Are depredation rates by reef sharks influenced by fisher behaviour?

Magen Schifiliti, Dianne L McLean, Tim Langlois, Matt Birt, Peter Barnes, Ryan Kempster

Shark depredation (damage to gear and loss of bait or hooked fish by a non-target species) is a common global occurrence. Depredation events by sharks can have negative impacts for the fishers, fishery targeted species and the sharks. It is, therefore important to better understand if learning behaviour of sharks can influence rates of depredation. Recreational fishers within the World Heritage Ningaloo Reef have reported increased rates of depredation by sharks over the last 5 years. This study aimed to determine if sharks are capable of learning to associate intensive recreational fishing activities with a food reward. We also aimed to test if sharks in areas frequently fished were more habituated to recreational fishing activities than those sharks within a no-take marine sanctuary. To simulate fishing activities baited underwater video systems were deployed in the morning (A.M.), midday, and afternoon (P.M.) for six consecutive days in *Fished* and *Unfished* sites. A significant decrease in time of arrival and time to first feed of sharks was seen across days at the *Fished* sites. The *Unfished* sites had very low numbers of sharks observed (n=3) and therefore was not statistically analysed. The relative abundance of sharks did not significantly increase across days, however there was a negative correlation between lemon sharks (*Negaprion* sp.) and whalers (*Carcharhinus* sp.). Our study suggests sharks are capable of being classically conditioned to recreational fishing activities and depredation rates are influenced by fisher behaviour. We have highlighted possible mitigation strategies designed to un-condition sharks to recreational fishing, including modifying fishing practices, use of deterrents based on the sensitivity of shark senses and management strategies. The best approach is likely to be enabling fishers to become more knowledgeable of how and why shark depredation events happen and take appropriate steps to avoid them.

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Magen Schifiliti [1], Dianne L. McLean[1], Tim J. Langlois[1], Matthew Birt[1], Peter Barnes[2], Ryan Kempster[3],

[1]The UWA Oceans Institute and School of Plant Biology, The University of Western Australia 35 Stirling Highway, Crawly, WA, 6009, Australia.

[2] Department of Parks and Wildlife 22 Nimitz Street, Exmouth, WA, 6707, Australia.

[3] The UWA Oceans Institute and School and School of Animal Biology, The University of Western Australia, 35 Stirling Highway, Crawly, WA, 6009, Australia.

Introduction

Depredation in commercial and recreational fisheries is a common problem worldwide for which the outcomes can have negative effects on the fishing industry as well as depredating species (MacNeil, Carlson & Beerkircher 2009; Tetley, Kiszka & Hoyt, 2012). In this study, we refer to depredation by sharks where they damage fishing gear and/or cause the loss of bait or a hooked fish during fishing activities. While the negative effect of this behaviour is obvious for fishers (loss of catch/bait/gear), the implications extend much further as the additional fishing effort exhibited by fishers to negate their loss results in a greater impact on target fish stocks. Depredation behaviour has been demonstrated in longline fishing activities by bottlenose dolphins, *Tursiops truncates* (Hernandez-Milian et al., 2008), false killer whales, *Pseudorca crassidens* and killer whales, *Orcinus orca* (Tetley et al., 2012) and by blue sharks, *Prionace glauca* (MacNeil, et al., 2009).

In order to minimise or avoid depredation events, it is first essential to understand how sharks are attracted to fishing activities. Among their many senses, sharks possess specialized electrosensory and mechanosensory receptors that have been shown to assist in the location of prey (Boord & Campbell, 1977; Theiss, Collin & Hart, 2012). However, these senses are only capable of detecting prey within close proximity of the head (on the order of centimetres). For the detection of prey at greater distances, sharks will likely rely more heavily on their auditory and chemosensory abilities, which are capable of detecting signals > 100 m away (Bres, 1993; Thesis et al., 2012).

Previous research on Chondrichthian species in the wild has been largely focused on their learning behaviours in response to ecotourism (Kiefer & Colgan, 1992). Southern stingrays (*Dasyatis americana*) in the Caribbean learned to associate tourist-feeding sites with a food reward and have exhibited higher site fidelity to these areas and desensitization to humans (Guttridge et al., 2009a). Desensitization through human encounters is also a cause for concern for white shark (*Carcharodon carcharias*) cage-diving operations (Bruce & Bradford, 2013). As white sharks are drawn to boats by the repeated use of chum (a liquefied mixture of fish), they are thought to associate ecotourism cage-diving events with a food reward (Johnson & Kock, 2006). This form of classical conditioning (Schmajuk, 2010) has been shown to decrease the time of arrival of white sharks to the bait and chum lines over time (Johnson & Kock, 2006; Guttridge et al., 2009a; Clual et al., 2010; Bruce & Bradford, 2013). The regular provision of food associated with human activity can also lead to increases in the local abundances of white sharks (Bruce & Bradford, 2013). Such behavioural changes have also been demonstrated in laboratory settings with Port Jackson sharks (*Heterodontus portjacksoni*) arriving faster to a food reward and a significant increase in abundance around the food reward after a conditioned stimulus was activated (Guttridge & Brown 2014). These sharks demonstrated a capacity to learn in the laboratory relatively quickly and retained the learned associations (Guttridge & Brown, 2014). Similar findings have also been reported for bamboo sharks (*Chiloscyllium griseum*; Schluessel & Bleckmann 2012). While it has been shown that certain species of sharks can modify their behaviour to obtain a food reward (e.g. white sharks Johnson & Kock, 2006; bamboo sharks Schluessel & Bleckmann, 2012; and Port Jackson sharks Guttridge & Brown, 2014) the implications of this for depredation events associated with recreational fishing activities is currently unknown.

At Ningaloo Reef in Western Australia, reports of depredation events have increased in recent years (Barnes, P., 2014 as pers. comm.) prompting questions as to whether there has been an increase in shark numbers or if sharks are learning to associate recreational fishing behaviour with a food reward. The Ningaloo Reef sits on the continental shelf only kilometres from shore and is known as one of the premier recreational and game fishing destinations in Western Australia (Exmouth Visitors Centre, 2014). Recreational fishing activity peaks between April and October (Beckley et al. 2010) and is very popular from small boats – particularly at the northern end of the reef (Smallwood & Beckley, 2012). Shark species commonly encountered on the reef include; tiger sharks (*Galeocerdo cuvier*), silvertip (*Carcharhinus albimarginatus*) and blacktip (*Carcharhinus limbatus*) reef sharks, grey nurse (*Carcharias taurus*), pigeye (*Carcharhinus).*

Marine natural resource and park managers are responsible for the two interrelated objectives of sustaining diversity and abundance of fish stocks while also maintaining quality opportunities for recreational and commercial fishing (DEC, 2005). The success of these objectives is reliant on a sound understanding of natural processes and human pressures to allow informed decision-making. It is important that depredation by sharks is included in this process to determine the potential effects on fish stocks, impacts on the recreational fishing 'experience' and strategies for mitigation. A key component is to understand the mechanisms driving shark behaviour and depredation.

No-take sanctuaries along Ningaloo Reef were first established in 1987. The absence of commercial and recreational fishing pressure in no-take sanctuaries allows these areas to act as controls to investigate the impacts from fishing (Ballantine 2014). Multiple studies on Ningaloo Reef have compared fished and unfished sites (Westera, Lavery and Hyndes, 2003; Fitzpatrick et al. 2012; Wilson et al. 2012) and Westera et al. (2003) found fishing significantly altered the target species composition compared with an unfished sites. Studies have documented how various species of shark can become habituated in the wild to stimuli associated with a food reward (Johnson & Kock, 2006; Schluessel & Bleckmann, 2012; Guttridge & Brown, 2014). We therefore predicted that sharks within established sanctuary zones would be less habituated to fishing activity and possible food rewards than sharks sampled throughout the fished areas at Ningaloo.

In the current study we used a baited video camera system to simulate fishing activities and investigate whether sharks are capable of learning to associate recreational fishing activity with a food reward at Ningaloo Reef. Investigations were conducted in areas open to fishing (where sharks may already be habituated to fishing activity) and within a Sanctuary Zone (where no fishing occurs) over multiple days. We hypothesised that with each subsequent day sampled:

1. The arrival time of sharks will decrease.
2. The time it takes for sharks to feed will decrease.
3. Shark relative abundance will increase.
4. These responses would be quicker in fished areas where sharks may already be habituated to the act of fishing.

Results will be discussed in relation to the development of mitigation strategies for recreational fishers and marine park mangers to decrease the frequency of depredation events.

Materials and Methods

This project was conducted in accordance with Animal Ethics Approval RA/3/100/1317 from The University of Western Australia. License approval from the Department of Parks and Wildlife license to take fauna for scientific purposes Regulation 17, SF009770.

Study area

This study was conducted in both *Fished* and *Unfished* sites within the Ningaloo Reef Marine Park. The *Fished* sites (VLF Bay), have frequent recreational fishing activity based on aerial surveys and observations by Marine Park Rangers (Smallwood and Beckley, 2012; Barnes, P., 2014 as pers comm. 12 April). The *Unfished* sites (Bundegi Sanctuary Zone) are in a no-take marine sanctuary established in 1987 where fishing activity was assumed to be absent or very small. These areas are respectively located 19 and 12 km north, of the Exmouth marina, Western Australia (Figure 1).

Experimental design

The experimental design consisted of three factors: Time (continuous variable across the six days of the study), Status (2 levels fixed: *Fished* and *Unfished)* and Site (2 levels random, nested in Status: Site 1 and Site 2). Two boats were used for this study, with one designated to the *Fished* sites and one to the *Unfished* sites. Each boat sampled both sites for 60 minutes within one of the areas at three times throughout each day; morning (A.M.), midday and afternoon (P.M.). On consecutive days, the order in which sites were sampled was alternated. Previous studies on reef fish assemblages with stereo-BRUVs and pelagic stereo-BRUV have found sample times of 60 minutes to be appropriate for sampling fished species (Watson et al., 2010, Santana-Garcon, Newman & Harvey, 2014b).

Each fishing level status and the sampling sites within them were chosen to ensure the comparable nature of the habitats, predominantly low-lying reef and rubble habitat in an average of 13.6 m water depth. Within each status two replicate sites were chosen, approximately 1 km away from each other to provide independence between sites, but close enough to maximize temporal sampling efficiency required in this study. It was not possible to intersperse sampling sites between status *Fished* and *Unfished* in this study due to strong habitat gradients on the southern side of Bundegi no-take Sanctuary and the logistical constraints involved in the temporal sampling used in this study.

Video equipment and analysis

This study used an adapted downward facing, midwater, remote observation research apparatus (RemORA) designed by the University of Western Australia Neuroecology Group for observing the behaviour of sharks around bait (Figure 2). Two GoPro Hero 3 cameras were mounted in a stereo-configuration on a cross bar frame 72 cm apart facing down into the water column. However, due to calibration issues with these systems no length measurements or range data were possible. The RemORA was tethered to the boat for the duration of sampling, and hung vertically in the water column filming in a downward orientation. The bait bag on the RemORA hung 5 m below the surface and was attached 2 m below the cameras. A mesh bait bag was filled with pilchards and two tuna heads were tied next to the bag simulating a hooked fish and acting as a visual stimulus for the sharks. While this design was used to simulate a hooked fish, it is likely to be a very different stimulus compared to a live and struggling hooked fish, which limits the inferences possible.

The software, EventMeasure (www.seagis.com.au) was used to analyse video footage. Four measures of shark behaviour were recorded: time of arrival, time to feed, species present and MaxN. All sharks were identified to species level. The maximum number of sharks (MaxN) present within the field of view of the cameras at the same time was used to avoid repeat counts of individual sharks entering and leaving the field of view (Priede et al., 1994).

Statistical analysis

The first time of arrival of any shark, the time it takes the first shark to feed, and MaxN were analysed across time using linear mixed models. The R language for statistical computing (R Development Core Team, 2013) was used to organise data, build statistical models and plot results, using the following packages; reshape2 (Wickham, 2007), plyr (Wickham, 2011), Hmisc (Harrell & Dupont, 2014), lme4 (Bates, 2014), and ggplot2 (Wickham, 2009).

Periods of strong water current were found to confound the sampling method at some time periods during the study. Undefined samples occurred in the analysis of time of arrival and time to feed, where either no sharks arrived or no feeding took place within the 60 minute sampling period and were therefore omitted from the analyses.

Results

A total of five species of shark were identified from 31 RemORA deployments (Table 1). Continuous sampling at both *Fished* and *Unfished* sites was interrupted on Day 3 due to strong winds and a large swell resulting in only the morning period (A.M.) being sampled.

The *Unfished* sites had very low numbers of sharks observed (n=3) throughout the study and therefore no formal statistical analysis was conducted. Although no sharks fed at this location, the MaxN increased from Day 4 (one shark) to Day 6 (two sharks). The first shark to arrive on Day 6 also arrived faster than the shark on Day 4.

At the *Fished* sites, time of arrival across days significantly decreased over the six days sampled (Table 2 and Figure 3A). On Day 5 and 6 the first shark arrived consistently less than one minute after the RemORA was deployed (Fig 3A). The time to feed also significantly decreased across the six days sampled (Table 2 and Figure 3B). While sharks arrived and fed more quickly across the course of the study, the total MaxN of all species of sharks did not significantly change with time sampled. When examined at the genus level, there was no significant difference in MaxN, however there was a strong negative correlation between the MaxN of *Negaprion* sp. and *Carcharhinus* sp. ($P<0.01$ Figure 4).

Discussion

On the first day of sampling a shark arrived after only 86 seconds from a RemORA deployment in the *Fished* sites. This observation combined with sharks arriving significantly sooner throughout the study, suggests sharks may already be conditioned to recreational fishing behaviour within fished areas at Ningaloo. This pattern was particularly strong when contrasted to the slow arrival times (46 minutes) and lack of feeding by sharks in the *Unfished* sites sampled. However, during our experiments sharks at the *Fished* sites were able to be further conditioned to the point where on some later RemORA deployments sharks were already circling under the boat before the cameras were lowered into the water. One plausible explanation for shorter arrival times is that sharks may have learned to associate vessel sounds with food. Hearing is a shark's longest-range sense (Reef Quest, 2014) and shark fishers in Melanesia have conditioned sharks to associate the sound of a coconut rattle with food (Rubel & Rosman, 1981). Therefore even if sharks are not present in the immediate vicinity of fishers they may likely be aware there is a boat in the area due to the detectible auditory cues (Johnson and Kock, 2006).

From Day 3 to Day 6, shorter times to first feed of under one minute at the *Fished* sites, indicate the sharks may have become increasingly desensitized to the RemORA and the boat over the course of the experiment. Desensitization to sampling gear has also been seen in a field experiment on Galápagos sharks by Robbins, Peddemors & Kennelly (2011) and in a lab study by Clark (1959) on lemon sharks. Reports of high levels of depredation on Ningaloo Reef (Barnes,P., 2014 as pers. comm. 26 Feb) suggest there may already be some level of desensitization in sharks to fishing vessels, with sharks approaching without hesitation to take a hooked fish from the line.

Species-specific behaviour

An inverse relationship was observed between *Negaprion* sp. and *Carcharhinus* sp. throughout the study at the *Fished* area (Figure 4). This suggests some behavioural dynamics exists between these species, as sampling was conducted at the same sites over time. *Negaprion* sp. are known to form groups based on size and sex (Guttridge et al., 2009b). If *Negaprion* sp. arrived to the RemORA first the larger numbers could of caused an increase in feeding motivation amongst conspecifics potentially keeping *Carcharhinus* sp. at a distance. In Galápagos sharks, changes in school numbers have been shown to influence their behaviour to hooked fish, where depredation rates increase when three or more individuals were present (Robbins et al., 2011). *Negaprion* sp. had the highest MaxN (n=4) during this study. *Carcharhinus* sp. live in a coastal pelagic habitat while *Negaprion* sp. live in a coastal benthic habitat. The implication for fishers fishing on the bottom is they could be more likely to experience depredation from *Negaprion* sp. compared to fishing in the water column where depredation may be more likely from *Carcharhinus* sp.

Shark senses

In trying to determine how and why depredation events happen, it is important to look at how sharks use their senses for detecting prey. Sharks senses are often specialized for the habitats in which they live (Kempster, McCarthy & Collin, 2012). Carcharhiniformes primarily live in coastal pelagic habitats and have the highest electrosensory pore abundance of all Selachimorpha (Kempster, McCarthy & Collin, 2012). This high abundance of electrosensory pores aid in locating fast moving prey reducing the energy expended giving them a higher advantage of finding food in the environment. Shark senses cover a wide range of detection distances from their hearing, which can detect sounds up to a kilometre away, olfaction at medium distances, and direct contact through taste (Collins, 2011; Reef Quest, 2014). It is likely sharks use hearing to form the association of boats and recreational fishing activity with a food reward, as hearing is a sharks longest range sense (Reef Quest, 2014).

Reducing depredation

Depredation may lead to increased mortality of fish stocks that is not accounted for in the current management of recreational fishing. The fish lost to depredation plus those kept by fishers, will result in greater mortality of the fish stocks than intended based on fisheries regulations. As we do not know the frequency and magnitude of depredation events, the impact on target fish stocks is currently unknown. Furthermore, fishers may pull in their catch at a fast rate to try and avoid depredation but in the process make this catch more vulnerable to barotrauma (Sumpton et al., 2010). Undersized fish returned to the water having suffered barotrauma would likely die (by the injury itself or by predation) with the fisher then continuing to fish (Brown et al., 2010; Sumpton et al., 2010). The best-case scenario is to reduce depredation events by providing fishers with mitigation strategies to alter fishing practices and improve fishing opportunities.

Commercial longline fisheries, which are known to be impacted by shark depredation and shark bycatch, use a variety of shark avoidance strategies, which recreational fishers could also implement (Gilman et al., 2007). Longline fishers may avoid fishing in areas with known high shark abundances and where high rates of depredation are known to occur, to reduce the further conditioning of sharks (Gilman et al., 2007). Similar strategies could be adopted by recreational fishers at Ningaloo. In addition, if a fisher experiences a high level of gear loss and depredation, they should stop fishing in that area. When a depredation event occurs, fishers should report the event through an existing data collection mechanism if one is available including the location they were fishing, the species of shark if known and the species lost if known. The promotion of communication between recreational fishers that experience depredation events should be developed so 'real time' depredation hot spots can be determined and action to reduce depredation can be taken (Gilman et al., 2007). No matter where a fisher is on the water they should aim to minimise bait discards and burley where possible to minimise the likelihood of attracting sharks to the area. Robbins et al. (2013) suggested in some extreme cases, park managers may need to consider monitoring and regulating fishing activities or implementing time-area closures in areas known to continually have shark depredation.

In addition to mitigation strategies, fishers can use and be knowledgeable about shark repellents. Depredation in recreational fishing has the potential to hinder the quality of a recreational fishing experience. By repelling sharks away from fishers lines and caught fish, sharks may be able to be negatively conditioned to dissociate fishing lines with a food reward allowing fishers a higher quality fishing opportunity (Gilman, et al., 2007). A successful repellent would reduce the number of shark depredation events without repelling the target fish species. Multiple studies in the field have tested electropositive metal alloys and magnets made from rare earth metals containing mostly neodymium-iron-boron and barium-ferrite in baited hook experiments, and have found significant evidence that Chondrichthyes, including blacktip sharks (*Carcharhinus limbatus*), juvenile lemon sharks and white sharks (2-4 m) are repelled (WWF, 2006; Mandelman et al., 2008; Stoner & Kaimmer, 2008; Brill et al., 2009; O'Connell et al., 2010, 2011a, 2011b, Robbins et al., 2011; O'Connell et al., 2014).

Future studies

Water current was a major confounding factor in our analysis. On days with strong to very strong currents, video analysis revealed sharks took longer to arrive and longer to feed. Day 5 of sampling had the largest tidal variation (1.7 m) due to the full moon. The sample locations were just inside of the Exmouth Gulf resulting in strong tidal currents when the tide switched. Upon completing video analysis an observation of a very strong current resulted in longer arrival and feeding times. The major limitation of the current study was the use of only two *Fished* and two *Unfished* sites, within the same no-take sanctuary. Future studies should attempt to increase the replication of sites and we recommend sampling inside and outside of multiple no-take sanctuaries to test the generality of patterns found in the current study (after Langlois et al. 2012). Furthermore, the current study was not able to intersperse sites due to the logistic constraints of the temporal sampling and a strong gradient in benthic habitat observed to the south of the no-take area sampled. Despite the resultant concern of spatial confounding it was more important for the current study to sample sites with as comparable habitat as possible.

This study used a downward facing midwater RemORA modified from a pelagic stereo-BRUV (Santana-Garcon et al., 2014a). The RemORA systems have been developed based on anecdotal observations that sharks make closer approaches to the extended downward facing system. In studies where multiple species of sharks are expected or targeted, the downward facing field of view of the RemORA system may be a limitation as sharks can be difficult to identify from above. *Carcharhinus* species have similar external features and murky water further complicates their correct identification (Santana-Garcon et al., 2014b).

Conclusion

This study suggests sharks are capable of being classically conditioned to recreational fishing activities and depredation rates are influenced by fisher behaviour. We have highlighted possible mitigation strategies designed to un-condition sharks to recreational fishing, including modifying fishing practices, use of deterrents based on the sensitivity of shark senses and management strategies. The best approach is likely to be enabling fishers to become more knowledgeable of how and why shark depredation events happen and take appropriate steps to avoid them. By reducing depredation it is possible to lessen the negative impacts on fish stocks due to the unknown amounts of target fish killed, improve the recreational fishing experience by reducing the loss of gear and prized fish from the line and minimising injuries or mortality to threatened and vulnerable species of shark.

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References

Ballantine, B. (2014) Fifty years on: Lessons from marine reserves in New Zealand and principles for a worldwide network. *Biological Conservation* 176: 297-307.

Bates D, Maechler M, Bolker BM, Walker S. 2014. lme4: Linear mixed-effects models using Eigen and S4. ArXiv e-print; submitted to Journal of Statistical Software. Available at http://arxiv.org/abs/1406.5823 (accessed 5 June 2014)

Beckley LE, Smallwood CB, Moore SA, Kobryn HT. 2010. Ningaloo Collaboration Cluster: Human use of Ningaloo Marine Park. *CSIRO, Ningaloo Collaboration Cluster Final Report* No. 2

Bres M. 1993. The behaviour of sharks. Reviews in fish biology and fisheries 3:133-159

Boord RL, Campbell CBG. 1977. Structural and functional organization of the later line system in sharks. *Integrative and comparative biology* 17(2):431-441

Brill R, Bushnell P, Smith, L, Speaks C, Sundaram R, Stroud E, Wang J. 2009. The repulsive and feeding-deterrent effects of electropositive metals on juvenile sandbar sharks (*Carcharhinus plumbeus*). *Fishery Bulletin* 107(3):298-307

Brown I, Sumpton W, McLennan M, Mayer D, Campbell M, Kirkwood J, Butcher A, Halliday I, Mapleston A, Welch D, Begg GA, Sawynok B. An improved technique for estimating short-term survival of released line-caught fish, and an application comparing barotrauma-relief methods in red emperor (*Lutjanus sebae* Cuvier 1816). *Journal of Experimental Marine Biology and Ecology* 385:1-7

Bruce BD, Bradford RW. 2013. The effects of shark cage-diving operations on the behaviour and movements of white sharks, *Carcharodon carcharias*, at the Neptune Islands, South Australia. *Marine Biology* 160:889-907

Clark E. 1959. Instrumental conditioning of lemon sharks. *Science* 130(3369):217-218

Clua E, Buray N, Legendre P, Mourier J, Planes S. 2010. Behavioral response of sicklefin lemon sharks *Negaprion acutidens* to underwater feeding for ecotourism purposes. *Marine Ecology Progress Series* 414:257-266

Collins SP, and Whitehead D. 2004. The functional roles of passive electroreception in non-electric fishes. *Animal Biology* 54(1):1-25

DEC, Department of Environmental Conservation. 2005.

Exmouth Visitors Centre, 2014. Available at http://www.visitningaloo.com.au (accessed 30 April 2014)

Fitzpatrick BM, Harvey ES, Heyward AJ, Twiggs EJ, Colquhoun J. 2012. Habitat specialization in tropical continental shelf demersal fish assemblages. *PLoS ONE* 7(6)

Gilman E, Clarke S, Brothers N, Alfaro-Shigueto J, Mandelman J, Mangel J, Petersen S, Piovano S, Thomson N, Dalzell P, Donoso M, Goren M, Werner T. 2007. Shark

Depredation and unwanted bycatch in pelagic longline fisheries: industry practices and attitudes, and shark avoidance strategies. *Western Pacific Regional Fishery Management Council*, Honolulu, USA

Guttridge TL, Myrberg AA, Porcher IF, Sims DW, Krause J. 2009a. The role of learning in shark behaviour. *Fish and Fisheries* 10(4):450-469

Guttridge TL, G.S., Gledhill KS, Croft DP, Sims DW, Krause J. 2009b. Social preferences of juvenile lemon sharks, *Negaprion brevirostris*. *Animal Behaviour* 78, 543-548.

Guttridge TL, and Brown C. 2014. Learning and memory in the Port Jackson shark, *Heterodontus portusjacksoni. Animal Cognition* 17:415-425

Haine OS, Ridd PV, Rowe RJ. 2001. Range of electrosensory detection of prey by *Carcharhinus melanopterus* and *Himantura granulata*. *Marine Freshwater Research* 52:291-296

Harrell FE, and Dupont C. 2014. Hmisc: Harrell Miscellaneous, R package version 3.14-5

Hernandez-Milian G, Goetz S, Varela-Dopico C,′ Rodriguez-Gutierrez J, Romo′ n-Olea, J, Fuertes-Gamundi JR, Ulloa-Alonso E, Tregenza NJC, Smerdon A, Otero MG, Tato V, Wang J, Santos MB, Lopez A, Lago R, Portela JM, Pierce GJ. 2008. Results of a short study of interactions of cetaceans and longline fisheries in Atlantic waters: environmental correlates of catches and depredation events. *Hydrobiologia* 612:251-268

Johnson R, and Kock A. 2006. South Africa's White Shark cage-diving industry - is their cause for concern? In: Deon C. Nel, T.P.P. (Ed.), Finding a balance: White Shark conservation and recreational safety in the inshore waters of Cape Town, South Africa, Cape Town, South Africa

Kajiura SM. 2003. Electroreception in neonatal bonnethead sharks, *Sphyrna tiburo*. *Marine Biology* 143:603-611

Kalmijn AJ. 1971. The electric sense of sharks and rays. *Journal of Experimental Biology*

55:371-383

Kalmijn J. 2000. Detection and processing of electromagnetic and near-field acoustic signals in elasmobranch fishes. *The Royal Society* 355:1135-1141

Kempster RM, McCarthy ID, Collin SP. 2012. Phylogenetic and ecological factors influencing the number and distribution of electroreceptors in elasmobranchs. *Journal of Fish Biology* 80:2055-2088

Langlois, TJ, Harvey, ES, and Meeuwig, JJ. 2012. Strong direct and inconsistent indirect effects of fishing found using stereo-video: testing indicators from fisheries closures. *Ecological Indicators* 23:524-534.

MacNeil MA, Carlson JK, Beerkircher LR. 2009. Shark depredation rates in pelagic longline fisheries: a case study from the Northwest Atlantic. *ICES Journal of Marine Science* 66(4):708-719

Maljkovic A, Cote IM. 2011. Effects of tourism-related provisioning on the trophic signatures and movement patterns of an apex predator, the Caribbean reef shark. *Biological Conservation* 144:850-865

Mandelman J, Stratton M, Tlusty M, Tallack S, Fisher T, Harary C, Wernerfelt N. 2008. The shifting baseline of threshold feeding responses to electropositive metal deterrents in two species of dogfish. AES Abstract

McGrouther, 2014. Available at http://australianmuseum.net.au (accessed 14 October 2014)

O'Connell CP, Abel DC, Rice PH, Stroud EM, Simuro NC. 2010. Responses of the southern stingray (*Dasyatis Americana*) and the nurse shark (*Ginglymostoma cirratum*) to permanent magnets. *Marine and Freshwater Behaviour and Physiology* 43(1):63-73

O'Connell CP, Abel DC, Gruber SH, Stroud EM, Rice PH. 2011a. Response of juvenile lemon sharks, *Negaprion brevirostris*, to a magnetic barrier simulating a beach net. *Ocean and Coastal Management* 54:225-230

O'Connell CP., Abel, D. C., Stroud, E. M., Rice, P. H., 2011b. Analysis of permanent magnets as elasmobranch bycatch reduction devices in hook-and-line and longline trials. Fisheries Bulletin (Fish. Bull.) 109:394-401

O'Connell CP, Andreotti S, Rutzen M, Meyer M, He P. 2014. The use of permanent magnets to reduce elasmobranch encounter with a simulated beach net. 2. The great white shark (*Carcharodon carcharias*). *Ocean and Coastal Management* 97:20-28

Priede IG, Bagley PM, Smith A, Creasey S, Merrett NR. 1994. Scavenging deep demersal fishes of the Porcupine Seabight, Northeast Atlantic, observations by baited camera, trap and trawl. *Journal Marine Biology* 74 (3):481–498

R Development Core Team. 2013

Reef Quest. 2014. Available at http://www.elasmo-research.org/index.html (accessed 13 Oct. 2014)

Robbins WW, Peddemors VM, Kennelly SJ. 2011. Assessment of permanent magnets and electropositive metals to reduce the line-based capture of Galapagos sharks, *Carcharhinus galapagensis*. *Fisheries Research* 109:100-106

Robbins WD, Peddemors VM, Broadhurst MK, Gray CA. 2013. Hooked on fishing? Recreational angling interactions with the Critically Endangered grey nurse shark *Carcharias taurus* in eastern Australia. *Endangered Species Research* 21:161-170

Rubel PG, Rosman A. 1981. Shark fishing in Melanesia. *Journal de la Socíété des oćeanistes* 37(72):251-253

Santana-Garcon J, Braccini M, Langlois TJ, Newman SJ, McAuley RB, Harvey ES. 2014a. Calibration of pelagic stereo-BRUVs and scientific longline surveys for sampling sharks. *Methods in Ecology and Evolution* 5(8):824-833

Santana-Garcon J, Newman SJ, Harvey ES. 2014b. Development and validation of a mid-water baited stereo-video technique for investigating pelagic fish assemblages. *Journal of*

Experimental Marine Biology and Ecology 452:82-90

Schluessel VA, Bleckmann H. 2012. Spatial learning and memory retention in the grey bamboo shark (*Chiloscyllium griseum*). *Zoology* 115:346-353

Schwarze S, Bleckmann H, Schluessel V. 2013. Avoidance conditioning in bamboo sharks (*Chiloscyllium griseum* and *C. punctatum*). *Journal of Comparative Physiology* 199(10): 843-856

Smallwood CB, Beckley LE. 2012. Spatial extent, seasonal variability and zoning compliance of recreational fishing in an Australian multiple-use marine park. CSIRO, Ningaloo Collaboration Cluster Final Report No. 2:95-121

Stoner AW, Kaimmer SM. 2008. Reducing elasmobranch bycatch: Laboratory investigation of rare earth metal and magnetic deterrents with spiny dogfish and Pacific halibut. *Fisheries Research* 92:162-168

Sumpton WD, Brown IW, Mayer DG, McLennan MF, Mapleston A, Butcher AR, Welch DJ, Kirkwood JM, Sawynok B, Begg GA. 2010. Assessing the effects of line capture and barotrauma relief procedures on post-release survival of key tropical reef fish species in Australia using recreational tagging clubs. *Fisheries Management and Ecology* 17:77-88

Tetley MJ, Kiszka JJ, Hoyt E. 2012. Defining hotspots for toothed cetaceans involved in pelagic longline fishery depredation in the western Indian Ocean: a preliminary approach. Indian Ocean Tuna Commission, Cape Town South Africa

Theiss SM, Collin SP, Hart NS. 2012. The mechanosensory lateral line system in two species of wobbegong shark (*Orectolobidae*). *Zoomorphology* 131:339-348

Tricas TC, and New JG. 1998. Sensitivity and response dynamics of elasmobranch electrosensory primary afferent neurons to near threshold fields. *Journal of Comparative Physiology* 182:89–101

Watson D, Harvey ES, Fitzpatrick BM, Langlois TJ, Shedrawi G. 2010. Assessing reef fish assemblage structure: how do different stereo-video techniques compare? *Marine Biology* 157:1237-1250

Westera M, Lavery P, Hyndes G. 2003. Differences in recreationally targeted fishes between protected and fished areas of a coral reef marine park. *JEMBE* 294:145-168

Wickham H. 2007. Reshaping Data with the reshape Package. *Journal of Statistical Software* 21:1-20

Wickham H. 2009. ggplot2: elegant graphics for data analysis. Springer, New York

Wickham H. 2011. The Split-Apply-Combine Strategy for Data Analysis. *Journal of Statistical Software* 40:1-29

Wilson SK, Babcock RC, Fisher R, Holmes TH, Moore J, Thomson DP. 2012. Relative and combined effects of habitat and fishing on reef fish communities across a limited fishing gradient at Ningaloo. *Marine Environment Research* 81:1-11

WWF. 2006. World Wildlife Fund Smart Gear Competition. World Wildlife Fund. Available at http://iss-foundation.org/2011/03/04/smart-gear-design-competition-to-reduce-fisheries-bycatch (accessed 25 September 2014)

Figure 1 (on next page)

Study Site

Map of study area in Ningaloo Marine Park, Western Australia. *Fished* sites are located in VLF Bay. *Unfished* sites are located in Bundegi Sanctuary. The border of Bundegi Sanctuary is displayed around the *Unfished* sites.

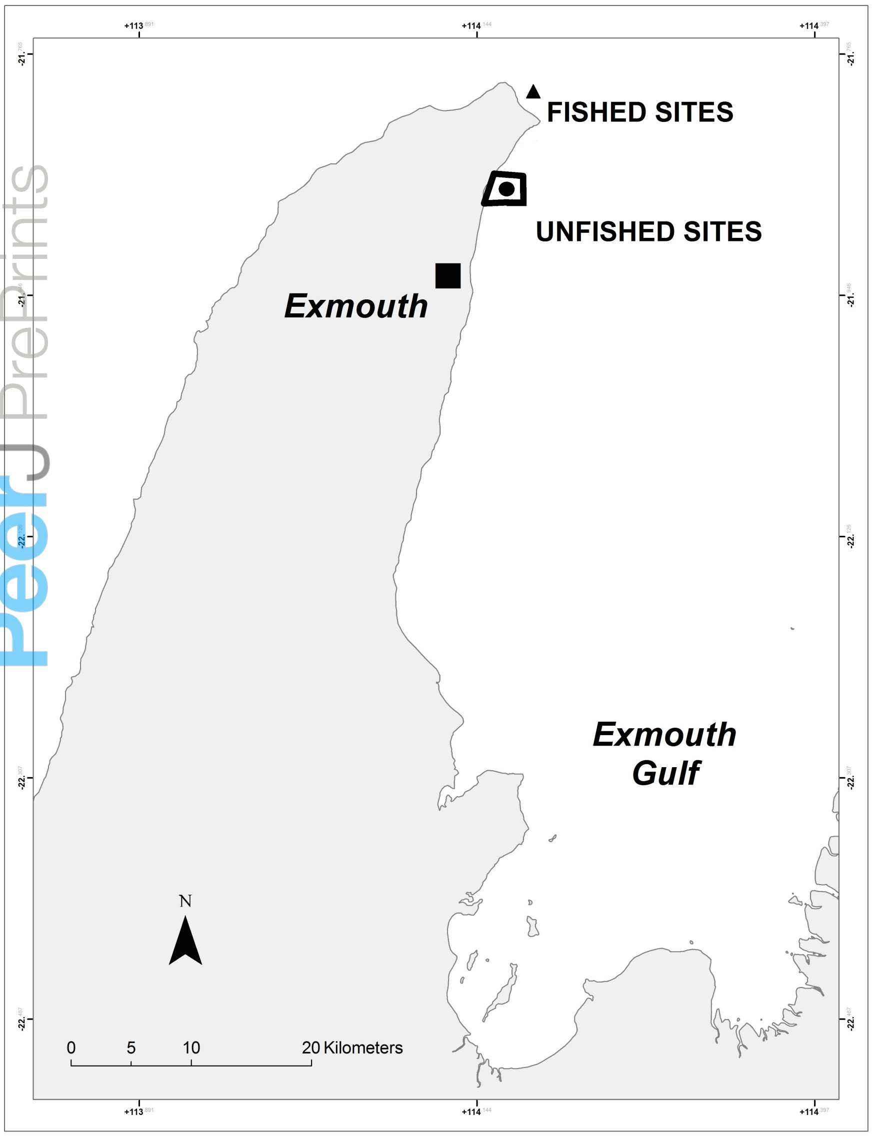

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Figure 2 (on next page)

RemORA

Deployment design of the specialized downward-facing, midwater RemORA camera system (adapted from Kempster, 2014).

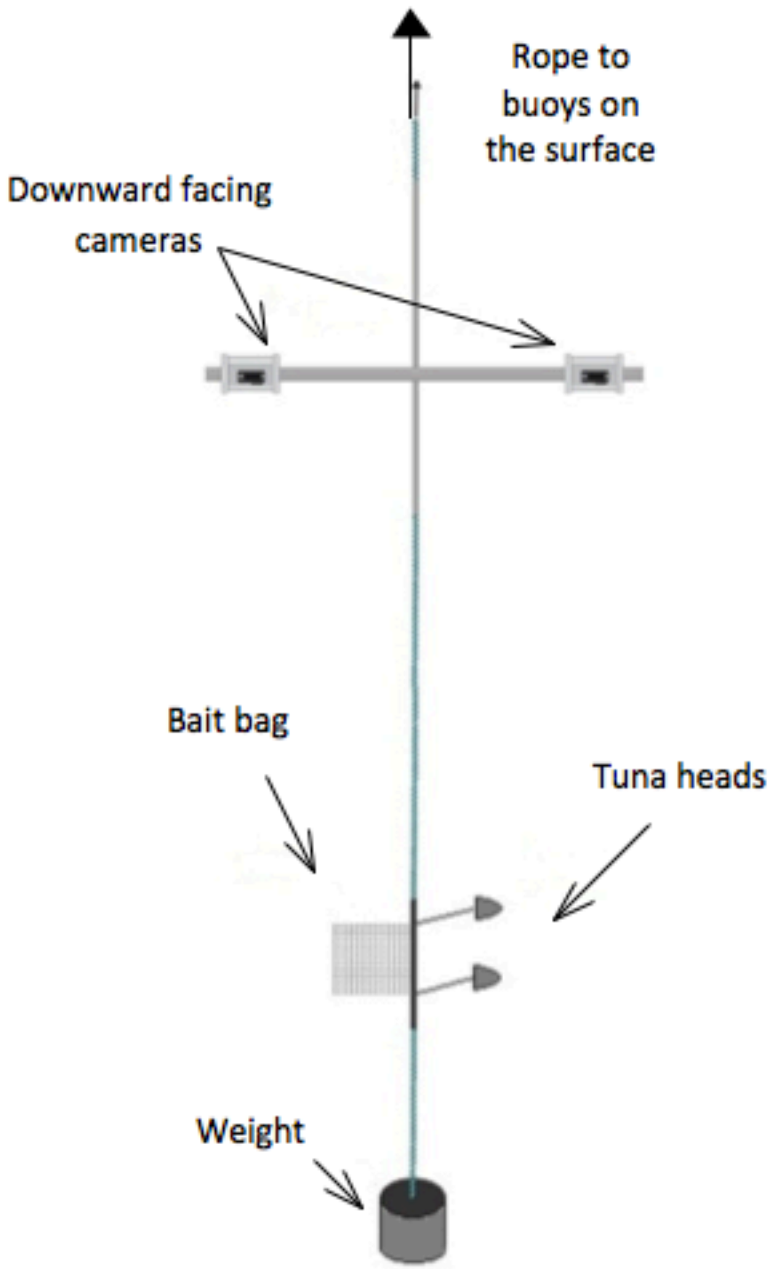
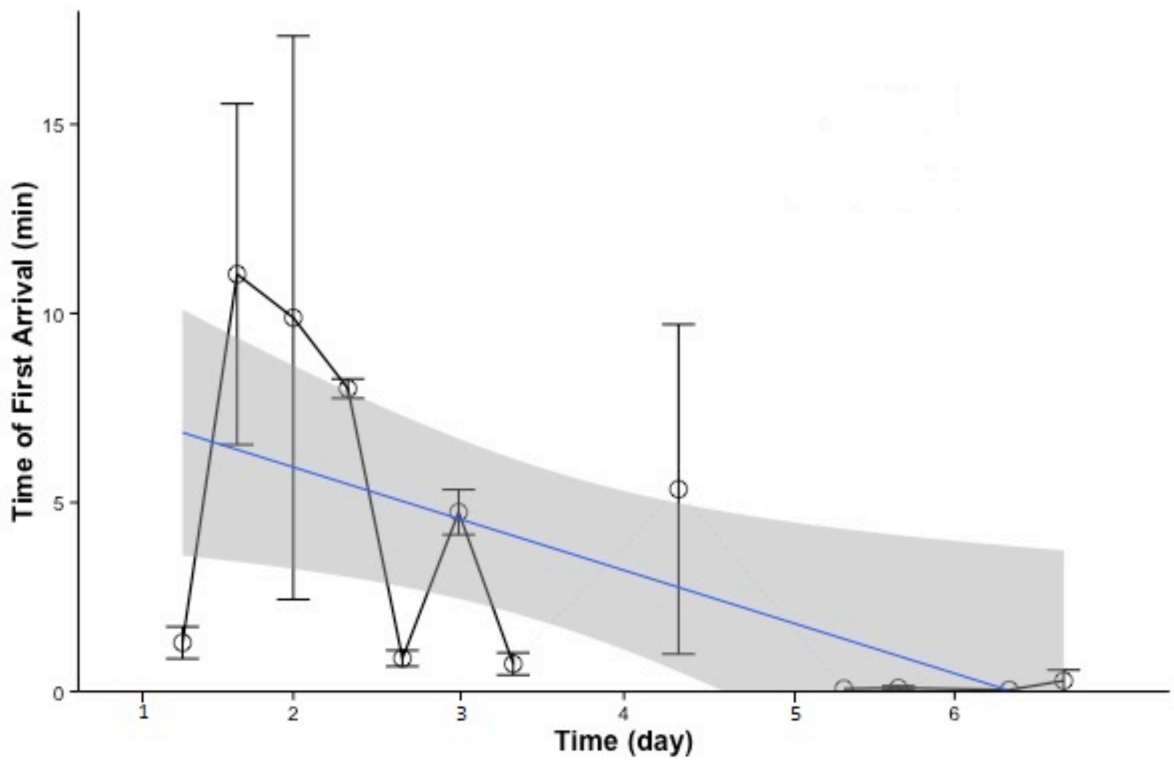

Rope to
buoys on
the surface
Downward facing
cameras
Bait bag
Tuna heads
Weight

Figure 3(on next page)

Figure 3A - Time of Arrival Unfished

Time of first arrival (A) and time to first feed (B; mean ± SE) of sharks with increasing time from the start of the experiment within the *Fished* sites. The line and grey shading represent the significant fitted linear model (± SE).



Time of First Arrival (min)
15
10
5
0
1
2
3
4
5
6
Time (day)

Figure 4(on next page)

Figure 3B - Time to First Feed Unfished

Time of first arrival (A) and time to first feed (B; mean ± SE) of sharks with increasing time from the start of the experiment within the *Fished* sites. The line and grey shading represent the significant fitted linear model (± SE).

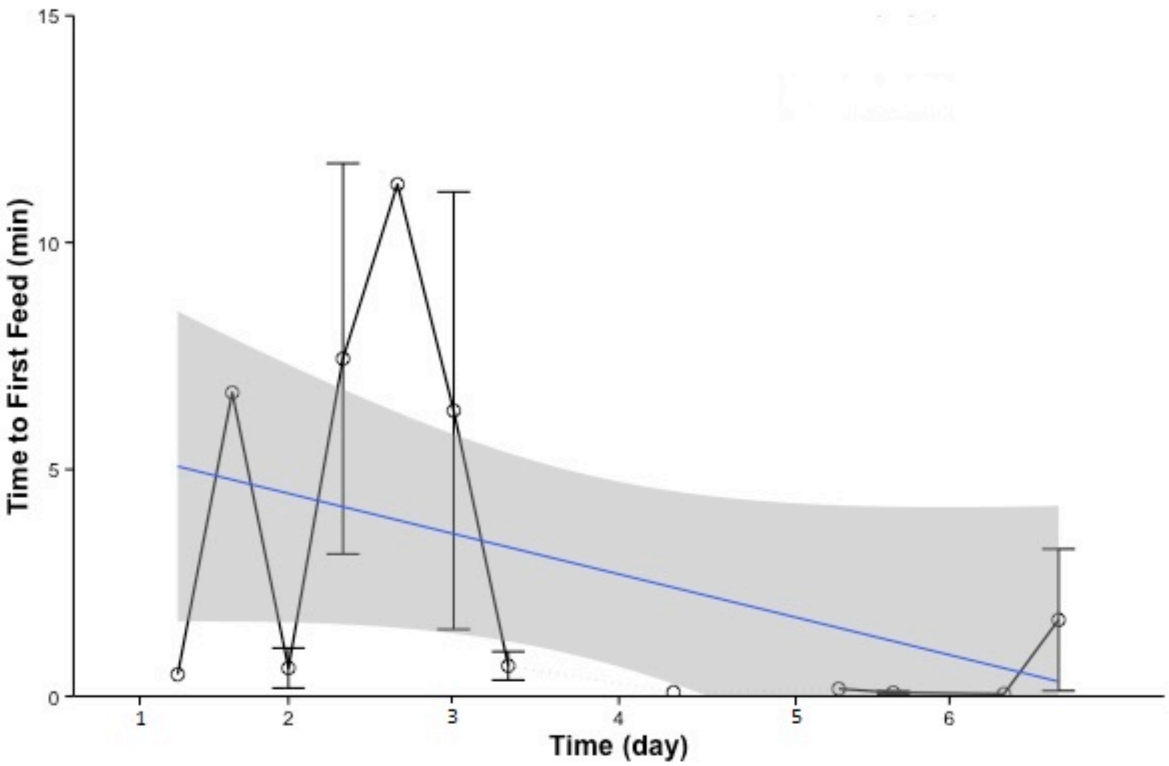

15
10
5
0
Time to First Feed (min)
1
2
3
4
5
6
Time (day)

Figure 5(on next page)

Figure 4 - Max N of species

Relative abundance (mean MaxN ± SE) of *Negaprion* and *Carcharhinus* with increasing time from the start of the experiment at the *Fished* sites.

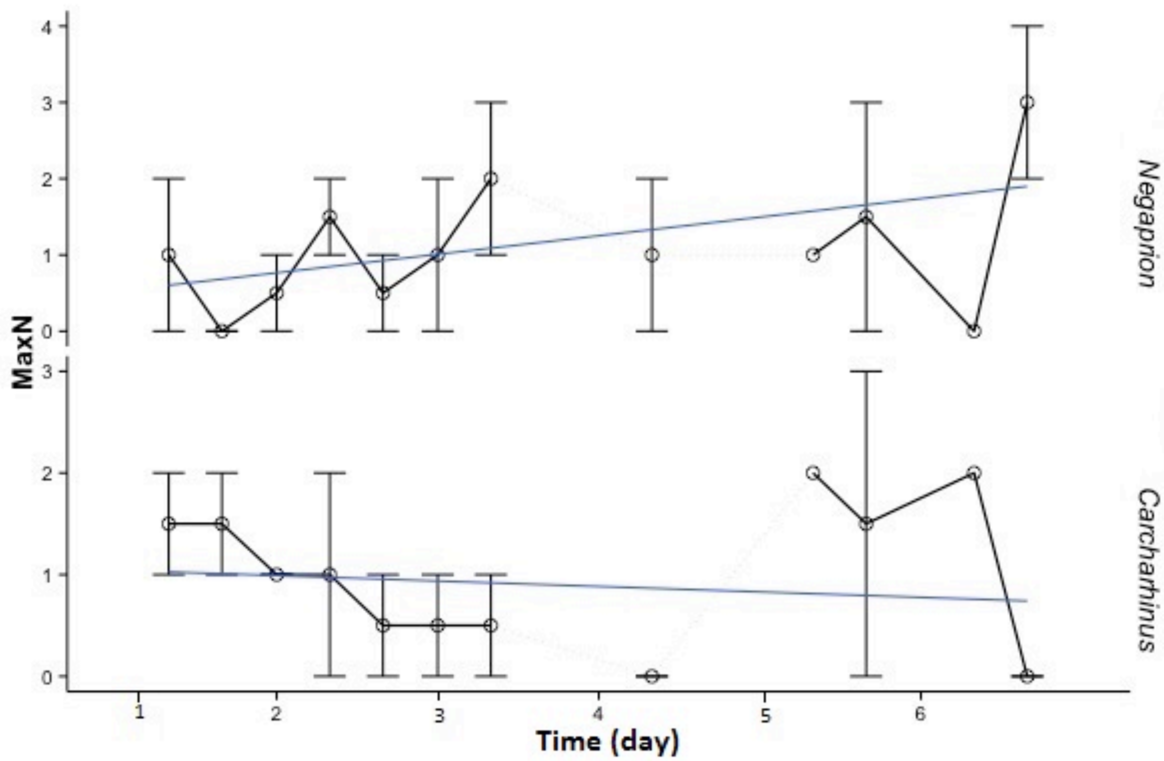

MaxN
Negaprion
Carcharhinus
Time (day)
0
1
2
3
4
1
2
3
4
5
6

Table 1(on next page)

MaxN of species

Table 1. Species of sharks seen and the MaxN of individuals recorded using RemORAs in Ningaloo Marine Park, Western Australia.

Species	Common Name	MaxN
Negaprion acutidens	Lemon shark	4
Carcharhinus ambionensis	Pigeye shark	3
Galeocerdo cuvier	Tiger shark	1
Carcharhinus limbatus	Blacktip shark	1
Carcharhinus obscurus	Dusky shark	1

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Table 2 (on next page)

Statistic p-values

Table 2. Linear mixed model summary of behaviour parameters and MaxN with time at *Fished* sites.

Measure	**df**	$\mathbf{R^2}$	**P-value**
Time of Arrival	20	0.232	0.017*
Time of First Feed	16	0.362	0.008*
MaxN *Negaprion*	20	0.13	0.098
MaxN *Carcharhinus*	20	0.01	0.644
MaxN Total	20	0.105	0.139

* shows significance at α 0.05