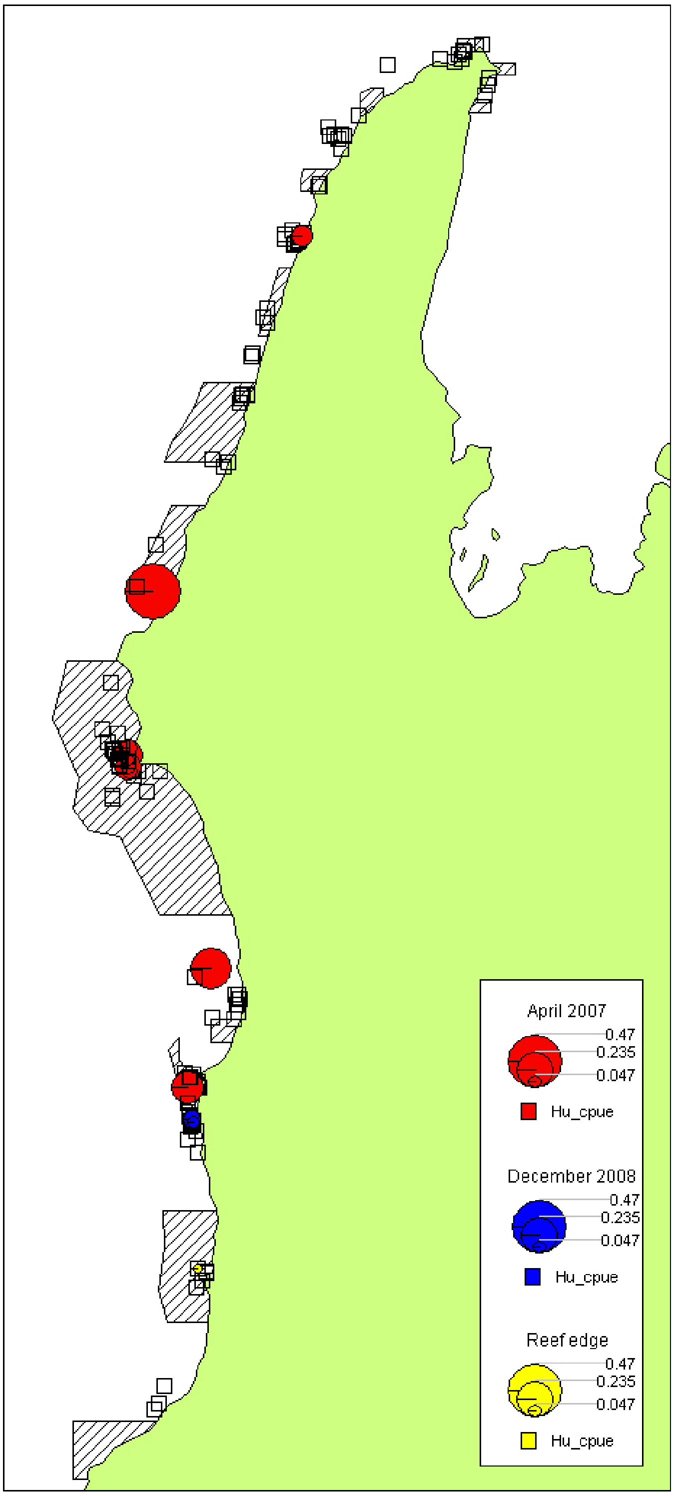


Figure 3.8. *Neotrygon kuhlii* SPUA. Hatched areas are sanctuary zones.

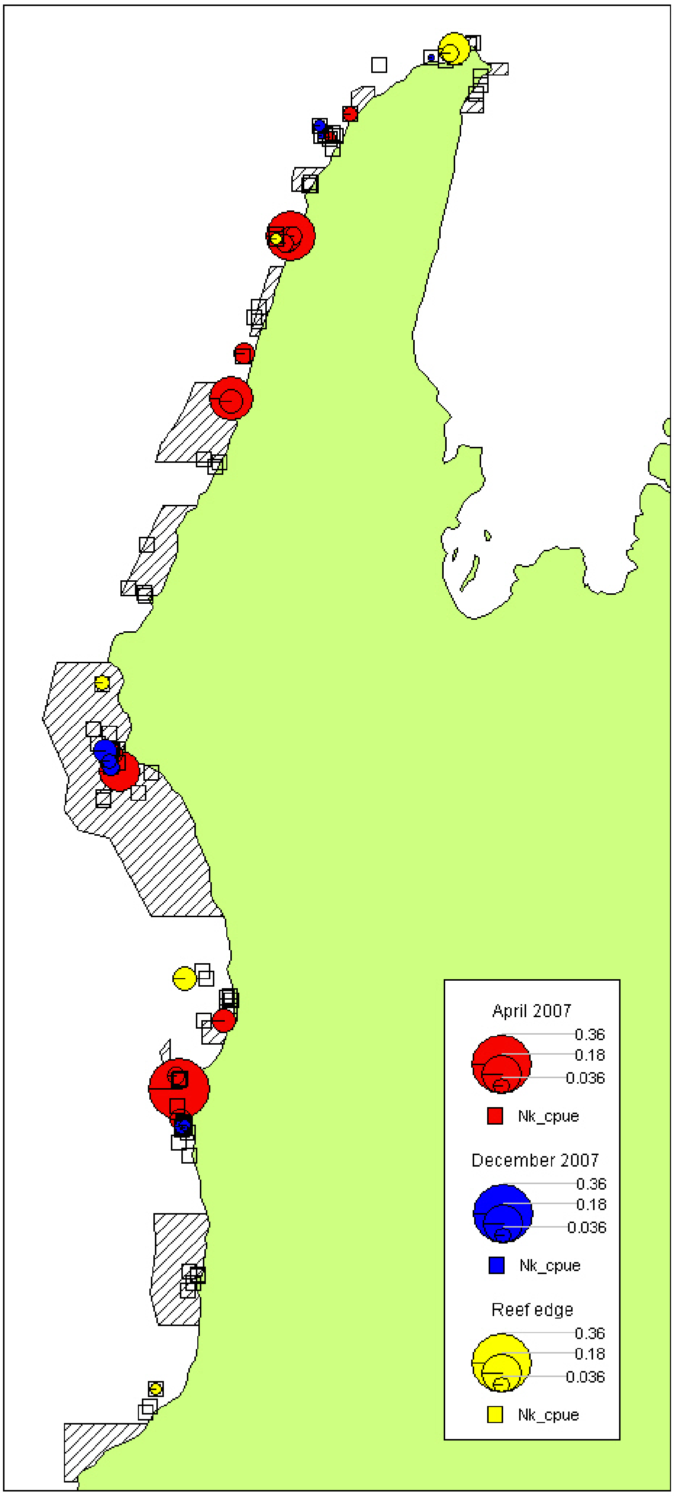


Figure 3.9. *Pastinachus atrus* SPUA. Hatched areas are sanctuary zones.

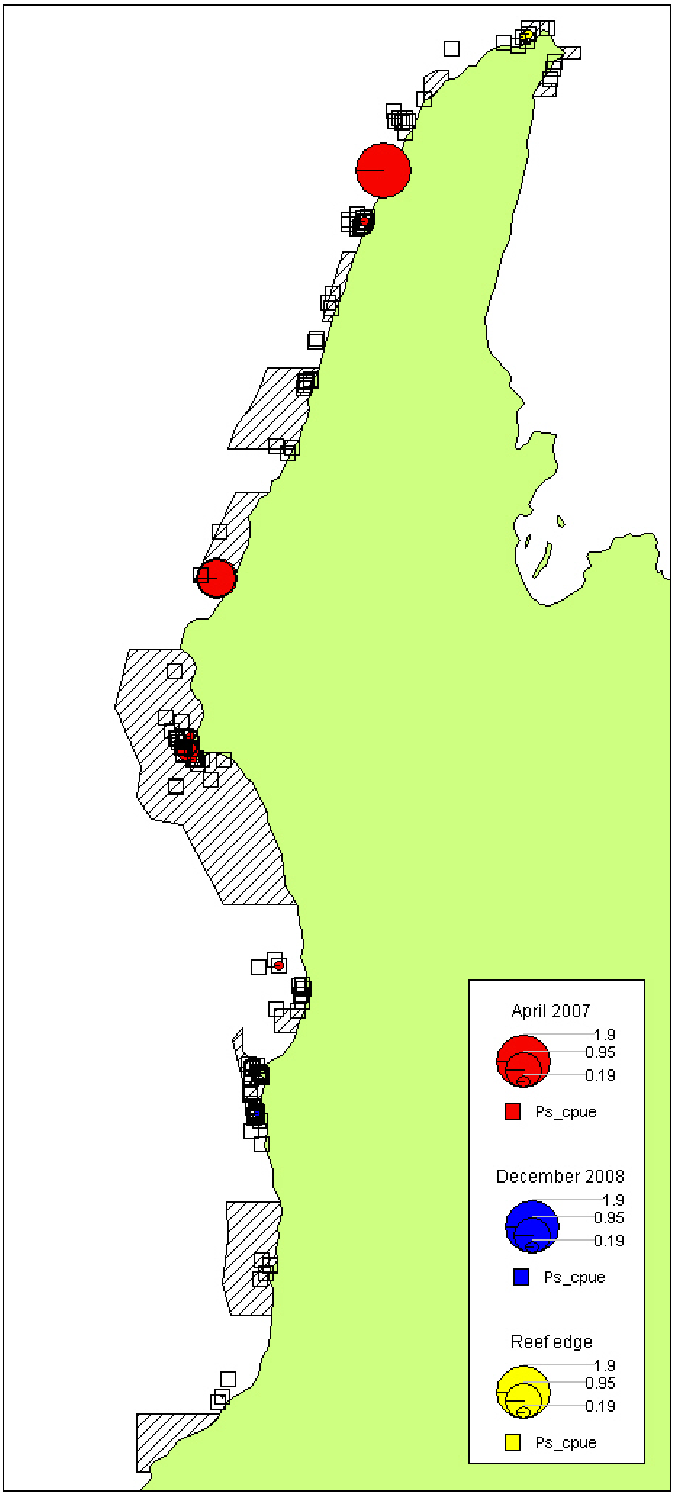


Figure 3.10. *Taeniura lymma* SPUA. Hatched areas are sanctuary zones.

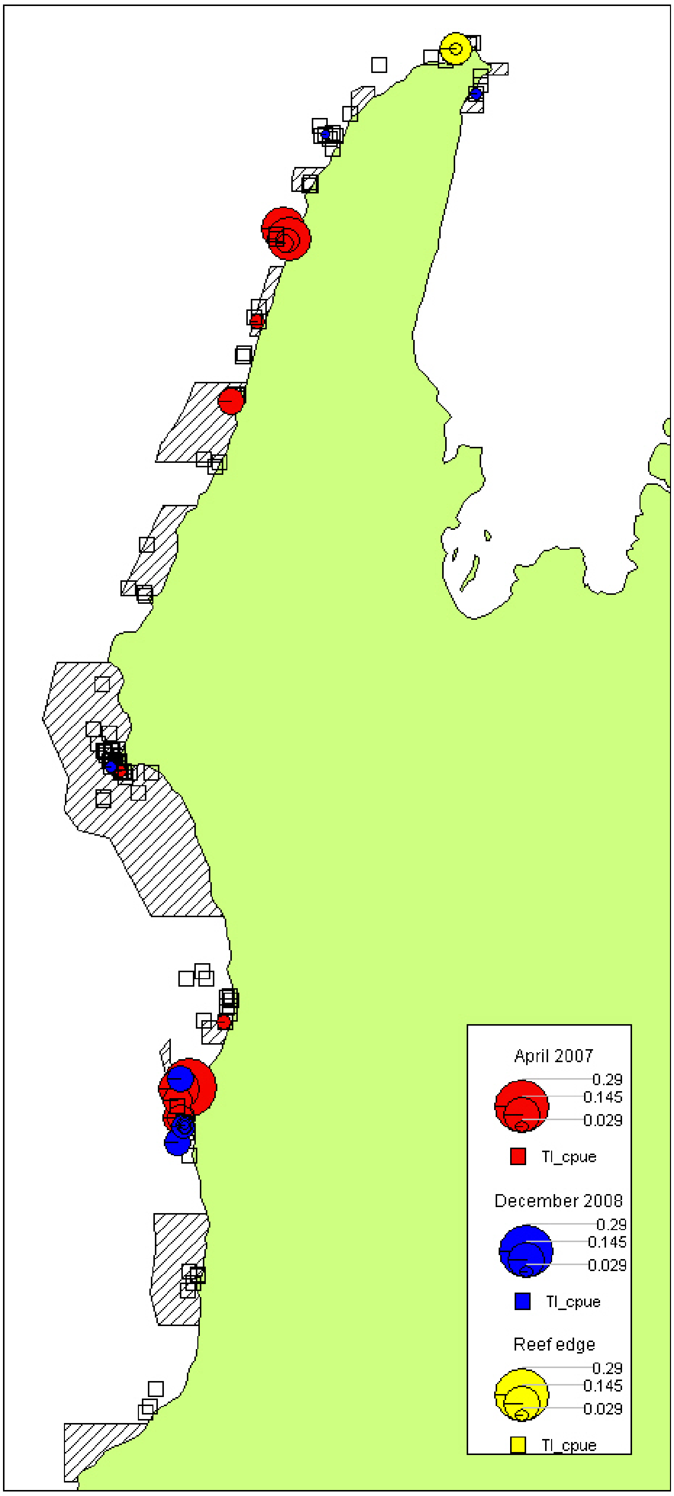


Figure 3.11. *Carcharhinus albimarginatus* CPUE from RV 'Naturaliste'surveys. Hatched areas are sanctuary zones.

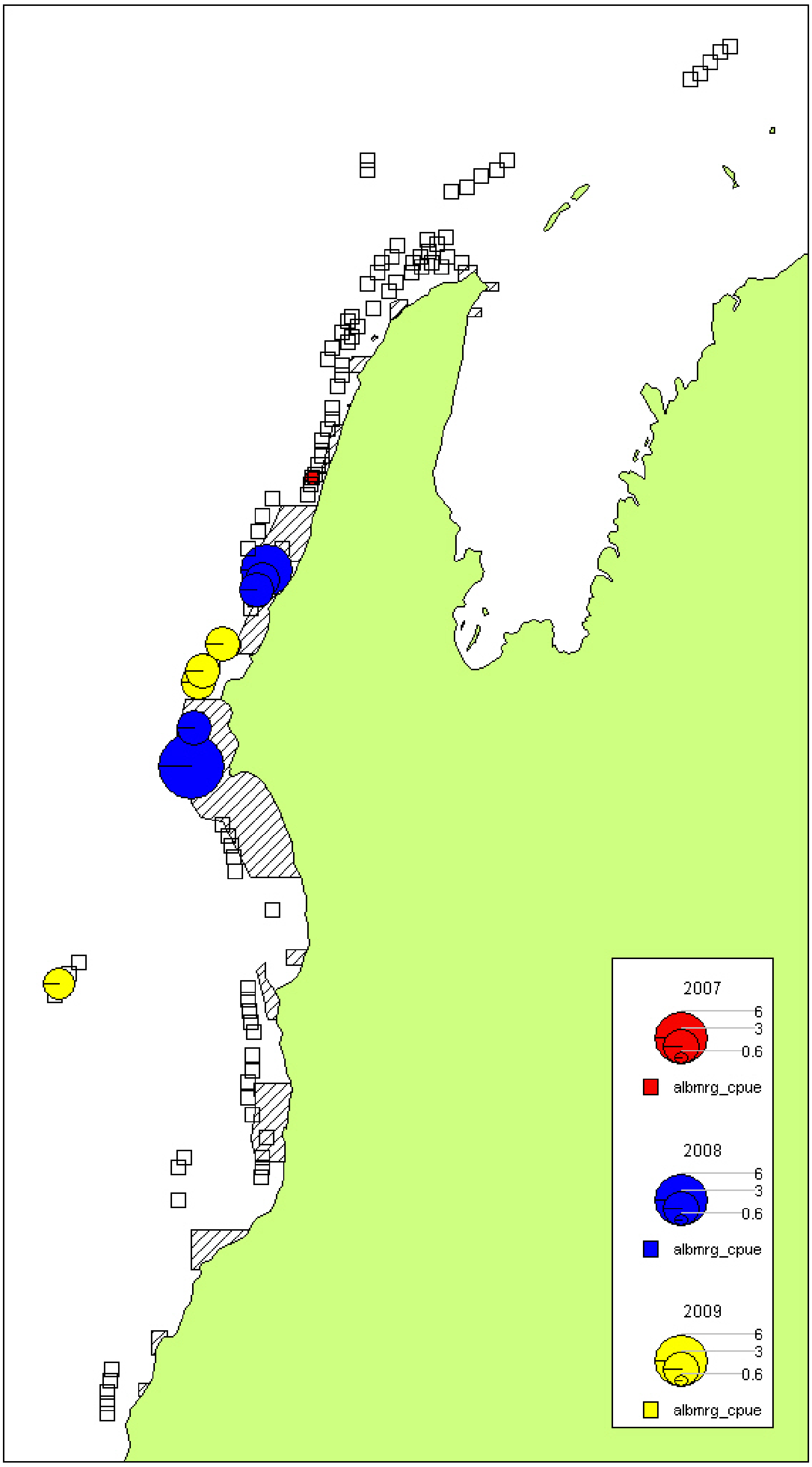


Figure 3.12. *Carcharhinus amblyrhynchos* CPUE from RV 'Naturaliste' surveys. Hatched areas are sanctuary zones.

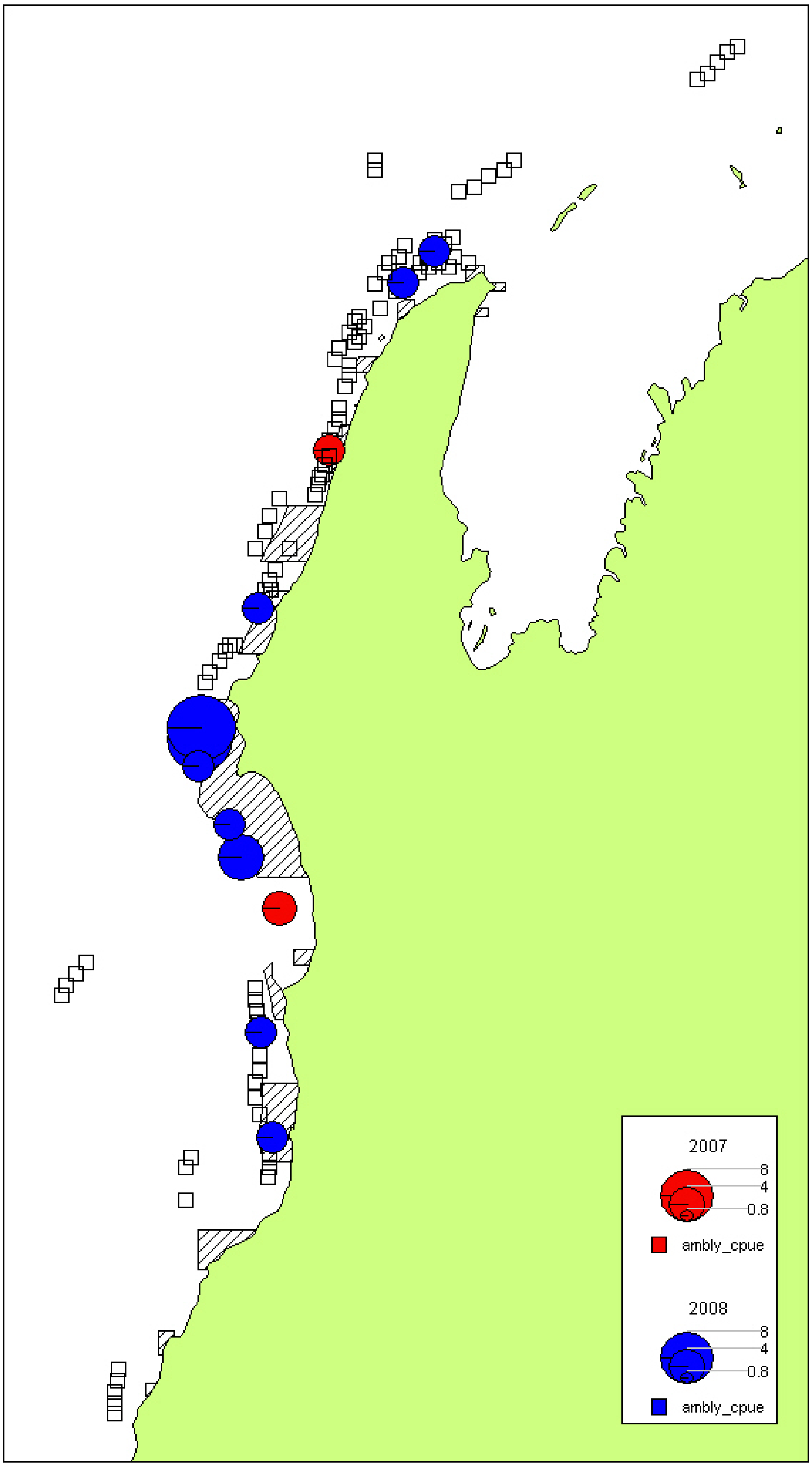


Figure 3.13. *Carcharhinus limbatus/tilstoni* CPUE from RV 'Naturaliste'surveys. Hatched areas are sanctuary zones.

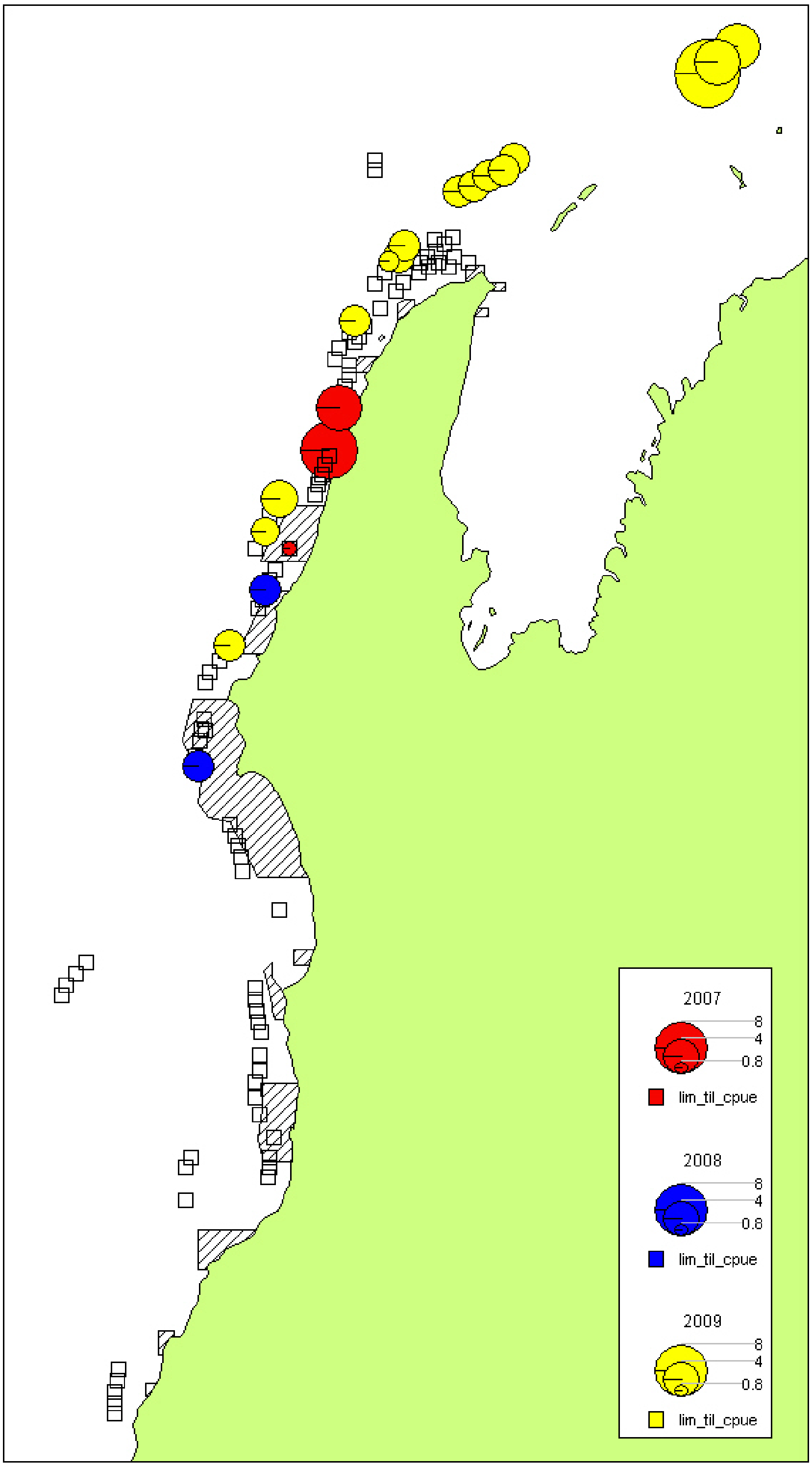
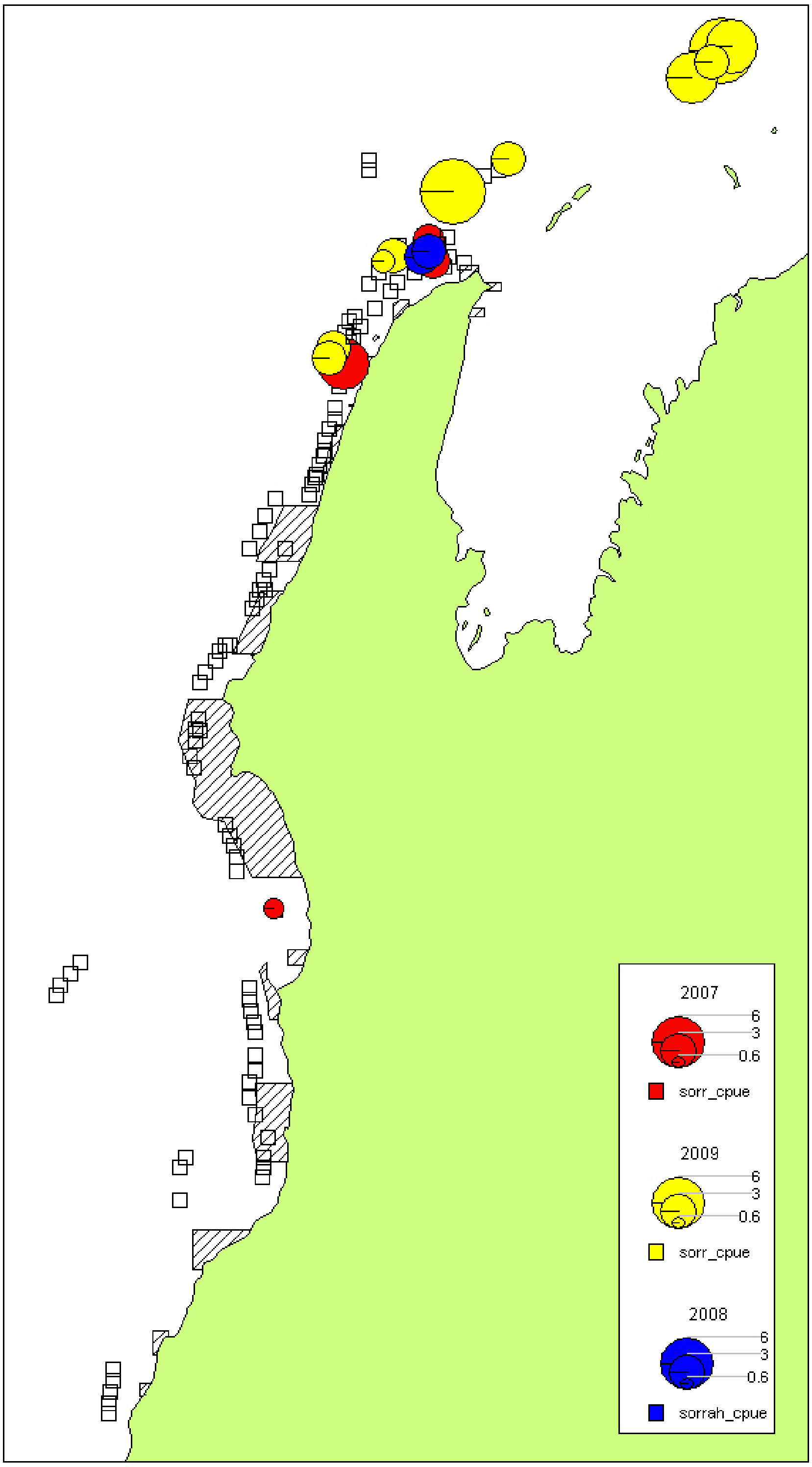


Figure 3.14. *Carcharhinus sorrah* CPUE from RV ‘Naturaliste’surveys. Hatched areas are sanctuary zones.



3.7.4 Appendix 4

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Table 4.1. Total number of sharks tagged at Ningaloo.

Tag ID	Species	Sex	TL (cm)	Location	No of detections
8219	*C. amblyrhynchos*	F	161	Mangrove Bay	355
8227	*C. amblyrhynchos*	F	176	Mangrove Bay	700
8228	*C. amblyrhynchos*	F	168	Mangrove Bay	0
8229	*C. amblyrhynchos*	F	146	Mangrove Bay	18764
8230	*C. amblyrhynchos*	F	150	Mangrove Bay	25334
8236	*C. amblyrhynchos*	F	97	Mangrove Bay	6
8327	*C. amblyrhynchos*	F	146	Skeleton Bay	10956
8346	*C. amblyrhynchos*	F	152	Mangrove Bay	143
8347	*C. amblyrhynchos*	F	160	Mangrove Bay	130
8349	*C. amblyrhynchos*	F	94.8	Mangrove Bay	148
8353	*C. amblyrhynchos*	F	113	Skeleton Bay	2067
53350	*C. amblyrhynchos*	F	165	Skeleton Bay	14361
53351	*C. amblyrhynchos*	F	172	Skeleton Bay	2397
53352	*C. amblyrhynchos*	F	156	Skeleton Bay	4098
53353	*C. amblyrhynchos*	F	147	Skeleton Bay	2751
53354	*C. amblyrhynchos*	F	130	Skeleton Bay	5170
53355	*C. amblyrhynchos*	F	167	Skeleton Bay	5095
53414	*C. amblyrhynchos*	M	115	Skeleton Bay	1631
8212	*C. cautus*	F	110	Mangrove Bay	6384
8214	*C. cautus*	F	90.5	Mangrove Bay	13
8215	*C. cautus*	F	117	Mangrove Bay	19568
8216	*C. cautus*	F	104.5	Mangrove Bay	14948
8231	*C. cautus*	F	114.3	Mangrove Bay	122
8232	*C. cautus*	F	109.9	Mangrove Bay	228
8233	*C. cautus*	F	107.9	Mangrove Bay	820
8247	*C. cautus*	F	74.9	Mangrove Bay	456
8248	*C. cautus*	Imm. M	74	Mangrove Bay	109
8250	*C. cautus*	F	79.8	Mangrove Bay	88
8341	*C. cautus*	F	77	Mangrove Bay	10117
8211	*C. melanopterus*	F	134	Mangrove Bay	365
8217	*C. melanopterus*	F	121	Mangrove Bay	16199
8218	*C. melanopterus*	F	134	Mangrove Bay	9997
8220	*C. melanopterus*	M	124	Mangrove Bay	0
8234	*C. melanopterus*	F	130	Mangrove Bay	10930
8252	*C. melanopterus*	F	90.1	Mangrove Bay	1777
8255	*C. melanopterus*	F	100	Mangrove Bay	3125
8256	*C. melanopterus*	Imm. M	78	Mangrove Bay	2947
8259	*C. melanopterus*	Imm. M	64	Mangrove Bay	195
8324	*C. melanopterus*	M	105	Skeleton Bay	460
8328	*C. melanopterus*	F	127	Skeleton Bay	4532
8329	*C. melanopterus*	F	140	Skeleton Bay	3589
8329	*C. melanopterus*	F	136	Skeleton Bay	18
8330	*C. melanopterus*	F	64	Skeleton Bay	6840
8331	*C. melanopterus*	M	60.2	Skeleton Bay	65381
8332	*C. melanopterus*	F	138	Skeleton Bay	2104

8333	*C. melanopterus*	F	126	Skeleton Bay	7826
8334	*C. melanopterus*	F	128	Skeleton Bay	1425
8335	*C. melanopterus*	F	121	Skeleton Bay	3677
14501	*C. melanopterus*	F	131	Skeleton Bay	2646
14502	*C. melanopterus*	F	144	Skeleton Bay	6500
14503	*C. melanopterus*	F	142	Skeleton Bay	4276
14504	*C. melanopterus*	F	134	Skeleton Bay	529
14505	*C. melanopterus*	F	141	Skeleton Bay	6637
53343	*C. melanopterus*	F	127	Skeleton Bay	4021
53344	*C. melanopterus*	F	137	Skeleton Bay	2310
53345	*C. melanopterus*	M	129	Skeleton Bay	1271
53346	*C. melanopterus*	M	134	Skeleton Bay	571
53347	*C. melanopterus*	F	128	Skeleton Bay	5453
53348	*C. melanopterus*	F	124	Skeleton Bay	329
53349	*C. melanopterus*	F	137.5	Skeleton Bay	3293
53359	*C. melanopterus*	M	127	Skeleton Bay	633
53360	*C. melanopterus*	F	150.5	Skeleton Bay	546
53361	*C. melanopterus*	F	138	Skeleton Bay	18290
53413	*C. melanopterus*	F	117	Skeleton Bay	3801
53415	*C. melanopterus*	M	126	Skeleton Bay	44
53418	*C. melanopterus*	F	100	Skeleton Bay	175
53419	*C. melanopterus*	M	128	Skeleton Bay	8
53420	*C. melanopterus*	M	118	Skeleton Bay	97
53421	*C. melanopterus*	M	104.5	Skeleton Bay	46
53422	*C. melanopterus*	M	126.5	Skeleton Bay	275
8235	*G. cuvier*	F	396	Mangrove Bay	6758
8246	*N. acutidens*	Imm. M	73	Mangrove Bay	16668
8326	*N. acutidens*	M	121	Skeleton Bay	3422
8339	*N. acutidens*	F	77	Mangrove Bay	51
8340	*N. acutidens*	M	81	Mangrove Bay	26
8342	*N. acutidens*	F	82	Mangrove Bay	7294
53342	*N. acutidens*	M	154.5	Skeleton Bay	8259
53356	*N. acutidens*	F	138	Skeleton Bay	18330
53402	*N. acutidens*	M	75	Skeleton Bay	6500
53416	*N. acutidens*	M	105	Skeleton Bay	123
53417	*N. acutidens*	M	127	Skeleton Bay	9751
53357	*T. obesus*	M	142	Skeleton Bay	3152
53358	*T. obesus*	M	136	Skeleton Bay	2174
Total					**432,605**

4. COMMUNICATION AND OUTPUTS

4.1 Communication Achievements

This section should include the relevant communication activities and achievements that have occurred through the life of the project. Information should be divided into the following subheadings

4.1.1 Students Supported

Conrad Speed, School for Environmental Research, Charles Darwin University. PhD program. Supervisor: Dr Mark Meekan, Australian Institute for Marine Science, Perth. Assisted in February 2008 fieldwork capturing elasmobranchs and playing a leading role in surgical implantation of acoustic tags for studies on spatial dynamics of key species. Responsible for analysis of acoustic data on elasmobranchs (mainly sharks) from the acoustic arrays.

Florencia Cerutti, School of Environmental and Life Sciences, Charles Darwin University. PhD program. Supervisor: Dr Mark Meekan, Australian Institute for Marine Science, Perth. Assisted with December 2008 dive survey of elasmobranchs. Responsible for analysis of acoustic data on elasmobranchs (mainly batoids) from the acoustic arrays.

4.1.2 PhD Theses and Dissertations and Student Placement

Conrad Speed, Movement, behaviour and feeding ecology of reef sharks at Ningaloo Reef, expected submission date June 2011, PhD, Charles Darwin University.

Florencia Cerutti, Ecological and genetic connectivity of stingrays at Ningaloo Reef, WA, expected submission date September 2011, PhD, Charles Darwin University.

4.1.3 Publications

4.1.4 Planned Publications

4.1.5 Presentations

J. Stevens, R. McAuley, P. Last, W. White, J. Chidlow, R. Pillans, M. Meekan, C. Huveneers, C. Speed, F. McGregor and M. Sugden. Diversity, abundance and habitat utilisation of sharks and rays at Ningaloo Reef, WA. Oceania Chondrichthyan Society, September 2008, Sydney.

4.2 Project Outputs

Subproject 3.2.1. Diversity, abundance and habitat utilisation of sharks and rays. May 2007 WAMSI progress report. 14 pp
Subproject 3.2.1. Diversity, abundance and habitat utilisation of sharks and rays. November 2007 WAMSI progress report. 10 pp
Subproject 3.2.1. Diversity, abundance and habitat utilisation of sharks and rays. November 2008 WAMSI progress report. 4 pp
Subproject 3.2.1. Diversity, abundance and habitat utilisation of sharks and rays. May 2008 WAMSI progress report. 21 pp

4.3 Data Management

Acoustic tag data are stored on the Integrated Marine Observing System (IMOS) database. Satellite tag data are stored on the CSIRO system (tag release and tag set-up details are on the Tuna–Tag Access database; ptt transmissions from ARGOS are logged and stored automatically). Dive survey data are stored and analysed on a series of 14 Excel files, longline survey data on 7 Excel files and satellite tag data on 7 Excel files. These files are stored on the CSIRO system with copies sent to WAMSI.

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