Likely effectiveness of netting or other capture programs as a shark hazard mitigation strategy in Western Australia

Associate Professor Daryl McPhee

A report prepared for Department of Fisheries,

Western Australia

Published by Department of Fisheries, Perth, Western Australia.
Fisheries Occasional Publication No. 108, August 2012
ISSN: 1447 - 2058 ISBN: 978-1-921845-48-2

www.fish.wa.gov.au

TABLE OF CONTENTS

Executive Summary

- There are three main locations where ongoing Shark Control Programs have been implemented – Queensland, NSW and KwaZulu-Natal (South Africa). There have also been a number of locations where programs have been undertaken for shorter time periods (e.g. Brazil, New Zealand, Hawaii)

- Shark Control Programs do not, as many people perceive, provide a continuous barrier that prevents access to beaches by sharks. Instead they aim to reduce the number of sharks that can potentially cause harm to humans through the use of shark meshing nets and/or drum-lines.

- A Shark Control Program is not a fishery as it does not capture fisheries resources for commerce or trade. Rather, a shark control program is specifically designed and implemented with the objective of improving public safety.

- Shark Control Programs result in the capture of a wide range of by-catch species including marine mammals, marine turtles, and sharks and rays not implicated in unprovoked attacks on humans.

- Information obtained from other shark control programs has documented that by-catch rates are often very high in the early years of a program. These rates subsequently decline which is likely due in part to the effect of shark control programs “fishing down” local populations of animals vulnerable to the gear.

- There is a high likelihood that the additional anthropogenic source of mortality that a shark control program in WA would generate has potential implications for the populations of any currently threatened marine species or where conservation concerns are emerging that would be vulnerable to this gear.

- Shark control activities would pose a risk to dolphins which can be an important tourist drawcard in a number of locations including in Western Australia (e.g. Bunbury).

- Any new shark control activities in WA would likely require Commonwealth approval under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act 1999*). The most likely approval pathways that the Commonwealth would require would cost the proponent (WA Department of Fisheries or other) an estimated $800,000 and $1,000,000 and take in the order of 18 months to two years. There would be no guarantee that the Commonwealth would approve the activity.

- As a Shark Control Program is not a fishery, it could not be assessed by the Commonwealth against the Commonwealth Guidelines for the Ecologically Sustainable Management of Fisheries.

- There would need to be significant investment by the WA Department of Fisheries in procedures, protocols and infrastructure to commence shark control activities. Once established and based upon estimates in NSW and Queensland, the likely annual cost of running a Shark Control Program is in excess of $1 million.

- Due to the environmental impacts of shark control activities, it is not recommended that either shark nets of drum-lines be introduced into Western Australia.

- Further consideration could be given to the feasibility of using shark enclosures for bather protection.

- Shark enclosures have the advantage of providing a complete physical barrier that prevents sharks from accessing an area and do not target the reduction in shark numbers or result in any bycatch of other large species like shark nets do. Such enclosures are better suited to calmer areas although new materials that are available potentially increase their scope of use.

- Shark enclosures are suitable for bathers only. They are unlikely to be desirable at locations for other watersport activities such as surfing or diving.

Introduction

Shark attack is an infrequent, but highly disturbing risk for bathing and water sport participants (e.g. surfing, scuba diving, and snorkelling) in coastal areas. Responses to mitigate shark attack involve public policies that contend with the needs of public safety as well as the responsibility to protect threatened species (Neff, 2012). In Western Australia, a recent series of shark attacks has catalysed an analysis of how shark attack risk to the public in Western Australia can potentially be mitigated. Shark attacks are low probability-high consequence events, but there vivid nature ensures a high degree of media reporting and public concern (Neff, 2012).

Of the eleven species of sharks that have been implicated in fatal attacks on humans, three species are considered responsible for 86% of recorded human fatalities: the white shark (*Carcharodon carcharias*), the tiger shark (*Galeocerdo cuvier*) and the bull shark (*Carcharhinus leucas*, also called the river whaler) (ISAF, 2011).The number of shark attacks overall in many parts of the world is increasing, but this is a product of more people in the water, and not a per capita increase in the number of shark attacks (Cliff, 2006, West, 2011). In addition to changing human demographics, as there is little information on population trends for potentially dangerous shark species in WA, understanding whether the risk of shark attacks might be changing due to changes in the species' abundance (e.g. due to the protection that has been afforded to white sharks in Australia) is very complicated. Nevertheless, the Commonwealth Recovery Plan for the white shark aims to increase the population level of the species[1] under the assumption that this population actually has the ecological capacity to increase in abundance.

One shark mitigation strategy employed in some jurisdictions is the use of shark control programs. The objective of shark-control programs is to provide the public with protection against shark attack at popular beaches by a local reduction in large shark numbers. This is achieved by fishing for sharks directly off the beaches, using large-mesh gill-nets or baited drum-lines or both, thereby reducing the likelihood of a dangerous shark coming into contact with humans. Notable shark control programs are in operation in NSW and Queensland, and KwaZulu-Natal (South Africa). Shark-control programs are dedicated programs and do not represent specific fisheries for shark products for human consumption (e.g. flesh or fins), although some catch from the KwaZulu-Natal program is sold. Unlike small-mesh shark-exclusion nets that are deployed in waters sheltered from currents and wave action, shark-control gear on exposed beaches does not form an impenetrable barrier and hence does not eliminate the risk of shark attack. Shark control programs are used in tandem with education material that alerts water users to the potential dangers and how these dangers can be mitigated by avoiding being in the water at times of higher risk.

The use of various methods to potentially reduce the risk from shark attacks can potentially result in impacts on non-target species of conservation significance. Further, a number of shark species that pose a risk to humans are themselves of conservation significance, including one species that is listed as a Vulnerable species in Australia (i.e. the white shark). Globally, sharks are the focus of significant emerging conservation interest and there are a number of dedicated environmental campaigns in Australia that strongly advocate for the removal of shark nets in particular[2]. Methods that protect humans from sharks can represent an anthropogenic source of mortality that negatively impacts the populations of these species of conservation significance. With the exception of shark enclosures, the

[1] http://www.environment.gov.au/coasts/publications/gwshark-plan/pubs/greatwhiteshark.pdf

[2] For example: http://www.removesharknets.com/

use of other destructive methods such as baited drum-lines and shark nets do not guarantee that beaches are free of sharks of a size or species that pose a risk to humans.

The objectives of this study are as follows:

1. A literature review of studies and reports undertaken on shark meshing and the use of shark exclusion areas in other national and international jurisdictions.
2. An objective assessment of the pros and cons of shark meshing and shark exclusion areas with a specific focus on the Western Australian circumstances.
3. A summary of the equipment used and reported catches of sharks and by-catch species, including mortality/survival of the latter.
4. An overview of the administration and costs involved in the installation and ongoing maintenance of these systems.
5. An assessment of the effectiveness, logistical constraints and cost estimates of shark netting/meshing programs and shark exclusion areas at Western Australian beaches given the unique environmental and topographical conditions.

Shark Control and Exclusion Methods in Australia and Overseas

This section provides an overview of shark control and exclusion methods used in Australia and overseas. There are three locations where shark control has a long history – two in Australia (Queensland and NSW) and one in South Africa (KwaZulu-Natal). A number of smaller scale programs have been undertaken in New Zealand, Brazil and Hawaii and are included here for completeness. There are also a number of locations, including in Australia where shark exclusion methods have been used.

Queensland

In Queensland, Australia the Queensland Shark Control Program (QSCP) uses a combination of baited drum-lines and mesh nets to catch large sharks in near-shore coastal waters. The QSCP was established in 1962 following a number of fatal attacks. The QSCP deploys approximately 6.5 kilometres of nets (each 186 metres in length, and 6 metres deep with a mesh size of 50 cm). Baited drum lines have continually been in place at popular swimming beaches along the Queensland coastline since 1962 with the traditional bait of fish and elasmobranchs being replaced in the early 1990s with predominantly a mono-specific bait of whole mullet (*Mugil cephalus*). Shark control measures are undertaken by contractors. The QSCP is unique in being the only such program around the world that has a long history of using baited drum lines to catch large sharks to mitigate the risk of shark attack on bathing beaches. Overall, a combination of shark nets and drum-lines in Queensland is considered to be the best mix of apparatus to meet the objectives of public safety while reducing by-catch. The QSCP deploys gear at 37 beaches adjacent to population centres and tourist areas all year round (Table 1).

Table 1 Deployment of QSCP shark control gear along the Queensland east coast (From Gribble et al. 1998)

Area	Nets	Drumlines
Cairns	5	24
Townsville	2	42
Mackay	5	24
Rockhampton	0	54
Tannum Sands	0	12
Rainbow Beach	3	12
Sunshine Coast	10	48
Point Lookout	0	24
Gold Coast	11	32

The cost of the program was:

- $1.39 million in 2002/03;
- $1.79 million in 2003/04; and,
- $1.70 million in 2004/05.

The most significant component of the cost was payments to contractors (Anonymous, 2006).

It is not considered that the use of baited hooks attracts sharks into an area as the distance at which sharks are sensitive to olfactory stimuli (smell) is measured in hundreds of metres (Dudley et al., 1998). As such, the shark must already be in the general area to be attracted to the baited hook.

New South Wales

The NSW Department of Primary Industries manages the Shark Meshing (Bather Protection) Program in NSW, hereinafter referred to as the SMP. A total of 51 ocean beaches from Wollongong to Newcastle are currently netted between 1 September and 30 April each year using bottom-set mesh nets. The shark mesh nets do not act as a complete barrier to sharks reaching beaches as they are not permanently set in the water, do not cover the whole length of the beach, and do not extend from the water surface to the seabed.

Since it was introduced in Sydney in 1937, the SMP has been effective in reducing incidences of fatal shark attack at major metropolitan beaches, with only one fatal shark attack on a netted beach since the SMP began. However, a number of shark attacks that have resulted in injury have occurred at beaches where the SMP is in operation. Shark meshing was chosen as the bather protection method after other approaches such as complete exclusion of beaches were considered. Shark control measures are undertaken by contractors. Funding for the program is provided by the NSW Treasury and in 2007/08 the cost was in excess of $800,000 and was estimated to be $990,000 in 2009/10 (Green et al., 2009). The costs include contract prices, salary for shark meshing observers and shark technicians, shark meshing equipment (including acoustic deterrents) and an allocation for undertaking compliance audits.

The configuration of nets currently used in the SMP was standardised in 1972, including a change from surface-set to bottom-set nets. The nets are set parallel to the beach and anchored in approximately ten metres of water. The nets are multifilament flat braid polyethylene with a cork line and leadline, with 160 kg breaking strength, 150 m long, 6 m high, 50 - 60 cm mesh size when measured between knots when stretched taut, 12 to 14 meshes deep, 0.67 hanging coefficient for the net on the corkline and leadline (i.e. 33% slack hung in) and 0.74 coefficient for the sidelines at the end of each net. The hanging coefficient determines the looseness of the net, and a coefficient of 29.3% would mean that the nets hang squarely. Beach meshing contractors are required to check their nets every 72 hours (weather permitting).

In NSW, a small number of shark enclosures are deployed, but only in calm waters such as Sydney Harbour and Pittwater. In the early days of the SCP, some shark enclosures were trialled at exposed beaches, but Green et al. (2009) reports they were severely damaged by storm events.

KwaZulu-Natal (South Africa)

The KwaZulu-Natal Shark Control program is described in Cliff and Dudley (2011). The KwaZulu-Natal shark-control program on the eastern coast of South Africa commenced in 1952 when shark nets were introduced at Durban, following a spate of attacks on the city's beaches. While the primary tool remains shark nets, drum-lines have also been trialled. Between 1952 and 1961, Durban was the only net installation. There was a steep rise in the number of protected beaches and the length of netting in the 1960s. After 1970, few new installations were added, although the length of netting continued to increase, peaking at 45 km in 1992, when there were 44 protected beaches. In 1996/97, the cost of the program was estimated to be $3.6 million (Dudley and Gribble, 1999). Drum-lines have complemented or replaced shark nets at a number of locations and have reduced the level of by-catch (Cliff and Dudley, 2011).

Hawaii (United States)

Weatherbee et al (1994) documents the series of shark control methods implemented at a number of popular tourist locations in Hawaii between 1959 and 1976. The approach adopted by the various programs has focussed on longline fishing for sharks, and also the use of standard game fishing gear. Following another series of shark attacks in 1991 and 1992, renewed targeted shark fishing took place and approximately 100 tiger sharks were caught (Dudley, 2006).

Dunedin (New Zealand)

Dudley (2006) reports that three beaches are protected by two shark nets each set permanently between December and February. Each net has a length of 100 metres and a drop of 5.5 metres with a relatively small mesh size of 30 cm. The nets were first installed in 1969 after four shark attacks (three fatal) between 1964 and 1968. The nets caught 14 great white sharks between 1973-74 and 1975-76, but Dudley (2006) reports that no great white sharks have been captured since, and questions the useful of the nets, but notes they remain in place because of public opinion. In 2011, the Dunedin City Council cancelled the netting program for a saving of NZ$ 38,000.

Recife (Brazil)

Between 1992 and 2006 approximately 47 shark attacks resulting in 17 fatalities occurred at Recife (State of Pernambuco) (Henzin et al. 2008). Dudley (2006) summarises shark control activities in Brazil. In 2004, 20 drum-lines and two longlines with 100 hooks each were deployed. Each week, all lines are set at dusk and retrieved at dawn for a four day period that encompasses the weekend. The longlines are set about 1 km from the shore and parallel to the coast, and the drum-lines are set about 200 metres from the shore.

The Use of Shark Exclusion Methods

Methods to completely exclude sharks from an area have been employed in a number of locations. Shark exclusion nets are the principal methods of bather protection in Hong Kong since the early 1990s when a series of shark attacks resulted in six fatalities. The nets are in place nine months of the year at all gazetted beaches and there have been no fatalities since their installation. The Hong Kong nets are designed and engineered to withstand 10 metre waves. Beaches in the Hong Kong area are very short stretches of sand interspersed between large rocky headlands meaning that beach activities are restricted to a relatively small part of the coastline. An example of shark exclusion nets in Hong Kong are shown in Figure 1 and the relatively short length of beaches are also illustrated. An average net enclosure would be 500 m long and either semi-circular or rectangular in shape. They are diver-inspected a minimum of twice a week, and independent verification is required. They also exclude floating refuse, and clearly define the swimming area.

Figure 1 An example of shark exclusion nets in the Repulse Bay area of Hong Kong.

There is also a proposal to deploy a shark exclusion net in Fish Hoek Bay (Cape Town) following a shark attack in that location.[3] The proposed exclusion net is 350 metres long.

Swimming enclosures are employed in the calm waters of the Gold coast region, Pittwater (NSW) and these are paid for and maintained by local councils. A small swimming enclosure is installed at Wallaroo (South Australia) and is used mostly for swimming lessons[4]. In Western Australia, a feasibility study of a proposed shark exclusion net at Coogee Beach (Cockburn Sound) was undertaken by the local council[5]. However, it was recommended that the installation of a net not proceed. Among the concerns raised that led to the recommendation included cost, potential liability, and uncertain

[3] http://www.scenicsouth.co.za/2012/03/shark-net-barrier-for-fish-hoek-letter-from-lifesavers/
[4] http://www.wallaroocommunity.org/Beaches.html
[5] http://www.cockburn.wa.gov.au/Meetings_and_Minutes/Minutes_and_Agendas/2012/May/ITEM_16_1.pdf

community attitude which could result in the area being avoided or alternatively over-utilised. The initial capital cost for the enclosure was estimated to be $150,000 with operating and depreciation costs of $72,500 per year.

Performance and Impacts of Shark Control Programs

There have been a number of studies and reports that have considered and addressed various aspects of bather protection from sharks. Overall, the literature can be divided into studies and reports that: 1) detail the effectiveness of the various programs, 2) document catch composition including by-catch captured in the various apparatus, and 3) trial and assess methods to reduce by-catch and improve the survival rates of by-catch when captured.

Effectiveness of Methods for Shark Hazard Mitigation

Shark control programs are generally considered to have improved the safety of people in the water. The main lines of evidence that support this assertion are comparison of shark attacks before and after implementation of shark control measures, and comparisons at locations with and without such measures. Shark mesh nets do not create a physical barrier to sharks; rather, they affect the local and potentially overall abundance of shark species responsible for attacks on humans. In effect, the logic is the less large sharks that are present, all things being equal, the less chance of an attack occurring. Approximately 40% of shark entanglements occur on the beach side of the nets, because sharks are able to swim over and around the nets. Shark attacks are however, recorded from beaches where shark nets are deployed (Green et al., 2009; Cliff and Dudley, 2011). Prior to their installation, there were 37 shark attacks (18 fatal) at NSW beaches and following installation there were 23 (1 fatal) (Green et al., 2009). The rate of fatalities is highly unlikely to be a result of meshing activities, but is likely to be a function of improved beach front response time and first aid procedures.

In Hawaii, Weatherbee et al. (1994) concluded that the effectiveness of shark control program in that location at removing large sharks in coastal waters is likely to have been previously overstated. They also concluded that the shark control program had no measurable effect on shark attacks. This was due in part to the methods employed and the sporadic nature of the program.

As well as the obvious human cost that results from shark attacks, there can be a perceived economic cost to the coastal tourism industry adjacent to where shark attacks or “scares” occur and also a belief that “unprotected beaches” may pose a relatively greater risk to humans than those that are protected, and thus may be avoided. While statements have been made regarding the economic benefits to coastal tourism from shark control (e.g. Gribble and Dudley, 1999), this review has not identified any published empirical information that supports or refutes claims of specific economic costs to coastal tourism from shark attacks in Australia. Dudley (2006) does report a third party estimate of a $US20 million tourism loss in the Brazilian state of Pernambuco after a series of shark attacks. However, this reported figure was from an unpublished source, and the method to obtain the estimate and its accuracy, and whether other confounding factors (e.g. macro-economic considerations) were significant in determining a change in economic activity cannot be determined. Further, this review has not identified any published information which documents that the level of protection from shark attack is a determinant of choosing a location for beach based water activities in Australia. Anecdotal historical information does strongly suggest though that the avoidance of beaches where “spates” of shark attacks occurred did result at KwaZulu-Natal and around Sydney, both of which gave the initial impetus to the shark control programs in those areas.

Following a shark attack, short term measures may be taken to attempt to capture the shark responsible for an attack to prevent it from attacking again. When such approaches have been taken, they have typically failed to capture the shark and this is in part at least due to the movement patterns of the animals which can be considerable (Holland et al., 1999).

Catch Composition - By-catch and its Mitigation

Shark control programs can pose significant risk to a number of non-target species, and this has been long established (e.g. Patterson, 1979). The risk posed is related to the gear deployed and the spatial overlap between the gear and individuals of the species concerned. When an animal is captured, in many instances it can be released alive. There have been a number of studies that have collated information on by-catch in shark control programs and key examples are included in Tables 2 and 3. The by-catch tends to be numerically dominated by elasmobranch species (sharks and rays) that are not implicated in unprovoked attacks on humans. While, early data is not completely reliable in terms of species identification and potential under-reporting, overall the information available on by-catch is considerable. Where data is available, there are clear regional differences in composition of by-catch (e.g. Dudley, 1996; Green et al., 2009), and there can also be significant seasonal differences (Green et al., 2009).

The environmental impacts shark control programs can have on some marine fauna is recognised in legislation. In NSW, it is listed as a Key Threatening Process (KTP) under both the NSW *Fisheries Management Act 1994* (FM Act) and the NSW Threatened Species Conservation Act (TSC Act) as it was identified to adversely impact two or more threatened species. It was identified that at the time of assessment, the shark meshing program in NSW had negative impacts on a number of threatened species including:

- Grey nurse shark;
- Loggerhead turtle;
- Dugong;
- Great white shark;
- Green turtle;
- Leatherback turtle;
- Humpback whale; and,
- Australian fur-seals.

Shark Control activities were also nominated as a key threatening process under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The nomination however was deemed ineligible for inclusion as a KTP under that legislation as it was only deemed to impact one listed species – the grey nurse shark.

Table 2 Catch Information for the NSW Shark Meshing Program from 1990/91 to 2007/08 (From Green et al. 2009)

Species (Common Name)	Number
ELASMOBRANCHS	
Hammerheads	1292
Stingrays	1269
Whalers	536
Angel sharks	259
Port Jackson sharks	107
Great white shark	100
Sevengill shark	92
Tiger shark	49
Thresher shark	40
Shortfin mako	31
Grey nurse shark	15
OTHER ANIMALS	
Dolphins	52
Turtles	47
Finfish	43
Whales*	6
Seal	4
Penguin	1
Dugong	1

* Green et al (2009) notes that this includes false killer whales which are members of the dolphin family.

Table 3 Catch and Size Distribution of Sharks and Other Animals Caught at the Mzamba Shark Nets (KwaZulu-Natal) between 1995-1998 (Modified from Dudley et al. 1998).

Scientific Name	Common Name	Catch No.	Released	Size Range (cm)
ELASMOBRANCHS				
Carcharhinus obscurus	Dusky shark	185	34	108-275
Carcharhinus brachyurus	Copper shark	73	8	136-220
Carcharias taurus	Grey nurse shark	44	19	95-214
Carcharhinus brevipinna	Spinner shark	39	7	147-212
Sphyrna zygaena	Hammerhead shark	37	3	70-150
Squatina africana	African angelshark	22	4	48-121
Carcharhinus limbatus	Blacktip shark	19	2	151-190
Sphyrna lewini	Scalloped hammerhead	18	1	60-140
Manta birostris	Manta ray	15	10	200-450
Rhynchobatus djddensis	Shovelnose ray	15	9	130-200
Carcharodon carcharias	Great white shark	13	0	148-231
Galeocerdo cuvier	Tiger shark	12	6	97-211
Myliobatus aquila	Eagle ray	4	1	60-70
Mobula spp.	Devil ray	4	3	132-230
Gymnura natalensis	Butterfly ray	3	2	39-125
Carcharhinus leucas	Bull shark	3	1	146-200
Pteromylaeus bovinus	Bull ray	3	1	60-150
Carcharhinus plumbeus	Sandbar shark	2	0	126-135
Isurus oxyrinchus	Shortfin mako shark	2	0	214-221
Sphyrna mokarran	Great hammerhead	1	0	192
CETACEANS				
Tursiops truncatus	Bottlenose dolphin	8	0	152-257
Delphinus delphis	Common dolphin	1	0	226
TELEOSTS				
Thunnus albacares	Yellowfin tuna	2	0	101-103
Argyrosomus japonicus	Mulloway	1	0	123
MARINE REPTILES				
Chelonia mydas	Green turtle	3	1	64

Marine Turtles

There is a high capture of marine turtles in the QSCP as a result of the large number of marine turtles that are in Queensland waters, and utilisation of a number of beaches by marine turtles for nesting. In Queensland, the average yearly capture of marine turtles in nets and drum-lines between 1962 and 1995 was 119.4 animals per year (Gribble et al., 1998). Historically turtle by-catch was not recorded to the species level, so long-term records of the capture of individual species are not in existence, however on the basis of interviews with shark contractors, Gribble et al. (1998) concluded that most turtles caught in nets were the vulnerable green turtle (*Chelonia mydas*), while most turtles caught on drum-lines were the endangered loggerhead turtle (*Caretta caretta*). Many turtles captured were released alive (Gribble et al., 1998), and tagging shows that individuals released from drum-lines are frequently recaptured, and this potentially overestimates the number of individual turtles that have been historically captured. However, repeated hooking may cause subsequent mortality if the turtle's injuries are significant. In NSW and KwaZulu-Natal marine turtle capture is much more infrequent, but nonetheless is still recorded (Dudley et al., 1998; Green et al., 2009).

Dolphins

Dolphins are captured in each of the three Shark Control Programs that use mesh nets. They are also recorded scavenging on the baits of drum-lines (Sumpton et al., 2010). In the NSW Shark Control Program, Krogh and Reid (1996) identified a total of 94 dolphins and "porpoises" were recorded in the shark meshing catches between 1950 and 1993, with a disproportionate number captured at Newcastle. Most of these were caught in the 1960s and 1970s and more recent catches average about one or two per year. Paterson (1990) recorded 520 dolphins caught in the Queensland shark meshing program between 1962 and 1988. He identified three species of dolphins in the southern Queensland shark meshing catches: the bottlenose dolphin (*Tursiops truncatus*)*;* the common dolphin (*Delphinus delphinus*)*;* and the Indo-Pacific humpback dolphin (*Sousa chinensis*). Only 13% of captured dolphins were recorded as released alive, although improvements in survival were predicted (Gribble et al., 1998). Cliff and Dudley (2011) also recorded low survival of dolphins captured in shark nets at KwaZulu-Natal.

Whales

Overall, the frequency of whale captures in shark control programs is low (Gribble et al., 1998; Green et al., 2009). For example, between 1962 and 1995, the QSCP captured eight humpback whales (*Megaptera novaengliae*) of which only five were released alive. In Queensland however; there is concern about the obstruction of humpback whale migratory routes from a number of shark control nets (Gribble et al., 1998). When a whale does become entangled in Queensland it frequently attracts media attention[6].

Pinnipeds

Compared to the other species of conservation interest discussed, the frequency of interaction is relatively low. This is largely due to shark control programs not implemented in areas where pinniped populations are naturally absent, or at the very least low. The capture of seals however is documented in the NSW Shark Control Program (Green et al., 2009).

---

[6] Some examples include: http://www.brisbanetimes.com.au/queensland/baby-whale-freed-from-gold-coast-nets-20100904-14uvi.html and http://subtropic.com.au/2010/09/16/heartless-and-inhumane-remove-shark-nets-in-whale-season/

Dugong

In Queensland Shark Control Program has been a significant source of anthropogenic mortality of dugong. In particular, the dugong capture in a number of nets was very high in early days of the QSCP (Marsh et al. 2001). In effect, the QSCP effectively made a significant contribution to "fishing down" dugong populations at the local level, and the cumulative impacts of these local declines is likely to be significant for the dugong population overall, given the life history of the animal, which is long-lived and has low fecundity.

Other Elasmobranch and Finfish Species

Species of sharks and rays that are not implicated in unprovoked shark attacks are frequently captured and generally make up the numerically dominant component of the bycatch (e.g. Weatherbee et al., 1994; Dudley et al., 1998; Green et al., 2009; Cliff and Dudley, 2011). Some of these species are recognised nationally and internationally as threatened species, while others are also garnering conservation attention. The survival of captured elasmobranchs is highly variable between species. In KwaZulu-Natal, Cliff and Dudley (2011) identify that tiger and raggedtooth (= grey nurse) sharks had the highest survival rates of approximately 40%, while very few hammerhead sharks were found alive.

Minimising Impacts and Alternative Methods

There have been a number of methods which have been trialled and evaluated in an attempt to reduce the impact of shark control methods on non-target species, while still providing a level of protection for beach users. In NSW, shark mesh nets are in place seasonally during the summer months which is the peak period of beach usage. This management approach reduces the overall soak time and hence, the number of non-target species that are caught annually.

The use of acoustic alarms or "pingers" has been trialled in Queensland with the aim of reducing by-catch of marine mammals – cetaceans and dugong. The use of pingers on shark control nets has been assessed in Queensland. The use of pingers was considered to result in an 18–90% reduction in shark catches (Anonymous 2001), which contradicted earlier observations reported in Gribble et al. (1998). The decrease in shark capture in nets fitted with pingers was regarded as a real decrease because drum-line catches at the same locations did not decrease to the same degree. In NSW, prior to the installation of pingers, an average of 3.3 dolphins were caught per year from 1990 - 2000, but since pingers were introduced the average has been reduced to 2 dolphins per year (Green et al., 2009). From the information in Green et al. (2009), it is not possible to determine whether the use of pingers has resulted in a statistically significant decrease in dolphin capture. In KwaZulu-Natal, on several occasions, bottlenose and Indo-Pacific dolphins were caught within ten metres of a dolphin pinger, suggesting that animals may have been attracted to the sound source (Cliff and Dudley, 2011).

There has also been considerable development and trialling of pingers in commercial net fisheries, and this information has relevance for nets used in shark control programs. Focusing on cetaceans, there has been a significant amount of overseas research focussing on the question of whether pingers work or not with considerable debate ensuing (e.g. Barlow and Cameron, 2003; Dawson and Lusseau, 2005; Teilmann, 2006). There are a number of particular challenges for testing the hypothesis in the field that pingers result in reduced cetacean by-catch and these include: pseudo-replication (the same dolphin and its response may be counted more than once), the generally low level of interactions leading to low statistical power, and the potential for habituation by dolphins to the devices (Dawson and Lusseau, 2005; Tielmann et al., 2006).

Sumpton et al. (2010) documented trials of different hook modification and baits on drum-lines that were aimed at reducing by-catch (Figure 2). Double hook lines did not differ significantly in shark catch compared with the standard single hook arrangement, but were more likely to catch green turtles. Plastic hook guards reduced the turtle bycatch by almost 70% but shark catch also declined significantly. Both mesh guards and hook shrouds dramatically reduced scavenging of baits by dolphins in the short-term but they may also increase the turtle catch and their impact on shark catch was inconclusive. None of the baits tested significantly reduced the incidental capture of marine turtles but several baits (particularly frozen shark flesh) reduced scavenging by dolphins.

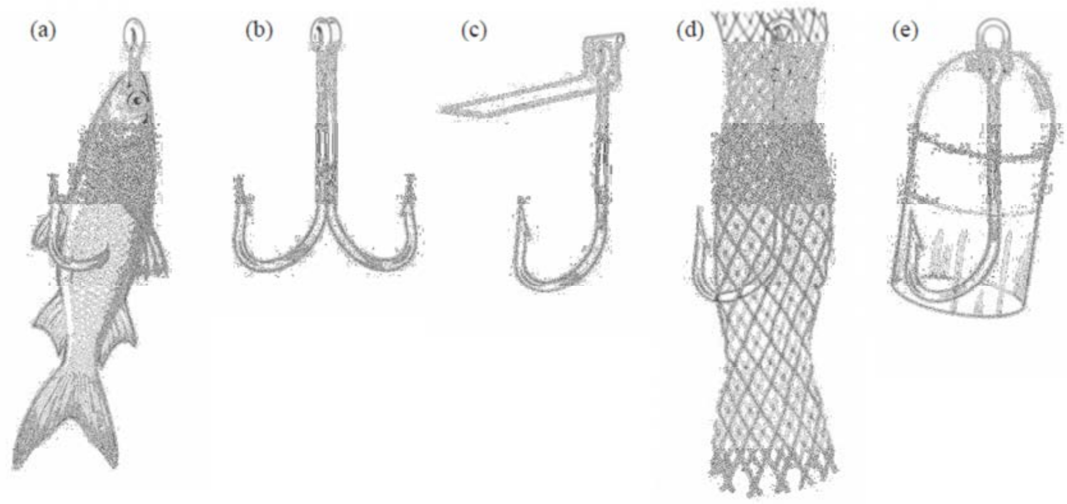

Figure 2 Hook arrangements trialled by Sumpton et al. (2010) to reduce bycatch. a) Single hook baited with mullet (standard traditional approach), b) Double hook, c) Hook with plastic guard, d) Hook with mesh guard, and e) hook with shroud guard.

Methods have also been employed to attempt to maximise the survival of captured animals. The regular checking of shark nets (weather permitting) is the key aspect.

An approach to reduce the actual incidence of capture of sharks in general is to stimulate an approaching shark's electro-sensory system with the use of powerful permanent magnetic fields. By doing this, sharks can be repelled from the general area of the net. In a preliminary quantitative study, Connell et al (2011) tested the use of permanent magnets on juvenile lemon sharks (*Negaprion brevirostris*) and found that permanent magnetic fields could exclude sharks from an area. However, Connell et al. (2011) also identified that further work needed to be undertaken on other sharks species including key species implicated in shark attacks, and impacts on other species. Green et al. (2009) reports that based on existing technologies, electrical deterrents were unlikely to be feasible and ongoing costs of the approach would have been prohibitive. While ongoing work on electrical repellents is being undertaken by the Natal Sharks Board, it is recognised that the deployment of electrical devices in surf conditions represents a significant (and as yet to be overcome) engineering challenge (Dudley et al., 2006). Chemical deterrents have also been trialled but their success under natural conditions is highly unlikely.

An Evaluation of the Applicability of Shark Control Methods for Western Australia

The WA coastline is considered to be a potential migratory pathway for great white sharks migrating between South Australia, the Southern and Indian oceans, and South Africa (Bruce et al., 2006). The great white shark is the main species implicated in shark attacks in WA. To date, Shark Attack Response Plans have been operational in WA since 2001 and these consist of conducting aerial surveillance patrols and public education strategies in an attempt to reduce risk of shark attack without the use of direct control measures. Following the recent shark attacks, the WA government is considering a potential range of additional measures and approaches to reduce the risk of shark attack.

As it currently stands, the *Fish Resources Management Act 1994* does not contain objectives related to public safety. In Queensland, the *Fisheries Act 1994* was amended to include the following: "*Despite the main purpose of this Act, a further purpose of this Act is to reduce the possibility of shark attacks on humans in coastal waters of the State adjacent to coastal beaches used for bathing.* Should the Western Australian Department of Fisheries decide to implement a shark control program, the objectives of the Act may need to be amended to include an objective related to reduce the possibility of shark attack in coastal waters.

Shark control measures in Queensland and NSW are concentrated at specific regions where the number of water users is high. Recent shark attacks in Western Australia have occurred over a relatively large spatial scale. This could in part be due to the migratory nature of the white sharks, which is the species implicated in the recent Western Australian attacks. This relatively large spatial scale means that a prioritisation process would need to be undertaken to identify potential locations for shark control measures to be introduced.

When Shark Control Programs were introduced in Queensland, New South Wales and KwaZulu-Natal, they were done so at a time when the conservation needs of sharks (and other marine animals) were a lower societal priority than they are today. Cliff and Dudley (1992) identify that in the Cape waters of South Africa, despite a number of shark attacks in that region where shark control is absent, the growing conservation ethic among the public is unlikely to allow the installation of shark control nets in those waters. This is a challenge also faced by WA.

A key environmental issue with the use of mesh nets for shark control in both Queensland and NSW, is that catch rates of by-catch species were exceptionally high in the years just after placement of the nets in the water and then declined to relatively constant levels (Green et al., 2009). The most likely explanation for this is that the mesh nets "fished down" the local populations of a number of by-catch species. This is not surprising since the aim of shark nets is to fish down local fauna – specifically larger individuals of key species. It follows that local by-catch species are also likely to be fished down. In the case of dugong in Queensland and grey nurse sharks in NSW, the declines in the local populations are important in the context of the population as a whole. Similarly, in Western Australia the implementation of shark nets is likely to result in very high catch rates of by-catch during the initial few years.

In NSW and Queensland, their Shark Control Programs are long standing. If Western Australia proposed to implement shark control measures using similar apparatus, it is likely that the activity (= action) would need to be referred to the Commonwealth Government under the *Environment Protection and Biodiversity Conservation Act 1999* to determine of the action is likely to affect Matters of National Environmental Significance (MNES). The key matter would be potential impacts on nationally threatened species or ecological communities, and listed migratory species.

Potential nationally threatened species of relevance to any proposed shark control activities in Western Australia includes:

- White shark (vulnerable, and a species implicated in shark attacks);
- Grey nurse shark (vulnerable, west coast population);
- Green sawfish (vulnerable);
- Freshwater sawfish (vulnerable);
- Loggerhead turtle (endangered);
- Leatherback turtle (endangered);
- Green turtle (vulnerable)
- Humpback whale (vulnerable);
- Southern right whale (endangered) and,
- Australian sea lion (vulnerable)

In the case of the NSW and Queensland shark control activities, they have little spatial overlap with pinnipeds. However, if shark nets were installed off southern Western Australian beaches, then these mammals, in particular the Australian sea lion (*Neophoca cinerea*) may also be captured. They may also hang around the nets and forage upon captured animals. Marine turtle interactions are likely to be significantly less than Queensland in the Perth and southern Western Australian regions due to latitude, however, loggerhead, green and leatherback turtles do utilise the area and individuals would potentially be at threat of capture. The threat of capture of marine turtles is likely to higher as you move further north.

Given the numerous potential impacts on MNES, it is highly likely that the WA Government would need to prepare an EPBC Referral for submission by the Commonwealth which would need to outline the proposed activity in detail, the potential impacts on MNES, how potential impacts will be mitigated, and alternative approaches considered instead of the proposed activity. If appropriate “in-house” expertise exists then the WA Department of Fisheries could prepare the Referral themselves or alternatively it could be out-sourced. Upon receiving the EPBC Referral, the Commonwealth Environment Minister will make a decision as to whether the activity is a “controlled action” or not. If it is not a controlled action then no further assessment by the Commonwealth is required. If the Commonwealth Environment Minister deems the activity a controlled action then he or she will decide on the level of environmental assessment. From lowest to highest, the levels of environmental assessment are:

- Preliminary documentation (PD);
- Public Environment Report (PER);
- Environmental Impact Assessment (EIS); and,
- Commission of Inquiry (CI).

While the decision on whether an activity is a controlled action or not, and the level of environmental assessment required if it is deemed to be, rests solely with the Commonwealth Minister, the author will put forward his view, based on extensive experience, of the most likely outcome. It is the author’s opinion that the Commonwealth Minister will deem the activity a controlled action if an EPBC Referral was prepared and lodged. Unlike most other activities where impacts on listed threatened species are incidental, shark control programs actually target the removal of one threatened species – the great white shark. Further though as this report has highlighted, they are well known to also impact other threatened species. The Shark Control Programs in both Queensland and New South Wales were in place prior to the establishment of the *EPBC Act 1999* and were not the subject of environmental assessment by the Commonwealth prior to their introduction.

A shark control program is not a fishery as it does not aim to take fisheries resources for trade or commerce. As such, a strategic assessment of fisheries under Part 10 of the EPBC Act would not be an appropriate assessment pathway. It is the author's opinion that the Commonwealth Minister would deem either a PER or an EIS as the appropriate level of environmental assessment, with an EIS the most likely. It is highly likely that the WA Department of Fisheries would need to outsource preparation of the EIS. It is difficult to provide an exact estimate of cost as there are no terms of reference available and no specific proposal that would indicate any desired scale of shark control activities, a rudimentary estimate would be in the vicinity of $800,000 to $1,000,000.

The exact species that are likely to be impacted by the implementation of shark control measures will be influenced by the exact location and timing of these measures. However, assuming a focus in the summer months and at beaches in the Perth and beaches where recent shark attacks have occurred, as well as species that are listed as threatened by the Commonwealth, significant components of by-catch are likely to include:

- Sandbar shark (*Carcharhinus plumbeus*);
- Dusky shark (*Carcharhinus obscurus*);
- Whiskery shark (*Furgaleus macki*);
- Bottlenose dolphins (*Tursiops truncatus* and *Tursiops aduncus*); and

Although the capture of penguins is likely to be rare, it may still feasibly occur if a net was sighted near known penguin rookeries and feeding habitat (such as Penguin Island in Warnboro sound, the site of a fatal shark attack in December 2008). There are a number of other whale species that frequent Western Australian waters, including blue whales (*Balaenoptera musculus*) that generally inhabit deeper waters and would therefore be unlikely but not impossibly be caught by shark control equipment. There is historical entanglement of humpback whales with commercial fishing gear as the whales move southwards in Spring when they travel closer to the coast. As such, entanglement of humpback whales in shark nets for bather protection is a clear possibility. Overall, it is not possible to predict the exact number of animals of each species that would be captured in Western Australia should Shark Control Methods be implemented.

Shark control programs have gathered biological information, often in a structured and standardised way; that makes a significant contribution to the knowledge base of sharks, and in some instances has also gathered similar information for the marine animals of conservation significance. This in itself however, is not a specific reason to commence measures to protect humans from shark attack in Western Australian waters.

There is scope to further consider shark enclosures in WA as a method for providing bather protection at selected locations. Enclosures have the advantage of providing a direct physical barrier that prevents sharks from accessing an area and do not target the reduction in shark numbers or have bycatch of other large species like shark nets do. While enclosures are more suitable for calmer waters, new innovations in materials (e.g. marine mesh that is used in offshore aquaculture), may increase the potential scope of their use. Enclosures would provide a shark free area for bathing, however, they are unlikely to be a highly desirable location for other watersports such as diving, surfing and surf-skiing.

Discussion

Shark meshing using fixed nets is the most commonly applied approach for shark control, although drum-lines are also used and are considered a more selective approach (Gribble et al. 1998). This selectivity however also extends to the species of sharks captured. It has been identified that drum-lines are not as effective as nets at catching one of the shark species commonly implicated in shark attack - the bull shark (*Carcharhinus leucas*) (Cliff and Dudley, 2011). They are however identified as being effective for other species implicated in shark attack. Further, drum-lines can still have high by-catch of threatened species including some marine turtles and mammals.

As well as large sharks that pose a potential risk to humans, shark control programs also capture marine mammals, marine turtles, sharks and rays that are not implicated in unprovoked attacks, and some species of finfish. While the survival of captured species is highly variable, the largely indiscriminate nature of shark control nets in particular is cause for conservation concern. In Western Australian, dolphins, are likely to be at significant risk. Shark control measures may have significant implications for current and future dolphin-based tourism activities.

Weighing-up the competing needs for human safety and the conservation of threatened species is not a simple task. The conservation of sharks (including dangerous species) has higher community priority now, than it did when the major shark control programs were introduced in Australia and South Africa. The conservation of marine animals in general is also higher, and societal acceptance of a large number of animals being killed to increase the level of protection of people voluntarily undertaking a water-based recreational pursuit is also less.

Currently, the use of pingers (acoustic alarms) on shark mesh nets is not a panacea for reducing by-catch. Experimental work to unequivocally demonstrate their effectiveness or otherwise is difficult, but certainly not impossible. There would appear to be a clear difference in the effectiveness of pingers based on the by-catch species and biophysical characteristics of the environment. In at least once case reported in Cliff and Dudley (2011) the use of pingers is implicated in attracting dolphins to the area where nets are deployed resulting in a higher chance of interaction between the nets and the animals. The trialling of pingers is likely to continue for the purposes of minimising by-catch in shark meshing and commercial net fishing in general. The use of large scale “electrical shields” has also been trialled, but the results using existing technologies are not encouraging and this method is likely to remain unfeasible and cost prohibitive for a number of years, but is likely to be a source of further research.

An important consideration for Western Australia is whether shark nets will be effective at reducing the populations of great white sharks that are implicated in shark attacks. Great white sharks are migratory, while shark nets aim to reduce the local abundance of sharks. It would be expected that they would be more effective at reducing population of sharks that are more localised (e.g. bull sharks, which are extremely uncommon outside of the Swan-Canning river system). Consistent with this, in Queensland it is documented that great white shark catches in shark nets have not altered, while the catch of whalers have declined (Paterson, 1990). From the available information from existing shark control programs it is not possible, however, to determine the effectiveness of shark control programs at mitigating the risk of shark attack from a particular shark species.

If the Western Australia Department of Fisheries proceeds with the implementation of a Shark Control Program using nets and or drum-lines, it should be recognised that it will have significant upfront costs as well as significant ongoing costs which are likely to be in the vicinity of a $1 million per year. The upfront costs would include an amount for environmental approvals which could be very significant, as well as the need to develop management protocols, data collection systems etc. If an Environmental

Impact Statement or a Public Environment Report were required by the Commonwealth, the timeframe to complete the environmental assessment and to gain the necessary approvals would most likely be 18 months to two years. There is no guarantee that should a Commonwealth approval be deemed necessary, that it would be granted by the Commonwealth.

There is scope to introduce shark enclosures which do constitute a barrier to sharks accessing a beach. This could be implemented on a seasonal or permanent basis. This approach is best implemented in calmer waters as heavy surf can damage gear, although new materials suggest that the approach can be more effective than has historically proven the case. Shark enclosures are the principal approach to protect swimmers in Hong Kong and since their installation, no fatalities have been recorded. Shark enclosures are only likely to be effective for bathers, but they will however avoid the significant environmental impacts that arise from using shark nets or drum-lines. A range of location specific issues would need to be addressed if shark enclosures were implemented and this includes local topography and the presence of existing structures (e.g. jetties), and any local changes to coastal processes (e.g. sand movement) as a result of the shark enclosures. Ongoing maintenance costs would need to be estimated and budgeted for. Liaison with City of Cape Town on their trial of a shark enclosure would be beneficial and would also assist understanding of whether shark enclosures changed beach usage patterns. Shark enclosures can be constructed and maintained by local authorities.

References

Anonymous (2001) *Review of Queensland Shark Control Program*. Queensland Department of Primary Industries, Brisbane.

Anonymous (2006) *A Report on the Queensland Shark Safety Program*. Queensland Department of Primary Industries, Brisbane.

Barlow, J. and Cameron, G.A. (2003) Field experiments show that acoustic pingers reduce marine mammal by-catch in the California drift gill net fishery. *Marine Mammal Science* 19(2): 265-283.

Bruce, B.D., Stevens, J.D. and Malcolm, H. (2006) Movements and swimming behaviour of white sharks (*Carcharodon carcharias*) in Australian waters. *Marine Biology* 150: 161-172.

Cliff, G. (2006) A review of shark attacks in False Bay and the Cape Peninsula between 1960 and 2005.In Nel D.C. and Peschak TP (eds) *Finding a balance: White Shark Conservation and Recreational Safety in the Inshore Waters of Cape Town, South Africa*. WWF South Africa Report Series - 2006/Marine/001.

Cliff, G. And Dudley, S.F.J. (2011) Reducing the environmental impact of shark-control programs: a case study from KwaZulu-Natal, South Africa. *Marine and Freshwater Research.* 62: 700-709.

Dawson, S.M. and Lusseau, D. (2005) Pseudoreplication problems in studies of dolphin and porpoise reactions to pingers. *Marine Mammal Science*. 21(1): 175-176.

Dudley, S. F. J. (1997) A comparison of the shark control programs of New South Wales and Queensland (Australia) and KwaZulu-Natal (South Africa). *Ocean and Coastal Management* 34(1):1-27.

Dudley, S.F.J. (2006) International review of responses to shark attack. In Nel D.C. and Peschak TP (eds) *Finding a balance: White Shark Conservation and Recreational Safety in the Inshore Waters of Cape Town, South Africa*. WWF South Africa Report Series - 2006/Marine/001

Dudley, S. F. J., Haestier, R. C., Cox, K. R. and Murray, M. (1998) Shark control: experimental fishing with baited drumlines. *Marine and Freshwater Research* 49: 653–661.

Dudley, S. F. J., and Gribble, N. A. (1999). Management of shark control programmes. In Shotton, R. (ed) *Case Studies of the Management of Elasmobranch Fishes*.

Dudley, S.F.J., Cliff, G., Anderson-Reade, M.D., Charter, G.E. and von Blerk, P.W. (2006) Shark deterrent options for Cape Town. In Nel D.C. and Peschak TP (eds) *Finding a balance: White Shark Conservation and Recreational Safety in the Inshore Waters of Cape Town, South Africa*. WWF South Africa Report Series - 2006/Marine/001

Green, M., Ganassin, C. and Reid, D.D. (2009) *Report into the NSW Shark Meshing (Bather Protection)* Program. NSW Department of Primary Industries.

Gribble, N.A., McPherson, G. and Lane, B. (1998) Effect of the Queensland Shark Control Program on non-target species: whale, dugong, turtle and dolphin: a review. *Marine and Freshwater Research* 49: 645-651.

Hazin, F.H.V, Burgess, G.H., Carvalho, F.C. (2008) A Shark Attack Outbreak Off Recife, Pernambuco, Brazil: 1992-2006. *Bulletin of Marine Science*, 82(2): 199-212.

Holland, K.N., Weatherbee, B.M., Lowe, C.G. and Meyer, C.G. (1999) Movements of tiger sharks (*Galeocerdo cuvier*) in coastal Hawaiian waters. *Marine Biology* 134(4): 665-673.

International Shark Attack File (2011) ISAF Statistics on Attacking Species of Shark. Species of shark implicated in attacks around the world.

Krogh.M. and Reid.D. (1996) Bycatch in the protective shark meshing programme off south-eastern New South Wales. *Biological* Conservation 77: 219-226.

Last, P.R. and Stevens, J. (1994) *Sharks and Rays of Australia.* CSIRO Publishing (Melbourne).

Marsh, H., De'ath, G., Gribble, N. and Lane, B. (2001) *Shark Control Records Hindcast Serious Decline in Dugong Number off the Urban Coast of Queensland.* Great Barrier Reef Marine Park Authority Research Publication No. 70.

Neff, C. (2012) Australian beach safety and the politics of shark attacks. *Coastal Management* 40(1): 88-106.

O,Connell, C.P., Abel, D.C., Gruber, S.H., Stroud, E.M. and Rice, P.H. (2011) Response of juvenile lemon sharks, *Negaprion brevirostris*, to a magnetic barrier simulating a beach net. *Ocean and Coastal Management*. 54: 225-230.

Paterson, R.A. (1979) Shark meshing takes a heavy toll of harmless marine animals. *Australian Fisheries*. 38: 17-23.

Paterson, R. A. (1990) Effects of long-term anti-shark measures on target and non-target species in Queensland, Australia. *Biological Conservation*. 52: 147-59.

Sumpton, W. D., Lane, B. and Ham, T. (2010) Gear modifications and alternative baits that reduce bait scavenging and minimize by-catch on baited drum-lines used in the Queensland Shark Control Program. *Proceedings of the Royal Society of Queensland*. 116: 23–35.

Tielmann, J., Miller, L.A., Kirketerp, T., Hansen, K. and Brando, S. (2006) Reactions of captive harbor porpoises (*Phocoena phocoena*) to pinger-like sounds. *Marine Mammal Science.* 22(2): 240-260.

Weatherbee, B.M., Lowe, C.G. and Crow, G.L. (1994) A review of shark control in Hawaii with recommendations for future research. *Pacific Science* 48(2): 95-115.

West, J. (2011) Changing patterns of shark attack in Australian waters. *Marine and Freshwater Research* 62: 744–754