Observer-based study of targeted commercial fishing for large shark species in waters off northern New South Wales

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EXECUTIVE SUMMARY

Commercial line fishing is a significant industry in the coastal waters of New South Wales (NSW), with an annual total retained catch of approximately 2,000 tonnes worth an estimated A$10 million at the first point of sale. It is managed as a component of the NSW Ocean Trap and Line (OTL) fishery and involves a range of different line-fishing methods such as handlining, trolling, droplining, setlining and trotlining, which are used to catch a wide variety of species including yellowtail kingfish, snapper, blue-eye trevalla, mackerels, tunas and sharks.

A lack of general knowledge regarding catches of sharks in the OTL fishery became of increased concern during the mid-2000s due to substantial increases in fishing effort for, and catches of sharks by commercial line fishers in NSW waters around that time. More specifically, the annual catch of sharks by OTL fishers increased by approximately 200% over a two-year period between 2004/05 and 2006/07, with the majority of this increase reported by the fishers as ‘Shark, Unspecified’. All evidence suggested that the increase was a result of increased targeting of large sharks – particularly species of whaler shark – using setlines and trotlines in the waters off northern NSW. These sharks are caught primarily for the high value of their fins, although the trunks (i.e., headless, gutless and finless carcass) are also sold.

Generally, sharks sexually mature late (4 – 20 years of age), have few young (2 – 25 pups per litter) and have long reproductive cycles (1 – 3 years) – a combination of factors that results in slow replacement potential for shark populations. If overfished over a sustained period, catch rates are likely to collapse and many years (or decades) are likely to be required for the depleted populations to rebuild to levels that might permit limited commercial exploitation. Therefore, relatively ‘new’ commercial shark fisheries such as the recently expanded northern NSW fishery must be managed conservatively to prevent overfishing and ensure their long-term health and viability to sustainable exploitation. With this in mind, I&I NSW implemented specific conditions and restrictions on shark fishing (targeted or otherwise) in the OTL fishery during 2008/09 that included a total allowable commercial catch (TACC) for large shark (i.e., whaler, hammerhead and mackerel shark) species; maximum catch limits for individual TACC shark fishing trips; and a restricted permit for fishers specifically targeting sandbar shark (a type of whaler shark). In addition, a two-pronged approach to improve the fisher-dependent catch-reporting system in relation to targeted shark fishing was implemented. A new catch-reporting form requiring more accurate, more detailed and more frequent reporting of sharks caught and fishing operations was introduced, while a shark species identification guide was also developed and distributed among NSW commercial fishers.

One of the conditions put in place for the sandbar-permit fishers was the requirement that they had to host an I&I NSW researcher during fishing trips when requested. This provided an opportunity for observer-based research to collect information onboard OTL vessels targeting sharks, allowing a much greater understanding of targeted shark fishing in NSW waters within a relatively short period of time. Acknowledging the importance of the ultimate outcomes, Northern Rivers Catchment Management Authority (NRCMA) collaborated with I&I NSW to fund observer-based research in the shark fishery of northern NSW during 2008/09 to take full advantage of that opportunity. Given this, the main objectives of this project were to address the urgent need for collection of: operational data; accurate, species-specific catch data; and biological samples onboard shark-fishing vessels operating in northern NSW coastal waters.

A total of 81 fishing trips (114 fishing days) were observed between 1 September 2008 and 30 June 2009 as part of this study. In general, the results demonstrated that the targeted shark fishery of northern NSW is a multi-species fishery employing a number of types of fishing gear to catch a range of species of large shark. However, the observer coverage achieved during this study was spatially and temporally variable within the study area. For example, from September 2008 to

January 2009 high observer coverage (50%) was achieved for waters within fishery management Zone 4 (Crowdy Head to South West Rocks), while very low coverage (5%) was achieved within Zones 1 – 3 (South West Rocks to Tweed Heads; all methods), despite comparable levels of reported fishing effort. In contrast, high observer coverage (66%) within Zones 1 – 4 was achieved from February to June 2009, although very little targeted shark fishing was done in Zone 4 during that period. As a consequence, generalisations or conclusions regarding catches of large sharks in Zones 1 – 3 during spring and summer months, and in Zone 4 during autumn and winter months cannot be made using the observer data collected during this study. In any case, the overall observer coverage achieved during the study was 37%, which can be considered high.

All observed trips combined, a total of 14 targeted TACC shark species, comprising around 85% of the overall total catch (i.e., all retained and discarded organisms) by number, was recorded. Whaler sharks dominated catches, with sandbar shark (35% of overall total catch), dusky whaler (15%) and spinner shark (11%) the main species observed in catches. Other TACC sharks caught in relatively smaller quantities (i.e., each > 3% of overall total catch) were common blacktip shark, tiger shark, smooth hammerhead and scalloped hammerhead. The species composition of catches of TACC sharks primarily depended upon the time of year and latitude. For example, in general, sandbar shark was dominant in many observed catches only during summer, autumn and early-winter months, mostly north of Coffs Harbour. In contrast, dusky whaler and spinner shark was present in observed catches throughout the study period and area. Although not numerically dominant with respect to overall catches, bronze whaler was the second-most observed TACC species in catches (behind dusky whaler) from Zone 4 during the spring and summer months, while it was rarely recorded in catches further north.

Biological samples and detailed biological data were collected from over 1,200 of the TACC sharks observed and will be analysed as soon as is practicable. The biological information gleaned will, where possible, provide the basis for individual stock assessments for the main whaler shark and hammerhead species being exploited, further strengthening the knowledge base available for the refining of fishery management strategies applied to the NSW targeted whaler shark fishery.

At least 30 (possibly 33) non-target (i.e., non-TACC) species were observed in catches, although some of these species could be classified as ‘byproduct’ species, as they were more often than not retained for sale (e.g., wobbegong, cobia, gummy shark, banded rockcod, bluespotted flathead and snapper). Of the overall total of 254 non-target individuals caught during observed trips, 42.5% were retained as byproduct, while the remainder (mostly stingrays and wobbegongs) were discarded – in most cases alive. Interactions with threatened and/or protected species were rare, with overall totals of six great white sharks, five grey nurse sharks and two green turtles hooked during observed trips. All but one of those animals were mouth-hooked, and all were alive upon capture and subsequent release. There were no observed interactions with marine mammals, seabirds or other marine reptiles.

In conclusion, this study has provided a considerable knowledge base regarding targeted shark fishing in northern NSW waters, and has demonstrated the value of concentrated, observer-based research in obtaining large amounts of reliable information within a short timeframe. The information gathered during the project, along with the continuing flow of biological information to come via shark sample analyses, will assist the formulation of management strategies that ensure the stocks of whaler and hammerhead sharks in NSW waters are harvested sustainably in future.

Given the high observer coverage achieved where hosting of an observer was mandatory, and the resultant quantity and quality of the data collected, it is recommended that mandatory hosting of observers (when requested) be adopted across all fisheries in NSW. It is also recommended that a second full year of intensive observer-based sampling be done to learn about inter-annual patterns in catches of large sharks, and then a suitable level of annual, observer-based monitoring be done to detect any future changes in catch rates or species compositions. Further research into the movements, migrations and rates of natural and fishing mortality via tagging studies would also greatly benefit the future management of targeted shark fishing in NSW waters.

Finally, it is recommended that fisheries researchers and managers from NSW and Queensland determine what collaboration is necessary with respect to the appropriate management of shark stocks common to fisheries in both states. Similarly, I&I NSW needs to develop collaborative research relationships with universities in NSW and elsewhere with a view to processing the large amount of biological samples and data collected during this project.

1. INTRODUCTION

1.1. Line fishing in the NSW Ocean Trap and Line (OTL) fishery

In New South Wales (NSW), Australia, commercial line fishing is permitted in continental shelf and oceanic waters as part of the Ocean Trap and Line (OTL) fishery managed by Industry & Investment (I&I) NSW. There are three distinct line-fishing endorsements: ‘line west’ (waters west of the 183-m depth contour); ‘line east’ (waters east of the 183-m depth contour to the 4000-m depth contour); and ‘school and gummy shark’ (a specific endorsement for taking these species is restricted to waters south of the Moruya River mouth) (NSW DPI, 2006a). Approximately 520 fishing businesses are licensed with one or more of these endorsements, with the annual total retained catch in the line-fishing component of the fishery estimated to be approximately 2,000 tonnes and worth approximately A$10 million at the first point of sale (I&I NSW, 2009).

The vessels used in the OTL fishery range in size between 4 and 20 m in length, while different line-fishing methods are used to target a range of species (Figure 1; Table 1). Handlining accounts for just over half (51.6%) of the OTL line-fishing effort (in fisher days) over the past decade, while the great majority of the remaining effort was attributed to trolling (17.5%), droplining (12.8%), setlining (7.0%) and trotlining (5.3%) (Table 1; I&I NSW, 2009).

Handlining generally refers to fishing from a stationary or very slow-moving vessel using handline, rod-and-reel and/or electric reel (NSW DPI, 2006a) (Figure 1A). Handlining is primarily used in shallow waters (i.e., down to 30-m deep) to target schooling pelagic (i.e., found near the surface or mid-water) or demersal (i.e., found near the seabed) species (Table 1), but is also sometimes used on deeper grounds (i.e., down to 500-m deep; in the form of electric reel) as a substitute for droplining (see below). ‘Trolling’ is similar to handlining but involves trailing a bait or lure positioned a substantial distance behind a vessel moving at speed to target pelagic fishes such as species of mackerel and tuna (Table 1).

Droplining generally involves using a vertically-oriented line weighted to the seabed that has multiple hooks extending from the line (connected to the main line via ‘snoods’ of approximately 1 m in length) for up to 40 m upwards from the weighted end (Figure 1B). This method is usually used in deep water (i.e., > 100 m) to target deepwater demersal species, but is sometimes used in shallower water to target yellowtail kingfish (Table 1).

Setlining and trotlining are similar to each other in that they both involve setting a horizontally-oriented, weighted groundline with multiple hooks attached (via snoods – see above) (Figures 1C and D). These gears are used in waters between 5 and > 250 m deep. By I&I NSW definition, for trotlines the groundline is positioned on or just above the seabed (‘bottom-set’) to target demersal species (Figure 1C), while for setlines it is suspended in midwater (i.e., well above the seabed and well below the surface) to target pelagic species (Figure 1D) (Table 1; NSW DPI, 2006b). In practice, however, the terms are used more-or-less interchangeably among OTL fishers depending on individual interpretation. It is notable that fishing effort reported as ‘longlining’ (Table 1) was most likely a result of misreporting of setlining or trotlining, as ‘surface’ longlining is not permitted in the OTL fishery, and setlines and trotlines are basically types of longlines.

The Environmental Impact Statement (EIS) for the NSW OTL fishery found that discarding is poorly understood in the OTL fishery, and there is therefore a need to identify and quantify levels of discarding in the fishery. Further, discarding of catch was concluded to be a potentially moderate to high risk to primary and key secondary species, non-target species, and some protected and/or threatened species (NSW DPI, 2006b). In response, I&I NSW is currently conducting a two-year, observer-based research program in the line-fishing sector of the NSW OTL fishery ('commercial line-fishing observer program') to systematically record data relating to gear operations, catches (retained organisms) and bycatches (discarded organisms) for four of the main fishing methods used: handline, dropline, setline and trotline. The final research report from this observer program is due for publication at the end of 2009.

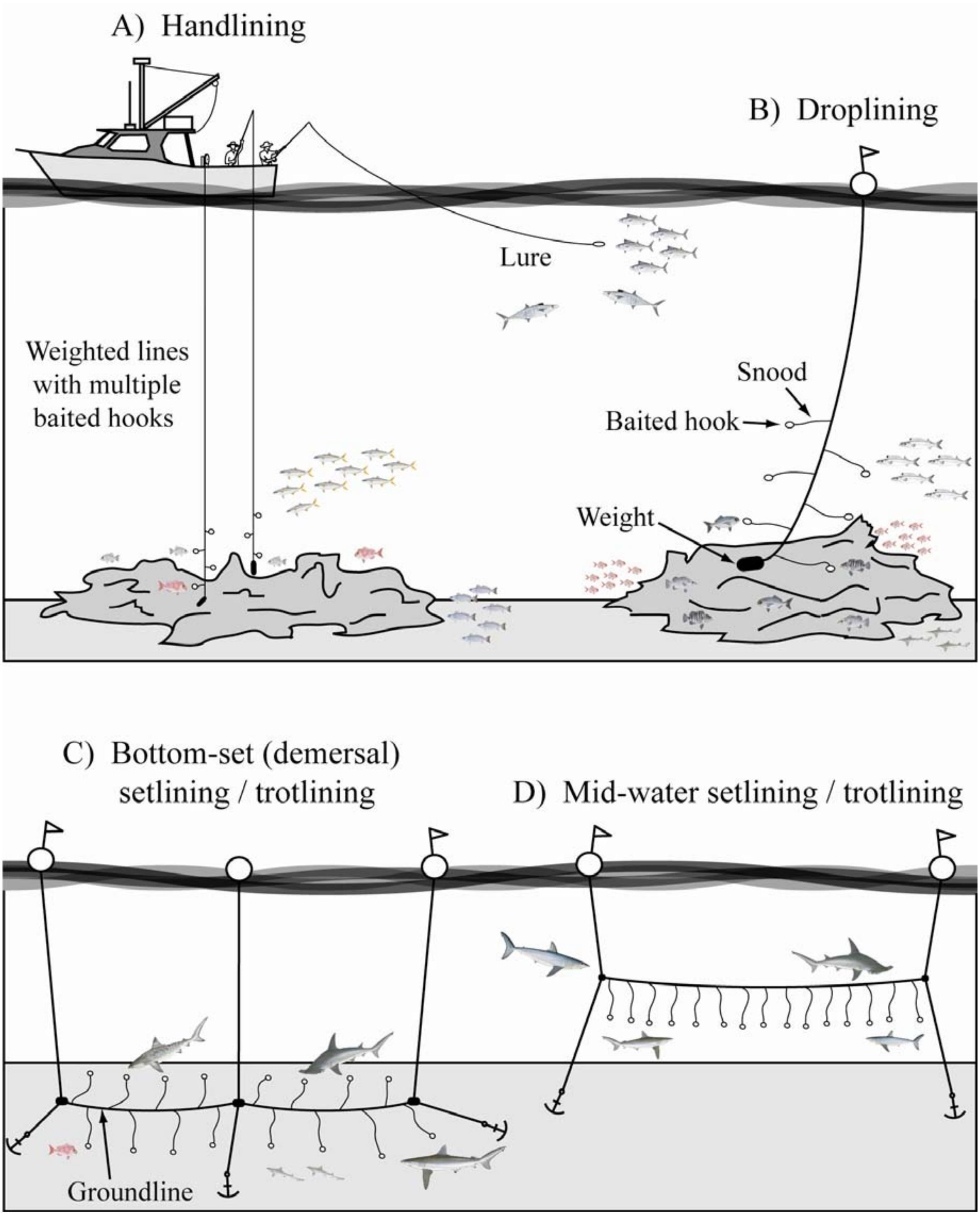

Figure 1. Diagrammatic representation of: A) various types of handlining; B) droplining; and C) bottom-set, and D) mid-water setlining / trotlining.

Table 1. Line-fishing methods used in the OTL fishery as reported by OTL fishers, showing for each method the main species (or groups) caught, the mean annual fishing effort (in total number of fisher days; ± standard error, se) over the past decade, and the proportion of the total line-fishing effort (expressed as a percentage) (I&I NSW, 2009).

Line-fishing method	Main target species or groups	Mean annual fishing effort 1998/99 – 2007/08 (fisher days ± se) (proportion of total, %)
Handlining	Yellowtail kingfish (*Seriola lalandi*) Mackerels and tunas (Family Scombridae) Snapper (*Pagrus auratus*) Tailor (*Pomatomus saltatrix*) Mulloway (*Argyrosomus hololepidotus*) Teraglin (*Atractoscion aequidens*) Silver trevally (*Pseudocaranx dentex*) Leatherjackets (Family Monacanthidae) Pearl perch (*Glaucosoma scapulare*) Banded rockcod (*Epinephelus ergastularius*) Silver sweep (*Scorpis lineolata*) Yellowtail scad (*Trachurus novaezelandiae*) Samson fish (*Seriola hippos*)	8,982 ± 526 (51.6%)
Trolling	Mackerels and tunas, yellowtail kingfish, tailor	3,033 ± 288 (17.4%)
Droplining	Yellowtail kingfish, banded rockcod, Blue-eye trevalla (*Hyperoglyphe antarctica*) Bass groper (*Polyprion americanus*) Hapuku (*Polyprion oxygeneios*) Gemfish (*Rexea solandri*)	2,218 ± 192 (12.7%)
Setlining	Snapper, morwongs (Family Cheilodactylidae) Gummy shark (*Mustelus antarcticus*) Draughtboard shark (*Cephaloscyllium laticeps*) Wobbegongs (*Orectolobus* spp.) Large sharks (species of whaler, hammerhead and mako – refer to Section 1.2 for details)	1,231 ± 84 (7.1%)
Trotlining	Gummy shark, large sharks, snapper Ocean perches (Family Serranidae) Pink ling (*Genypterus blacodes*)	934 ± 53 (5.4%)
Jigging	Yellowtail kingfish, mackerels and tunas	606 ± 55 (3.5%)
Driftlining	Mackerels and tunas, snapper	187 ± 29 (1.1%)
Poling	Yellowtail kingfish, mackerels and tunas	134 ± 16 (0.8%)
Longlining	Large sharks, yellowtail kingfish	79 ± 18 (0.5%)

The level of understanding of catches of sharks by commercial fishers in NSW has, until now, been very poor; in particular there was little data available on the composition of catches via demersal and mid-water line-fishing methods used within the OTL fishery to specifically target sharks. This situation was primarily a result of the difficulty for fishers to correctly identify shark species, and a complete lack of independent, observer-type data from such fishing operations. Given that an improved understanding of the catch of sharks from commercial fisheries was a commitment made within the Australian National Plan of Action for the Conservation and Management of Sharks (these commitments were presented as a series of actions within the Operational Plan for the Sustainable Use of Tropical East Coast Australian Shark Resources, particularly Theme 3: Improve Data Collection and Handling), an intensive observer-based research project specifically addressing the targeted large-shark fishery was urgently required.

1.2. Shark fishing in the NSW OTL fishery

The available data with respect to shark catches via commercial line fishing has traditionally been restricted to official I&I NSW commercial catch records archives, which comprise a compilation of compulsory monthly catch reports from all licensed fishing businesses in NSW dating back to 1940 (Pease and Grinberg, 1995). In the case of the OTL fishery, prior to 2008/09 each catch report required the fisher to complete a form summarising their fishing activities (catch by species or group, number of fishing days and broad location for each fishing method used) for that month. The resulting data were deficient in the spatial and temporal resolution, and in the accuracy of species identifications. These issues have been addressed for the 2008/09 year via an improved catch reporting system for targeted shark fishing (see section 1.3 below).

The general lack of knowledge regarding catches of sharks in the OTL fishery became of increased concern during the mid-2000s due to substantial increases in fishing effort for, and catches of sharks by commercial line fishers in NSW waters around that time (Figure 2) (I&I NSW, 2009). The mean (± se) annual reported catch of sharks (by 'processed' or 'dressed' weight – head, innards and other trimmings removed; all sharks combined; excluding stingrays and stingarees) in the OTL fishery between 1998/99 and 2004/05 was 173.2 (± 9.8) tonnes, ranging between 144.2 (2003/04) and 219.7 tonnes (2001/02). Subsequent to 2004/05 (152.0 tonnes), the annual catch increased considerably to 231.1 tonnes in 2005/06, and then doubled in 2006/07, peaking at 457.2 tonnes. This represents a 200% increase in shark catches over a two-year period, with the majority of this increase reported as 'Shark, Unspecified' (Figure 2).

During 2007/08, and while new restrictions and conditions on targeted shark fishing were being formulated for implementation in 2008/09, a further 369.4 tonnes of shark was retained for sale (Figure 2). There was, however, a substantial reduction in the use of the catch category 'Shark, Unspecified' correlating with an increase in the reporting of 'Shark, Sandbar' and 'Shark, Unidentified Whaler' (Figure 2).

Despite the list of whaler, hammerhead and other large shark species known to inhabit NSW waters (Table 2; Last and Stevens, 2009; Daley *et al.*, 2002), it was stated by some of the fishers primarily responsible for the increase in shark catches that sandbar shark (*Carcharhinus plumbeus*) – a type of whaler shark – was their main target species and comprised the vast majority of their catches. Unfortunately, attempts during 2007/08 to place a scientific observer onboard during these sandbar shark fishing trips as part of the Commercial Line-fishing Observer Program were unsuccessful.

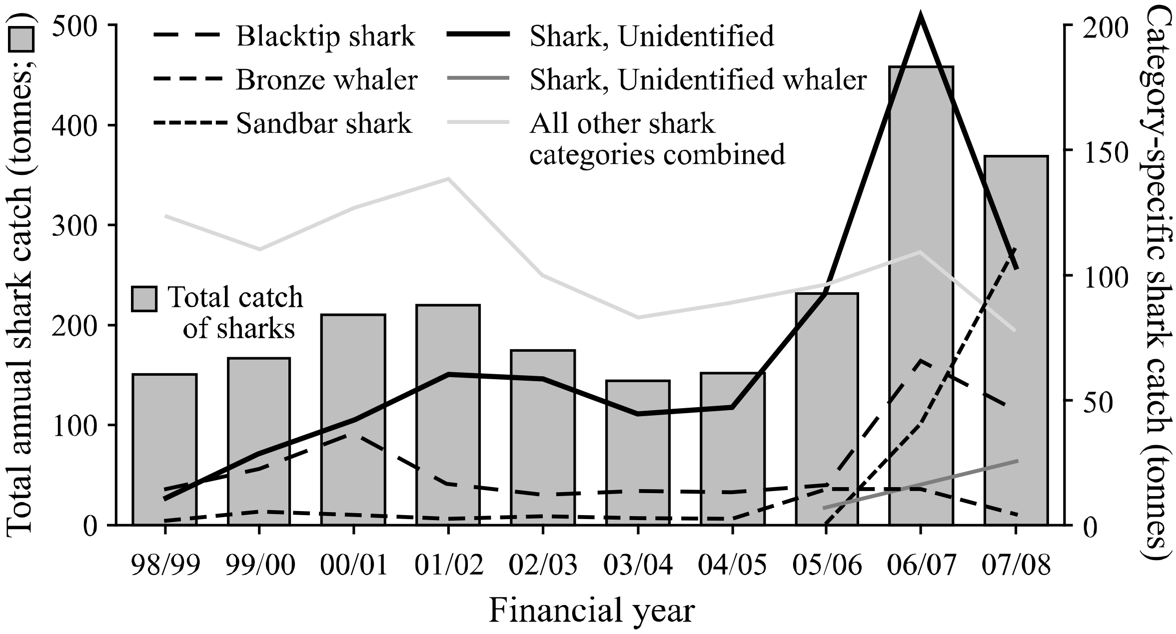

Figure 2. Reported catches of sharks (by processed weight - head, innards and other trimmings removed) in the NSW OTL fishery during the past decade, as reported via the fisher-dependent catch-reporting system (I&I NSW, 2009). Column data (left y-axis) are for the total catch of all sharks combined (includes shark-like rays but excludes stingrays and stingarees); line data (right y-axis) are for the main relevant catch-reporting categories (or groups of categories), as used by fishers during that period.

Table 2. Species of whaler, hammerhead and mackerel shark known to inhabit NSW continental shelf waters (excluding Lord Howe Island) (Last and Stevens, 2009; Daley *et al.*, 2002). *, protected species. With the exception of great white shark, these species comprised the entire list of large shark species relating to the total allowable combined catch (TACC) imposed by I&I NSW for 2008/09.

Whaler sharks Family Carcharhinidae	**Hammerhead sharks** Family Sphyrnidae
Sandbar shark (*Carcharhinus plumbeus*) Bignose shark (*C. altimus*) Dusky whaler (*C. obscurus*) Silky shark (*C. falciformis*) Oceanic whitetip shark (*C. longimanus*) Common blacktip shark (*C. limbatus*) Spinner shark (*C. brevipinna*) Bull shark (*C. leucas*) Bronze whaler (*C. brachyurus*) Tiger shark (*Galeocerdo cuvier*) Blue shark (*Prionace glauca*) Lemon shark (*Negaprion acutidens*)	Great hammerhead (*Sphyrna mokarran*) Scalloped hammerhead (*S. lewini*) Smooth hammerhead (*S. zygaena*) **Mackerel sharks** Family Lamnidae Shortfin mako (*Isurus oxyrinchus*) Longfin mako (*I. paucus*) Porbeagle (*Lamna nasus*) Great white shark (*Carcharodon carcharias*)*

It was well into the 2007/08 season before the increase in shark catches during the previous year was confirmed through catch-record summaries. Anecdotal (and other) evidence had suggested that the increase was a result of increased targeting of large sharks – particularly species of whaler shark (Family Carcharhinidae) – using setlines and trotlines in NSW waters north of South West Rocks, and detailed analysis of the catch records revealed that this was most likely the case (Figure 2). These large sharks were, and are, being caught primarily for the high value of their fins, although the processed, or 'dressed' trunk of each shark is also sold, albeit at much lower financial benefit. Five fishing businesses were found to be responsible for the majority of the doubling in catch during 2006/07, although reliable information regarding the species composition of those particular catches was not possible owing to the use of 'Shark, Unspecified' on catch returns.

Worldwide there has been a marked increase in the level of targeted fishing for large pelagic and demersal sharks such as whaler, hammerhead and mackerel shark species over the past 50 years or so, with many fisheries experiencing substantial declines in shark stocks owing to the inherent vulnerability of shark populations to overexploitation (Stone *et al.*, 1998; Camhi *et al.*, 2008). Generally, sharks sexually mature late (4 – 20 years of age), have few young (2 – 25 pups per litter) and have long reproductive cycles (1 – 3 years) – a combination of factors that results in slow replacement potential for shark populations (Stone *et al.*, 1998). If overfished over a sustained period, catch rates are likely to collapse and many years (or decades) are likely to be required for the depleted populations to rebuild to levels that might permit limited commercial exploitation (Stone *et al.*, 1998). Despite diligent catch monitoring and fishery management, such a situation gradually developed over the past 30 years in the south-eastern U.S. large shark fishery – a fishery with more-or-less the same target species as the northern NSW fishery. As a consequence, in that fishery there are now heavy restrictions on the quantities and species permitted to be retained (see section 4.3.2 for detailed discussion). Therefore, when presented with: 1) the opportunity early enough; and 2) the benefits of past lessons learned in other, similar fisheries; relatively 'new' commercial shark fisheries such as the northern NSW fishery must be managed conservatively to prevent overfishing and ensure their long-term health and viability to sustainable exploitation.

Given the above, and as a direct response to the situation in northern NSW waters, on 1 September 2008 I&I NSW implemented specific conditions and restrictions on shark fishing (targeted or otherwise) in the OTL fishery. These restrictions followed intensive consultation with fishing industry representatives both informally via meetings with OTL shark fishers, and formally via the Seafood Industry Advisory Council (SIAC); and a review of comparable shark fisheries elsewhere in Australia and the world. Also identified was the need for intensive research into the fishing operations, composition of catches and biological characteristics (e.g., abundance, distribution, population structure, growth and reproduction) of the main species involved. In summary, the following arrangements were put in place for the capture and retention of sharks by OTL fishers between 1 September 2008 and 30 June 2009:

- A total allowable combined catch (TACC) of 160 tonnes (processed weight) that included all species of whaler, hammerhead and mackerel shark (excluding the protected great white shark). All other species, such as thresher (*Alopias* spp.) and six-gill (*Hexanchus* spp.) sharks, for example, were not included in this TACC, although there were pre-existing fishing restrictions in place for some of those other species (e.g., wobbegongs – *Orectolobus* spp., gummy sharks – *Mustelus* spp., and school shark – *Galeorhinus galeus*).
- The TACC comprised two components: 1) 100 tonnes of sandbar shark to be caught via a restricted permit system ('sandbar-permit shark fishery'); and 2) a total of 60 tonnes of all other TACC shark species combined (i.e., excluding sandbar sharks) open to all OTL fishers not holding a sandbar permit ('non-permit shark fishery'). These components (and their constituents) were intended to be mutually exclusive in that those fishers holding a sandbar permit ('sandbar fishers') were not allowed to retain more than the permissible 'bycatch limit' of other whaler, hammerhead or mako species combined per trip (see below), while all other

OTL fishers ('non-permit fishers') were not allowed to retain more than two sandbar sharks per fishing trip.

- Bycatch limits per fishing trip were applied to sandbar-permit fishers (four carcasses of any TACC species other than sandbar shark up to a maximum combined weight of 200 kg) and non-permit fishers (two sandbar sharks per fishing trip). Once the respective TACCs were reached, all OTL fishers were restricted to retaining four carcasses of any TACC species up to a maximum combined weight of 200 kg until 1 July 2009.
- Sandbar-permit fishers were subject to additional conditions in that they were required to: 1) host an I&I NSW observer during fishing trips when requested (for non-permit fishers, hosting an observer was voluntary rather than compulsory); 2) each pay a permit fee to fund I&I NSW observer work onboard OTL vessels targeting sharks; and 3) inform I&I NSW (via the local Fisheries Officers) of impending shark fishing trips at least one hour (eventually changed to six hours) prior to departing port.

The extra conditions put in place for the sandbar-permit fishers provided an opportunity to collect data and biological samples onboard OTL vessels targeting sharks, allowing a much greater understanding of targeted shark fishing in NSW waters within a relatively short period of time. Acknowledging the importance of the ultimate outcomes, Northern Rivers Catchment Management Authority (NRCMA) provided substantial funding for additional observer trips during 2008/09 to collaborate with I&I NSW in taking full advantage of that opportunity.

1.3. Improved infrastructure for fisher-dependent reporting of shark catches

In July 2007 it was acknowledged by all parties present at an OTL Management Advisory Committee (MAC) meeting that changes to the fisher-dependent catch-reporting system in relation to targeted shark fishing were urgently required. An improved catch-reporting infrastructure would allow for a faster flow of more accurate information about fishing effort and catches associated with shark fishing to I&I NSW fishery managers. A two-pronged approach was implemented: 1) improved catch-reporting forms requiring more accurate, more detailed and more frequent reporting of sharks caught and fishing operations; and 2) the development of a shark species identification guide for widespread distribution among NSW commercial fishers.

In September 2008 new reporting arrangements were put in place for OTL fishers requiring all catches of TACC shark species to be recorded on a daily basis. On a given fishing day, and for each TACC species caught, the total number and combined processed weight of sharks are now recorded (along with a code indicating the type of carcass processing used). These daily shark catch reports complement the traditional monthly catch reporting system by providing more refined, higher-resolution catch data. This was implemented in coordination with the provision of resources (i.e., species identification guide – see below; ongoing support from shark researchers at I&I NSW) and fisher education (training and guidance in shark identification via onboard observers).

During November 2008 I&I NSW distributed a waterproof field identification guide to all OTL fishers to assist them in correctly identifying: 1) the TACC species they target; 2) threatened and/or protected shark species such as grey nurse shark (*Carcharias taurus*), great white shark (*Carcharodon carcharias*) and green sawfish (*Pristis zijsron*); and 3) some of the other shark species they may encounter in NSW waters (Figure 3). The guide provides a set of simple, easy-to-use identification keys that allows the user to look at a succession of easily assessable features on a given specimen to ultimately determine its species (or genus) (Figure 3B). The keys are supported by more detailed diagnostic information about each species (or group) (Figure 3C). To provide a direct link to the species codes the fishers are required to use for their I&I NSW daily catch reporting, the codes are published for each species (or group) at the top right of each of these pages (Figure 3C). A full electronic copy of the guide can be viewed and downloaded at:
http://www.dpi.nsw.gov.au/fisheries/commercial/fisheries/otl-fishery/identifying-sharks-and-rays.

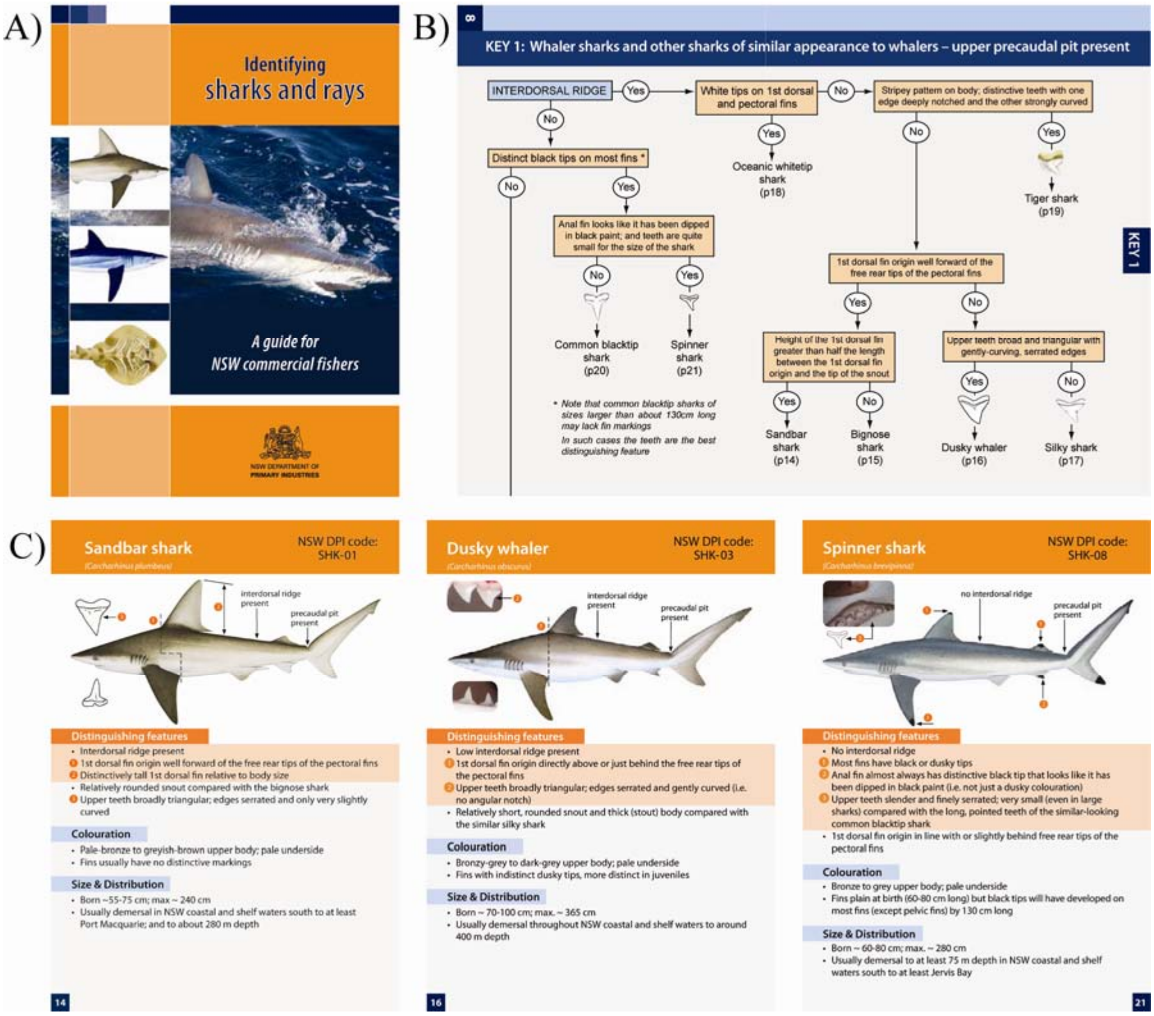

Figure 3. Selection of pages from the shark species identification guide distributed to all OTL fishers showing: A) the front cover; B) part of the identification key for whaler sharks; and C) detailed diagnostic information about three species.

1.4. Objectives of the research

The main objective of this project was to address the urgent need for collection of accurate, species-specific catch data and biological samples onboard shark-fishing vessels in northern NSW coastal waters. This was to be achieved by directing extra observer effort towards these vessels to compliment that allocated as part of the existing I&I NSW commercial line-fishing observer program. Given the compulsory requirements of the sandbar-permit fishers to host observers, we aimed for observer coverage nearing 100% in the 100-tonne sandbar-permit shark fishery between September 2008 and June 2009. Despite the voluntary nature of the observer work, we also aimed to have as high an observer coverage as possible for fishing trips done by fishers in the 60-tonne non-permit shark fishery during that period.

The second objective of the project was to educate the shark fishers with respect to the correct identification of the shark species being caught. Observers carrying out the field sampling for this project were required to demonstrate the use of the shark species identification guide developed by I&I NSW. Ultimately this should provide for more detailed and accurate reporting of shark catches as part of the fishers' compulsory catch reporting. Such an outcome will provide a solid platform for the future management of targeted shark fishing on the east coast of Australia.

2. MATERIALS AND METHODS

2.1. Study area

The marine Zone of the NRCMA region extends three nautical miles (nm) directly east of the coastline along the stretch of coast bounded by the NSW/Queensland border and a point approximately 2 – 3 nm north of Crowdy Head on the mid-north coast of NSW. This latitudinal extent of continental shelf water corresponds with I&I NSW fishery management Zones (termed 'Zones' for this report) 1, 2 and 3, and the majority of Zone 4 (Figure 4). This area includes the home ports of 26 OTL fishers whose catch records indicate targeting of TACC sharks during 2008/09 (Crowdy Head inclusive).

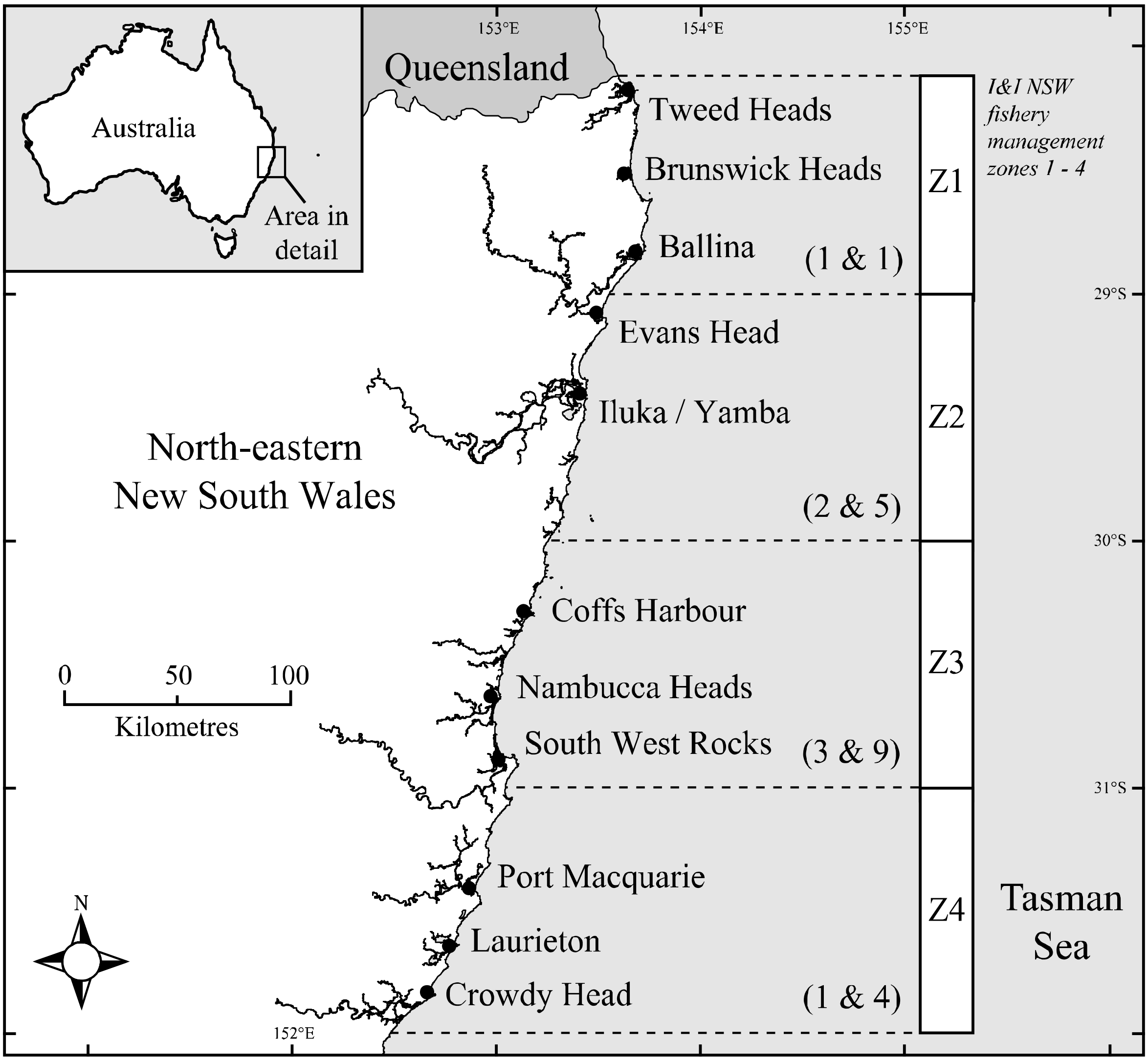

Figure 4. Map of the northern NSW coast showing the relevant NSW OTL fishery management Zones ('Zones') and the main ports in each Zone. Figures in parentheses for each Zone refer to the number of fishers specifically targeting TACC shark species during 2008/09 (sandbar-permit holders & non-permit OTL fishers respectively).

2.2. Observer sampling strategy and organising observer trips

With funding for the extra observer work secured and the issuing of the sandbar permits finalised during August 2008, extra observer sampling onboard OTL vessels targeting TACC shark species was sought from 1 September 2008 and ceased on 1 July 2009. The general sampling strategy was fully opportunistic in that as many fishing trips targeting TACC shark species were observed as possible. The reasons for targeted shark-fishing trips not being observed can be can be summarised into two main categories: 1) fisher unwillingness to participate; and 2) no observer available. These are detailed further in the Results section.

Our approach to securing observer trips differed according to whether the OTL fisher held a sandbar permit or not. The primary factor driving this difference was the condition attached to sandbar permits making it compulsory for sandbar-permit fishers to host a I&I NSW observer during each and every shark-fishing trip undertaken.

2.2.1. Non-permit OTL shark fishers

Between 1 September 2007 and 31 August 2008, a total of six trained and equipped scientific observers were actively seeking observer trips with commercial line fishers working in waters north of Crowdy Head as part of the commercial line-fishing observer program. There were no conditions associated with OTL endorsements that made it compulsory for OTL fishers to host observers, and so observer sampling for the commercial line-fishing observer program was done on a voluntary basis. Observers approached fishers with a polite request to join them on a fishing trip, with some fishers agreeing to cooperate, and some choosing not to be involved.

The sampling design associated with the commercial line-fishing observer program required a total of 16 fishing days (including 4 setlining or trotlining days) to be observed in waters north of South West Rocks (Figure 4), during each of three full 'seasons' coinciding with the sampling timeframe associated with the study (i.e., September – November 2008; December 2008 – February 2009; March – May 2009). Similarly, a total of 12 – 16 observed fishing days (including 4 setlining or trotlining days) was required from waters between South West Rocks and Sydney during each of those seasons. Observer trips done as part of the commercial line-fishing observer program with OTL fishers: 1) based at ports north from Crowdy Head between 1 September 2008 and 1 July 2009 targeting TACC shark species were included in data summaries and analyses for this report. Further, from 1 September 2008 the six observers were instructed to try to complete as many extra observer trips with non-permit shark fishers as possible (i.e., in addition to the prescribed number of trips done as part of the commercial line-fishing observer program outlined above), given the voluntary basis of the non-permit OTL observer work.

2.2.2. Sandbar-permit OTL shark fishers

The condition associated with the sandbar shark permit making it compulsory to host an observer when one is available provided the opportunity to, in theory, achieve 100% observer coverage with respect to the seven fishers involved in the sandbar-permit shark fishery. At around the time the sandbar-permit fishers began their fishing (December 2008 – see Results section), the team of six observers was expanded to nine, with at least one observer specifically assigned to each sandbar-permit fisher with a view to achieving close to that level of coverage. The fisher-specific observer system was implemented to also: 1) simplify communication channels; and 2) appease concerns that some fishers had regarding confidentiality of their fishing operations; and it proved very successful with respect to these objectives.

2.3. Data and sample collection

Data and samples collected during field operations for the current study can be categorised into three types: fishing operation data; basic catch data; and biological data and samples from sharks.

2.3.1. Fishing operation data

The duration of fishing trips observed ranged between one and four calendar days, with each day considered a separate fishing day and the data recorded accordingly. Fishing day data simply comprised the name of the fisher and port, date of the fishing day (with gear retrievals between 0000 and 2359 hrs being allocated to that fishing day regardless of the gear-set date), and name of the observer. During each fishing day, operational data collected for each and every line retrieval comprised: fishing method; length of the groundline (for set/trotlines); total number of hooks on the line; bait used; fishing area (general GPS location and depth); date and time of the start and finish of the line deployment; and date and time of the start and finish of the line retrieval. Any apparent habitat interactions were also recorded where possible.

2.3.2. Basic catch data

For each line retrieval, basic catch data collected for each organism brought to the side of the vessel comprised: date and time of capture; taxonomic identity; location of hook (mouth, throat, gut or foul); lengths (pre-caudal – PL, fork – FL, and total – TL, for sharks – Figure 5A; FL and TL for other finfish) where possible; weight (for whole weight and/or weight components – see below) where possible; fate (retained or discarded); and apparent condition (alive or apparently dead – see below). If the animal was released at the side of the vessel and lengths could not be measured, every effort was made to estimate the TL by eye as accurately as possible. Species names and standard common names used throughout this report are sourced from the Codes for Australian Aquatic Biota (CMAR, 2008).

Where it was possible to obtain weights, the weight-component categories used were: whole shark; landed trunk (head and guts missing); dressed trunk (landed trunk plus finned and trimmed of gut flaps); head; viscera; fins; trimmings; and ‘other’. It proved logistically very difficult to obtain accurate and reliable measures of weight onboard the vessels and so the summaries of catches in this report are based on number rather than weight.

It is important to note that the condition of any animal brought to the side of the vessel and subsequently released without being brought onboard was subjective in that it was inherently very difficult for observers to definitively determine whether the animal was dead. Therefore, observers were instructed to use the ‘alive’ or ‘apparently dead’ options, and also provide comments on the apparent condition of the animal, particularly in the case of any threatened or protected species. For example, observers noted whether the animal was thrashing around by the side of the vessel or if it was alive but not providing much resistance to being caught.

2.3.3. Biological data and samples from sharks

Extra biological data and samples were collected in the cases of all sharks and some rays caught according to a pre-determined sampling protocol. After the basic catch data were recorded, supplementary biological data were recorded in the following order of priority: 1) sex; 2) reproductive status (Table 3; Robbins, 2006); clasper length for males (Figure 5B) and uterus width(s) for females (Figure 5C); and 4) TL and sex of embryos (i.e., ‘pups’) found in the uteri of females.

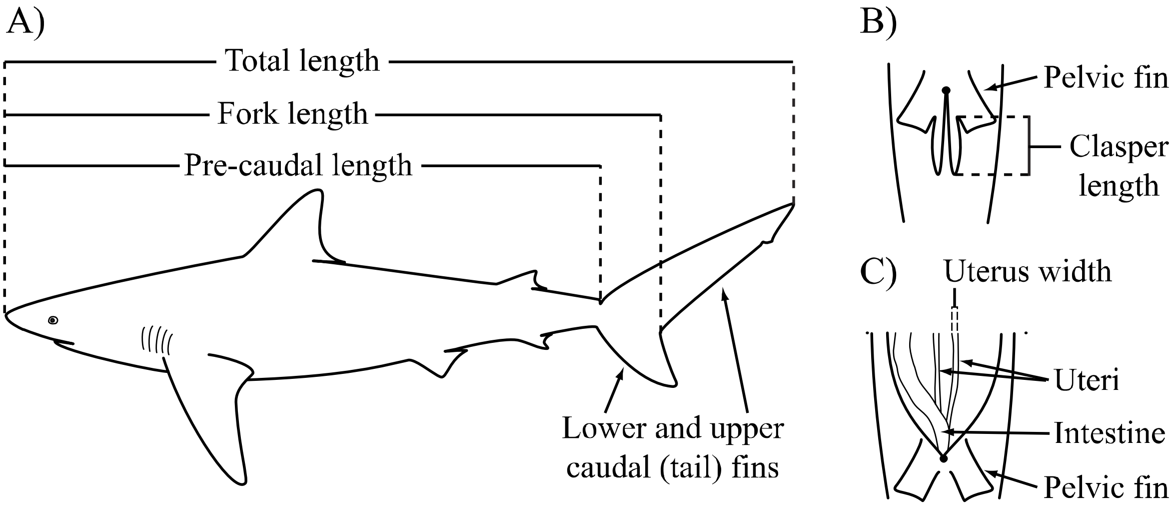

Figure 5. Diagrammatic representation of: A) a typical shark showing the pre-caudal, fork and total length measurements; B) the pelvic fin region of a male shark showing the clasper length measurement; and C) a section of a dissected female shark showing the uterus width measurement.

Table 3. Reproductive statuses for male and female sharks and rays as applied to those caught during this study (adapted from Robbins, 2006).

Sex	Reproductive status	Definition – description of visible characteristics
Male	A	Sexually immature – claspers small and uncalcified (soft)
	B	Maturing – claspers elongated, but not fully calcified
	C	Sexually mature – claspers fully calcified (hard)
Female	A	Sexually immature – uteri thin along entire length and empty
	B	Maturing – uteri enlarged posteriorly and empty
	C	Sexually mature – uteri enlarged along entire length and empty
	D	Sexually mature – uteri contain yolky eggs but no visible embryos
	E	Pregnant – uterus/uteri contain visible embryos (pups)
	F	Post-birth – uterus/uteri large and flaccid

Following the recording of biological data according to the above protocol, biological samples were opportunistically taken from each shark caught for future laboratory determination of age (vertebrae) and genetic studies (flesh samples). Flesh samples were also taken from pups where possible. Vertebrae were frozen as soon as practicable, while flesh samples were immediately preserved in vials filled with 90 – 95% ethanol.

2.4. Data summary and analysis

Summaries of all organisms caught and all biological samples taken during the study, by species, are provided. However, detailed examination of the observer data revealed the necessity for the observed fishing trips to be stratified into categories (groupings) for the purpose of more detailed summary and analysis of catch data. This partitioning was done according to logically-derived combinations of the main operational variables: permit status; fishing method; and latitudes (Zones) and/or months fished; and is explained in detail in the Results section (section 3.3.1).

For each logical grouping, the observer sampling operations were summarised according to the total number of fishing trips, fishing days (24-hour period), gear deployments and hook deployments observed, along with an estimate of the observer coverage achieved (as a proportion of the total reported fishing effort during the sampling period). General fishing operations were summarised according to the above, along with the mean and range for the number of hooks set per gear deployment.

Catches within each grouping were summarised according to the species of whaler, hammerhead and mako (i.e., TACC) sharks caught, and the non-target species caught and subsequently retained (byproduct) or discarded. The ratio of discarded bycatch to retained catch (including byproduct) was calculated for each grouping. To enable meaningful comparison among these species categories and among groupings, catch data for each gear deployment were also converted to a measure of catch per unit effort (CPUE), or 'catch rate', which for this report was defined as the number of individuals caught per 100 hooks per gear deployment.

More detailed assessments of catch rate among spatial (Zone – Figure 4) and temporal (month) distinctions was done for the main species of whaler, hammerhead and mako (i.e., TACC) sharks caught, as were basic summaries concerning size frequency (TL) and reproductive status by sex. More detailed analyses of reproduction information were not attempted as part of this preliminary reporting of the results of the observer work.

For species for which the quantity of data permitted, attempts were made to fit simple linear regression models to investigate the relationship between catch rate and the depth of water being fished. Two-sample Kolmogorov-Smirnov (KS) tests were used to compare size-frequency distributions between sexes where appropriate.

3. RESULTS

3.1. Cooperation and participation by OTL fishers targeting sharks

A total of 12 OTL fishers targeting TACC shark species participated in this study – the seven sandbar-permit holders, plus five non-permit fishers who volunteered to host observers. After some teething problems regarding the communication between fishers and observers, observer sampling with sandbar-permit holders was ultimately successfully implemented as they became more accepting of the compulsory hosting of observers.

Apart from the five non-permit fishers who hosted observers, fisher-dependent catch reporting indicated a further 14 non-permit fishers based at ports from Crowdy Head north targeted whaler shark at least once during the study period (I&I NSW, 2009). This tally was based on fishers who reported at least one fishing day during which at least five TACC sharks were caught and subsequently retained. These latter fishers either: 1) were not contacted by observers owing to previous refusals; 2) were not contacted by observers as observers were unaware of their shark-targeting activities, 3) did not follow up on assurances that they would inform observers of their fishing trips; or 4) simply refused, giving a wide range of reasons for refusal. Given the voluntary nature of the hosting of observers for those fishers, nothing further could be done under the circumstances to observe their fishing operations. Catches of TACC sharks for all other north coast OTL fishers who reported such catches were relatively small in quantity and very sporadic, suggesting that the TACC sharks were not being targeted *per se*.

3.2. Species recorded on observed commercial shark-fishing trips

A total of 1,637 organisms, comprising a total of 44 different species (or higher taxonomic groups containing unidentified species), was caught during the 81 fishing trips (114 fishing days) observed as part of this study (Table 4; Figures 6 and 7). Overall, 84.5% of the overall total catch by number comprised the targeted TACC shark species, with the remainder comprising non-target species of shark, ray, bony (teleost) fish and sea turtle.

3.2.1. TACC shark species (whaler, hammerhead and mackerel sharks)

Most of the whaler, hammerhead and mackerel (TACC) shark species listed in Table 2 were recorded (Figures 6 and 7), with sandbar shark accounting for just over one third of the overall total observed catch (i.e., all species combined) by number (Table 4A). Just over a quarter of the overall total catch by number comprised dusky whaler (15.2%) and spinner shark (10.6%), while notable quantities of common blacktip shark, tiger shark, and smooth and scalloped hammerhead were also caught. One whaler shark of a species not listed in Table 2 – Australian blacktip shark (*Carcharhinus tilstoni*), which was previously not known to inhabit waters south of Moreton Bay in Queensland (Last and Stevens, 2009) – was recorded off Tweed Heads. In light of this, it is therefore possible that some of the sharks identified as common blacktip sharks may have actually been Australian blacktip sharks owing to the strong morphological similarities between the two species (Ovenden *et al.*, 2009).

With the exception of tiger shark, almost all individuals of TACC species were retained. Only around half of the tiger sharks caught were retained, with the rest discarded (or, more accurately in most cases, released) immediately following capture.

3.2.2. Non-target species – retained or discarded

The non-target species caught comprised: 12 (possibly 13) shark species; 9 (possibly 12) ray species; 8 teleost fish species; and 1 species of sea turtle (Table 4B). Some of the non-target species recorded can be classified as 'byproduct' as they were more often than not retained for sale. For example, banded rockcod (known locally as bar cod), cobia, gummy shark, bluespotted flathead, eastern fiddler ray, white-spotted guitarfish, pearl perch, snapper, yellowtail kingfish, and species of wobbegong, thresher shark and shovelnose ray are all of economic value and sometimes targeted and/or routinely retained as byproduct by commercial fishers in northern NSW waters. Of the 254 non-target individuals caught, 42.5% were retained as byproduct, with the remainder discarded.

Of the non-target species that were mostly discarded the two most abundant were large stingray species – smooth (*Dasyatis brevicaudata*) and black (*D. thetidis*) stingray (Table 4B). Collectively, these two species accounted for 36.2% of all non-target individuals caught and 63.0% of all non-target individuals subsequently discarded, although it is notable that approximately one-third of the total catch of the former species was retained. The remaining discards comprised a range of species that included: Port Jackson shark (17 individuals); sub-legal-sized banded wobbegong (14) and spotted wobbegong (10); great white shark (6); grey nurse shark (5); gummy shark and blue catfish (3 each); and, notably, two green turtles (*Chelonia mydas*) (Table 4B).

3.2.3. Interactions with threatened and/or protected fish species

As mentioned above, totals of five grey nurse shark, a threatened (and therefore protected) species, and six great white shark, a protected species, were hooked during the observed commercial shark-fishing trips. In the case of grey nurse shark, interaction(s) occurred on three of the 114 targeted shark-fishing days observed, with one triple- and two single-hook-up occurrences, while in the case of great white shark, a single hook-up was recorded on six of the 114 targeted shark-fishing days observed. Observer measurements and estimates of TL for the grey nurse sharks caught ranged between 180 and 250 cm, while for the great white sharks this range was 200 to approximately 300 cm. All 11 of these sharks were alive and active upon capture, and anecdotal accounts from observers indicated that they all swam down and away from the vessel upon release.

3.2.4. Interactions with marine reptiles, marine mammals and seabirds

Interactions with two individuals of one species of marine turtle – green turtle – occurred during one of the 114 targeted shark-fishing days observed, while there were no other potentially detrimental interactions with any marine reptile, marine mammal or seabird during the other 113 fishing days observed. The two green turtles hooked were both alive and active upon capture, and swam away upon release.

3.2.5. Biological samples obtained from species of shark

Biological samples in the form of vertebrae and/or flesh were taken from a total of 1,207 sharks during the observed trips (Table 5). These samples have been archived with a view to future investigation of the age and growth (vertebrae) and genetic characteristics (flesh) of populations of those species inhabiting NSW waters. Laboratory processing of some of the samples has begun and will continue well into the future via multiple collaborations with universities and research institutes based in NSW, interstate and overseas.

Table 4. Summary of total catches (irrespective of subsequent retention or discarding) for all species (or higher taxonomic groups containing unidentified species) recorded during the 81 fishing trips (114 fishing days) observed as part of this commercial shark-fishing observer project. Data are for: A) the targeted TACC shark species; and B) all other species recorded. For each species (or group) the proportion that its total catch comprises of the overall total catch (all species combined), and the proportion of its total catch that was retained (as opposed to discarded), are shown. 'Unid.', unidentified.

Standard common name (species or group)	**Scientific name (Family or *Genus species*)**	**Total number caught**	**Prop. of overall catch (%)**	**Prop. retain (%)**
A) TACC shark species				
Sandbar shark	*Carcharhinus plumbeus*	569	34.8	99.3
Dusky whaler	*Carcharhinus obscurus*	249	15.2	97.6
Spinner shark	*Carcharhinus brevipinna*	174	10.6	97.7
Common blacktip shark	*Carcharhinus limbatus*	104	6.4	99.0
Tiger shark	*Galeocerdo cuvier*	97	5.9	51.5
Smooth hammerhead	*Sphyrna zygaena*	71	4.3	100
Scalloped hammerhead	*Sphyrna lewini*	53	3.2	88.7
Bronze whaler	*Carcharhinus brachyurus*	23	1.4	100
Shortfin mako	*Isurus oxyrinchus*	16	1.0	100
Bull shark	*Carcharhinus leucas*	10	0.6	100
Great hammerhead	*Sphyrna mokarran*	9	0.5	100
Silky shark	*Carcharhinus falciformis*	6	0.4	100
Bignose shark	*Carcharhinus altimus*	1	< 0.1	100
Australian blacktip shark	*Carcharhinus tilstoni*	1	< 0.1	100
Total for TACC species		*1,383*	*84.5*	*95.1*
B) Other species				
Smooth stingray	*Dasyatis brevicaudata*	72	4.3	30.6
Spotted wobbegong	*Orectolobus maculatus*	26	1.5	61.5
Cobia	*Rachycentron canadum*	23	1.4	100
Black stingray	*Dasyatis thetidis*	20	1.2	5.0
Port Jackson shark	*Heterodontus portusjacksoni*	17	1.0	0
Banded wobbegong	*Orectolobus halei*	15	0.9	0.1
Gummy shark	*Mustelus* sp. or spp. *	14	0.8	78.6
Blue catfish	*Arius graeffei*	8	0.5	62.5
Eastern fiddler ray	*Trygonorrhina* sp.	6	0.4	66.7
Great white shark	*Carcharodon carcharias*	6	0.4	0
Banded rockcod	*Epinephelus ergastularius*	5	0.3	80.0
Bluespotted flathead	*Platycephalus caeruleopunctatus*	5	0.3	100
Grey nurse shark	*Carcharias taurus*	5	0.3	0
White-spotted guitarfish	*Rhynchobatus djiddensis*	5	0.3	100
Snapper	*Pagrus auratus*	4	0.2	100
Thresher shark	*Alopias vulpinis*	4	0.2	100

Standard common name (species or group)	**Scientific name (Family or *Genus species*)**	**Total number caught**	**Prop. of overall catch (%)**	**Prop. retain (%)**
Unid. stingrays	Family Dasyatidae	3	0.2	0
Coffin ray	*Hypnos monopterygium*	2	0.1	0
Green turtle	*Chelonia mydas*	2	0.1	0
Unid. eagle rays	Family Myliobatidae	2	0.1	0
Bigeye sixgill shark	*Hexanchus nakamurai*	1	< 0.1	0
Blind shark	*Brachaelurus waddi*	1	< 0.1	0
Unid. devilray	Family Mobulidae	1	< 0.1	0
Pearl perch	*Glaucosoma scapulare*	1	< 0.1	100
Sandyback stingaree	*Urolophus bucculentus*	1	< 0.1	0
Unid. dogfish	Family Squalidae	1	< 0.1	0
Unid. moray eel	Family Muraenidae	1	< 0.1	0
Unid. shovelnose ray	Family Rhinobatidae	1	< 0.1	100
Yellowtail kingfish	*Seriola lalandi*	1	< 0.1	100
Zebra shark	*Stegostoma fasciatum*	1	< 0.1	0
Total for non-TACC spp.		*254*	*15.5*	*42.5*
Total for all species		**1,637**	**100**	**86.9**

* While *Mustelus antarcticus* is known to inhabit NSW waters, it is also suspected that the distribution of another, morphologically similar species of gummy shark, *Mustelus walkeri*, extends south from Queensland into northern NSW waters (Last and Stevens, 2009). Given this, the true accuracy of field identifications of gummy shark observed during this study are uncertain. Genetic analysis of gummy shark flesh samples taken during this study is currently being undertaken by a Macquarie University PhD student to address this issue.

Table 5. The number of individuals from which vertebrae (V) and flesh (F) samples were obtained and archived for shark species sampled during this study.

Standard common name	**V**	**F**	**Standard common name**	**V**	**F**
Sandbar shark	448	481	Gummy shark	10	11
Dusky whaler	231	235	Great hammerhead	10	10
Spinner shark	157	157	Bull shark	8	8
Common blacktip shark	93	94	Silky shark	6	6
Smooth hammerhead	68	68	White-spotted guitarfish	4	5
Scalloped hammerhead	43	44	Thresher shark	4	4
Tiger shark	28	29	Australian blacktip shark	1	1
Bronze whaler	23	23	Bignose shark	1	1
Shortfin mako	15	15	Banded wobbegong	1	1
Spotted wobbegong	14	14			

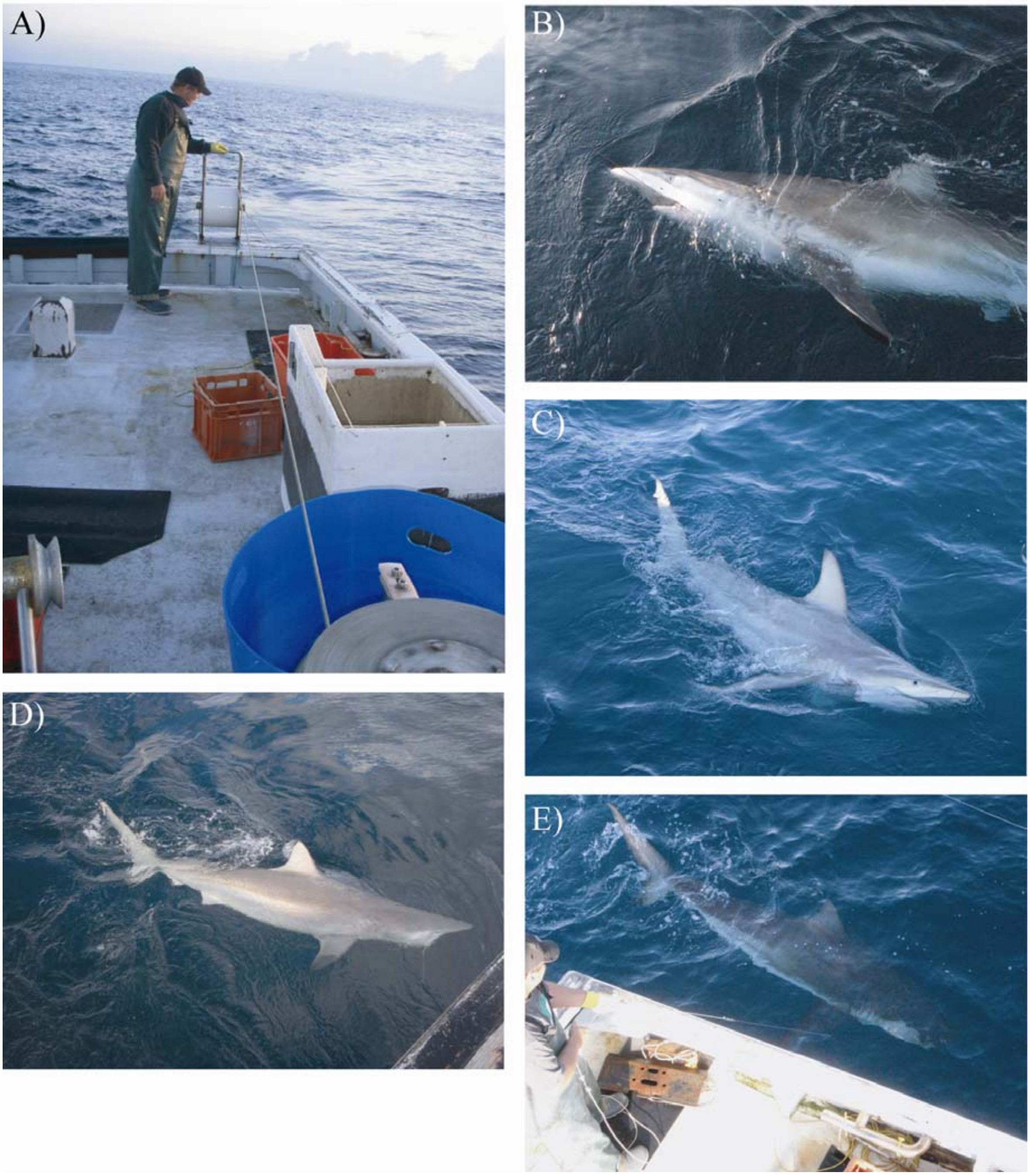

Figure 6. Photographic images taken during observer work: A) retrieval of a setline; and a hooked B) bronze whaler; C) common blacktip shark; D) spinner shark; and E) dusky whaler being manoeuvred alongside the vessel during capture.

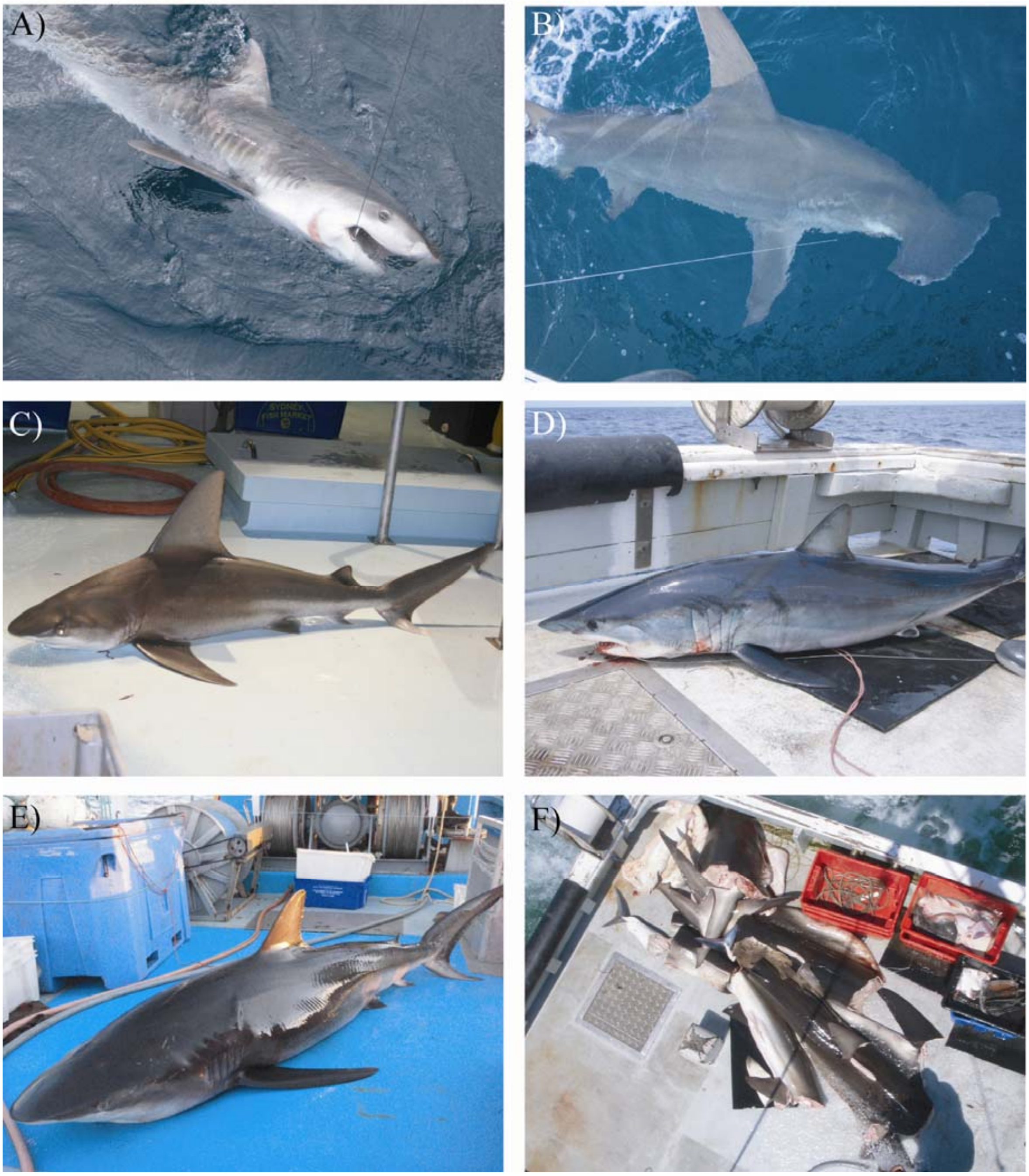

Figure 7. Photographic images taken during observer work: a hooked A) tiger shark, and B) great hammerhead; a C) sandbar shark, D) shortfin mako, and E) dusky whaler on deck following capture; and F) dressed trunks (i.e., headed, gutted and trimmed carcasses) and fins on deck prior to landing.

3.3. Summary of catches from observed shark-fishing trips

3.3.1. Post-hoc stratification of observed fishing trips for summary of catches

As stated in section 2.4, detailed examination of the observer data collected revealed the necessity for the fishing trips observed to be stratified into categories (groupings) for the purpose of summary and preliminary analysis (Table 6). This partitioning was done according to logically-derived combinations of the main operational variables: permit status; fishing method; and latitudes (Zones) and/or months fished (Table 6A).

The first grouping involved non-permit (‘NP’) setlining in Zone 4 (i.e., 31˚00’ – 32˚00’S latitude) between September 2008 and January 2009 (termed ‘NP-set-Z4’). Observed trips in this grouping (and the three other non-permit groupings – Table 6) ceased around mid-February after a letter was sent to all OTL fishers on 10 February 2009 informing them that the 60-tonne TACC limit had been reached, as it was assumed that targeting of TACC shark species had stopped. However, an inspection of fisher-dependent catch reports in July 2009 revealed that targeting of TACC shark species by some non-permit fishers was still occurring between February and July 2009, albeit adhering to the quantities allowed according to the trip bycatch limit (i.e., no more than four carcasses of any TACC species up to a maximum combined landed weight of 200 kg). The observed trips in the NP-set-Z4 grouping are restricted to those done in Zone 4 because observer coverage of non-permit shark fishing in that Zone was much higher than coverage achieved for Zones 1, 2 and 3 combined (i.e., 28˚22’ – 31˚00’S latitude; Table 6B), primarily owing to relatively greater cooperation by the active Zone 4 shark fishers.

As mentioned above, three smaller, non-permit observer trip groupings distinct from the NP-set-Z4 grouping were deemed necessary owing to clear operational differences with respect to fishing method and latitude, and disparities in the levels of observer coverage (Table 6). The first, the ‘NP-set-Z3’ category comprised just one observed setline trip done in Zone 3 – the only non-permit setline trip observed for Zones 1, 2 or 3. The considerable distance between that Zone 3 trip and the cluster of trips in Zone 4 comprising the NP-set-Z4 grouping justified its distinction. The remaining two non-permit groupings were formed to account for methods distinctly differing from setlining. The ‘NP-drum’ grouping (Table 6) accounted for a method similar to droplining in that it involved a mainline weighted to the seabed at one end and connected to a float (in this case a drum) at the other (Figure 1). However, unlike droplining, the mainline was hookless and instead had a second branching line, with only two snoods and hooks attached, extending from the mainline near the weighted end. For the purpose of reporting of results for this study, this method was termed ‘drumlining’. Finally, the ‘NP-hand’ grouping (Table 6) accounted for the single targeted shark handlining trip observed during the sampling period.

The fifth and final grouping included all fishing trips done by sandbar-permit fishers and was termed ‘SP-set’ (Table 6). Very sporadic ‘prospect’ fishing for sandbar sharks had begun in late-December 2008 and continued through January 2009, and it was not until late-January 2009 that the first full-effort, sandbar-permit fishing trip was observed. Although this observed trip occurred before the final observed non-permit shark-fishing trip (in early-February), the temporal distinction between the vast majority of the observed non-permit shark-fishing trips and the SP-set trips provided a justifiable reason to separate non- and sandbar-permit fishing trips for reporting purposes. Another reason was that the observer coverage of the seven sandbar-permit fishers was far in excess of that achieved for the non-permit shark fishers overall, but comparable to that achieved for the NP-set-Z4 grouping (Table 6B).

Table 6. The five logical *post-hoc* stratifications (groupings) applied for the summary and analysis of targeted commercial shark-fishing (TACC shark species) observer data showing the: A) operational parameters that define them; and B) observer sampling done and summary statistics the fishing gears used. Note: 'number of fishing days reported via fisher catch reporting' refers to at least an informed estimate of the targeted fishing for TACC species as determined via the reporting of catches of TACC species. That is, considerably more handlining and setlining to target other OTL species occurs in addition to the fishing effort estimated here.

	Commercial shark-fishing observer data groupings				
A) Operational parameters	**NP-set-Z4**	**NP-set-Z3**	**NP-drum**	**NP-hand**	**SP-set**
Permit status	Non-permit	Non-permit	Non-permit	Non-permit	Sandbar permit
Fishing method	Setline	Setline	Drumline	Handline	Setline
Zones represented	Z4	Z1 – Z3	Z1 – Z4	Z1 – Z4	Z1 – Z4
Months represented	Sep 08 – Feb 09	Sep 08 – Feb 09	Sep 08 – Feb 09	Sep 08 – Feb 09	Jan 09 – Jun 09
Range of depths fished	27 – 85 m	65 – 77 m	29 – 76 m	7 m	10 – 132 m
B) Sampling and gear statistics					
No. fishing trips observed	17	1	4	1	58
No. fishing days observed	17	1	4	1	91
No. gear deployments observed	26	1	37	86	95
Total no. hooks observed	2,924	130	74	86	35,190
Mean no. hooks per gear deployment (± se)	112 (± 13)*	na	2 (± 0)	na	370 (± 17)
Range of no. hooks per gear deployment	6 – 230*	na	na	na	80 – 670
No. fishing days reported via fisher catch reporting	34	90	#	34	145
Observer coverage (%)	50.0	1.1	na	2.9	65.5

* Note: if the two six-hook setline deployments in the NP-set-Z4 grouping are excluded, the mean (± se) and range of number of hooks per deployment are 121 (± 13) and 41 – 230 respectively.
# No correlating catch records in 2008/09 daily TACC shark catch reporting database as of 17 August 2009.

It is also important to note that on 16 March 2009 the specific condition associated with the sandbar permit restricting the number of TACC shark species other than sandbar shark allowed to be retained per fishing trip (i.e., four sharks) was lifted owing to concerns over the potential for discarding of dead sharks. This meant that any given sandbar-permit fisher could retain all TACC species, but that these TACC shark catches would be subtracted from their available 'sandbar' quota (i.e., 100 tonnes combined) after any given fishing trip. Despite this, anecdotal evidence suggested that for the most part the sandbar-permit fishers continued to primarily target sandbar sharks, albeit less selectively with respect to the areas fished.

3.3.2. Total catches reported by fishers targeting TACC sharks during the study period

Observer coverage for the five groupings listed above ranged between 1 and 66% (Table 6B), so there were many fishing trips not observed. Following is a table summarising the total reported catches for each TACC species, as derived from fisher-dependent catch reporting by the fishers identified as having targeted TACC sharks, and according to the spatial, temporal and methodological groupings defined above.

Table 7. Summary of total reported catches (dressed weight) for TACC species from 1 September to 30 June 2009, derived from fisher-dependent catch reporting by fishers identified as having specifically targeted TACC sharks. Data are separated according to the spatial, temporal and methodological groupings used to summarise the observer data.

	Total fisher-reported catches for observer study groupings							
	NP-set-Z4		**NP-set-Z3**		**NP-hand**		**SP-set**	
Common name	**No.**	**Wt (kg)**	**No.**	**Wt (kg)**	**No.**	**Wt (kg)**	**No.**	**Wt (kg)**
Sandbar shark	3	225	40	830	3	30	981	19,597
Dusky whaler	58	3,591	35	555	35	222	204	10,893
Spinner shark	11	442	113	80	4	8	89	3,221
Common blacktip shark	11	519	583	23,106	554	2,810	216	4,948
Tiger shark	11	494	56	1515			71	1,111
Smooth hammerhead	7	100	32	728			10	71
Scalloped hammerhead	1	10	39	760			86	1,321
Bronze whaler	58	3,070	181	6,999			6	354
Shortfin mako	14	151	33	153			3	57
Bull shark	1	81	16	974			14	628
Great hammerhead	2	79	30	633			9	287
Silky shark	1	56	6	80			6	350
Bignose shark							2	75
TOTAL	**178**	**8,814**	**1,164**	**36,410**	**596**	**3,069**	**1,697**	**42,913**

According to the fisher catch reports, as many bronze whalers as dusky whalers were caught in Zone 4 between September and February (i.e., NP-set-Z4), while approximately five-times as many bronze as dusky whalers were caught in Zones 1 – 3 during that period (i.e., NP-set-Z3) (Table 7). Similarly, catch records indicated that approximately five-times as many common blacktip as spinner sharks were caught for the largely unobserved NP-set-Z3 grouping. In any case, the main species reported as being caught in the non-permit fishery were common blacktip shark, bronze whaler, spinner shark, dusky whaler and tiger shark, while those species (excluding bronze whaler) plus sandbar shark and scalloped hammerhead were reported as the main species caught in the sandbar-permit fishery (Table 7). The total retained catch of TACC species in the sandbar-permit fishery to 30 June 2009 by dressed weight was approximately 42.9 tonnes, or only 42.9% of the TACC allocated to all sandbar-permit fishers combined up to that date (i.e., 100 tonnes).

3.3.3. NP-set-Z4 grouping – (non-permit setlining in Zone 4; Sep 08 – Feb 09)

A total of 192 organisms, comprising 21 species, was caught during the 17 non-permit TACC-shark setlining trips observed in Zone 4 between September 2008 and February 2009. Approximately 41.1% of this catch (by number) comprised the targeted TACC shark species, with the remainder comprising non-target species of shark, ray and teleost fish. Note that all trips initially involved the deploying of setlines the previous afternoon and then retrieval on the morning of the trip, so each trip correlates to one fishing day. On the day of retrieval an additional set (or two) using gear with fewer hooks and shorter soak-time(s) was also sometimes (though rarely) done.

The two six-hook setline deployments in the NP-set-Z4 grouping of trips were distinct outliers with respect to the range of numbers of hooks per setline deployment within and among the three setline groupings (Table 6B). To prevent the potential for these two line deployments exerting a disproportionately great influence on overall summaries of catch rate for the grouping owing to the small number of hooks, it was decided that they be excluded from all catch rate calculations. Given this exclusion, the number of line deployments observed for September, October, November, December, January and February was 2, 4, 6, 9, 3 and 0 respectively, giving a total of 24 for the purpose of calculation. Note that one of the six-hook setline deployments caught nothing, while the other caught an eastern fiddler ray (retained), Port Jackson shark and smooth stingray (both discarded).

The mean catch rate (± se) of all TACC species combined and that for all other (i.e., non-TACC) species combined were similar, at 3.2 (± 0.6) and 3.3 (± 1.1) individuals per 100 hooks per setline deployment respectively (Figure 8A). Dusky and bronze whaler were the two dominant TACC species in catches with mean catch rates of 1.4 (± 0.4) and 0.7 (± 0.2) sharks per 100 hooks per setline deployment respectively (n = 24 setline deployments; Figure 8A). This was more-or-less consistent with the reported catches (Table 7) when one particularly large catch of 23 bronze whalers from an unobserved trip is taken into account. Mean catch rates of < 0.5 sharks per 100 hooks per setline deployment were recorded for shortfin mako, smooth hammerhead, and spinner, tiger and common blacktip shark (Figure 8A).

Approximately 43.4% of the catch of non-TACC species was retained as byproduct, with the remainder discarded (or released) (Figure 8A). The overall ratio of bycatch to retained catch (by number) for the NP-set-Z4 grouping was exactly 0.5:1. The main byproduct species were (in order of decreasing catch rate) smooth stingray, spotted wobbegong, gummy shark, bluespotted flathead, eastern fiddler ray and thresher shark, with five or fewer individuals recorded in total for the latter four species. The major discard species were smooth stingray and Port Jackson shark, with a total of five grey nurse sharks and one great white shark also caught and released alive. Refer to Appendix A for a complete summary of catches and catch rates.

3.3.4. NP-set-Z3 grouping – (non-permit setlining in Zones 1 – 3; Sep 08 – Feb 09)

As mentioned above, only one setlining trip, involving one setline deployment (a 130-hook line deployed and retrieved during the same early morning), was observed in waters north of South West Rocks during the sampling period. The difficulty in securing a more useful number of observer trips with non-permit TACC-species shark fishers north of 31˚ 00’ S latitude was disappointing, particularly given the current lack of knowledge regarding catches of these sharks north of South West Rocks during the spring and summer months (i.e., September – February).

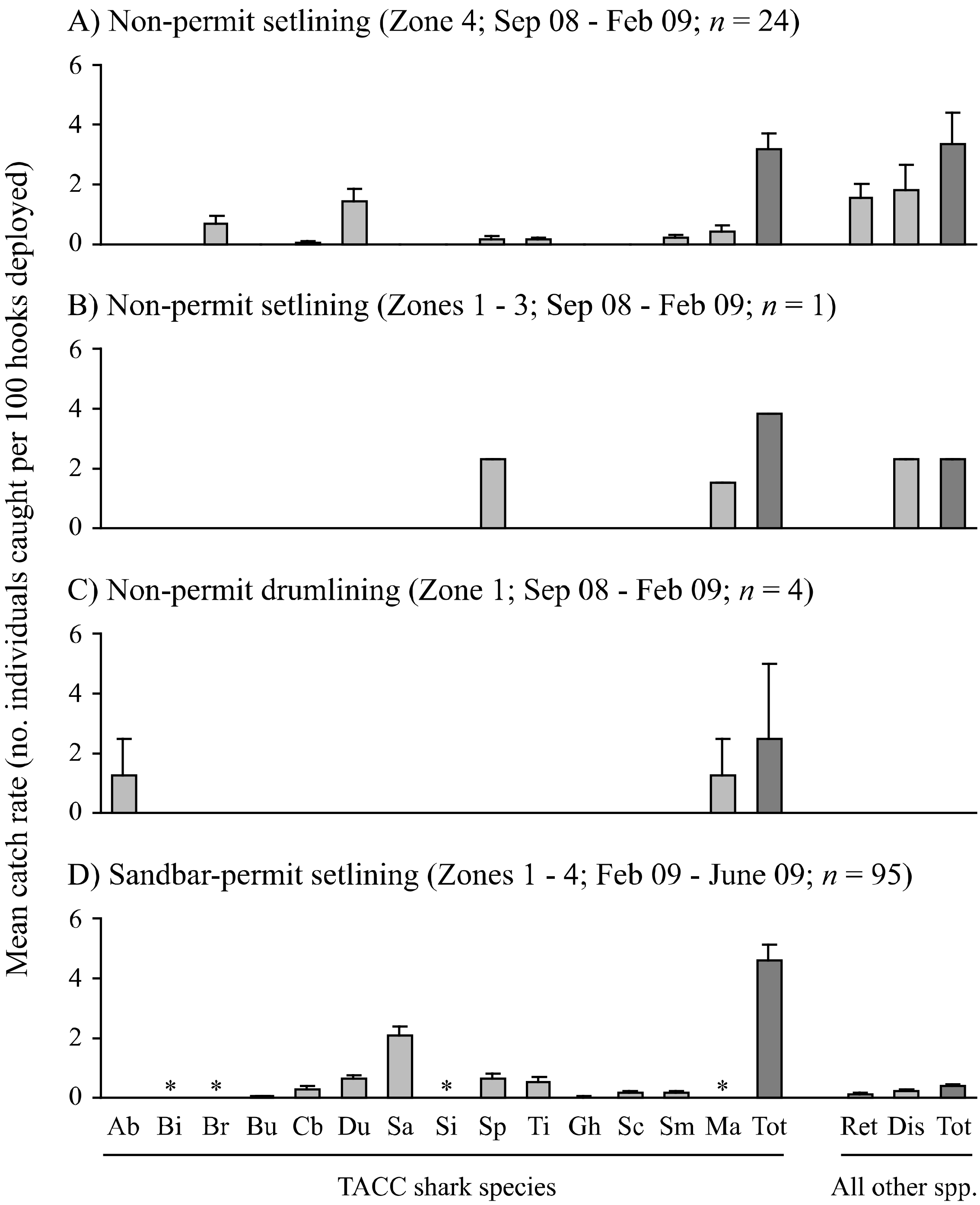

Figure 8. Mean catch rate (± se where appropriate) for various species or groups, expressed as the number of individuals per 100 hooks per setline deployment for: A) non-permit setlining in Zone 4 (NP-set-Z4); B) non-permit setlining in Zones 1 – 3 (NP-set-Z3); C) non-permit drumlining in Zones 1 – 3 (NP-drum); and D) sandbar-permit setlining in Zones 1 – 4 (SP-set). Codes for TACC sharks: Ab, Australian blacktip; Bi, bignose; Br, bronze whaler; Bu, bull; Cb, common blacktip; Du, dusky whaler; Sa, sandbar; Si, silky; Sp, spinner; Ti, tiger; Gh, great hammerhead; Sc, scalloped hammerhead; Sm, smooth hammerhead; Ma, mako; and Tot, all TACC species combined. Codes for all other (i.e., non-TACC) species: Ret, retained byproduct; Dis, discards; Tot, all non-TACC species (retained byproduct and discards) combined. *, value between 0.0001 and 0.02.

A total of eight organisms, comprising four species, were caught during the trip observed. This catch consisted of five TACC sharks (three spinner sharks and two shortfin makos) and three, subsequently discarded non-target individuals (two black stingrays and one coffin ray) (Figure 8B). Although little can be reliably concluded about shark setlining north of South West Rocks during the spring and summer months based on these data, it is nevertheless worth noting that: 1) the catch rates for TACC species combined and non-TACC species combined for the setline deployment were approximately 3.8 and 2.3 individuals per 100 hooks respectively; and 2) the ratio of bycatch to retained catch (by number) was 0.6:1; and in particular that these measures were comparable to those calculated for the NP-set-Z4 grouping (Figure 8B).

3.3.5. NP-drum grouping – (non-permit drumlining in Zones 1 – 4; Sep 08 – Feb 09)

A total of four observer days (one-day trips) was done with a non-permit fisher targeting TACC sharks using drumlines (see section 3.3 for a description of the gear). (Note that the method currently being recorded on catch report forms by fishers using drumlines is 'setline', which is somewhat understandable given the similarities.) This drumlining was done in Zone 1 and involved the retrieval of between 7 and 11 two-hook drumlines during a given fishing day (drumlines are baited the previous day). The spacing between drumlines ranged from tens of metres to kilometres.

Three of the four trips yielded no catch at all, while the remaining trip yielded two organisms – a shortfin mako and an Australian blacktip shark, both of which are TACC shark species and were retained (Figure 8C). As is the case with the NP-set-Z3 and NP-hand groupings, the relative lack of observer effort means that any conclusions about drumlining catches must be made with extreme caution, particularly as the true extent of its use as a method in NSW waters is currently unclear.

3.3.6. NP-hand grouping – (non-permit handlining in Zones 1 – 4; Sep 08 – Feb 09)

In January 2009 an observer trip was done with a fisher using handlines to target relatively small whaler sharks (i.e., < 150-cm TL) in relatively shallow coastal waters (i.e., < 10-m deep) off the far north coast. Anecdotal evidence suggests that this type of shark fishing, which only occurs when the sharks appear on the fishing grounds over around a four- to five-month period beginning around November, is traditional for some of the local OTL fishers.

A total of 20 organisms were caught from the 86 handline deployments during the trip. This catch comprised 19 common blacktip sharks ranging in size (TL) between 73 and 127 cm, and a dusky whaler of 94-cm TL, all of which were retained. No organisms other than the targeted whaler sharks were caught. Owing to the considerable difference in fishing method, type of fishing grounds and sizes of TACC sharks being targeted, along with the relative paucity of handlining trips observed, specific comparisons of catch rates with other methods would be of little value and so will not be made here.

3.3.7. SP-set grouping – (sandbar-permit setlining in Zones 1 – 4; Feb 09 – Jun 09)

As mentioned above, other than some prospect fishing for sandbar sharks during December 2008 and January 2009, it was not until mid-January 2009 that sandbar-permit shark fishing began in earnest. Observer data indicated that most sandbar-permit fishing effort was concentrated in Zones 1 and 2, and the month during which effort was greatest was June (Table 8).

One notable operational difference between the sandbar-permit and non-permit setlining was that most of the sandbar-permit fishers undertook fishing trips involving multiple days at sea when the weather permitted. The main reason for this was the distances between their home port and preferred fishing grounds and the economic implications of 'commuting'. In any case, the vast majority of sandbar-permit fishing days observed involved just one setline deployment, although it should be noted that the mean number of hooks per deployment was more than three-times that for the non-permit setlines used in Zone 4 (Table 6).

Table 8. Total number of observed sandbar-permit setline deployments for Zones 1 – 4 for each month during which sandbar-permit fishing was done (i.e., January – June 2009).

	Total number of observed sandbar-permit setline deployments						
Zone	**January**	**February**	**March**	**April**	**May**	**June**	**Total**
Zone 1	1	5	6	4	4	22	42
Zone 2	0	3	8	6	11	6	34
Zone 3	0	0	2	5	3	7	17
Zone 4	0	0	2	0	0	0	2
Total	1	8	18	15	18	35	95

A total of 1,415 animals, comprising around 37 – 40 species (accounting for unidentified individuals), was caught during the 58 sandbar-permit shark setlining trips (91 fishing days involving 95 setline deployments) observed. Approximately 90.2% of this catch (by number) comprised the targeted TACC shark species, with the remainder (138 animals) comprising non-target species of shark, ray, teleost fish and marine turtle. Note that almost all setline deployments involved setting the line in the afternoon and/or evening, then retrieving it the following morning. Additional line deployments and subsequent retrievals within a given fishing day were sometimes (though rarely) done.

The mean catch rate of all TACC species combined was 4.6 (± 0.5) sharks per 100 hooks per setline deployment, which was around 10-times the catch rate of all other (i.e., non-TACC) species combined (0.4 ± 0.1). Notably, this latter catch rate was almost an order of magnitude lower than the catch rate of all other (i.e., non-TACC) species combined for the NP-set-Z4 grouping (Figure 8). Sandbar shark was by far the dominant TACC species in sandbar-permit catches during observed trips (Figure 8D), comprising 44.6% of the total catch of TACC sharks (by number). According to the fisher-dependent catch reporting, however, sandbar shark comprised 45.7% of the total catch of TACC sharks by weight and 57.8% by number across all sandbar-permit catches (i.e., observed and unobserved trips combined) (Table 7). The mean catch rate of sandbar shark during observed sandbar-permit trips (all Zones combined) was 2.1 (± 0.3) sharks per 100 hooks per setline deployment (n = 95 setline deployments; Figure 8D). Mean catch rates were similar to one another in the cases of spinner shark (0.6 ± 0.2 sharks per 100 hooks per setline deployment), dusky whaler (0.6 ± 0.1) and tiger shark (0.5 ± 0.2) (Figure 8D). Mean catch rates ranging between 0.05 and 0.5 sharks per 100 hooks per setline deployment were recorded for common blacktip shark, scalloped hammerhead, smooth hammerhead and bull shark, in order of decreasing rate (Figure 8D). The majority of these sharks were retained, except in the case of tiger shark, where many were released upon capture.

Approximately 42.8% of the catch of non-TACC species was retained as byproduct, with the remainder discarded (or released) (Figure 8D). The overall ratio of bycatch to retained catch (by number) for the SP-set grouping was approximately 0.044:1. The main byproduct species (those for which more than one individual was retained) were (in order of decreasing quantity) cobia, spotted wobbegong, gummy shark, blue catfish, white-spotted guitarfish, banded rockcod and snapper, with five or fewer individuals retained in total for the latter four species. The major discard species were black and smooth stingray, and banded and spotted wobbegong, with a total of five great white sharks and two green turtles also caught and then released alive. As mentioned above, the great white sharks and green turtles were all alive and active upon capture, and swam away when released. Refer to Appendix A for a complete summary of catches and catch rates.

3.4. Spatial, temporal and biological profile of catches for TACC shark species

3.4.1. Sandbar shark

A combined total of 569 sandbar sharks was caught during observed sandbar-permit shark-fishing trips in Zones 1, 2 and 3 during the period January to June 2009 (Table 4; Figure 9A), although catch reporting by sandbar-permit fishers indicated that this species was also caught in northern NSW waters during prospecting trips in December 2008, albeit in lesser quantities. The fisher-dependent catch reporting indicated that a total of around 980 sandbar sharks at a landed weight of approximately 19.6 tonnes was caught (i.e., observed and unobserved trips combined).

Approximately 38.3% of the total observed catch of sandbar sharks (by number) occurred in Zone 1 during June (Figure 9A). In contrast, no more than 11% of the total observed catch was caught in the cases of all other Zone/month combinations. In the case of Zone 1, this was despite similar mean catch rates of sandbar shark for months between March and June (i.e., 1.8 – 3.6 sharks per 100 hooks per setline deployment), and higher catch rates in February and January (approximately 5.6 and 10.9 sharks per 100 hooks per setline deployment respectively) (Figure 9B). This indicates that it was likely the result of the increase in fishing effort in Zone 1 during June (Table 8), rather than any variability in the pattern of dispersal of sandbar sharks among those months on those fishing grounds.

For any given month other than March, the mean catch rates of sandbar shark in Zone 1 were at least twice as high as for any other Zone (Figure 9B). Mean catch rates in Zone 2 were reasonably consistent among months (Figure 9B), while few sandbar sharks were caught during observed trips in Zone 3 and none in Zone 4. There was no significant relationship between catch rate of sandbar shark and depth of water in which fishing took place, for deployments that caught sandbar shark ($P > 0.30$, $n = 69$) (Figure 10). However, the five highest catch rates occurred in waters between around 60 to 80 m in depth (Figure 10).

The sizes of sandbar sharks caught during this observer study ranged between 76- and 228-cm TL, although the bulk of the catch (i.e., 87.1%) by number comprised sharks of 160-cm TL or larger (Figure 11A). One sandbar shark was recorded as being 250-cm TL, but this measurement (or, alternatively, species identification) is considered doubtful, and so it was disregarded for the purposes of this section. Of 560 sandbar sharks measured and sexed, males comprised 60.0% (i.e., 336 sharks), giving an overall ratio of males to females of 1.50:1. The mean TL (± se) of males and females > 159-cm TL was 187.3 (± 0.5) and 203.6 (± 0.8) cm ($n = 301$ and 188 respectively), and the difference in the size-frequency distributions of males and females at these sizes was found to be significant (KS test, $P < 0.001$, df = 2; Figure 11A). In the case of sandbar sharks smaller than those sizes the size-frequency distributions of males and females were similar (Figure 11A).

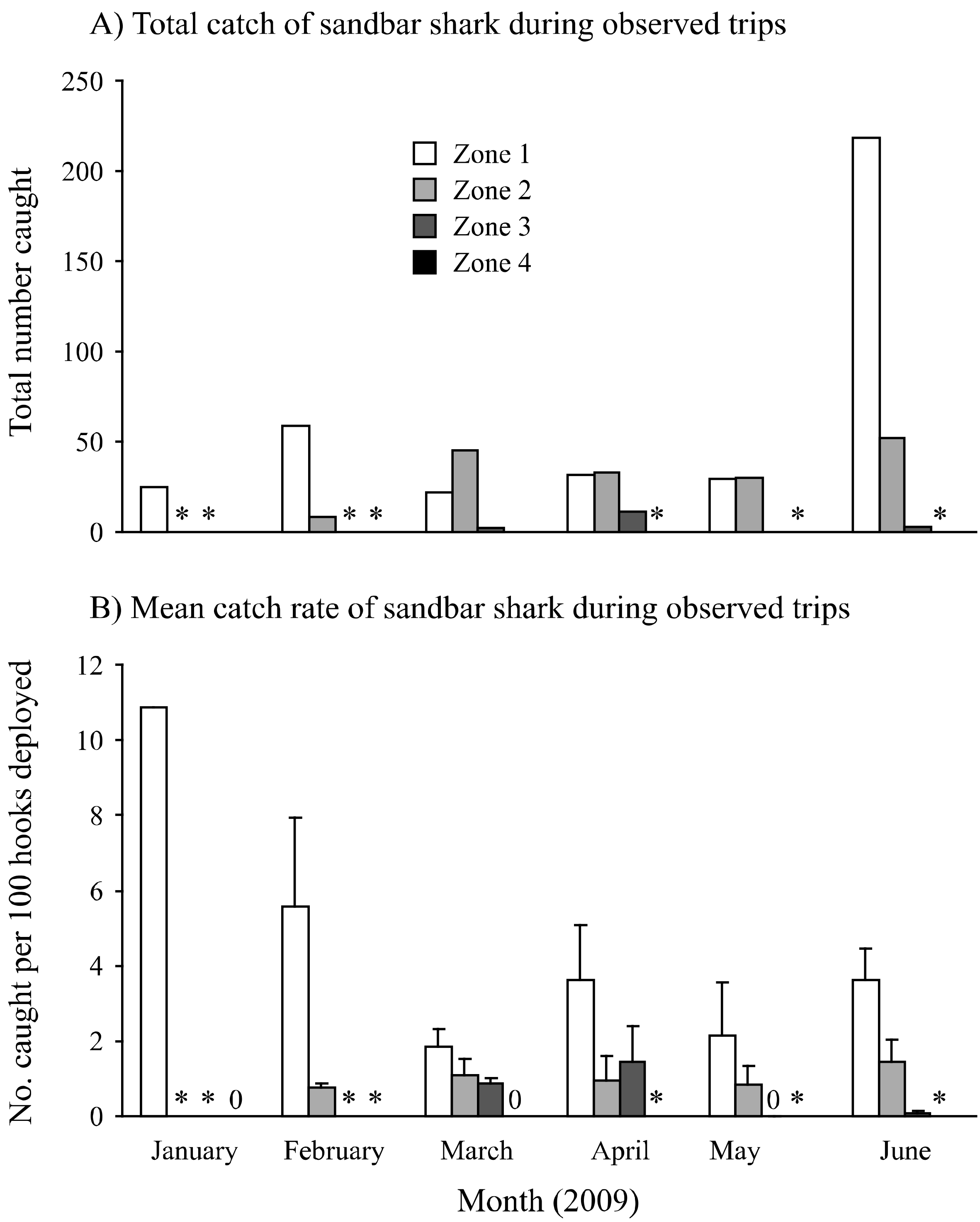

Figure 9. A) Total number caught, and B) mean catch rate (± se where appropriate), for sandbar shark in Zones 1, 2, 3 and 4 during each month from January to June 2009. Catch rate expressed as the number of sharks per 100 hooks per setline deployment. Handline data are excluded. Refer to section 3.3 for sample sizes (*n*). 0, catch rate of zero. *, no fishing trips observed.

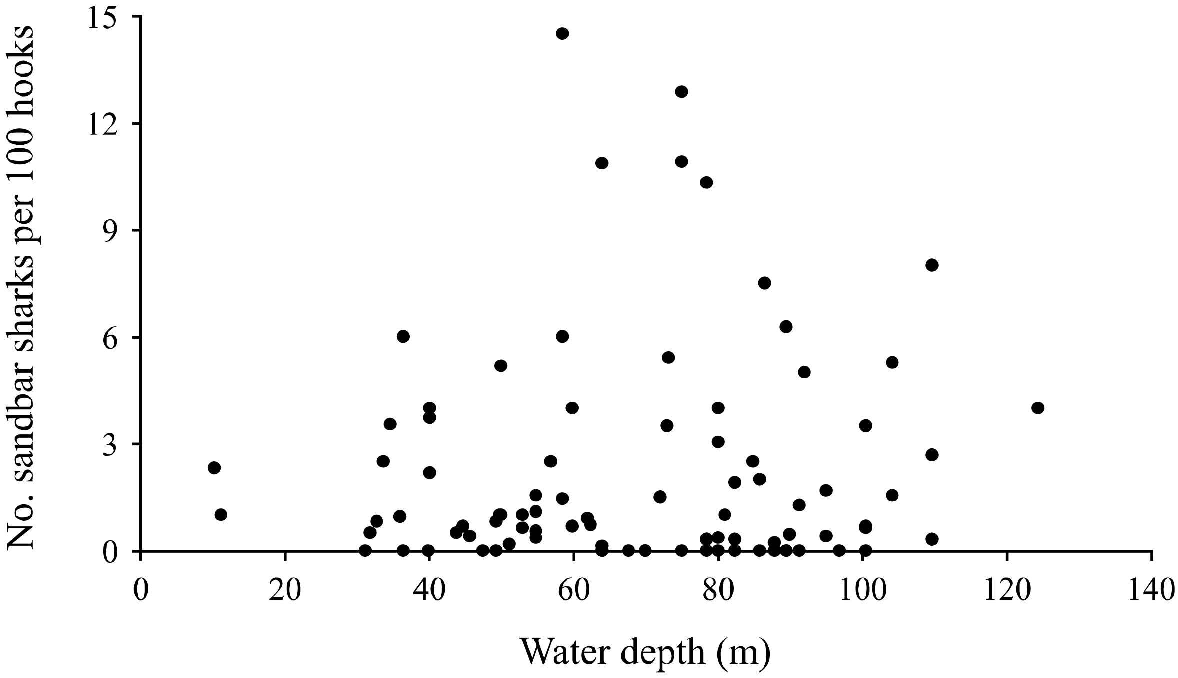

Figure 10. Plot of catch rate of sandbar shark (number of sharks per 100 hooks) vs. mean water depth for sandbar-permit setline deployments (*n* = 90).

Data concerning the reproductive status of 327 male and 214 female sandbar sharks were recorded (Table 9). These data indicated that males up to 149-cm TL were all sexually immature (i.e., clasper status A – Table 3), while most of the males > 165-cm TL were sexually mature (i.e., clasper status C), with the remainder of those larger males comprising mostly of transitional, 'maturing' – 'B' – clasper status individuals (Table 9). Given that it can often be difficult to distinguish between the B and C clasper status categories, and that clasper lengths ranged up to 80 mm in length for sharks < 150-cm TL and were at least 106 mm for sharks > 165-cm TL (Table 9), it can be concluded that males in the population of sandbar sharks that inhabit northern NSW waters mature between 150- and 165-cm TL. No male sandbar sharks between 150- and 159-cm TL were observed during this study (Figure 11A; Table 9).

Female sandbar sharks of sizes < 165-cm TL were sexually immature (i.e., uterus status A or B – Table 3) (Table 9). A pregnant, 175-cm TL sandbar shark was caught, while the majority of female sandbar sharks larger than that size were sexually mature (i.e., uterus status C, D, E or F), demonstrating that at least some sharks sexually mature at 175-cm TL. The uterus status and width data suggest that some female sandbar sharks start sexually maturing at quite large sizes (i.e., up to 215-cm TL). Given the above information, it is reasonable to conclude that female sandbar sharks that inhabit northern NSW waters generally mature at TLs between 160 and at least 175 cm. Very few females between 150- and 185-cm TL were observed during this study (Figure 11A; Table 9).

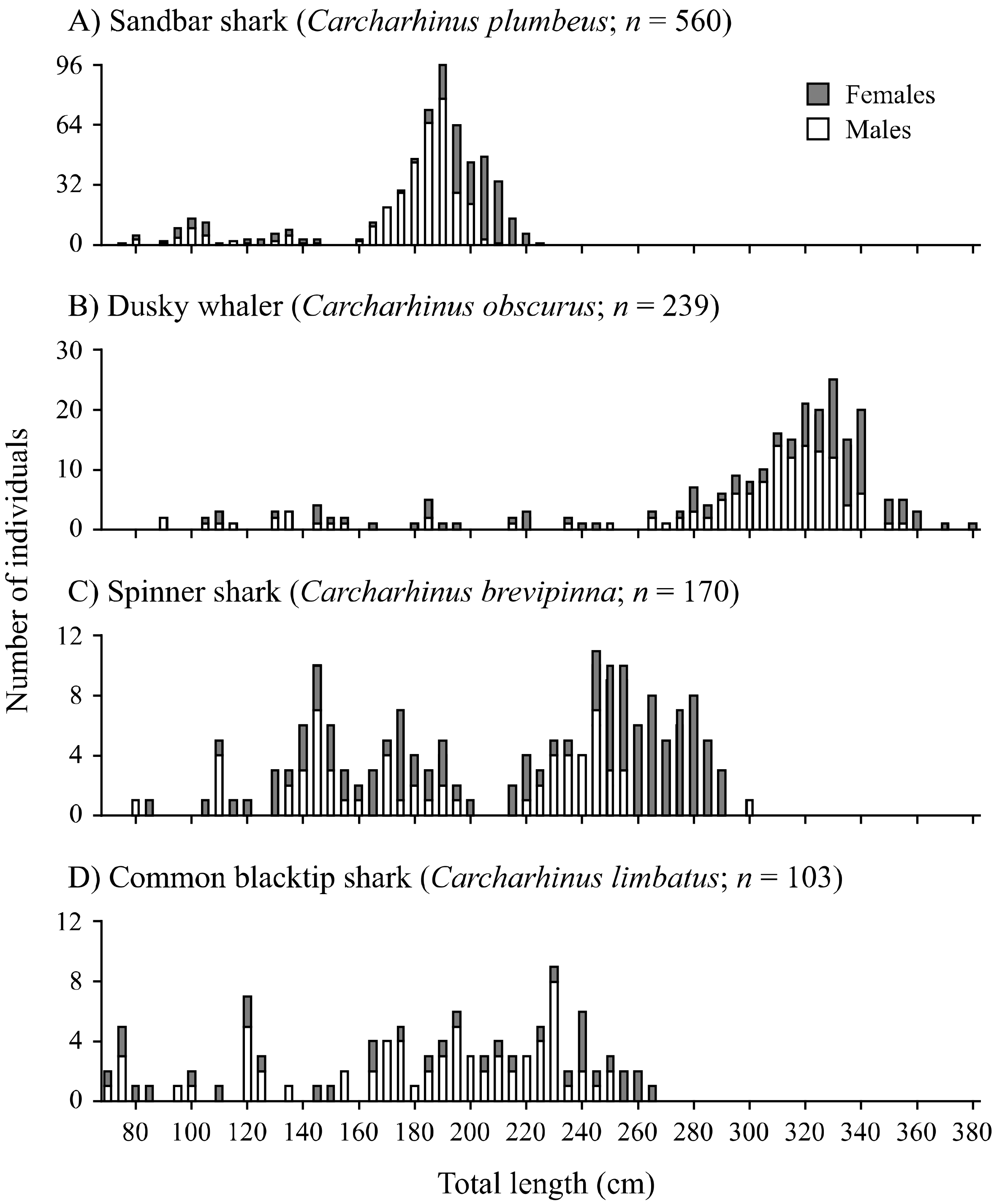

Figure 11. Length-frequency histograms of catches of the main four shark species caught: A) sandbar shark; B) dusky whaler; C) spinner shark; and D) common blacktip shark; combined across all shark-fishing trips observed during this study. Data are consolidated into 5-cm length (TL) classes (e.g., length class 200 = 200 – 204 cm in TL), with each partitioned into males and females.

Table 9. Summary of reproductive status data recorded for male (*n* = 327) and female (*n* = 214) sandbar shark. Data concerning clasper length of males and uterus width of females are also presented (*n* = 308 and 83 respectively). *, refer to Table 3 for definitions of clasper and uteri status categories.

TL (cm)	Male clasper status (%) *			Range of clasper lengths (mm)	Female uteri status (%) *			Instance of pups or yolky eggs in uteri	Range of uterus widths (mm)
	A	B	C		A	B	C – F		
75 - 114	100	0	0	14 – 55	100	0	0		1 – 10
115	100	0	0	33 – 34					
120	100	0	0	20	0	100	0		
125					66.7	33.3	0		
130	100	0	0	20 – 80	100	0	0		
135	80	20	0	40 – 75	100	0	0		3 – 4
140	100	0	0	45 – 45	0	100	0		
145	100	0	0	37 – 40	100	0	0		2
150									
155									
160	0	0	100	140	100	0	0		3
165	0	0	100	110 – 160	100	0	0		6
170	0	5	95	120 – 220					
175	3.6	0	96.4	125 – 230	0	0	100	Yes	
180	0	7.5	92.5	108 – 245	100	0	0		5
185	0	9.5	90.5	106 – 245	0	28.6	71.4	Yes	50 – 55
190	1.3	19.5	79.2	119 – 310	20	13.3	66.7	Yes	5 – 90
195	3.6	21.4	75	145 – 280	8.6	2.9	88.6	Yes	6 – 185
200	0	18.2	81.8	120 – 245	0	0	100	Yes	30 – 120
205	0	33.3	66.7	171 – 230	7.7	12.8	79.5	Yes	6 – 165
210					3.3	16.7	80	Yes	30 – 180
215					14.3	7.1	78.6	Yes	4 – 190
220					16.7	16.7	66.7	Yes	6 – 60
225					0	100	0		

Some sexually mature female sandbar sharks were found to have yolky eggs (i.e., uterus status D) and/or embryos (i.e., uterus status E) within the period February to June 2009 (Figure 12). In contrast, the only post-birth females recorded were in June. A total of 24 female sandbar sharks with embryos in their uteri were recorded, with these pregnant sharks present in catches from February to June 2009 (Figure 12). The mean number of unborn pups per shark (± se) was 7.8 (± 0.5), with litter sizes ranging between 3 and 12 pups (*n* = 22). The three females with unborn pups sampled during February had embryos with TLs ranging between 52 and 58 cm, while in March the unborn pups in another shark ranged between 58 and 66 cm in TL. Interestingly, the second 'pregnant' shark sampled in March had considerably smaller embryos – 31 – 34 cm in TL. The TLs of embryos in April (36 – 40 cm) and June (37 – 52 cm) were then successively larger (on average). The pups from the pregnant female caught in May were not measured.

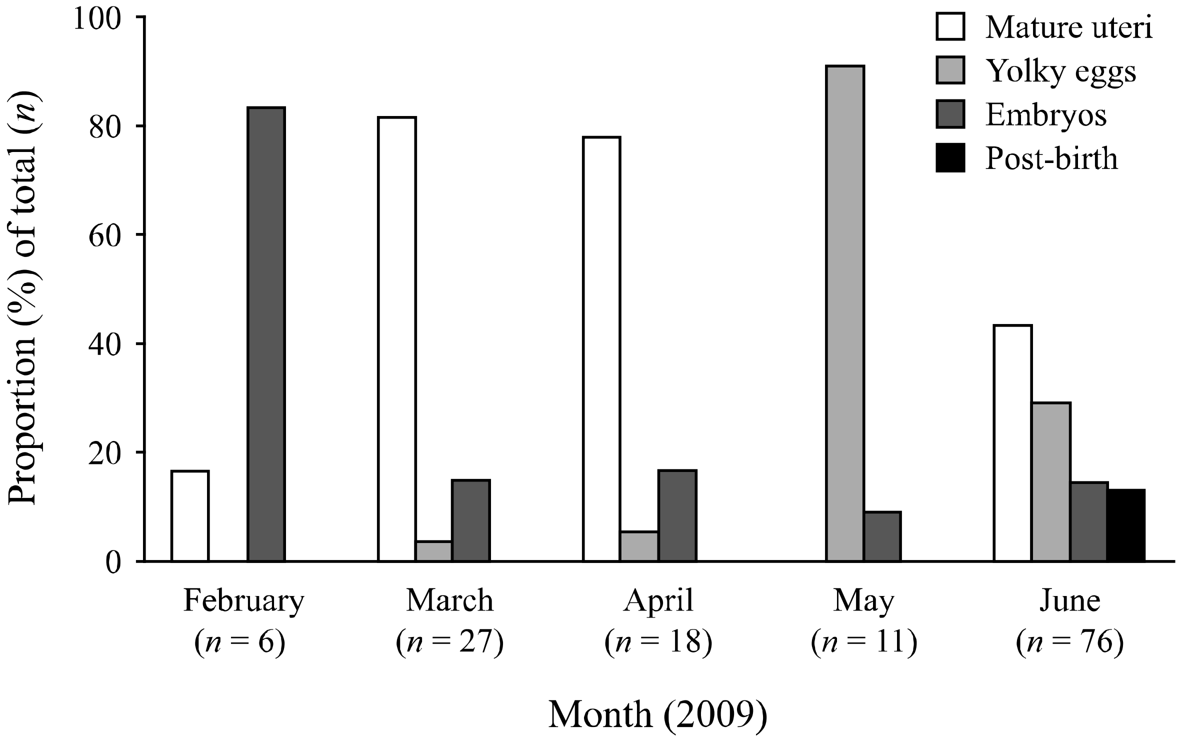

Figure 12. Proportion of the catch of sexually mature female sandbar sharks with: mature uteri without yolky eggs or embryos (uterus status C); uteri containing yolky eggs (uterus status D); uteri containing embryos (uterus status E); or flaccid uteri typical of post-birth. Data are for the five months during which mature female sandbar sharks were observed (February-June 2009), and the number of mature females recorded (*n*) is shown for each month.

3.4.2. Dusky whaler

Dusky whalers were caught along the full extent of the northern NSW coast; by both non-permit and sandbar-permit fishers; and throughout the entire sampling period (September 2008 to June 2009) (Figure 13). The overall total observed catch was 249 dusky whalers, with 29 and 219 recorded in the NP-set-Z4 and SP-set groupings respectively, and one caught via handline (i.e., NP-hand). However, the corresponding fisher-dependent catch reporting for the SP-set grouping of shark-fishing trips indicated that 204 dusky whalers were caught overall (i.e., observed and unobserved trips combined; Table 7), suggesting data on reported catches were lacking.

The observer data indicated that approximately 88.0% of the total catch of dusky whalers (by number) occurred during sandbar-permit fishing trips done from February to June, and mostly in Zones 1, 2 and 3 (Figure 13A). In general, this more-or-less reflected the distribution of observed fishing effort with respect to the NP-set-Z4 and SP-set groupings, as the mean catch rates of dusky whaler were similar among Zone/month combinations (Figure 13B). These catch rates were also similar to catch rates of sandbar shark in Zones 2 and 3, but far lower compared with the catch rates of sandbar shark in Zone 1. There was no significant linear regression relationship between catch rate of dusky whaler and depth of water in which fishing took place, for deployments that caught dusky whaler ($P > 0.67$, $n = 60$).

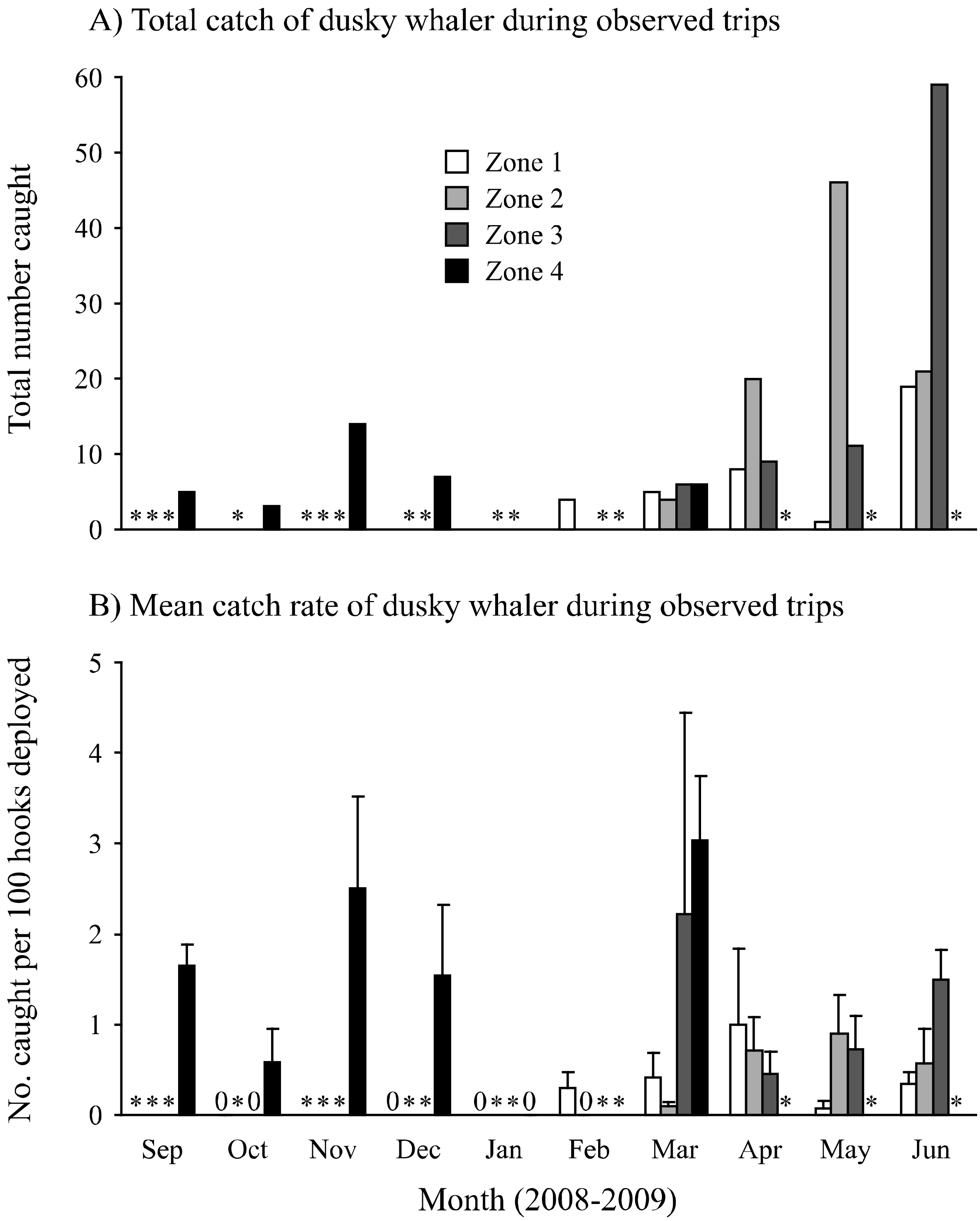

Figure 13. A) Total number caught, and B) mean catch rate (± se where appropriate), for dusky whaler in Zones 1, 2, 3 and 4 during each month from September 2008 to June 2009. Catch rate expressed as the number of sharks per 100 hooks per setline deployment. Handline data are excluded. Refer to section 3.3 for sample sizes (*n*). 0, catch rate of zero; *, no fishing trips observed.

The sizes of dusky whalers caught during observed trips ranged between 90- and 380-cm TL, with the majority of the catch (i.e., 82.8%) by number comprising sharks of 265 cm in TL or larger (Figure 11B). Of 239 dusky whalers measured and sexed, males comprised 54.4% (i.e., 130 sharks), giving an overall ratio of males to females of 1.19:1. The mean TL (± se) of males and females at > 264-cm TL was 315.0 (± 1.7) and 328.2 (± 2.4) cm (n = 112 and 86 respectively), with the size-frequency distributions of males and females at these larger sizes significantly different (KS test, $P < 0.001$, df = 2). The size composition of dusky whalers < 265-cm TL for each sex were similar (Figure 11B).

Of the 130 male and 109 female dusky whalers encountered by observers, data concerning the reproductive status of 126 and 95, respectively, were recorded (Table 10). These data indicated that males up to 239-cm TL were all immature, while most of the males > 265-cm TL were sexually mature, with the remainder of those larger males comprising mostly of individuals with transitional, maturing claspers (Table 10). Given that clasper lengths did not exceed 79 mm for sharks < 255-cm TL and were almost always > 200 mm for sharks > 265-cm TL (Table 10), it can be concluded that males in the population of dusky whalers that inhabit northern NSW waters mature at sizes between 250- and 270-cm TL.

Females of sizes < 290-cm TL were sexually immature, while most females > 300-cm TL were mature (Table 10). The uterus width data support this with widths not exceeding 45 mm up to 290-cm TL, and being generally > 70 mm for sharks 300-cm TL and larger (Table 10). Given these data, it is reasonable to conclude that female dusky whalers inhabiting northern NSW waters mature at sizes between 285- and 310-cm TL.

Totals of two and six female dusky whalers were found to have yolky eggs and pups, respectively, with these sharks being caught between February and June. The mean number of unborn pups per shark (± se) was 9.5 (± 1.1), with litter sizes ranging between 5 and 12 pups (n = 6). The range of pup sizes (TL) for the six pregnant females were: 63 – 68 cm (February; two pregnant females); 90 – 105 cm (April); 49 – 63 cm (May); and 42 – 59 cm and 60 – 67 cm (June; two pregnant females). A total of 11 females were found to have wide and flaccid uteri typical of a female that has recently given birth, with 10 of these recorded in May and June, and the other in October.

Table 10. Summary of reproductive status data recorded for male (*n* = 126) and female (*n* = 95) dusky whaler. Data concerning clasper length of males and uterus width of females are also presented (*n* = 117 and 51 respectively). Refer to Table 3 for definitions of clasper and uteri status categories.

TL (cm)	Male clasper status (%)			Range of clasper lengths (mm)	Female uteri status (%)			Instance of pups or yolky eggs in uteri	Range of uterus widths (mm)
	A	B	C		A	B	C – F		
90 – 230	100			17 – 70	94.4	5.6			2 – 45
235	100			65					
240					100				3
245					100				2
250		100		79					
255									
260									
265			100	290	100				
270		100		120					
275			100	220	100				5
280			100	237	100				10 – 15
285			100	227 – 230	100				5
290			100	240 – 290		100			40
295		33.3	66.7	230 – 299	50	50			40 – 42
300		16.7	83.3	170 – 300		50	50		70
305			100	230 – 410	100				
310		7.7	92.3	230 – 360			100		80
315			100	220 – 415			100	Yes	80
320			100	240 – 405	14.3		85.7	Yes	70 – 110
325		7.7	92.3	230 – 467			100		70 – 120
330		16.7	83.3	230 – 400			100	Yes	100 – 270
335			100	250 – 270			100	Yes	60 – 240
340			100	250 – 312			100	Yes	250 – 280
345									
350			100	332.5			100	Yes	90 – 100
355			100	292			100		100 – 260
360							100		
365									
370							100		
375									
380							100		

3.4.3. Spinner shark

Like the dusky whaler, spinner sharks were caught along the full extent of the northern NSW coast during the sampling period (September 2008 to June 2009), and by both non-permit and sandbar-permit fishers (Figure 14), with a total observed catch of 174 sharks. The majority of the catch (95.4%) by number came during trips observed between January and June (Figure 14A). With the exception of some large catches in March and April, mean catch rates were generally < 1 shark per 100 hooks per setline deployment, and most captures were from Zones 2 and 3 (Figure 14B).

There was no significant relationship between catch rate of spinner shark and depth of water in which fishing took place, for deployments that caught spinner shark ($P > 0.26$, $n = 47$), although the three setline deployments that had a catch rate > 5 spinner sharks per 100 hooks were from water between 49 and 63 m deep (Figure 15).

The sizes of spinner sharks caught during this observer study ranged between 80- and 300-cm TL, with two distinct groups according to size apparent in the catches – 100 – 200-cm and 215 – 300-cm TL – along with other less-distinct groups at smaller sizes, possibly representing cohorts (Figure 11C). Of 170 spinner sharks measured and sexed, males comprised 36.5% (i.e., 62 sharks), giving an overall ratio of males to females of 0.57:1. There was a significant difference in the size distributions between the sexes for the 215 – 300-cm TL spinner sharks (KS test, $P < 0.001$, df = 2), with the mean TL (± se) of males and females 243.4 (± 2.7) and 263.2 (± 2.3) cm (n = 29 and 68 respectively) (Figure 11C). However, the size composition of spinner sharks < 200-cm TL for each sex were similar.

Of the 62 male and 108 female spinner sharks encountered by observers, data concerning the reproductive status of 60 and 79, respectively, were recorded (Table 11). These data indicated that males up to around 200-cm TL were immature, while those > 220-cm TL were sexually mature; a finding supported by the clasper length data (Table 11). Therefore, it can be concluded that males in the population of spinner sharks that inhabit northern NSW waters mature at sizes between 200- and 220-cm TL.

Female spinner sharks of sizes < 205-cm TL were found to be immature (with the one record of a 185-mm TL shark declared mature considered dubious) while most females > 235-cm TL were mature (Table 11). The uterus width data generally support this with widths not exceeding 3 mm up to 204-cm TL (with the exception of the aforementioned dubious record), and being mostly > 50 mm for sharks 235-cm TL or larger (Table 11). The smallest pregnant spinner shark encountered was 245-cm TL. Given these data, it is reasonable to conclude that female spinner sharks inhabiting northern NSW waters sexually mature at sizes somewhere between 200- and 235-cm TL.

A total of nine sexually mature female spinner sharks were found to have pups in their uteri, with these sharks being caught in February, March and April. Where further data regarding pups were recorded, the mean number of unborn pups per shark (± se) was 10.9 (± 0.8), with litter sizes ranging between 7 and 14 pups (n = 8). The range of pup sizes (TL) for the seven pregnant females for which pup sizes were recorded were: 70 – 78 cm and 75 – 78 cm (February); 68 – 74 cm and 74 – 80 cm (March); and 76 – 82 cm, 76 – 80 cm and 78 – 79 cm (April). A total of six sexually mature females were found to have enlarged and flaccid uteri typical of a female that has recently given birth, with one of these recorded in March, two in May and three in June.

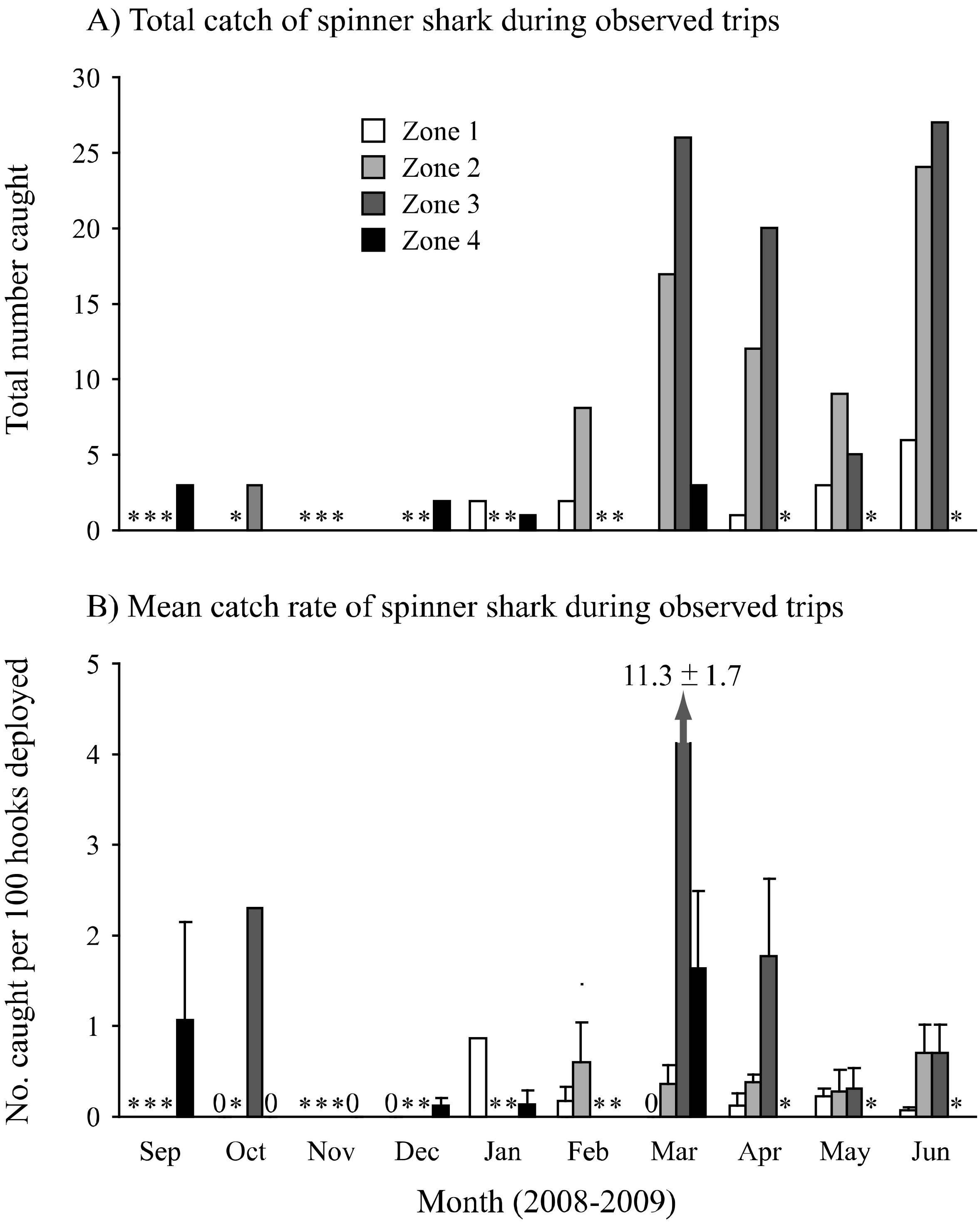

Figure 14. A) Total number caught, and B) mean catch rate (± se where appropriate), for spinner shark in Zones 1, 2, 3 and 4 during each month from September 2008 to June 2009. Catch rate expressed as the number of sharks per 100 hooks per setline deployment. Handline data are excluded. Refer to section 3.3 for sample sizes (*n*). 0, catch rate of zero. *, no fishing trips observed.

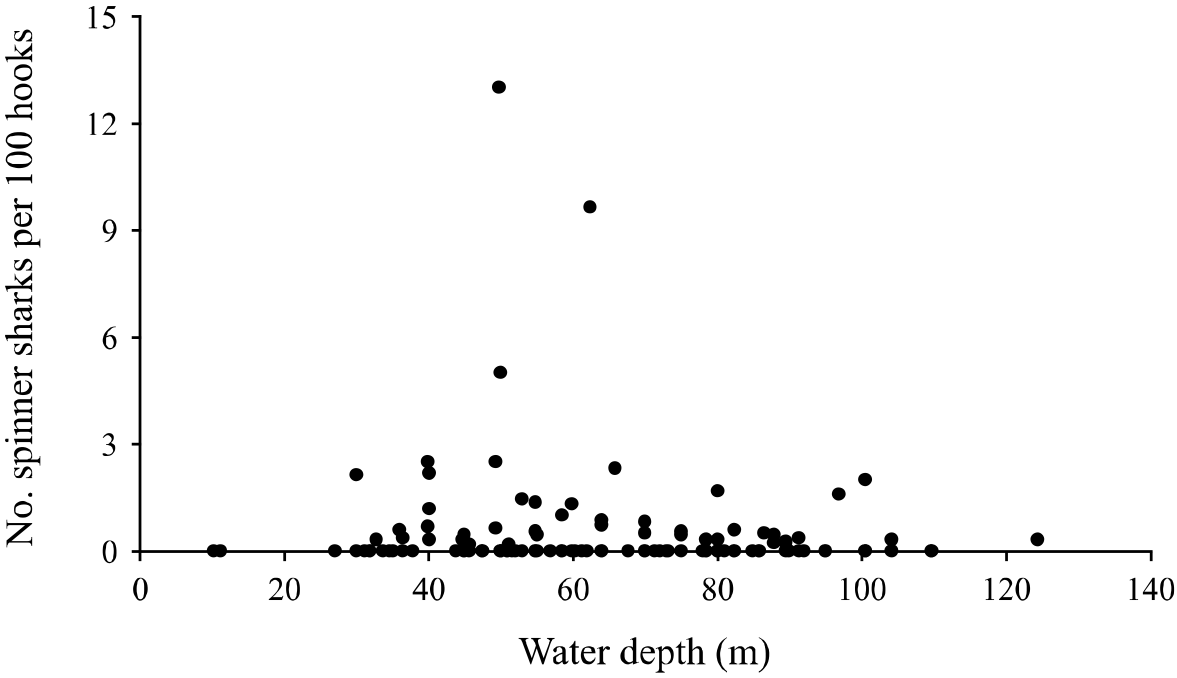

Figure 15. Plot of catch rate of spinner shark (number of sharks per 100 hooks) vs. mean water depth for setline deployments (*n* = 121).

Table 11. Summary of reproductive status data recorded for male (*n* = 60) and female (*n* = 79) spinner shark. Data concerning clasper length of males and uterus width of females are also presented (*n* = 40 and 48 respectively). Refer to Table 3 for definitions of clasper and uteri status categories.

TL (cm)	Male clasper status (%)			Range of clasper lengths (mm)	Female uteri status (%)			Instance of pups or yolky eggs in uteri	Range of uterus widths (mm)
	A	B	C		A	B	C – F		
80 – 160	100			18 – 40	100				1 – 3
165					100				2 – 4
170	50	50		45 – 78					
175	100			60	100				2 – 3
180	100			50	100				5
185	100			90			100		42
190	50	50		60 – 70	100				2 – 5
195	100			90	100				2 – 3
200					100				2 – 3
205									
210									
215					50	50			10 – 40
220			100						
225			100			100			40
230			100	180 – 245					
235			100	177 – 190			100		60
240			100						
245		14.3	85.7	167 – 270			100	Yes	50
250			100	162 – 270		25	75		70 – 140
255			100	255			100	Yes	47 – 100
260						20	80		40 – 70
265							100		80 – 210
270							100	Yes	100 – 108
275							100	Yes	60 – 160
280							100	Yes	90
285							100		110 – 230
290							100	Yes	
295									
300			100						

3.4.4. Common blacktip shark

Common blacktip sharks were caught along the full extent of the northern NSW coast during the sampling period (September 2008 to June 2009), and by both non-permit and sandbar-permit fishers (Figure 16), with a total observed catch of 104 sharks. The majority of these (98.1% by number, including the January handline catch) came from Zones 1, 2 and 3 between January and June (Figure 16A). It is important to note yet again, however, that it is possible that some of the sharks identified as common blacktip sharks may have actually been Australian blacktip sharks (Ovenden *et al.*, 2009). Pending genetic analyses of the relevant flesh samples will address the issue.

As was the case for spinner shark, there were some relatively large setline catches of common blacktip shark in March and April, although mean catch rates were generally < 0.5 sharks per 100 hooks per setline deployment (Figure 16B). There was no significant relationship between catch rate of common blacktip shark and depth of water in which fishing took place, for deployments that caught that species ($P > 0.45$, $n = 37$), although the three setline deployments that had the highest catch rates (i.e., 2 – 7 sharks per 100 hooks compared with < 1.4 for all other deployments) were done in water around 50 m deep.

The sizes of common blacktip sharks caught during this observer study ranged between 70- and 265-cm TL (Figure 11D). Most of the sharks < 130-cm TL were caught during the observed handlining trip, while all sharks larger than this were caught using setlines. Of 103 common blacktip sharks measured and sexed, 66.0% (i.e., 68 sharks) were male, giving an overall ratio of males to females of 1.94:1. Although a KS test was not done here owing to limited data, there did appear to be a difference in the size distributions between the sexes for sharks > 165-cm TL, with males comprising 80.7% of the sharks 165 – 234-cm TL and females comprising 66.7% of the sharks > 235-cm TL (Figure 11D). In the case of the smaller common blacktip sharks (i.e., < 165-cm TL) there was no clear difference in size distributions between the sexes (Figure 11D).

Data concerning the reproductive status of all but one of the common blacktip sharks observed were recorded, and these indicated that males up to around 185-cm TL were immature, while those > 205-cm TL were sexually mature; a finding supported by the clasper length data (Table 12). Therefore, it can be concluded that males in the population of common blacktip sharks that inhabit northern NSW waters mature at sizes between 185- and 205-cm TL.

Female common blacktip sharks of sizes < 209-cm TL were found to be immature, while most females 210-cm TL or larger were mature (Table 12). The smallest pregnant common blacktip shark encountered was 225-cm in TL. The uterus width data generally support this with widths not exceeding 10 mm up to 209-cm TL, and being > 40 mm for sharks 210-cm TL and larger (Table 12). Given this, it is reasonable to conclude that female common blacktip sharks inhabiting northern NSW waters mature at sizes somewhere between 200- and 215-cm TL.

The uteri of six female common blacktip sharks were found to contain yolky eggs (all caught in May and June), while the uteri of another caught in late-June contained nine pups ranging in size from 54- to 57-cm TL. One female, caught in June, was found to have enlarged and flaccid uteri typical of a female that has recently given birth.

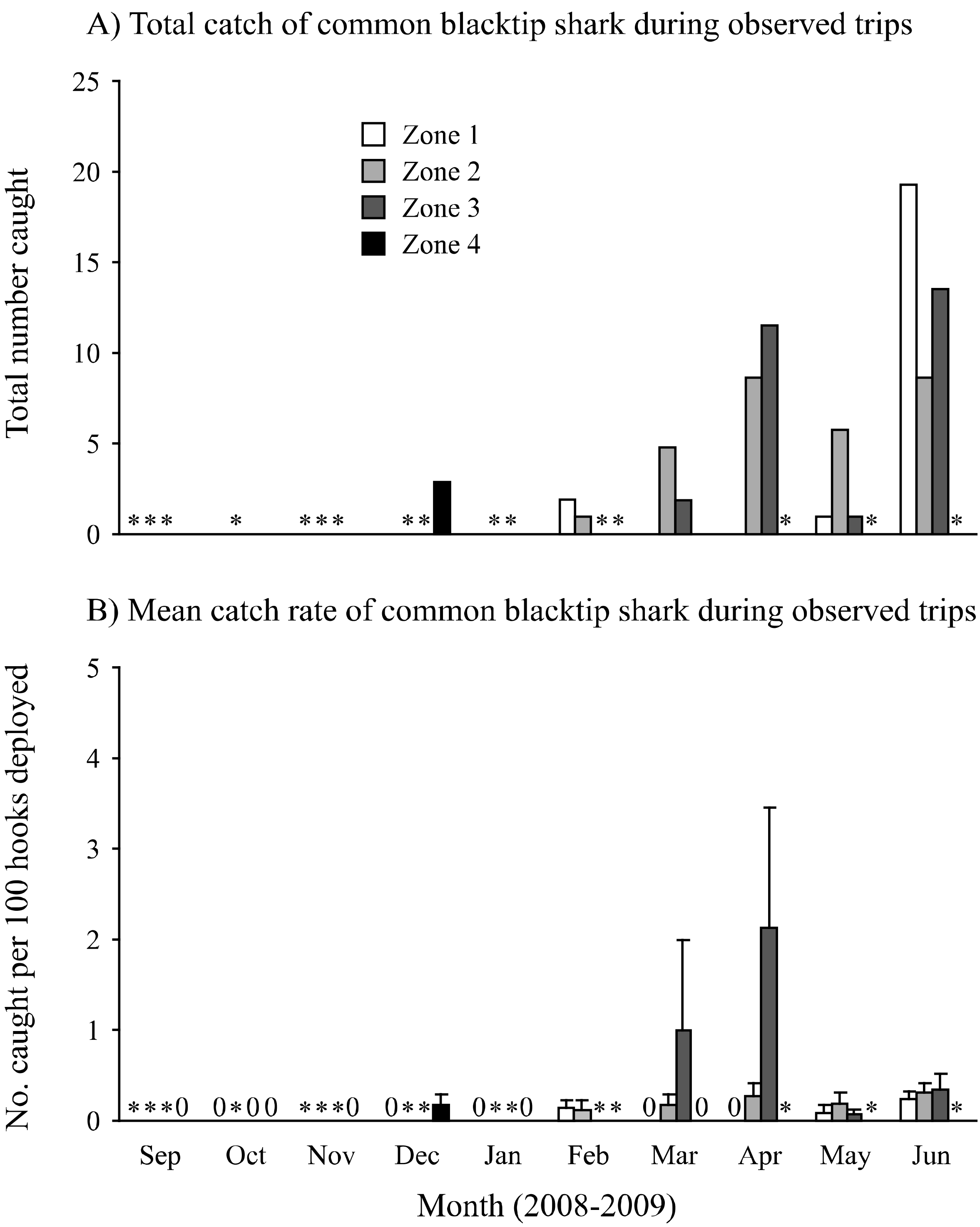

Figure 16. A) Total number caught, and B) mean catch rate (± se where appropriate), for common blacktip shark in Zones 1, 2, 3 and 4 during each month from September 2008 to June 2009. Catch rate expressed as the number of sharks per 100 hooks per setline deployment. Handline data are excluded. Refer to section 3.3 for sample sizes (*n*). 0, catch rate of zero. *, no fishing trips observed.

Table 12. Summary of reproductive status data recorded for male (*n* = 68) and female (*n* = 34) common blacktip shark. Data concerning clasper length of males and uterus width of females are also presented (*n* = 41 and 11 respectively). Refer to Table 3 for definitions of clasper and uteri status categories.

TL (cm)	Male clasper status (%)			Range of clasper lengths (mm)	Female uteri status (%)			Instance of pups or yolky eggs in uteri	Range of uterus widths (mm)
	A	B	C		A	B	C – F		
70 – 110	100			35	100				2
115									
120		100			100				2
125	50	50		60	100				
130									
135	100			35					
140									
145					100				3
150					100				3
155	100			50 – 60					
160									
165	100			45	100				2 – 3
170	75	25		50 – 77					
175	50	50		81 – 100	100				3
180	100			65					
185	100			60 – 75		100			
190	66.7		33.3	90 – 110	100				
195	20	40	40	110 – 235					
200		100		70					
205			100	133 – 185	100				10
210			100	133 – 175			100		
215			100	130 – 250			100		40
220			100	137 – 200					
225			100	160 – 178			100	Yes	
230	12.5		87.5	120 – 193			100	Yes	
235			100				100		175
240			100	130 – 145		25	75	Yes	60
245			100	210			100		
250			100	160 – 175			100	Yes	
255							100		
260							100	Yes	
265						100			

3.4.5. Other TACC shark species

The majority (93.8%) of the total catch of tiger sharks was from waters in Zones 1, 2 and 3 from January to June, including a few large catches (by number) of this species in Zone 3 during March and April (Figure 17A). With the exception of those large catches, mean catch rates for each Zone/month combination did not exceed 0.6 sharks per 100 hooks per setline deployment.

A total of 26 of the 97 tiger sharks were released alive immediately upon being brought to the side of the vessel so were not measured using equipment nor sexed, explaining most of the shortfall in TL measurements for this species evident in Figure 18A compared with the numbers observed. Rough estimates of TL by observers regarding discards unable to be measured ranged between 100 and 200 cm, with a mean (± se) of 140.6 (± 6.1), meaning the frequency values for the larger range of sizes in Figure 18A are underestimated. Of the 66 tiger sharks for which sex was determined, 81.8% were smaller than 190-cm TL, while 31 were male (Figure 18A), providing an overall ratio of males to females of 0.89:1. There was no apparent difference in the size distributions between the sexes (Figure 18A). Preliminary interpretation of the limited reproductive data showed that the male tiger sharks smaller than around 210-cm TL and females < 260-cm TL were all immature, while males > 320-cm TL and females > 380-cm TL were all mature. No pregnant females were caught.

Smooth hammerheads were sporadically present in catches in Zone 4 during September to February and in Zones 1, 2 and 3 during February to June, although, given the large amount of fishing effort in Zone 1 (Table 8), few were caught in Zone 1 waters (Figure 17B). The mean catch rate of smooth hammerhead did not exceed 0.6 sharks per 100 hooks per setline deployment for any Zone/month combination. All bar one smooth hammerhead caught were smaller than 195-cm TL, while the overall ratio of males to females was 0.86:1, with no clear difference in the size distributions between the sexes (Figure 18B). All individuals < 195-cm TL were immature, while the 235-cm TL female was found to be mature.

The small catches of scalloped hammerheads in Zones 1, 2 and 3 were more-or-less proportional to the amount of fishing effort in these Zones during the months of January to June, while none were caught in Zone 4 (Figure 17C). The mean catch rate of scalloped hammerhead did not exceed 0.8 sharks per 100 hooks per setline deployment for any Zone/month combination. Five of the scalloped hammerheads had been partially eaten upon retrieval (presumably by sharks), which explains the disparity between numbers caught and numbers measured and sexed (Figures 17C and 18C). The sizes of scalloped hammerheads caught ranged between 125- and 299-cm TL (Figure 18C). While the overall ratio of males to females was 1.18:1, males comprised 40% of the smaller sharks (< 210-cm TL) and 92.3% of the larger sharks (> 230-cm TL) (Figure 18C). Reproductive data indicated that with the exception of a single mature 205-cm TL male, the males and females < 210-cm TL were all immature, suggesting that the males may mature at around 200-cm TL. All of the scalloped hammerheads > 230-cm TL were mature, so it can be concluded that the females mature between 195- and 260-cm TL. One mature female, which was caught in Zone 1 in May, was found to have yolky eggs in her uteri.

Most (87.0%) of the 23 bronze whalers were recorded from Zone 4 (Figure 17D), with the mean catch rate (± se) of bronze whaler in Zone 4 at its highest in September (1.34 ± 0.09 sharks per 100 hooks per setline deployment) and October (1.59 ± 0.85). Mean catch rates then successively decreased to lower levels in November (0.52 ± 0.27), December (0.43 ± 0.43) and January (0.31 ± 0.16). One bronze whaler was caught in each of Zones 1, 2 and 3 during June (Figure 17D). With the exception of a 176-cm TL shark, all bronze whalers observed ranged in size between 220- and 299-cm TL, and all but four individuals were male (Figure 18D), giving an overall ratio of males to females of 4.75:1. The sparse reproductive data collected indicated that the males between 220- and 250-cm TL were either maturing or mature, with males > 250-cm TL all sexually mature. The reproductive data for the four females did not allow size at maturity to be estimated.

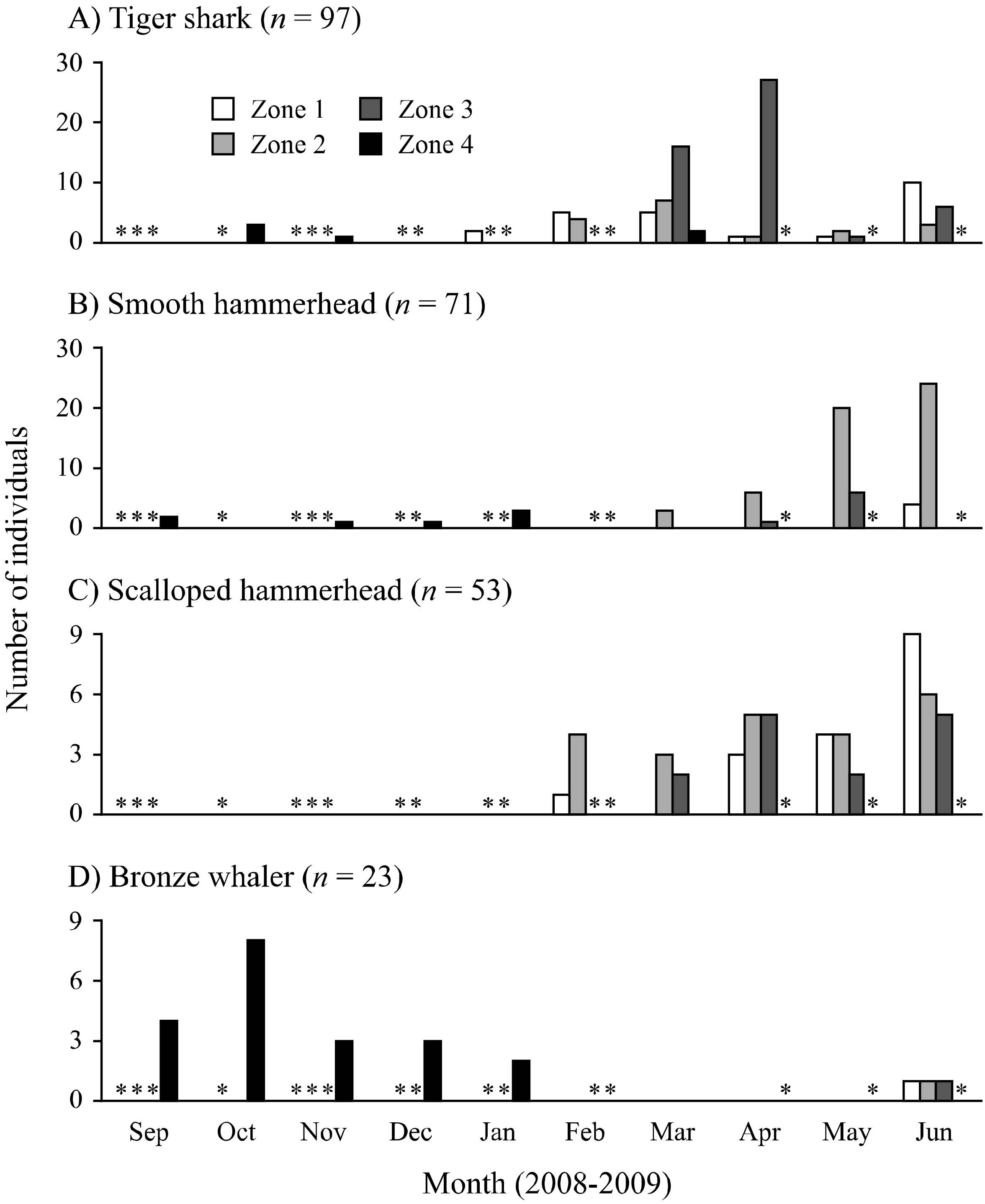

Figure 17. Total number of A) tiger sharks, B) smooth hammerheads, C) scalloped hammerheads, and D) bronze whalers caught in Zones 1, 2, 3 and 4 during each month from September 2008 to June 2009. Refer to section 3.3 for number of line deployments per Zone/month combination. *, no setline trips observed.

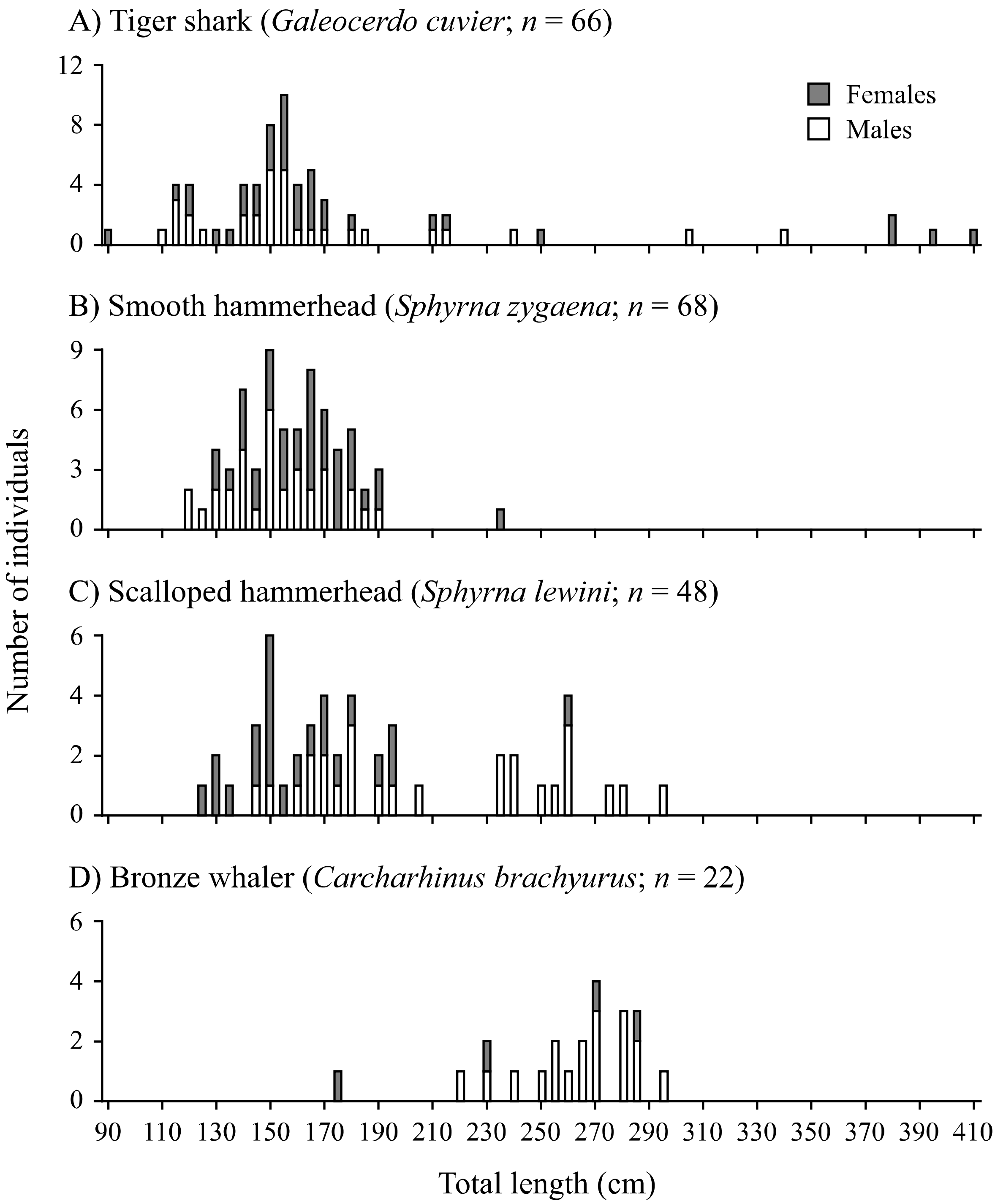

Figure 18. Length-frequency histograms of catches of A) tiger sharks, B) smooth hammerheads, C) scalloped hammerheads, and D) bronze whalers, combined across all shark-fishing trips observed during this study. Data are consolidated into 5-cm length (TL) classes (e.g., length class 200 = 200 – 204-cm TL), with each partitioned into males and females.

Despite the large amount of fishing effort in the northern Zones between February and June, most of the shortfin makos recorded were caught in Zone 4 during September to December 2008. Of 16 shortfin makos observed, 11 were males ranging between 95- and 185-cm TL, and the remainder were females ranging between 105- and 232-cm TL. All were classified as immature.

Bull sharks were caught in Zones 2 and 3 during April and Zone 2 during June, with most (i.e., 8 of 10 sharks) being female. The four caught in Zone 3 ranged between 240- and 300-cm TL (one 240-cm TL male and three females > 248-cm TL) and were all mature. The remainder, caught in Zone 2, ranged between 94- and 261-cm TL and included two immature females < 110-cm TL and three mature females > 193-cm TL.

All of the great hammerheads recorded, which were mostly male (7 of 9 sharks) and ranged in size between 190- and 350-cm TL, were caught in Zones 1 and 2 from April through June. Males < 220-cm TL were immature, while those > 252-cm TL were mature. Yolky eggs were found in the 326-cm TL female, while no reproductive data were recorded for the other, 252-cm TL female.

Six silky sharks were recorded in Zones 2 and 3 between March and May. Of the two males, one was 195-cm TL and maturing (i.e., clasper status B), while the other was 212-cm TL and mature. There were two immature females of 89- and 196-cm TL, while the 223- and 250-cm TL females were mature.

The bignose shark recorded was a 237-cm TL, mature male caught in Zone 3 in May, and appeared to be in particularly poor condition. The Australian blacktip shark was caught on a drumline in Zone 1 in October 2008, and was a 250-cm TL male.

3.5. Hooking location (mouth/throat/gut/body)

The majority of sharks for which hooking location was recorded were mouth-hooked (Table 13). Three species were primarily gut-hooked: spotted wobbegong (79.2% gut-hooked; *n* = 24); banded wobbegong (86.7%; *n* = 15); and shortfin mako (66.7%; *n* = 9). One of the grey nurse sharks observed appeared to be gut-hooked upon capture, and was released alive with the hook left *in situ*.

3.6. Condition of organisms upon capture

The duration of time that setlines were fished (i.e., soak duration) was variable, ranging between approximately 7 and 27 hours. For the purpose of comparison, each of the setline deployments for which the start- and finish-time for both deployment and retrieval were recorded were categorised into one of three soak-duration distinctions: 7 – 12 (*n* = 29 setline deployments), 12 – 15 (*n* = 37), and 15 – 27 hours (*n* = 36). However, the results outlined below must be considered with caution as the range of soak durations among hooks within a setline deployment is inherently greater the longer the gear is soaking owing to the different speeds at which the line is deployed and retrieved, and the dependency of the latter speed on the numbers of sharks being caught. The single soak-duration value allocated to the setline deployments included here was derived by calculating the duration between start times, and between finish times, and obtaining the mean of these two time intervals.

3.6.1. Targeted whaler and hammerhead shark species

For setline deployments where the condition of organisms upon capture was recorded, most of the top eight TACC shark species exhibited high levels of mortality upon retrieval of the setline, irrespective of soak duration (Figure 19). However, two species – sandbar and tiger shark – displayed relatively lower levels of mortality. Sandbar sharks displayed a pattern of increasing mortality with increasing soak duration, while the mortality of tiger sharks was relatively low, irrespective of soak duration. These observations suggest that these two species might be relatively hardy compared with other whalers and hammerheads with respect to surviving extended periods of time hooked on a setline.

3.6.2. Discarded non-target organisms

For setline deployments where the condition of organisms upon capture was recorded, of all of the non-target organisms discarded (95 individuals in total), 88.4% were alive at the time of retrieval to the vessel and upon subsequent release. The apparently dead non-target discards comprised seven banded wobbegongs, a moray eel, a gummy shark, a spotted wobbegong and a banded rockcod. As mentioned previously, all of the threatened and/or protected species caught – grey nurse shark (5 in total), great white shark (6 in total) and green turtle (2 in total) – were alive and active upon capture, and anecdotal accounts from observers indicated that they all swam down and away from the vessel upon release.

Table 13. Tally of hooking location (M – mouth or jaw; G – gut; others were either throat- or foul-hooked) for all individuals for which this variable was recorded (*n*). Data are for: A) the targeted TACC shark species; and B) other species recorded.

Common name	***n***	**M**	**G**	**Common name**	***n***	**M**	**G**
A) TACC shark species							
Sandbar shark	559	551	3	Bronze whaler	11	9	1
Dusky whaler	240	235	1	Bull shark	10	10	0
Spinner shark	167	163	2	Great hammerhead	10	10	0
Tiger shark	93	86	3	Shortfin mako	9	2	6
Common blacktip shark	85	81	1	Silky shark	6	5	1
Smooth hammerhead	69	67	0	Bignose shark	1	0	0
Scalloped hammerhead	53	50	0				
B) Other species							
Stingrays (combined)	41	39	1	Eastern fiddler ray	4	4	0
Spotted wobbegong	24	3	19	Grey nurse shark	4	3	1
Banded wobbegong	15	2	13	Snapper	4	4	0
Gummy shark	14	14	0	Green turtle	2	2	0
Cobia	9	9	0	Bigeye sixgill shark	1	1	0
Blue catfish	8	8	0	Blind shark	1	1	0
Port Jackson shark	6	6	0	Unid. dogfish	1	1	0
Great white shark	5	5	0	Unid. moray eel	1	1	0
White-spotted guitarfish	5	5	0	Pearl perch	1	1	0
Banded rockcod	4	4	0	Yellowtail kingfish	1	1	0
Bluespotted flathead	4	4	0	Zebra shark	1	1	0

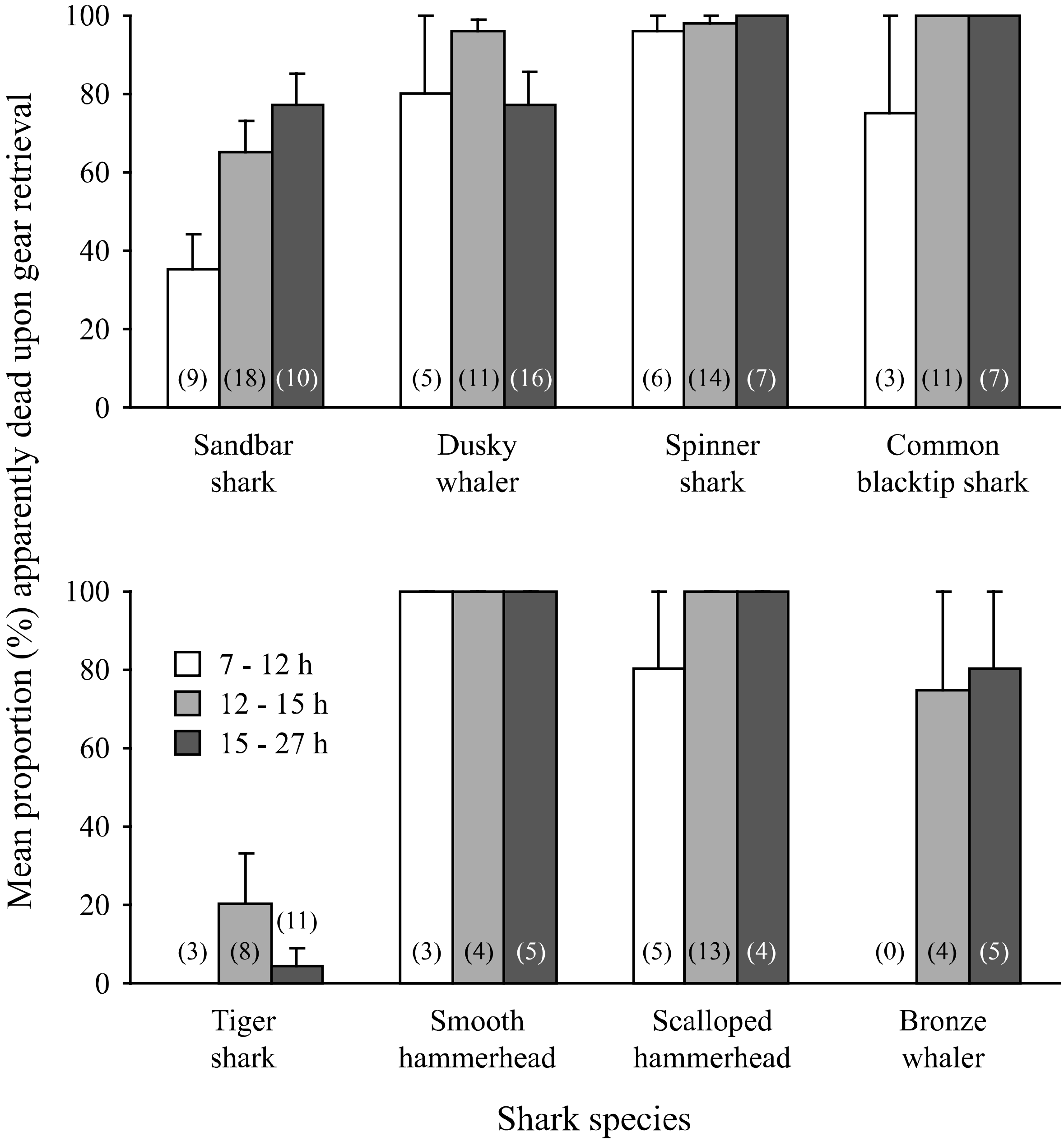

Figure 19. Mean proportion of sharks apparently dead upon retrieval of fishing gear (± se where appropriate) for setlines soaked for a median duration of: between 7 and 12 hours; between 12 and 15 hours; and between 15 and 27 hours. Data are for the top eight TACC shark species caught overall (by number). Figures in parentheses are the number of deployments (*n*) for which that species was caught, and the start and finish times of deployment and retrieval were recorded.

4. DISCUSSION

4.1. Value of observer-based research

Whether done intensively in a short-term fashion such as for this study, or done to a strict, representative monitoring design over longer-term timeframes, observer-based, scientific sampling of catches is arguably the most reliable source of data regarding commercial fishing activities (including recreational charter-boat fishing) (McVea and Kennelly, 2007). When implemented effectively, such approaches minimise the potential biases, limitations and shortcomings associated with the compilation and interpretation of data via fisher-dependent catch reporting – an advantage that can be worth the initial and ongoing investment by both the fishing industry and government.

The effectiveness of observer-based research strategies can be severely limited if co-operation of the commercial operators is on a voluntary basis only. This was demonstrated during this study by the disparity in extent of information gained about commercial shark fishing during the September to January period within NSW fishery management Zones 1 – 3 (1.1% observer coverage for active fishers) and Zone 4 (50% observer coverage for active fishers), despite comparable levels of reported fishing effort when the difference in available fishing area is considered (90 and 34 fisher days respectively). To maximise the value of observer-based research, a legislative framework associated with licensing of commercial fishing operations providing fisheries scientists with a mandate to conduct observer research on any vessel at any time, such as that imposed via the sandbar shark permit during 2008/09, would clearly be of great benefit. Such progress in NSW would require collaboration among: 1) I&I NSW in providing suitably trained and equipped observers; 2) commercial fishers and their insurers in accepting the concept of compulsory hosting of observers (when requested); and 3) NSW Maritime in providing an avenue for trained and equipped observers to do their job while satisfying marine safety guidelines. There would, of course, be some logical exceptions to compulsory hosting of observers, such as in the case of very small commercial fishing vessels with prohibitively limited deck space (Baremore, 2007; Vestre, 2007). Most operators of commercial fishing vessels in NSW do, however, have the capability to make arrangements that would allow an observer onboard without too much disruption to fishing activities.

Many fisheries around the world – primarily (but not exclusively) associated with fully developed countries including Canada, U.S. and New Zealand – already have some form of compulsory observer arrangement in place, although the purposes of these are usually not only for scientific assessment of stocks or bycatches, but also to ensure strict compliance to fishery regulations (McVea and Kennelly, 2007). Further, some fisheries systematically achieve 100% observer coverage for all or a specifically defined part of the fishery via a ‘no observer – no fishing trip’ policy (e.g., North Pacific U.S. groundfish fisheries – Loefflad *et al.*, 2007; British Columbian groundfish trawl fishery – Sinclair, 2007; Namibian fisheries in south-eastern Atlantic waters – Voges and Kruger, 2007; south-eastern U.S. shark fisheries – Bethae and Baremore, 2007; NOAA, 2009a). In contrast, levels of observer coverage in fisheries in the European Union that are accepted locally are suitably achieved via a voluntary system, although currently there are plans to change to mandatory coverage (Borges, 2007). While the relative merits of voluntary vs. compulsory observer programs and limited vs. extensive levels of observer coverage are constantly being debated among the world’s commercial fishers, fisheries managers and scientists (e.g., Borges, 2007; Buston, 2007; Carlson *et al.*, 2007; Erikson, 2007; Loefflad *et al.*, 2007; Sinclair, 2007), it is clear that the most useful strategy for any given fishery should be determined on a case-by-case basis according to considerations such as: total value of the fishery; number and type of vessels; extent of interactions with protected and/or non-target species; and source and availability of funding.

The most useful and practical strategy with respect to initial observer-based data collection in low-value fisheries comprising a fishing fleet of relatively few vessels, such as the large shark fishery examined in this study, is to begin with the 'snap-shot' approach (Begg *et al.*, 2007). In principle, this involves sampling catches from as large a subset of the fleet as possible over a period of one or two years to establish a reliable set of 'baseline' data, against which any future, relatively less intensive observer-based data collection done as part of ongoing fishery monitoring can be compared.

Although the current study serves as an initial snap-shot of the fishery for large sharks in northern NSW waters, ideally a second full year of intensive observer work covering all NSW coastal waters and involving mandatory hosting of observers should be done to: 1) investigate the year-to-year variability of catches in northern NSW waters; 2) quantify targeted catches of these sharks in central and southern NSW waters; and ultimately 3) consolidate and enhance a nominal 'baseline' data set concerning this targeted shark fishery for future reference. Once these nominal baseline catch levels are defined, the next major step in data collection will be to design and implement a less intensive and ongoing onboard catch monitoring program using observers or, alternatively, some sort of co-ordinated electronic monitoring (EM) system involving onboard video cameras and a vessel monitoring system (VMS – i.e., satellite tracking). The EM approach has been developed for a number of fisheries around the world (e.g., British Columbian trap and line fisheries – McElderry, 2007; north-western U.S. trawl fishery – Cusick and McElderry, 2007), with the technologies involved becoming less expensive and more reliable through time. Ultimately, however, it will be the progressive attitude of commercial fishers with respect to the changing levels of responsibility and accountability required from both fishers and fisheries managers now and in the future that will be the key to making the necessary progress in this area (Erikson, 2007).

4.2. General overview of the targeted shark fishery of northern NSW

This observer study has demonstrated that the targeted shark fishery of northern NSW is a multi-species fishery employing a number of types of fishing gear to catch a range of species of Carcharhinid (whaler), Sphyrnid (hammerhead) and Lamnid (mako) shark. It is important to note, however, that the results of, and therefore conclusions from this study should be restricted to the spatial and temporal extent of observer coverage achieved. This is particularly important given the current state of flux associated with the planning of future management arrangements governing commercial shark fishing in NSW.

The composition of observed catches differed according to latitude and time of year, although within the northern NSW study area there still remains latitudes and times of year for which no reliable assessment of catches can be made owing to: 1) a lack of observer coverage where fishing effort was occurring due to lack of fisher cooperation or observer availability (i.e., in Zones 1, 2 and 3 during September 2008 to January 2009); 2) fishery management arrangements preventing targeted shark fishing (i.e., in Zone 4 from February to July 2009); and 3) the ten-month period of the study (i.e., excluding information about catches in the months of July and August 2008). As previously stated, further observer work in the NSW large shark fishery is required during coming years to address those shortcomings in reliable catch information.

In waters north of around Coffs Harbour (i.e., within Zones 1 to 3) the main target species from late-January to June was sandbar shark, with this species by far the most numerically dominant in the overall catch for that spatial/temporal profile, comprising almost 45% of all TACC sharks caught. Considerable quantities of spinner shark and dusky whaler were also caught and retained, while tiger shark, common blacktip shark and scalloped hammerhead were also present in catches and retained, although many of the tiger sharks were released alive. It must be noted, however, that an unknown proportion of the sharks identified as common blacktip sharks may have actually been Australian blacktip sharks, as the two species are morphologically very similar and a southern range for the latter has not been reliably determined using genetic techniques as of yet (Ovenden *et al.*, 2009). The majority of fishing effort for, and overall catch of, TACC species for this spatial/temporal profile was in the two northern-most Zones (i.e., Zones 1 and 2). In contrast, catches from within Zones 1 to 3 during the period September through to mid-January (inclusive) as reported by fishers as part of their mandatory catch reporting requirements (but not observed for this study) indicated that the main species caught during those months were common blacktip shark and bronze whaler, with considerably fewer spinner shark and dusky whaler caught, and sandbar shark a relatively minor component of the overall catch. However, given that: 1) only one of those trips was observed; and 2) there is historical evidence that spinner sharks and dusky whalers have been misidentified as 'blacktip shark' and 'bronze whaler' respectively; the reliability of these data is questionable.

The main target species south of around Coffs Harbour during September to February were dusky and bronze whaler, although some spinner shark, tiger shark, common blacktip shark, smooth hammerhead and shortfin mako were also caught. It should be noted, however, that this species composition might have been different for the period February to June had targeted shark fishing (and therefore observer sampling) taken place. Anecdotal evidence from past years has suggested that sandbar shark was sometimes caught in these waters during those months, but not in any substantial quantity. Therefore, in the case of these more southern waters, sandbar shark could not be considered a primary target species *per se*.

The quantities of unwanted bycatch (by number) from targeted shark fishing in northern NSW waters observed during this study were low in comparison with those reported for other types of fishing, such as trawling, done in oceanic waters off northern NSW (Andrew and Pepperell, 1992; Kennelly *et al.*, 1998; Macbeth *et al.*, 2008). Similarly, the ratio of bycatch to retained catch (by number) for each of the two main groupings of observed trips (i.e., Zone 4 during September to January – 0.5:1, and Zones 1 – 3 during February to June – 0.044:1) was low compared with those apparent for many ocean trawl fisheries (Andrew and Pepperell, 1992; Kennelly *et al.*, 1998; Liggins, 2001; Macbeth *et al.*, 2008). Further, the discarded animals were, in the vast majority of cases, alive upon capture and subsequent release.

In the cases of threatened and/or protected species, such as grey nurse shark, great white shark, marine mammals, reptiles and birds, interactions with targeted shark fishing in northern NSW waters were infrequent during the fishing operations observed. Further, in all cases where an interaction was observed, the interaction was not fatal to the individual involved – at least prior to their release back into their environment. There is, of course, no guarantee that the released grey nurse sharks, great white sharks and green turtles did not eventually die as a direct or indirect result of the interaction some time after release. The question of post-release survivorship of discards from commercial fishing activities is one that has recently been addressed for a number of NSW commercial and recreational fisheries by I&I NSW researchers (Broadhurst *et al.*, 2005; Uhlmann and Broadhurst, 2007; Broadhurst, 2008; Broadhurst *et al.*, 2008; Butcher *et al.*, 2008a, 2008b; Hall *et al.*, 2009; McGrath *et al.*, 2009), although commercial setlining (i.e., longlining) has not yet been studied.

Investigations into post-release survival of shark and fish discards in some other longline fisheries suggest that the rates of survival for live discards is likely to be quite high (i.e., around 70% or greater – Neilson *et al.*, 1989; Kaimmer and Trumble, 1998; Kerstetter *et al.*, 2003; Skomal, 2007; Campana *et al.*, 2009). These studies showed that in the cases of sharks and fish of sizes typical of longline catches, two of the main factors influencing survivorship of live discards were the extent of physical stress, injury and trauma sustained during capture and release (e.g., from gaffing and rough hook extraction) and hooking location (i.e., greater mortality rates for gut-hooked than for mouth-hooked fish). For example, Campana *et al.* (2009) fitted 40 blue sharks, discarded live following capture by commercial pelagic longline in the far-north Atlantic Ocean, with satellite pop-up archival transmission (PAT) tags (up to 6-months transmission) to assess their rates of post-release mortality. None of the 10 mouth-hooked but otherwise uninjured sharks died before the PAT tag released itself weeks or months later, while 3 of 8 gut-hooked sharks (presumably with hook left *in situ*) died before the PAT tag was released. The proportion of sharks mouth-hooked and injured in some other way that died was also around a third (Campana *et al.*, 2009). Although the sample sizes were small and the reliability of the methodology debatable (Chaloupka *et al.*, 2004), those results nevertheless provide an indication of what the potential rates of post-release mortality of live discards in the northern NSW shark fishery might be. Given that the observed rate of gut hooking for most discard species in the northern NSW fishery during this study was quite low (with the notable exception of wobbegongs), it can be reasonably suggested that the overall post-release mortality of discards in the fishery might also be low, particularly in comparison with other oceanic fisheries such as those involving trawling (Macbeth *et al.*, 2008). Further research to investigate the rates of mortality associated with post-release discards using the technologies mentioned above would be of benefit, particularly in the cases of threatened and/or protected species that are sometimes encountered, such as grey nurse and great white shark.

4.3. Comparisons with other shark fisheries

Industrial and artisanal shark fisheries are responsible for the bulk of reported shark landings worldwide (Bonfil, 1996). Many of these shark fisheries are comparable to the targeted shark fishing in northern NSW waters examined during the current study with respect to the fishing strategies used, the target species, or both. Of equal note, however, is the fact that other shark-fishing practices that have generated considerable concern are not directly comparable to the NSW fishery owing to almost mutual exclusivity in the species caught and/or habitats being fished.

4.3.1. Catch composition

The observed catch composition of the northern NSW targeted whaler shark fishery was similar to those reported for a number of targeted shark fisheries. For example, the demersal longline fishery in south-eastern U.S. coastal waters of the Atlantic Ocean and Gulf of Mexico targets sandbar, common blacktip, spinner, bull, silky and tiger shark, while Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) are also caught and retained, along with hammerhead species (Musick *et al.*, 1993; Heist and Gold, 1999; Brewster-Geisz and Miller, 2000; Carlson and Baremore, 2003; Conrath and Musick, 2008; NOAA, 2009; Doughtie, 2009). There is also a large Mexican targeted shark fishery that operates in the southern waters of the Gulf of Mexico and Caribbean Sea, with the type of vessel and specific gears used (predominantly longlines and gillnets) varying regionally (Bonfil, 1997). The main target species include six whaler species (silky, bull, common blacktip, sandbar and milk shark, and dusky whaler), three hammerhead species (scalloped and great hammerhead, and bonnethead – *Sphyrna tiburo*), and dusky smooth-hound (*Mustelus canis* – similar to gummy shark) (Bonfil, 1997). A Taiwanese commercial shark fishery in the East China Sea lists sandbar and spinner shark as the predominant species caught and retained (Joung and Chen, 1995), while Madagascar also has active industrial, artisanal and traditional fisheries targeting hammerhead and whaler sharks using surface-set longlines and bottom-set gillnets (McVean *et al.*, 2006). Catches in those fisheries are dominated by scalloped and smooth hammerhead, with tiger shark, sandbar shark, bronze whaler, bull shark, silky shark, grey reef shark (*Carcharhinus amblyrhynchos*) and silvertip shark (*Carcharhinus albimarginatus*) comprising the remainder of the reported catch (McVean *et al.*, 2006).

The Sultanate of Oman has a long established traditional shark fishery involving artisanal fishermen deploying bottom-set longlines (setlines), bottom-set gillnets and driftnets (Henderson *et al.*, 2007). Landings from the Omani shark fishery are dominated by eight species – spot-tail shark (*Carcharhinus sorrah*), common blacktip shark, silky shark, hardnose shark (*C. macloti*), milk shark (*Rhizoprionodon acutus*), bigeye houndshark (*Iago omanensis*), sliteye shark (*Loxodon macrorhinus*) and scalloped hammerhead (Henderson *et al.*, 2007). Shark fishing is also one of the major secondary fishing activities in the Maldives, with the main methods employed including bottom-set gillnet, setline, driftline, dropline and handline (Anderson and Ahmed, 1993). The fishery targets tiger shark, silvertip shark (*C. albimarginatus*), bignose shark, grey reef shark (*C. amblyrhynchos*), silky shark, oceanic whitetip shark, spot-tail shark and blacktip reef shark (*C. melanopterus*) (Anderson and Ahmed, 1993).

The waters off the south-western coast of Western Australia (WA) support a demersal gillnet fishery that targets small, juvenile dusky whaler (i.e., < 135-cm FL), adult whiskery shark (*Furgaleus macki*) and gummy shark (Lenanton *et al.*, 1990; Simpfendorfer and Unsworth, 1998; Simpfendorfer, 1999). This is in contrast to the NSW setline fishery, which catches mostly large dusky whalers of sizes > 260-cm TL. A targeted shark setline fishery also operates in the same general region, with landings dominated by sandbar shark, although that stock of sandbar sharks is certainly separate from the population being exploited in waters off eastern Australia (McAuley *et al.*, 2005; 2006).

Closer to NSW waters, whaler and hammerhead sharks are taken commercially in the inshore and offshore waters of Queensland using gillnets as part of the multi-species Queensland East Coast Inshore Fin Fish Fishery (Queensland DPI&F, 2006a). Shark catches have consisted predominantly of Australian blacktip shark, common blacktip shark, scalloped hammerhead, spot-tail shark, nervous shark (*C. cautus*), grey reef shark, hardnose shark, lemon shark and milk shark (Queensland DPI&F, 2007). It is interesting to note that apparently sandbar shark, dusky whaler and spinner shark have not been prominent components of those shark catches despite their presence in Queensland waters. This could be due to the different fishing methods used to catch whaler sharks in Queensland compared with NSW waters, or alternatively due to the patterns of distribution and abundance of these species in Queensland waters preventing effective commercial fishing for them, or a combination of these two factors. In any case, the only main species in the Queensland fishery that overlap with the main species caught in the NSW targeted whaler shark fishery are common blacktip shark, scalloped hammerhead, and possibly also Australian blacktip shark (Ovenden *et al.*, 2009). This has ramifications with respect to the effective management of both fisheries, as it is likely that for each of those species there is just the one stock being exploited by both states. Genetic analysis of biological samples from sharks of those species caught along the entire eastern Australian coast will be required to address this question, and then management strategies devised collaboratively by the NSW and Queensland fisheries management agencies will be needed to ensure the stocks are not being overfished.

Possibly the highest profile fishing activity from a shark-conservation perspective is pelagic longlining, although there is only minor overlap between the main shark species caught in pelagic longline fisheries and the northern NSW demersal whaler shark fishery. The capture and subsequent retention of large oceanic sharks such as blue shark, shortfin mako and porbeagle in pelagic longline fisheries primarily targeting billfish and tuna has historically been extensively practiced by multi-national commercial fishing fleets operating in the North Atlantic and Pacific oceans (Holts *et al.*, 1998; Hurley, 1998; Matsunaga and Nakano, 1999; Francis *et al.*, 2001; Mejuto *et al.*, 2002; Heessen, 2003; Aires-da-Silva *et al.*, 2008a). It has been estimated that this byproduct probably accounts for a significant proportion – possibly up to 50% – of the commercial catch of sharks worldwide (Bonfil, 1994). In fact, blue shark was recently shown to be the dominant species in the Hong Kong shark fin market via an analysis of molecular genetics and fin-trade records (Clarke *et al.*, 2006). There are also fisheries specifically targeting blue shark and other pelagic sharks, such as those in the north-west Atlantic Ocean (Hurley, 1998; Aires-da-Silva *et al.*, 2008b). The west coast of the U.S. has also historically supported a targeted pelagic shark fishery using drift nets and longlines, with the main species exploited being thresher shark (*Alopius vulpinus*), bigeye thresher (*A. supercilious*) and shortfin mako, and with blue shark caught mainly as byproduct (Hanan *et al.*, 1993; Holts *et al.*, 1998). Reported landings of these species combined steadily declined from 1,916 tonnes in 1980 to 382 tonnes in 1994 (Holts *et al.*, 1998).

Although the specific targeting of pelagic sharks such as blue shark and shortfin mako by Australian commercial fishers in Australian waters does not occur, those are the main species of large shark caught and often retained in the Eastern-Australian Tuna and Billfish Fishery (ETBF) – a pelagic longline fishery that operates in oceanic waters within the Australian Economic Exclusion Zone off NSW (and other eastern states), but to the east of the eastern-most extent of the northern NSW whaler shark fishery at any given latitude (Stevens and Wayte, 1999; Power and Peddemors, 2009). Those two species accounted for around 75% of the reported catch of sharks in the ETBF off NSW during the 2008/09 fiscal year, with substantially smaller numbers of bronze whaler, tiger shark and hammerhead also caught (Power and Peddemors, 2009). Most of the mako sharks were retained, while a large proportion of the blue sharks caught were discarded (Power and Peddemors, 2009). Given the clear differences in the: 1) habitats fished (i.e., demersal vs. pelagic); 2) latitudes/longitudes fished (i.e., spatially mutually exclusive); and 3) main shark species being caught by the northern NSW whaler shark fishery and the federally-managed ETBF, there is, arguably, no urgent need for a combined management arrangement for the two fisheries other than further co-operation with respect to monitoring of catches, providing those particular variables do not change.

4.3.2. Catch quantity and catch rate

Despite the similar species being targeted and/or caught in some of the abovementioned and other fisheries, in most cases their scale with respect to quantities being caught far exceed the 160-tonne annual TACC currently permitted in the NSW whaler shark fishery. Indonesia has the largest shark fishery in the world, with an estimated 58,000 tonnes of shark landed in 2003 alone (White, 2007). Sharks are caught in both a targeted fishery by means of tangle nets, longlines and demersal gillnets, and as byproduct in other fisheries (White, 2007). The most abundant whaler sharks caught by number were silky shark and spadenose shark (*Scoliodon laticaudus*), while the most abundant in terms of biomass were dusky whaler, silky shark and blue shark. Similarly, shark fishing is an important commercial enterprise in waters off India, with the average annual harvest of shark at around 34,000 tonnes (Hanfee, 1999), while Kroese and Sauer (1998) estimated a total combined reported shark catch of 39,000 tonnes from waters off the African continent during 1994. Average annual catch in the aforementioned Mexican shark fishery was estimated at 13,000 tonnes from 1983 to 1992, with an estimated 44 and 56% of the total catch of sharks being small (< 150 cm TL) and large (> 150 cm TL) individuals respectively (Bonfil, 1997), while for the Maldives fishery it was estimated at approximately 1,300 tonnes during the years 1979 to 1991 (Anderson and Ahmed, 1993).

The observed mean catch rates (per 100 hooks) of 'large sharks' (i.e., TACC species combined) in the northern NSW whaler shark fishery for non-permit (3.2 sharks in Zone 4 from September to February) and sandbar-permit shark fishing (4.6 sharks in Zones 1 – 3 from February to June) are comparable with that reported for the aforementioned south-eastern U.S. large shark fishery during 1983/84 (4.7 'large coastal sharks' per 100 hooks) ('Castro *et al.* in press' – referenced by Litherland, 2008). At its peak in 1989, the annual catch of large sharks in south-eastern U.S. fishery reached 4,600 tonnes ('dressed' weight – i.e., not whole but processed to some degree), but with the ever expanding fishing effort, the CPUE in the fishery was actually declining during the 1980s (Brewster-Geisz and Miller, 2000). In response to this apparent overfishing, and with catch rates of large coastal sharks (species combined) at relatively low levels of around 0.4 sharks per 100 hooks (1994/95), in 1994 an annual quota of 2,570 tonnes was set. However, with continued decline in CPUE between 1994 and 1996 under this arrangement, in 1997 'large coastal sharks' was, as a collective, declared overfished (Stone *et al.*, 1998) and the quota was further reduced to 1,285 tonnes (Brewster-Geisz and Miller, 2000). Since 1997 there have been significant changes to the management of that fishery, including: compulsory VMS; compulsory observers when requested; an annual quota of approximately 700 tonnes of large sharks; prohibition of the retention of dusky and bronze whaler; and restriction of annual catches of sandbar shark to a maximum of 90 tonnes to be caught only within a special permit 'research fishery' involving 100% observer coverage (NOAA, 2008; Doughtie, 2009).

In the south-eastern U.S. large shark fishery, between 400 and 700 tonnes (dressed weight) of sandbar shark was landed annually between 1992 and 2007 (NOAA, 2009), while more recently the aforementioned 90-tonne restricted quota has been implemented due to concerns over overfishing (NOAA, 2008). In comparison, the reported total catch of sandbar sharks in the targeted NSW fishery during 2008/09 (ten-month period September 2008 to June 2009) of approximately 20 tonnes (dressed weight) was small. Had the full TACC have been caught in the NSW fishery, a rough projection of total sandbar shark catch (during that ten-month period and under the prescribed management arrangement) of around 40 – 50 tonnes would still be well below the 90-tonne annual catch limit in the south-eastern U.S. fishery, and below the annual quantities of sandbar shark permitted to be caught in other comparable fisheries such as the Taiwanese fishery (170 tonnes – Joung *et al.*, 2005) and the WA targeted shark fisheries (around 400 tonnes in 2004 – McAuley *et al.*, 2006; 195 tonnes in 2005/06 – Fletcher and Santoro, 2007). Given that annual catches of sandbar shark from Queensland waters are unlikely to have exceeded 40 – 50 tonnes in recent years (Queensland DPI&F; 2006b), an estimated maximum overall catch of sandbar shark for eastern-Australian waters of 80 – 100 tonnes (dressed weight) might be appropriately conservative, although a comprehensive stock assessment is required to make such a judgement with any certainty. Until such analyses are done, close monitoring of catch rates would provide early indications of any depletion of the eastern-Australian sandbar shark population. The monthly catch rates of sandbar shark in the northern-most Zone off NSW (i.e., Zone 1; excluding January) of between 1.8 and 5.6 sharks per 100 hooks per setline deployment) appear to be at levels that indicate the sandbar shark population is of a size that would allow limited commercial exploitation, but catch rates must be monitored on an ongoing basis from now on.

During the 1990s, annual catches of juvenile dusky whaler in the WA targeted shark fisheries were estimated at 500 – 700 tonnes (whole weight; Simpfendorfer, 1999), but have more recently been estimated at 274 tonnes (whole weight; Fletcher and Santoro, 2007); both of which dwarf the reported catch of around 15 – 20 tonnes (dressed weight) in northern NSW waters during 2008/09 under the current TACC (around 25 – 30 tonnes if all 160-tonnes of TACC had have been caught). However, the area of the WA coastal waters being fished is substantially greater, so this comparison should not be considered simplistically. Further, it should be noted that the dusky whalers taken in NSW are large, sexually mature individuals and, when fished exclusively, the sustainable catch of large sharks from a given population will certainly be different from the sustainable catch of small juveniles. A detailed assessment of the WA dusky whaler fishery found that there would be a high probability that even quite low levels of fishing mortality (i.e., < 5% per year) associated with dusky whalers of sizes caught in the NSW fishery would lead to a steady decline in that population (McAuley *et al.*, 2005). It is also interesting to note that the taking of dusky and bronze whaler has been prohibited in the south-eastern U.S. large shark fishery for around 8 years due to concerns over the status of populations of those species in the region (NOAA, 2009). As with sandbar shark, a comprehensive, multijurisdictional stock assessment is required to determine the sustainable harvest of large dusky whaler from eastern Australian waters. In the meantime it will be important to try to ensure that the amount of dusky whaler permitted to be taken from NSW waters annually is not at a level that might result in systematic depletion of the local population.

Commercial catches of large sharks (species combined) from Queensland waters increased steadily from ~400 tonnes in 1988 to a peak of over 1,400 tonnes in 2003, after which annual catches decreased (Queensland DPI&F, 2006b), and are now capped at 600 tonnes per annum. It is important to the long-term viability of commercial shark fishing in eastern Australian waters that I&I NSW and Qld DPI&F work closely to develop collaborative and complementary management strategies for their respective fisheries. These strategies should include co-operative research into the biology of east-coast populations of the relevant whaler, hammerhead and mackerel sharks.

This will be particularly important in the cases of sandbar shark, dusky whaler, spinner shark, common blacktip shark and scalloped hammerhead, as these are species for which there is current or potential target fishing in both states.

Future management of commercial fishing for whaler sharks in NSW waters

At the time of writing, I&I NSW Commercial Fisheries Management was formulating a number of management options associated with targeted whaler shark fishing to formally present to industry representatives for consideration, and then implement next year. These options might include the continuation of a TACC; a restricted shark-fishing permit similar to the 'sandbar permit' with or without associated catch limits per permit; geographical partitioning of the TACC; and/or trip, weekly or monthly catch limits for each fisher. It must, however, be considered that with shorter temporal catch limits such as daily, trip or weekly, there is inherently greater potential for up-sizing (i.e., discarding small sharks to allow the retention of large ones) and dumping of excess sharks. Such unreported discarding may compromise the effective management of the TACC fishery owing to the high observed mortality of hooked whaler sharks.

Whichever options are ultimately adopted for the near future, it is important to realise that the sudden increase in exploitation of large sharks in northern NSW waters occurred only five years ago, and this increase has been reversed to a substantial extent within a few years of the increase via strict management regulations. In contrast, in the south-eastern U.S. large shark fishery relatively large quantities of large sharks were landed consistently for many years before problems with exploitation levels were identified and acted upon by fishery managers. Such comparisons do not necessarily serve to justify current or future management strategies employed by I&I NSW, but to make the point that the TACC restrictions on annual catches in NSW waters during 2008/09 were a solid platform to: 1) conduct much-needed observer-based research; and then 2) use the data and samples collected to formulate scientifically-defensible management strategies to protect shark stocks. So, in the short-term, it will be important to identify suitably precautionary levels of exploitation of large sharks – preferably on a species-specific basis – until detailed stock assessments have been done using the information collected as part of this and future observer-based studies. In the medium- to long-term, such an approach would place the NSW targeted whaler shark fishery in a favourable position with respect to identifying sustainable levels of exploitation of the species being targeted.

Prior to 2008/09 the quality and reliability of the data pertaining to catches of large sharks being reported in the OTL fishery relied upon a number of factors. The catch-reporting framework historically implemented for commercial fisheries required only broad-scale spatial and temporal resolution of catch information to broad areas and monthly summaries. Further, many fishers deferred the undesirable task of filling in and submitting catch returns, sometimes for considerable periods. Second, identification to species level was poor and not required by the catch return forms. For example, when not reported as 'Shark, Unspecified': dusky and bronze whalers were almost always reported as 'bronze whaler'; common blacktip and spinner sharks were almost always reported as 'blacktip whaler'; and sandbar sharks were often reported as 'Shark, unspecified Whaler'. Although it could be argued that this situation might not have been a major problem at the catch levels of whaler sharks (species combined) evident prior to 2004/05, the increase in catches after that time highlighted the importance of accurate, species-based catch reporting. The improved catch-reporting infrastructure described in section 1.3 represents a much-needed advancement for fisheries management in NSW. With the provision of the shark species identification guide, and further onboard instruction by scientific observers on the correct identification of shark species, it is hoped that the quality of catch-record data provided by fishers will be far more useful for stock assessment purposes.

With a conservative approach to managing the NSW TACC shark fishery, which would include: 1) a suitably precautionary TACC; 2) ongoing (albeit less intensive) onboard monitoring of catches via scientific observers; and 3) the improved fisher catch reporting system, the catch rates observed in the northern NSW shark fishery would, in theory, be carefully monitored, maintained, and even improved, while ensuring the stocks are not over-exploited. Nevertheless, formal stock assessment will be required for each of the main target species using catch and biological data derived from this study and future observer work to confirm or refute the ongoing sustainability of the current levels of catch of each of those species.

5. CONCLUSIONS AND RECOMMENDATIONS

On the basis of the above findings, the following conclusions and recommendations are made:

1. Observer-based research programs provide an effective strategy for collecting reliable catch and biological data pertaining to commercial fishing activities, although their effectiveness can be limited if co-operation of the commercial operators is on a voluntary basis only. Therefore, if possible, I&I NSW scientists should be provided with a mandate to conduct observer-based, onboard sampling of catches for research purposes, where such research is deemed necessary for the effective monitoring and management of stocks of aquatic and marine animals.

2. The main species observed as being caught in the targeted whaler shark fishery of northern NSW coastal waters were sandbar shark, dusky whaler, spinner shark, common blacktip shark and bronze whaler, while some tiger sharks, and scalloped and smooth hammerheads were also caught and retained. Most fishing effort occurred north of Coffs Harbour, where sandbar shark comprised over 40% of the shark catch (by number). Laboratory analysis of flesh samples from common blacktip sharks should be done to determine if any of those sharks were Australian blacktip sharks.

3. The information compiled for this research report has provided a considerable knowledge base regarding targeted shark fishing in northern NSW waters. This will greatly assist the imminent formulation of management strategies that ensure the stocks of whaler and hammerhead sharks are harvested sustainably in the future by the commercial fishers of NSW. Nonetheless, a second full year of intensive observer-based sampling, followed by less-intensive, observer-based monitoring of commercial catches in this fishery during subsequent years, will be of cumulative and ongoing benefit with respect to monitoring catch rates and, therefore, shark populations.

4. With the exception of common blacktip shark and possibly Australian blacktip shark, currently there appears to be little overlap in the main target species of the NSW and Queensland targeted whaler shark fisheries. This situation should, however, be carefully monitored over coming years in case of any changes to the species being targeted. In the meantime, fisheries researchers and managers from both states should determine what collaboration is necessary with respect to the appropriate management of shark stocks common to both fisheries.

5. Overall there were few interactions with threatened and/or protected marine species during the observed targeted shark-fishing trips. There were infrequent captures of grey nurse sharks, great white sharks and green turtles. Nonetheless, I&I NSW and industry should work together to investigate strategies to minimise the probability of such interactions.

6. Finally, it is recommended that I&I NSW develop collaborative research relationships with universities in NSW and elsewhere with a view to processing the large amount of biological samples and data collected during this project. Further research into the movements, migrations and rates of natural and fishing mortality via tagging studies would also greatly benefit the future management of targeted shark fishing in NSW waters.

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APPENDIX A: Mean catch rates (number caught per 100 hooks per setline deployment) (± se) for each species recorded in observed catches during the study. Data are for the two main groupings of observer trips: non-permit trips done in Zone 4 between September 2008 and January 2009 ('NP-set-Z4' – 24 setline deployments); and sandbar-permit trips done between January and June 2009 ('SP-set' – 95 setline deployments). Species are ordered according to: A) TACC species or B) otherwise; then Family; and then species or group. 'Unid.', unidentified.

Family (*Species or* Group*)*	**Standard common name**	**Mean catch rate ± se (i.e., per 100 hooks)** (*n* = total no. individuals observed)	
		NP-set-Z4 group	**SP-set group**
A) TACC SHARK SPECIES			
Carcharhinidae			
Carcharhinus altimus	Bignose shark	-	< 0.01 ± < 0.01 (*1*)
Carcharhinus brachyurus	Bronze whaler	0.71 ± 0.12 (*20*)	0.01 ± 0.01 (*3*)
Carcharhinus brevipinna	Spinner shark	0.16 ± 0.09 (*6*)	0.63 ± 0.18 (*165*)
Carcharhinus falciformis	Silky shark	-	0.01 ± 0.01 (*6*)
Carcharhinus leucas	Bull shark	-	0.05 ± 0.03 (*10*)
Carcharhinus limbatus	Common blacktip shark	0.07 ± 0.05 (*3*)	0.31 ± 0.09 (*82*)
Carcharhinus obscurus	Dusky whaler	1.44 ± 0.41 (*29*)	0.63 ± 0.10 (*219*)
Carcharhinus plumbeus	Sandbar shark	-	2.07 ± 0.31 (*569*)
Carcharhinus tilstoni	Australian blacktip shark	-	-
Galeocerdo cuvier	Tiger shark	0.16 ± 0.08 (*4*)	0.54 ± 0.18 (*93*)
Lamnidae			
Isurus oxyrinchus	Shortfin mako	0.44 ± 0.20 (*10*)	0.01 ± 0.01 (*3*)
Sphyrnidae			
Sphyrna lewini	Scalloped hammerhead	-	0.18 ± 0.04 (*53*)
Sphyrna mokarran	Great hammerhead	-	0.02 ± 0.01 (*9*)
Sphyrna zygaena	Smooth hammerhead	0.21 ± 0.09 (*7*)	0.16 ± 0.06 (*64*)
Total TACC sharks		3.16 ± 0.57 (*79*)	4.63 ± 0.52 (*1,277*)
B) NON-TACC SPECIES			
(ELASMOBRANCHES)			
Alopiidae			
Alopias vulpinus	Thresher shark	0.13 ± 0.11 (*4*)	-
Brachaeluridae			
Brachaelurus waddi	Blind shark	-	< 0.01 ± < 0.01 (*1*)
Dasyatidae			
Dasyatis brevicaudata	Smooth stingray	1.71 ± 0.81 (*58*)	0.05 ± 0.02 (*13*)
Dasyatis thetidis	Black stingray	-	0.04 ± 0.02 (*18*)
Unid. Dasyatid	Unid. stingray	-	0.01 ± < 0.01 (*3*)
Heterodontidae			
Heterodontus portusjacksoni	Port Jackson shark	0.37 ± 0.24 (*15*)	< 0.01 ± < 0.01 (*1*)
Hexanchidae			
Hexanchus nakamurai	Bigeye sixgill shark	-	< 0.01 ± < 0.01 (*1*)
Hypnidae			
Hypnos monopterygium	Coffin ray	-	< 0.01 ± < 0.01 (*1*)
Lamnidae			
Carcharodon carcharias	Great white shark	0.03 ± 0.03 (*1*)	0.01 ± 0.01 (*5*)

Family (*Species or* Group)	**Standard common name**	**Mean catch rate ± se (i.e., per 100 hooks)** (*n* = total no. individuals observed) NP-set-Z4 group	SP-set group
Mobulidae			
Unid. Mobulid	Unid. devilray	-	< 0.01 ± < 0.01 (*1*)
Myliobatidae			
Unid. Myliobatid	Unid. eagle ray	-	< 0.01 ± < 0.01 (*2*)
Odontaspididae			
Carcharias taurus	Grey nurse shark	0.20 ± 0.12 (*5*)	-
Orectolobidae			
Orectolobus halei	Banded wobbegong	0.03 ± 0.03 (*1*)	0.06 ± 0.03 (*14*)
Orectolobus maculatus	Spotted wobbegong	0.48 ± 0.26 (*10*)	0.03 ± 0.1 (*16*)
Rhinobatidae			
Trygonorrhina sp.	Eastern fiddler ray	0.08 ± 0.04 (*3*)	0.01 ± 0.01 (*2*)
Unid. Rhinobatid	Unid. shovelnose ray	0.03 ± 0.03 (*1*)	-
Rhynchobatidae			
Rhynchobatus djiddensis	White-spotted guitarfish	-	0.01 ± 0.01 (*5*)
Squalidae			
Unid. Squalid	Unid. dogfish	-	< 0.01 ± < 0.01 (*1*)
Stegostomatidae			
Stegostoma fasciatum	Zebra shark	-	< 0.01 ± < 0.01 (*1*)
Triakidae			
Mustelus sp. or spp. *	Gummy shark	0.13 ± 0.08 (*5*)	0.02 ± 0.01 (*9*)
Urolophidae			
Urolophus bucculentus	Sandyback stingaree	0.03 ± 0.03 (*1*)	-
TELEOSTS			
Ariidae			
Arius graeffei	Blue catfish	-	0.04 ± 0.03 (*8*)
Carangidae			
Seriola lalandi	Yellowtail kingfish	-	< 0.01 ± < 0.01 (*1*)
Glaucosomatidae			
Glaucosoma scapulare	Pearl perch	-	< 0.01 ± < 0.01 (*1*)
Muraenidae			
Unid. Muraenid	Unid. moray eel	0.03 ± 0.03 (*1*)	-
Platycephalidae			
Platycephalus caeruleopunctatus	Bluespotted flathead	0.11 ± 0.06 (*5*)	-
Rachycentridae			
Rachycentron canadum	Cobia	-	0.05 ± 0.02 (*23*)
Serranidae			
Epinephelus ergastularius	Banded rockcod	-	0.01 ± 0.01 (*5*)
Sparidae			
Pagrus auratus	Snapper	-	0.02 ± 0.01 (*4*)
REPTILES			
Cheloniidae			
Chelonia mydas	Green turtle	-	< 0.01 ± < 0.01 (*2*)

* The true accuracy of field identifications of gummy shark (*Mustelus* spp.) caught during this study are uncertain. Refer to Table 4 for further explanation.

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