Do Alternative Shark Attack Prevention Technologies Exist for North Stradbroke Island, Queensland, Australia?

Ethan Estess
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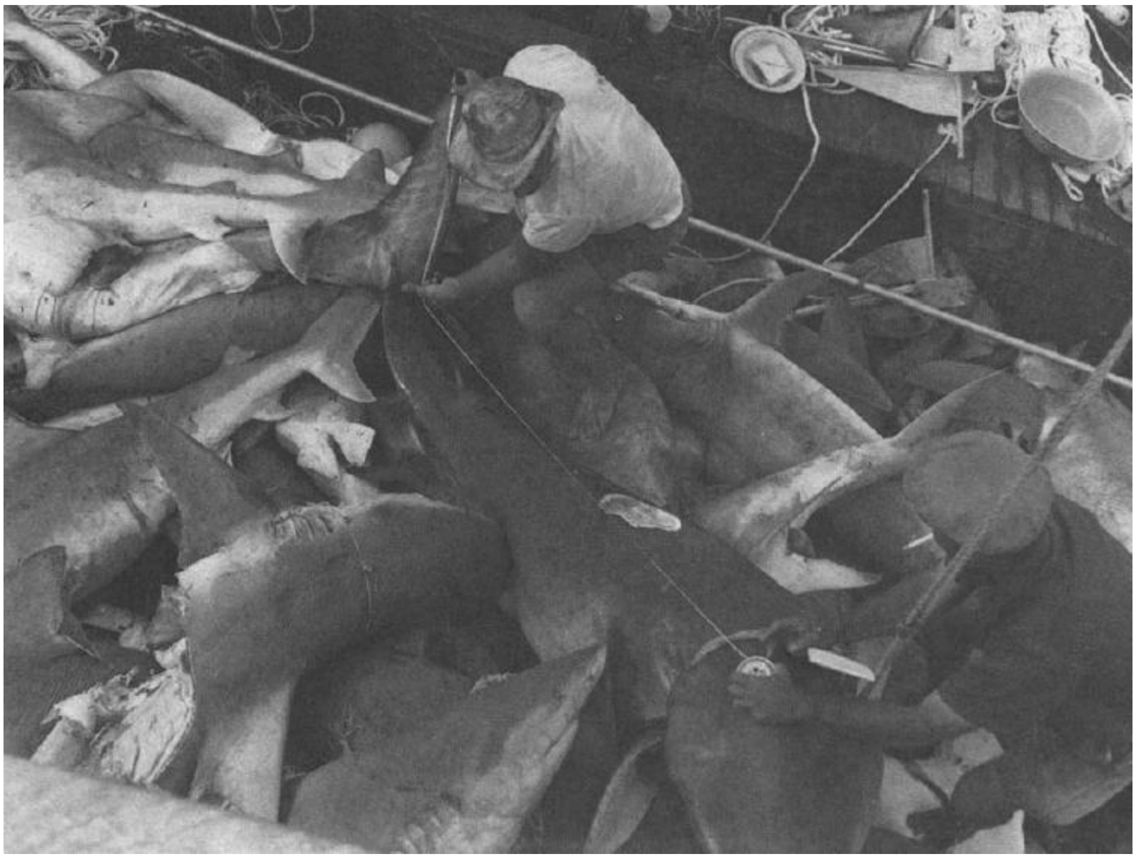

"Some believe that protection of humans from the possibility of shark attack is of paramount importance and incidental losses of marine animals are inconsequential. Others consider that man is an invader of the sea and should be prepared to risk the statistically unlikely event of shark attack. Some regard man's destruction of innocent animals, although unintentional, as wrong. The moderate position is to recognize the value of the protective program to bathers but to explore ways of reducing the incidental killing of marine animals."
-R.A. Paterson (image and quote)

Introduction:

The coastal waters of Queensland, Australia are home to an abundance of shark species, and as a result shark attacks on human bathers, surfers, and divers do occur. These incidences are incredibly rare, at an average rate of one attack per year (QDPI&F, *A Report on the QSSP*, 2006). The threat of shark attack is bad for tourism, which contributes significantly to Queensland's economy by directly employing 122,000 people and contributing $9.2 billion towards the Gross State Product *Duc Pham et al.* (2010). Surfing and bathing destinations like the Gold and Sunshine Coasts are some of the top contributors to this large source of income for the state *Duc Pham et al.* (2010). The government response to reducing the threat of shark attack was to establish the Queensland Shark Safety Program in 1962. The QSSP uses gill nets and/or drumlines moored offshore of popular bathing/surfing beaches to catch and kill sharks with the intent to reduce their population size to decrease the probability of a shark attacking a human (QDPI&F, *A Report on the QSSP*, 2006). Currently 10 different regions along the coast from Cairns to the Gold Coast have SSP equipment on them, with over 84 beaches protected by 35 gill nets and 344 drumlines (QDPI&F, *A Report on the QSSP*, 2006).

The Queensland Shark Safety Program has been shown to cause population declines of target shark species, but bycatch of other harmless marine organisms is also high. The shark species targeted by the Queensland's control program include the tiger shark *Galeocerdo cuvier*, white pointer *Carcharadon carcharias*, whaler sharks (including the bull *Carcharhinus leucus* and dusky *Carcharinus obscurus*, and hammerheads (family Sphyrnidae) *Paterson* (1989). When the program first began, over 1,500 sharks were caught per year, but more recently this figure has dropped to 600 per year, even with a major increase in fishing effort over that 48 year period *Last and Stevens* (2009). A review on the shark control programs activities in Townsville demonstrated that hammerheads, whalers, and blacktip sharks may have been reduced by 80% their historical abundance as a result of shark control *Dudley* (1996). An average of 20 white sharks were caught by the nets in the first 20 years of the program, but in the past 10 years this rate has dropped to 10/year (White Shark Recovery Plan, 2002). Since 1962, 670 white sharks have been caught by the QSSP, and one study has shown that this may resulted in a decline to 60-75% their historical number *Malcolm et al.* (2001). An additional issue is that, on average, for every potentially harmful shark caught (>2 meters) a harmless (<2 meter) shark is caught (See Figure 1), though this ratio varies by location. For example, most white sharks caught by the beach meshing program in Queensland are under 2 meters long (White Shark Recovery Plan, 2002). Populations of non-target organisms are impacted by the Queensland Shark Safety Program as well. From 1962-1988, 13,765 rays, 3,656 turtles, 576 dugongs, and 520 dolphins were killed by SSP gear *Last and Stevens* (2009). Other impacted groups include whale sharks *Rhincodon typus*, Humpback whales which migrate along the Queensland coast, and Manta Rays *Paterson* (1989).

The activities of the Queensland Shark Safety Program over the past 48 years have several ecological implications. Simple ecology tells us that by removing top predators, populations of lower trophic level species will expand and change in unpredictable ways. Examples of this include the expansion of Cownose Ray populations in Chesapeake Bay due to the overexploitation of the local shark populations which predated on them *Meyers et al.* (2007). Shellfish farms in this region have suffered as a result of the rays eating their product, and the structure of the local ecosystem there has been dramatically altered. In the case of shark control, South African gill nets and drumlines have been implicated in causing a large increase in the abundance of small sharks as a result of removing the larger predatory sharks which feed on them. As a result, valuable local fisheries have been impacted by the increased amount of predation from the overabundance of these fish-eating small sharks *Last and Stevens* (2009). In the Queensland context, the long-term impacts of shark control may be changing the regional shark species composition, as indicated by the relative increase in catch rates of tiger sharks on drum lines reported b the QSSP in recent years, though this is a subject in need of further study *Paterson* (1989).

There is a low baseline of shark attacks throughout Queensland, and the pre-netting shark attacks may have been strongly influenced by processes which no longer occur, including the discharge from abattoirs into coastal waters. Before shark control measures were implemented in Queensland the injury rate from shark attack was around 1.1/year and the fatality rate was around 0.7/year, and since shark control began in 1962 the injury rate increased to 1.9/year and the fatality rate dropped to 0.5/year (Scientific Shark Protection Summit, 2006) **See Figure 1**. The rate of injury has also increased collectively for all Australian states, going from an average of 1.9/year from 1900-1936 to 5.1/year in the last 32 years. This likely reflects increasing population size- 4 million in 1900 to over 22 million in 2010- and increased tourism. There has only been one attack at a beach with shark control gear, and this occurred off Amity Point on North Stradbroke Island in 2006 (QDPI&F, *A Report on the QSSP*, 2006). 35% of all non-fatal attacks were by harmless species including the wobbygong (Scientific Shark Protection Summit, 2006). To contextualize this, according to the Australian Bureau of Statistics from 1998-2002 alone, 1,249 people died from accidental drowning or submersion (swimming, diving, surfing, rockfishing, etc.), an average of 250/year. Twice as many people are killed in Australia by lightning strikes and bee stings, and 3,000 people die in car accidents for every death by shark attack (Scientific Shark Protection Summit, 2006). Globally, 8 million people die each year from starvation (Tawonga Zoo Shark Attack File, 2010).

	1900-1936	**1937-1973**	**1974-2006**
Number of Injuries	**38**	**44**	**60**
Average Number of Injuries/Year	**1.1**	**1.2**	**1.9**
Number of Fatalities	**26**	**27**	**15**
Average Number of Fatalities/Year	**0.7**	**0.8**	**0.5**

Figure 1: Injuries and fatalities from shark attacks in Queensland over time (Data from the 2006 Scientific Shark Protection Summit)

The current protection methods may be effective at reducing the risk of shark attack at protected beaches- the QSSP advertises the fact that there has only been one fatal attack on a protected beach in its entire operational history- but there are several issues with the program and the technologies it utilizes. The concept of fishing down local shark populations to reduce the risk of attack does not apply when considering the highly migratory nature of many shark species *Dudley* (1996). For example, adult white sharks seasonally migrate thousands of kilometers up the east and west coasts of the

Australian continent, and this is evidenced in the SSP catch data by the seasonal cycle to their capture and the overall constant catch rate over time *Bruce et al.* (2006), *Paterson* (1989). Another issue with the use of drum lines and gill nets is that they do not offer full protection to bathers and surfers. In fact, 35% sharks are caught leaving the surf zone *Dudley* (1996). Also, the scale over which beach meshing and drum lines are effective at preventing shark attack is unknown *Dudley* (1996). It has been suggested that the effects of Queensland's program are localized as a result of large distances between protected beaches *Dudley* (1996). Nets and drumlines are also criticized because they can have the effect of attracting sharks into an area because they may be attracted to the bait used on the hooks or previously caught sharks and marine animals *Paterson* (1989). Also, in the early years of the program, identification of shark species was very poor, and little if any research was done on the animals before they were discarded at sea *Last and Stevens* (2009). Contractors are now trained in species identification and $100,000 is directed towards research a year, but still many specimens go unused. Also, much of this research funding is directed towards reducing bycatch rather than better understanding the behavior and ecology of sharks (QDPI&F, *A Report on the QSSP*, 2006).

North Stradbroke Island is a unique area in the context of shark control. It is frequented by a variety of highly-mobile shark species including tiger, white, hammerhead, and many species of whalers, including *C. leucas Paterson* (1989). The island is also a very popular tourist destination with surfers, bathers, and divers. There have been 4 recorded shark attacks at North Stradbroke, the most notable being the 2006 fatal attack on a 21 year-old girl off of Amity Point (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). There are 28 drumlines installed on the island off of Amity Point and Cylinder and Ocean Beaches, and these are regularly maintained**.** There are also swimming enclosures located at Amity and Dunwich which have been installed by the local councils. Signage warning visitors about the risk of sharks are posted at some of the beaches, though mainly at Amity **See Figure 2**. Shark control measures have been implemented on the island since 1973, and these historically included gill nets, though these are now absent (QDPI&F, *A Report on the QSSP*, 2006), *Paterson* (1989). In the larger context of the Queensland program, North Stradbroke Island has the lowest catch rate of large (>2 meters) and small (<2 meters) sharks **See Figure 3**. Drumlines are used instead of nets because the surrounding waters support a large diversity of marine organisms, including protected dugongs and sea turtles, which would likely be caught and killed. Also, currents speeds average 4 knots at Amity, peaking at 7 knots during periods of high tidal flux, meaning that nets cannot be anchored at that or nearby sites (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). Ocean beach is highly exposed to wave action, though the currents there only average 1.5 knots. The drumlines used at N. Stradbroke can get washed away during storms, however, and can foul hook turtles, manta rays, and dolphins *Paterson* (1989). Also, a significant recent decline in tiger shark catches has been observed off of Point Lookout, and on the whole the total catch off of Point Lookout has declined since the program began, though this record is highly variable and 10 years of catch data were unavailable to this author (QDPI&F, *A Report on the QSSP*, 2006) **See Figure 4**. In its report on the recent attack at Amity- the first attack at a protected beach in the 48 years the program has been running- the QSSP discussed the fact that traditional SSP gear is not functional at North Stradbroke Island due to the highly transient shark population in the region and the subsequent inability to fish it down (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). In the light of future changes for the island- by 2027, 80% of it will become a national park- and the increased tourism that will likely result, it is imperative that a functional and sustainable shark attack prevention system be designed for North Stradbroke which does not compromise the conservation goals of an-eco-tourism based economy nor the stated goal of the Queensland Shark Safety Program- bather safety.

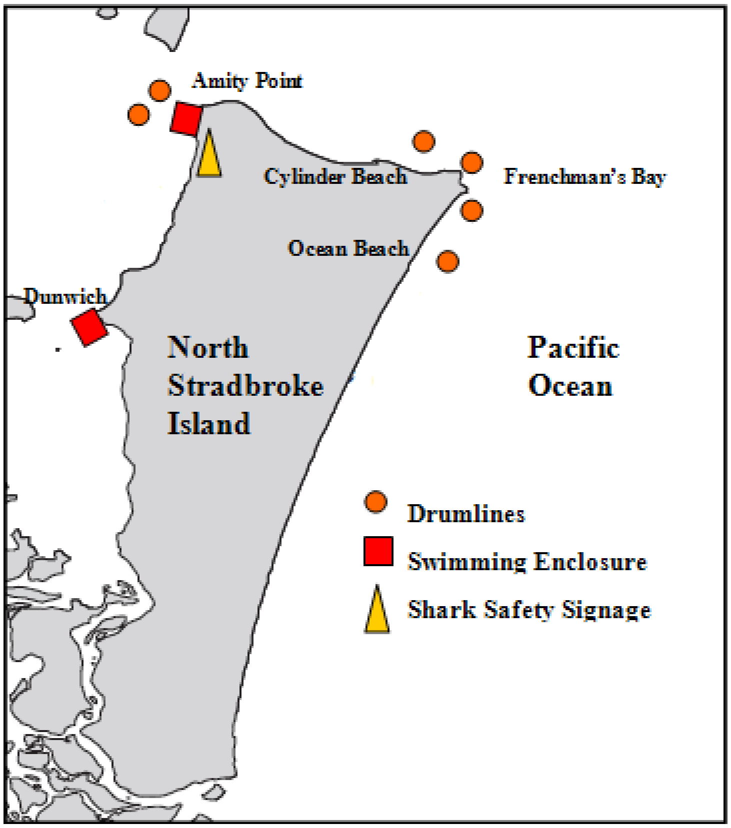

Figure 2: Map of North Stradbroke Island with locations of current shark attack prevention equipment

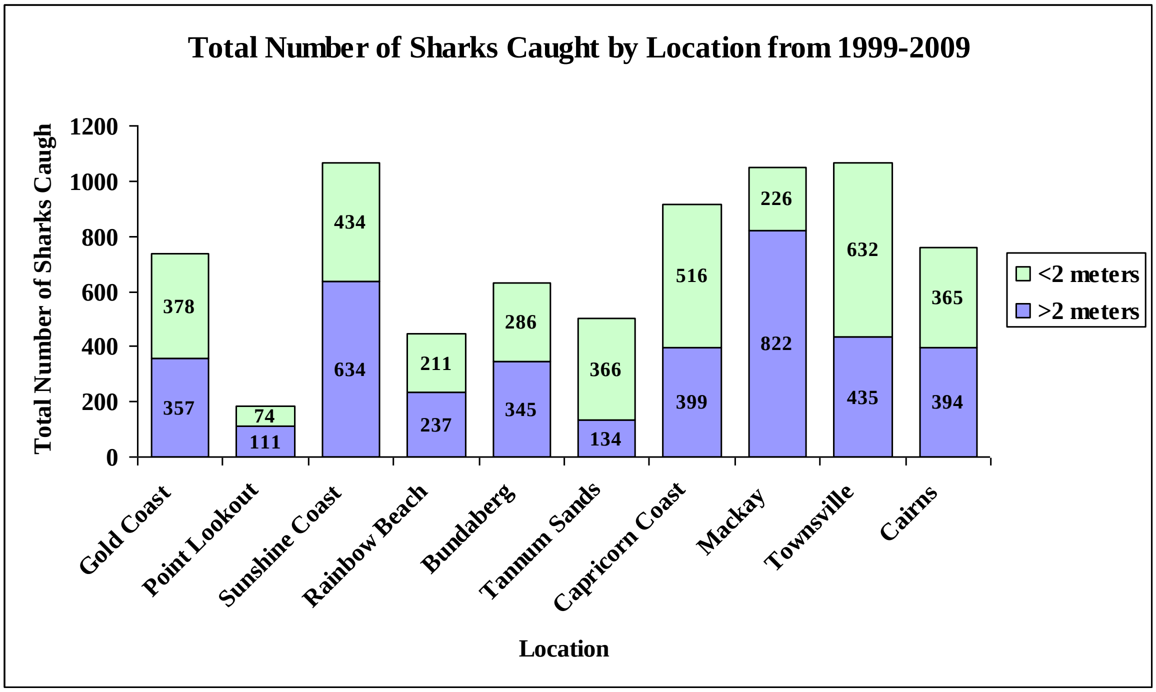

Figure 3: Total number of large and small sharks caught from 1999-2009 (QGOESR, *Shark control program: Sharks caught by area, Queensland, 1999–00 to 2009–10)*

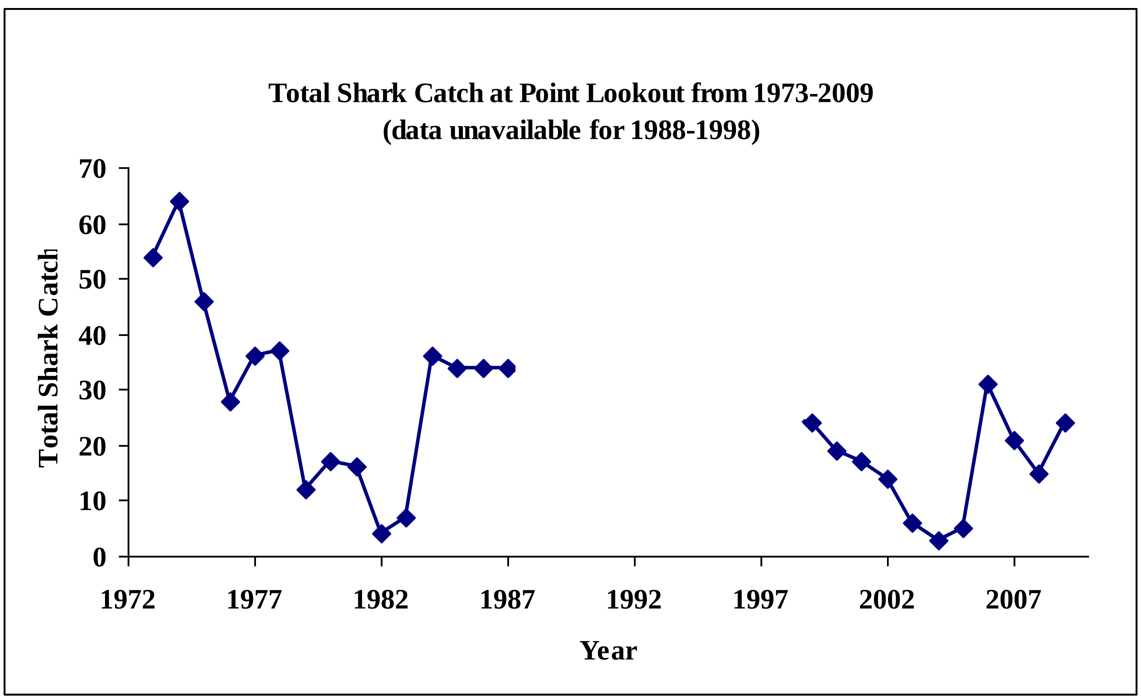

Figure 4: Total shark catch from 1973-2009, omitting 1988-1998 when data was not accessible *Paterson* (1989), (QGOESR, *Shark control program: Sharks caught by area, Queensland, 1999–00 to 2009–10)*

Given the high value placed on shark attack prevention measures along the popular beaches of Queensland, this program is not likely to be ceased or scaled back in the foreseeable future. One view is that any negative environmental impacts that may occur as a result of shark control are secondary concerns relative to human safety *Paterson* (1989). Often times the media will publish articles concerning shark sightings, catches, and attack, citing these as rationale for the continuation of the shark control program. These facts, combined with the natural susceptibility of shark species to overfishing, means that more sustainable and effective shark attack prevention technologies need to be explored if we wish for sharks to exist in this region in the future. This study reviews the existing and developing anti-shark attack technologies and ranks them on several different metrics to gauge their potential viability for integration into a theoretical design for a shark attack prevention system on North Stradbroke Island and for Queensland in general. The guiding concept is that a shark attack prevention program could be designed which integrates several different currently available and developing technologies to result in a more sustainable, cost effective, lower maintenance program compared to the current system; it could look more like a mosaic of different technologies whose use depends on the biological and physical parameters of the different sites. It will represent the future of shark control- moving past the current blanket approach to use science to inform our pursuit of bather safety, rather than shear technological brawn.

The available shark attack prevention methodologies reviewed by this study are:

Aerial Surveys

Aerial surveys involve using airplanes and trained surveyors to look for sharks near popular beaches. The plane flies at an altitude around 150 meters at approximately 45 knots, allowing the observer to view a "footprint" that is 200-500 meters along the beach for 25-50 seconds. If a shark is sighted, the observer will radio the nearest Surf Life Saving station so that they can clear swimmers from the area and attempt to move the shark from the region using Personalized Water Crafts (Scientific Shark Protection Summit, 2006) (See Appendix 1).

Beach Meshing

Beach meshing is the practice of using large gill nets positioned offshore of beaches to catch and kill sharks. These nets are 186 meters long by 6 meters tall and are made of white 50cm mesh. They are anchored to the seafloor and have buoys to keep them suspended vertically in the water column. They are set parallel to the shore in 3 to 15 meters of water about 200 meters from the waveline, or far enough away to prevent bather interaction *Dudley* (1996) (QDPI&F, *A Report on the QSSP*, 2006). The nets catch sharks when they swim into them and become entangled, suffocating because they cannot pump water over their gills. There are currently 35 such nets in use throughout Queensland (See Appendix 2).

Drumlines

Drumlines are used to catch and kill sharks by using baited hooks suspended from a buoy system. The system uses a 14/0 shark hook connected by a 2 meter long 6 mm chain to a buoy which is anchored to the seafloor using 12 mm polypropylene rope and a

Danforth or CQR anchor. These hooks are baited every other day with mullet, which attracts sharks to bite the hook so that they become caught until they die by suffocation or the contractor comes and kills the animal. There are 344 such drumlines positioned offshore of bathing/surfing beaches throughout Queensland (QDPI&F, *A Report on the QSSP*, 2006) (See Appendix 3).

Electric Barriers

Electric barrier technologies use electromagnetic fields to deter sharks. Sharks use a finely-tuned sensory system to sense electrical currents to identify prey, and electrical barriers exploit this by emitting high frequency electromagnetic waves which overwhelm the animal's senses and cause it discomfort within the electric field. A personal shark-repelling device utilizing this technology is marketed towards divers and surfers who use high-risk waters, and it has been tested and found to be overall effect at deterring sharks (QDPI&F, *A Report on the QSSP*, 2006). The technology has demonstrated that the electromagnetic fields it produces are not harmful to humans *Smith* (1991). The idea of scaling up of the electrical deterrent to protect an entire beach or embayment has been heavily research and experimented with, with mixed results. The basic design involves generating an electrical current in a power hub on the shore and channeling this along a thick electrical cable submerged beneath the sediments offshore of a beach. The cable would emit an electromagnetic field of the specific frequency and strength necessary to deter sharks from entering the area *Smith* (1991), (See Appendix 4).

Increasing Education Effort

Properly informing the public about shark safety through advertising and outreach has been shown to promote safer behavior. Education campaigns are conducted by the Shark Safety Program which use brochures, signs, posters, radio commercials, videos, children's books, and websites. These campaigns inform the public not to swim or surf at dawn or dusk or in murky water, to not gut fish near bathing areas, and always swim on protected beaches, covering other relevant topics as well (QDPI&F, *A Report on the QSSP*, 2006). Education campaigns often focus on packaging information such that it can be used in school curricula (QDPI&F, *A Report on the QSSP*, 2006) (See Appendix 5).

No Effort

This methodology involves directing zero resources towards preventing shark attacks.

Personal Protection

Several personalized shark repellents have been developed by the private and military sectors, and this methodology involves individuals using these to prevent shark attacks. Such available technologies include the use of personal electric shark deterrents and chemical deterrents which dissuade sharks from remaining in the vicinity of the individual (Shark Shield Product Website). Theoretically, a government program could be designed which makes personal shark deterrents available for hire at a reduced cost at bathing beaches (See Appendix 6).

Shark Forecasting

Shark attacks are random events, but many attacks occur in areas of high shark abundance during seasonal periods when sharks are more active in the coastal zone. The idea behind the shark forecasting methodology is that if we can understand shark behavior and ecology well enough, we may be able to model their abundances in the coastal zone in relationship to other environmental parameters. This information can be used to close high-risk beaches, to guide aerial surveys and other protection methods, or just to inform bathers and surfers of the risk associated with certain areas so that they can make safe decisions (Scientific Shark Protection Summit, 2006). The idea of identifying hotspots of shark activity along the coast throughout the year is supported by the highly seasonal catch rates of certain species in the QSSP. For example, 90% of white sharks caught in Queensland by SSP gear were on the Gold and Sunshine Coasts when water temperatures were low *Paterson* (1990) and *Paterson* (1989). A multi-variable shark risk model would have to be constructed which uses inputs from local oceanographic buoys, satellite imagery, local fishermen, atmospheric conditions, knowledge of shark and shark prey migrations patterns, among others. A new government funded program would likely be needed to develop and operate this model (See Appendix 7).

Shark Towers

The use of elevated towers and platforms by Queensland's Surf Life Savers to detect sharks in a bathing area is not new. Lifeguards have been using such structures to increase their ability to monitor an area for distressed swimmers and sharks for many decades. SLSQ officials operate at most popular swimming beaches throughout Queensland. Lifesavers must be trained in shark surveillance and equipped with polarized sun glasses, binoculars, and a PA system to instruct bathers to evacuate the water if a shark is sighted (Scientific Shark Protection Summit, 2006). A Personalized Water Craft may also be required to encourage a shark to leave an area. Elevated towers enable lifesavers to see if anything is in the water out to 200 meters from shore if conditions permit (Scientific Shark Protection Summit, 2006) (See Appendix 8).

Swimming Enclosures

Swimming enclosures physically prevent sharks from entering a bathing area. They use different types of nets/barriers to block off a section of beach or an embayment. They are the primary method of shark attack prevention used off Hong Kong's beaches, and can be found throughout Queensland where they have been implemented by local governments. The Hong Kong swimming enclosures use thick nets suspended off of 225mm pipe and float lines and are anchored to the seafloor *Paterson* (1989). Many of the enclosures used in Queensland, for example at North Stradbroke Island, are smaller, lower-budget versions which drape thick meshed nets off of wooden pilons driven vertically into the sediment, with the bottom of the net anchored to the sea floor. These structures protect an area approximately 30 meters along the shore by 30 meters perpendicular to the shore (See Appendix 9).

This study is significant because it voices a rational, more sustainable alternative to traditional shark attack prevention, and it hopefully will help to establish a framework from which future technologies can be analyzed for their suitability in shark attack prevention programs.

Methods:

This technological review is based on scientific literature and government reports, as well as available information on the different technologies and products. This information was used to evaluate different shark attack prevention technologies on several parameters. These specific parameters were developed by looking at the Shark Safety Program's list of criteria for implementing equipment at new locations. These criteria include:

-an evaluation of the shark threat
-environmental consequences of the proposal, including the impact on non-target animals
-stakeholder expectations
-beach usage/visitation
-potential tourism/local business impacts
-community views
-servicing of the location by SLSQQ or other similar professional group.

This review uses many related criteria, as well as some additional ones, to rank the different shark attack prevention methodologies. These metrics are:

Community Support: Would people feel safe with this technology and how would different stakeholder groups react to its implementation?

Cost: What are the physical costs of installing and operating this protective measure?

Effectiveness: What level of bather safety can this approach deliver?

Feasibility: Is the implementation of this technology realistic? Has it been used successfully in the past?

Flexibility: Can this technology be easily moved, altered, or applied to nearby regions to accommodate changing conditions or new knowledge of shark behavior/risk?

Integration Capacity: Can this technology be used side-by-side with another, and does this effectively increase bather safety?

Maintenance Required: Is this a robust technology or will maintenance needs be unrealistically high?

Scalability: What types of environments can this technology be used in i.e. canals vs. exposed beaches? Is there high potential to expand its use spatially?

Sustainability: What are the impacts on target and non-target species? How many sharks or turtles of a certain species and size range does the technology kill? Would this technology have any negative impacts on the surrounding ecosystem?

The process of rating each technology on each of these metrics involved contextualizing the performance of the technology in the available literature and knowledge on the subject. This study is inherently relative, with extreme performances for certain criteria defining the maximum and minimum score ranges. Where specific information was not readily available, approximate values and general sentiments were used to compare a technology to another.

The second part of this study uses the outputs of this ranking system to inform a hypothetical plan on how to alter the shark safety program on North Stradbroke Island. The four technologies with the highest scores were chosen to be applied to suitable locations on the island, and a potential process for how to implement and monitor these changes is discussed.

Results:

Aerial Surveys

Aerial shark surveys are relatively common along Australian coasts, particularly in Western and South Australia, though in Queensland they are not formally integrated into the Shark Safety Program (QDPI&F, *A Report on the QSSP*, 2006). It would be possible to create an aerial surveying program for the Gold Coast region which also covered North Stradbroke Island, though this would be logistically complicated and capitally intensive. The operational costs associated with this method are exceptionally high, and particularly capital intensive aspects include airplane maintenance and fuel costs, paying pilots for many flying hours, and pilot training. For example, the operating costs of a relatively small scale New South Wales aerial surveying program which covered 60-130km's of coast were $170/hr for 600 hours of flight. Including maintenance costs, this program cost approximately $150,000AU/year in total (Scientific Shark Protection Summit, 2006). Maintenance needs include aircraft maintenance, a strong infrastructure for communication between pilots and SLSQ personnel, and pilot training. This approach does have a high capacity to integrate with other approaches, particularly with SLSQ surveillance and shark forecasting. The effectiveness of aerial surveys is hindered by several factors including the difficulties in detecting sharks in anything but perfect weather, as well as the fact that sharks are highly mobile and may enter a bathing area between surveys (QDPI&F, *A Report on the QSSP*, 2006). Other issues include the difficulty in detecting sharks over different substrate types and at dawn and dusk. In one South Australian study, dolphins and seals composed 90% of the sightings, with 3% of sighting confirmed to be shark species. Of these sharks sighted, a majority were small to medium sized and only 2 large sharks were sighted in a single year (Scientific Shark Protection Summit, 2006). In a study in Newcastle, an average of 500 sharks/year were sighted over a 10 year period (Scientific Shark Protection Summit, 2006). One conference on shark attack prevention rule out aerial patrols as an effective method (Scientific Shark Protection Summit, 2006). In the context of North Stradbroke, the effectiveness of such a program would be hindered due to high turbidity levels and the fact that sharks could easily enter a bathing area from the nearby channel in between surveys. Where aerial survey programs do operate the public generally support this safety measure, or the "eye in the sky" as it is often referred to. That said, panic can ensue on beaches when survey planes are seen to be hovering over an area for an extended amount of time. The aerial survey approach is exceptionally flexible in that a pilot can target different beaches in a region if need be. An additional benefit of the aerial survey techniques is that it does not involve the culling of sharks, but rather relies on detecting sharks and then informing Surf Living Saving personnel so they can close beaches accordingly and persuade a shark to leave an area using Personalized Water Craft and Rescue Boats. One proposed solution to the problems with traditional aerial surveys is the use of micro-light aircrafts which fly more slowly, thus increasing the amount of time an observer has to survey a beach.

Beach Meshing

The idea was proposed in 1929 that "regular and systematic netting affords a cheap and effective way of greatly minimizing the shark peril" *Dudley* (1996). The major costs associated with beach meshing include payments to shark contractors, bait, and equipment, with the total cost for Queensland's SSP coming out to approximately 1.7$ million/year, though a large portion of this funds the drumlines (QDPI&F, *A Report on the QSSP*, 2006). Beach meshing is a widely accepted protection measure throughout Queensland, though there are subgroups in the populations which oppose it. Many marine scientists and environmental groups including Greenpeace, Sea Sheppard, Shark Savers, Shark Angels, the Humane Society International, Surfers for Cetaceans, the Surfrider Foundation, the Australian Marine Conservation Society, among others, oppose the use of nets, often mentioning bycatch of iconic or endangered dugongs and turtle species as a major concern. The meshing program is supported by a majority of bathers and surfers, and members from the fishing community have defended their use. There is, however, a major gap in understanding of how beach meshing works within the public, with many people assuming that the nets form a physical barrier which prevents sharks from entering an area. Gill nets do have a good integration capacity, as where nets are used they often are accompanied by drumlines. There is no beach meshing at North Stradbroke for several reasons, mainly because the nets would result in high bycatch of iconic species and would therefore not be consistent with the tourism industry on the island. Equally important, however, is the fact that the regular high-velocity currents in the region make it too difficult to keep a net anchored in place. The nets would likely require higher than average maintenance due to the strong currents, waves, and likelihood of bycatch of sensitive species. Typically nets at other locations are checked on 20 out of every 28 days, but the Stradbroke nets would probably have to be checked daily in order to have a chance at mitigating bycatch by releasing the entangled organisms while they are still alive *Dudley* (1996). The highly transient population of sharks in the Moreton Bay region also prevents beach meshing from effectively reducing the local population of sharks as it has been shown to do in other regions. Almost all of the waters around North Stradbroke are non-ideal settings for beach meshing, with the rapid tidal currents on the north and western sides of the island and high surf on the eastern side *Last and Stevens* (2009). Gill nets do not guarantee bather safety, and are not suitable for locations like Stradbroke as they can give bathers a false sensation of safety (QDPI&F, *A Report on the QSSP*, 2006). Large gill nets would also be a navigational hazard to recreational and commercial fishermen and other boater which frequent these waters (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). Gill nets were used at North Stradbroke in the early years of its program (likely at Ocean Beach where conditions are more similar to the exposed beaches of the Gold Coast), but they encountered too many problems and their use was discontinued. Gill nets are one of the most indiscriminate fishing techniques available and it results in high bycatch of non-target species, including whales, dolphins, dugongs, rays, and turtles (QDPI&F, *A Report on the QSSP*, 2006) *Dudley* (1996). In terms of target species, the total shark catch in the Queensland Shark Safety Program declined over time, as did the catch rate in the nets *Dudley* (1996). Small individuals of target species are also caught very frequently. Gribble demonstrated in his 1998 review that the SSP does not contribute significantly to a population decline in any vulnerable or threatened species, but it can be argued that it does slow their recovery. There is no rationale available as to why Queensland chooses to mesh year round, where other programs in South Africa and New South Wales cycle the net use *Dudley* (1996). In many cases, the amount of gear deployed depends only on the operational capacity of the contractors, not the specific shark threat of a particular region *Dudley* (1996). Compared to other net technologies like full swimming enclosures, gill nets are more mobile and can be relocated relatively easily. New techniques and technologies experimenting with net color, hang-in coefficient, and the position of the net in the water column may become available which reduce bycatch of non-target and small target species, but a total solution is unlikely (QDPI&F, *A Report on the QSSP*, 2006), *Dudley* (1996). One mitigation strategy for bycatch has been the creation of Marine Animal Release Teams (MART's), which are volunteer groups that undertakes marine mammal and turtle release efforts. These groups receive significant community support (Scientific Shark Protection Summit, 2006). In the past, species identification and use of sharks for research were limited, but funding has been directed towards improving this with good outcomes *Dudley* (1996) (Scientific Shark Protection Summit, 2006). The DPI&F's collaborates with academic institutions throughout Queensland (Scientific Shark Protection Summit, 2006).

Drumlines

The use of drumlines on North Stradbroke is widely supported by the community, particularly by SLSQ officials, local government, fishermen, the local tourism industry, bathers, and surfers *Paterson* (1989) (Scientific Shark Protection Summit, 2006). Many scientists and environmental groups think that the drumlines are cruel and should not be used in the context of such low shark attack risk, on humanitarian grounds, and because these drumlines have killed mantas, turtles, and dolphins in the past (QDPI&F, *A Report on the QSSP*, 2006), (Scientific Shark Protection Summit, 2006). Significant funding goes into operating North Stradbroke's relatively low number of drumlines, with 80% of the expenditure going towards the private contractor, equipment, and bait. For the

Queensland SSP in general, approximately $80,000 goes towards bait (QDPI&F, *A Report on the QSSP*, 2006). Drumlines are checked and re-baited every other day at N. Stradbroke by the local contractor, weather permitting. Drumlines have a high integration capacity with other approaches, and they are often accompanied by gill nets and occasionally signage. Drumlines have been used in a range of conditions throughout Queensland and are relatively easy to relocate and implement if conditions change. The drumlines at N. Stradbroke are located on a variety of different beach types ranging from tidally affected channels to fully-exposed, high-surf beaches. It is this flexibility which is the main reason that drumlines, not nets are used off NSI. They are significantly more resilient to the strong, dynamic currents that affect this region. However, drumlines have been shown to be relatively ineffective in protected canals and embayments, and the number of sharks caught on drumlines at North Stradbroke is the lowest in the entire Queensland Shark Safety Program. The recent review of the 2006 attack at Amity raised several questions about the suitability of drumlines for this region (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). Drumlines are effective at reducing localized populations of sharks at most sites, but in the context of the abundant prey items in Moreton Bay, baited hooks are not competitive enough and the sharks are too mobile to have any localized effect (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). This means that the probability of shark attack in the waters of NSI is not effectively reduced by the use of drumlines there. As a poignant example, a young woman was killed by a shark while swimming near the Rainbow Channel off Amity Point in 2006, a site where 4 drumlines have been located for many years. Also, questions have been raised as to the degree to which baited drumlines draw other sharks into an area to feed on the bait or previously caught sharks. Shark olfaction is effective on the scale of several hundred meters, so realistically the drumlines at North Stradbroke Island could be encouraging migratory sharks that would typically be passing through the Rainbow Channel to forage in Moreton Bay to investigate the shallows near Amity Point *Dudley* (1996). The benefit of drumlines is that they generally catch fewer small sharks and have overall lower bycatch of non-target species *Dudley* (1996), (QDPI&F, *A Report on the QSSP*, 2006). One review did show that the current shark control methods in Queensland do not result in any significant decline in any populations of non-target organisms, but there has been an observed decline in tiger shark catches off of Point Lookout *Gribble et al. (1998)*,(QDPI&F, *A Report on the QSSP*, 2006). Also, though better than the nets, the size of the sharks caught is still exceptionally small. For example, the average size for white sharks caught on the drumlines is 2.84 meters, but white sharks are not considered to be a dangerous until they are greater than 3 meters because they do not start eating pinnipeds until then, making a case of mistaken identity of a human as a prey source less likely. Suggested improvements to the drumline design includes a less-flexible buoying system to increase the capture rate of large sharks, hook guards which prevent turtles from becoming caught, and acoustic pingers which prevent whales and dolphins from going near them. A definite benefit of drumlines is that sharks can survive for many hours and even for days while on the line, and this means that contractors could be ordered to release small, harmless sharks.

Electric Barriers

Electric shark barriers have been researched since their development in the 1980's in South Africa (QDPI&F, *A Report on the QSSP*, 2006). The scientific literature includes case studies looking at the safety and effectiveness of such technologies, and the results confirm that sharks will not penetrate an area protected by such electrical barriers in experimental settings *Smith* (1991). These systems are not dangerous to people as long as they maintain a short distance from the main electrical cable *Smith* (1991). A personalized electromagnetic shark repelling device called the Shark Shield is available on the market which is overall effective at deterring sharks. The developers of this technology have put several millions of dollars into scaling this protection to the level of an entire beach with limited success (QDPI&F, *A Report on the QSSP*, 2006). This technology is plagued by a range of technical issues, including damage by wave action at exposed beaches, difficulties in transferring power to the main cable, and overall, we don't know enough about how wild sharks will interact with these electromagnetic fields and if they will become desensitized over time *Smith* (1991) (Scientific Shark Protection Summit, 2006). Also, the effectiveness of this technology and the confidence that mangers have in it will be compromised should the electric barrier fail to be functioning properly for any length of time. Ensuring this would be very difficult and require a tremendous and continual maintenance effort. High initial and maintenance costs will likely accompany this technology, and it will take many years of considerable study before this technology will be trusted by the Shark Safety Program to the extent that it will be implemented on a Queensland beach or embayment. Even if these logistical issues are overcome, the technology will likely only be applicable to sheltered bays, which in the case of North Stradbroke could mean the areas near Dunwich, but the low bather densities there would not justify the huge capital investment (QDPI&F, *A Report on the QSSP*, 2006). The large infrastructure required for this technology to be effective renders it essentially immobile and inflexible to changing conditions, though it can be effectively integrated with educational signage. This technology would not kill any animals in order to protect bathers, though there is a possibility that it would exclude large fish and rays from accessing a section of coast.

Increased Education Effort

Improved educational campaigns could help to encourage safe swimming i.e. swimming in full enclosures if they are available, not swimming at dawn and dusk, and always swimming at protected beaches. These campaigns do not directly prevent shark attacks, as many have occurred in what are otherwise "shark safe" conditions. The costs associated with designing, fabricating, and distributing informational brochures, signs, children's books, videos, fact sheets, posters, and other educational media for all of Queensland totaled to $100,000 AU in 2006 (Scientific Shark Protection Summit, 2006) (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). There is an existing infrastructure around the development and dispersal of educational media, and this program requires a medium degree of maintenance. The capacity of this system is large; around 1 million leaflets were distributed over a 10-15 year period (Scientific Shark Protection Summit, 2006). For N. Stradbroke, improving public education of shark risks could increase the use of swimming enclosures and support swimming at beaches with SLSQ protection. Previous to the 2006 attack at Amity, no information booklets were directed directly to North Stradbroke; the intention was that an overabundance of educational materials on the mainland would overflow to the island (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). After the attack, educational brochures were distributed throughout North Stradbroke to local schools and ferry operations, as well as to tourism information centers (QDPI&F, *A Report on the QSSP*, 2006). New signage was installed at Amity saying "Environmental conditions make sharks more active in this area," as a warning to bathers. More information could be given on the biology of the dangerous shark species in the area and the current methods of shark attack prevention, possibly to greater effect on bather behavior (QDPI&F, *Fatal Shark Attack at Amity Point, NSI*, 2006). The Shark Safety Program acknowledged the lack of shark safety signage at Amity in its review of the fatal 2006 shark attack there. Signage is regulated by local governments, and it should be sensitive to tourism interests in the area such that its design, imagery, and wording do not illicit undue fear in bathers. Education efforts are highly flexible to changing conditions, and local governments can stockpile excess signage in case it is needed. They also integrate very effectively with all shark attack prevention methods. Some themes for future signage on N. Stradbroke could involve advising fishermen no to clean their catch near bathing zones, encouraging use of swimming enclosures, and informing bathers that the surrounding waters support a rich ecosystem of which involves sharks. Improving education about sharks and safe swimming will not have any negative impact on the environment. In fact, a properly crafted campaign could inform the public that sharks are not voracious killing machines but rather important members of coastal ecosystems which fulfill a necessary role and rarely attack humans- a positive message for shark conservation.

No Effort

It is unlikely that Queensland's Shark Safety Program will ever remove gear from a beach once it has been put in place due to the overwhelming community support for these protection measures. If this were done at a place like North Stradbroke, the money saved would be significant, though there would be an initial cost associated with removing and repurposing gear. The attack rate would not necessarily increase in the absence of SSP gear, as the island has a low historical incidence of attack and the abundance of natural prey in the region makes shark attacks less likely. Though such a program would be politically infeasible, it would require zero maintenance and could be scaled across the entire island and state of Queensland. It is also an exceptionally flexible approach in the sense that it can be readily applied to any site by removing the existing prevention technologies. It would clearly not be suitable for integration with other attack prevention methods. The impact of reducing the use of SSP gear would likely be an overall increase in shark and non-target species populations along the coast.

Personal Protection

Shark attack prevention in Queensland has historically been a public good, and any efforts to change that will likely lack support from the community. If, however, the government subsidized the cost of shark protection units or made them available for cheap hire at popular beaches, the public could be receptive. Personal shark attack prevention technologies are relatively expensive ($600-$800AU) and if a program were designed which integrated such devices into a beach infrastructure, the Queensland government would likely have to purchase or subsidize the cost of the units at great expense. If each of the 84 protected beaches in Queensland had 1,000 units for hire, the initial investment would be in the range of 40-50 million dollars. The effectiveness of personal shark attack prevention systems, in particular the Shark Shield electromagnetic shark attack repellent system, has been studied extensively with mixed results. Overall, the devices seem to be effective in deterring most species of shark. According to Rod Hartley, the director of Shark Shield company, "Company policy is to recommend the use of Shark Shield against sharks only in their investigative mode if possible. Nevertheless, we have a number of examples where Shark Shield has stopped large sharks in full attack mode" (Shark Shield Product Website). The likelihood of any government plan being implemented which makes personal electronic shark repellents available at low cost to the public is very low due to the shear volume of bathers that would have to be supplied. Also, the infrastructure required to effectively distribute electronic shark deterrents would require large amounts of maintenance for the devices to operate efficiently. For example hundreds of batteries would need to be charged and replaced daily. Each individual Shark Shield unit protects an area approximately 3 meters in diameter, so on a crowded day at the beach fewer units relative to the number of bathers would be required. Such a program could be implemented at open ocean beaches and in canal environments. This technique is highly flexible for an individual with a Shark Shield, but it is inflexible when considering the large-scale, infrastructural approach because it cannot be readily applied to a new site should conditions necessitate it. This approach could be used simultaneously with drumline, beach meshing, and shark forecasting technologies, among others. Using personal devices to deter sharks on a large scale would not kill or harm any animals and would not have any negative ecosystem effects.

Shark Forecasting

Connections between shark abundance and factors like sea surface temperature, salinity, rainfall, the presence of baitfish, turbidity levels, the number of people likely to be in the water, and ocean current activity have been observed from long-term catch data (QDPI&F, *A Report on the QSSP, 2006*). For example, it is established that most shark attacks in Queensland occur in the late-spring to mid-autumn (QDPI&F, *A Report on the QSSP*, 2006). Also, the highest catch rates for white sharks occur in September and October, and most white shark attacks have occurred during these months (White Shark Recovery Plan, 2002). These patterns could be incorporated into models of shark abundance along the coast, and though they cannot ensure that sharks will not be present in an area, they can tell us which regions are the riskiest and during what time of the year. This can inform bathers and surfers to make the best decisions and reduce the risk of shark attack. An infrastructure would need to be developed for developing accurate, up-to-date, high-resolution shark abundance forecasts and integrating those into Queensland's shark attack prevention program. Such a forecasting program could be assimilated into an existing government department/program, operated by a privately-owned company, or a new department could be developed altogether. Each of these possibilities is associated with a range of costs, and for such a system to be sustained on the long-term, the surrounding infrastructure would have to be maintained regularly. In the context of North Stradbroke, the number of tourists is relatively low compared to the nearby Gold and Sunshine Coasts, and these regions would therefore be far more likely to implement a forecasting infrastructure. Also, the flexibility of this approach depends on the scope of its models i.e. does this model include a particular beach or section of coast that needs a forecast due to changing conditions? The scope of the model will determine how its benefits are distributed across a region. It is likely that the public would be receptive to a daily shark risk report, much as they are with lightning strike, dangerous surf condition, and marine stinger risk forecasts. Whether these forecasts would be heeded or not is a subject in need of further study. It would be possible for shark forecasting model outputs to be integrated with a pulse fishing strategy similar to that used in New South Wales, where SSP protective gear is used at regions of high bather density during specific times of the year when the risk of shark attack is statistically higher (QDPI&F, *A Report on the QSSP*, 2006). This approach would integrate effectively with several others, particularly increased education efforts, personal protection, and possibly with drumlines should a pulse fishing approach be taken. No sharks would be directly killed as a result of the shark forecast, but it is possible for data to be used to place drumlines or gillnets in areas where shark abundance is projected to be high. Temperature data loggers are being implemented on SSP gear on the Gold Coast in an effort to better understand environmental influences on shark catch and bycatch, a step in the right direction towards actualizing this developing technology (QDPI&F, *A Report on the QSSP*, 2006).

Shark Towers

The use of trained Surf Life Saving Association officials positioned in shark towers to detect sharks in a bathing area is an effective strategy. If a shark is identified, bathers and surfers can be quickly alerted to evacuate the water. This technique is applicable to most beach sites that bathers and surfers frequent, but changing environmental conditions can render it ineffective. There could be large costs associated with constructing and implementing shark towers along North Stradbroke's beaches, with each new tower costing approximately $50,000 (Scientific Shark Protection Summit, 2006). There are several sites at Stradbroke that could benefit from the implementation of shark towers, though increasing the number of towers requires more trained observers, effectively increasing the cost of the program. Also, there is currently no SLSQ protection at Amity beach (QDPI&F, *Fatal Shark Attack at Amity Point, NSI,* 2006). There is potential to utilize the high cliffs along many of the popular beaches as lookout points. Also, portable towers could be used to enable SLSQ observers to move from one beach or section of coast to another depending on bather densities and changing conditions, a highly flexible approach. There could also be a seasonal component to the observation program, involving only using the towers when bather densities are high during tourist season. The public are generally supportive of shark towers, finding confidence in the idea that their safety is being actively pursued by a trusted representative of the SLSQ. Queensland's Surf Life Savers operates year-round with a variety of life saving equipment at their disposal. This approach has a high integrative capacity with aerial survey and educational approaches. The use of shark towers has decreased compared to several decades ago, but local councils continue to erect towers as additional safety measures (Scientific Shark Protection Summit, 2006). No sharks or other organisms will be killed by the use of watch towers, nor in the process of attempting to remove them from bathing areas.

Swimming Enclosures

Swimming enclosures have been shown to effectively prevent sharks from entering an area, though there has been one attack recorded in an enclosure in Townsville in 1933 (QDPI&F, *A Report on the QSSP*, 2006). The SSP does not utilize full enclosures, but local governments have decided to install them to benefit from the greater level of security this technology offers (QDPI&F, *A Report on the QSSP*, 2006). Many bathers will willingly swim in enclosures like those at Amity and Dunwich on North Stradbroke, and the general attitude seems to be one of appreciation towards the extra safety measure. These enclosures are generally safer places for young children to swim and play. At the same time, many bathers dislike swimming in enclosures, and cases of vandalism towards the enclosures have occurred. Swimming enclosures are expensive to make and install, and they require consistent monitoring and maintenance to be effective (QDPI&F, *A Report on the QSSP*, 2006). The nets are easily damaged by storms and large waves, but the core structure can last for many decades, as the enclosure at Dunwich has. Hong Kong utilizes large-scale swimming enclosures year-round which are resilient to large typhoons and are well maintained by contractors, and there have been no attacks since their installation in 1995 *Paterson* (1989). A similar success story can be seen in the stinger nets used in northern Queensland which handle the natural forces on them and effectively prevent jellyfish from entering the swimming area (QDPI&F, *A Report on the QSSP*, 2006). Maintenance of swimming enclosures is made more costly and difficult by the fact that divers must enter the water several times a week to survey and repair the net, but at North Stradbroke tidal fluxes are large enough that the net and structure is exposed at low tide, facilitating repair. It is a difficult task to remove and store the nets if they are removed before storm seasons to prevent damage or loss, and of course, any swimmers would be unprotected at those times. Swimming enclosures are installed at Amity Point and Dunwich and are used frequently by locals and tourists, though the enclosures are old and degrading. Expanding and rebuilding theses enclosures would be possible but this would represent a large and risky investment as they are vulnerable to damage by fast currents, large storms, and waves reaching over 5m high. Expanding the use of swimming enclosures on Stradbroke is not likely as there are few locations where the beaches are stable enough for full enclosures to last through a season and be effective. That said, net technologies are improving with the large amounts of research and development in the aquaculture industry, and it may be realistic to have a durable swimming enclosure system in the near future. Also, evolving swimming enclosure technology will likely improve the flexibility of this approach if nets are easier to install or move. Swimming enclosures integrate very well with educational signage about safe swimming. Full enclosures allow small fish and plankton to drift through the net webbing, and large marine animals and sharks are not caught or entangled but are excluded from the area.

	Community Support	Cost	Effectiveness	Feasibility	Flexibility	Integration Capacity	Maintenance Requirements	Scalability	Sustainability	Total
Aerial Surveys	4	1	1	2	5	5	2	4	5	29
Beach Meshing	4	2	3	2	3	4	1	2	1	22
Drumlines	5	2	2	5	4	4	3	5	3	33
Electric Barriers	3	1	3	2	1	3	1	1	5	20
Inceasing Education Effort	3	3	3	5	4	5	3	4	5	35
No Effort	1	4	1	1	5	1	5	5	5	28
Personal Protection	2	1	3	1	2	5	2	3	5	24
Shark Forecasting	4	2	2	2	3	5	3	4	5	30
Shark Towers	4	3	3	5	5	5	3	4	5	37
Swimming Enclosures	4	1	5	4	2	5	2	3	5	31

Figure 5: Table of resulting scores from the technological review

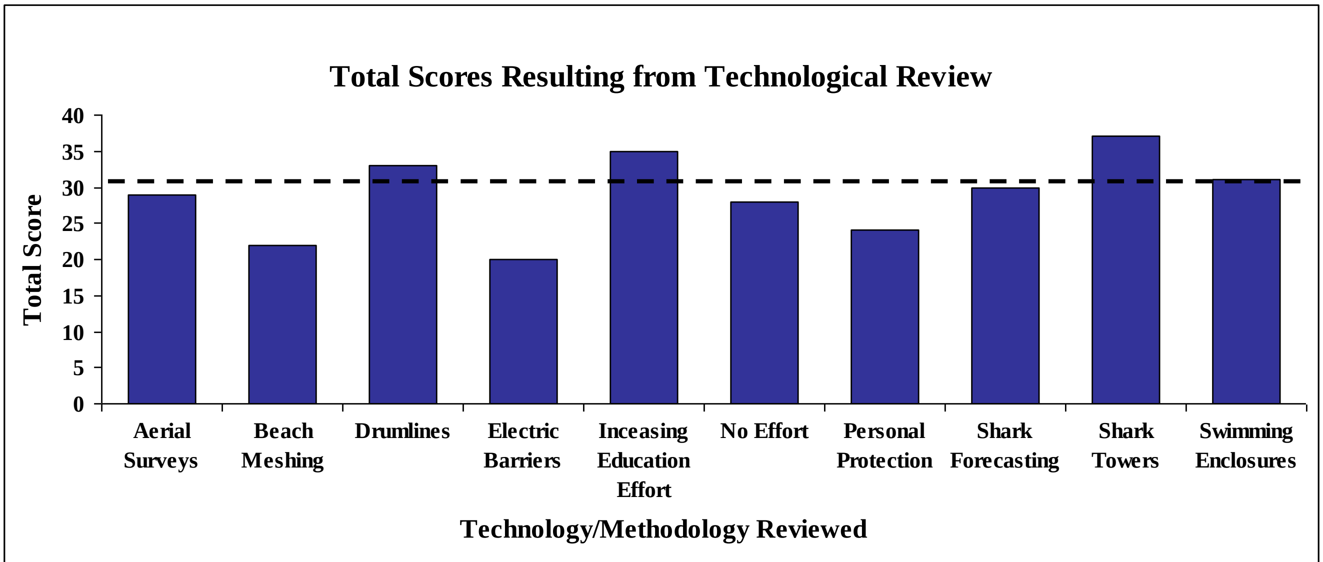

Figure 6: Graph of total scores resulting from the technological review with cutoff line, above which the approach will be incorporated into the proposed Shark Safety Program for North Stradbroke Island

Discussion:

The results of this technological review show that shark towers are the most viable shark attack prevention method for North Stradbroke Island, followed by increased education effort, drumlines, and swimming enclosures **See Figures 5 and 6.** They have demonstrated their suitability to be integrated into the island's attack prevention system based on several criteria, and each particular technology/methodology will occupy a particular niche in the following theoretical program. Note, however, that electric barriers, beach meshing, and personal protection were the least viable options in this case, followed by no prevention effort, aerial surveys, and shark forecasting methodologies. Behind this plan is the vision of sustainable shark attack prevention.

Several sites on North Stradbroke could benefit from the use of shark towers manned by trained and equipped SLSQ observers. Optimal sites around Point Lookout include Cylinder Beach and Frenchman's Bay, medium to high wave exposed beaches frequented by many bathers and surfers and where a total of over 16 drumlines are currently positioned. Both of these sites have high cliffs rising steeply from the water's edge, on which shark observation platforms could be positioned at relatively low cost. SLSQ officials currently operate at Cylinder, though not at Frenchman's Bay, and trained officials could easily begin incorporating use of the observation platforms, likely with a small increase in personnel size. The waters around Amity Point and Dunwich could be effectively observed by using a shark tower, though there is currently no SLSQ surveillance at this beach either. Ocean Beach would not be an ideal site for the implementation of shark towers because surfers are typically too far offshore at the second sand bar for observers to get an adequate view of the waters around them. These shark towers would likely only be manned on weekends year round and daily during peak tourist seasons

North Stradbroke is not heavily targeted by the Shark Safety Program for educational campaigns, and the number of brochures and public service announcements on the radio, television, and ferry boat trips to the island could be increased. Additionally, there is no signage encouraging safe swimming/surfing in regards to sharks at Ocean Beach, Frenchman's Beach, Cylinder Beach, or Dunwich. Also, the message on shark safety signs should be changed to be more instructive **See Figure 7**.

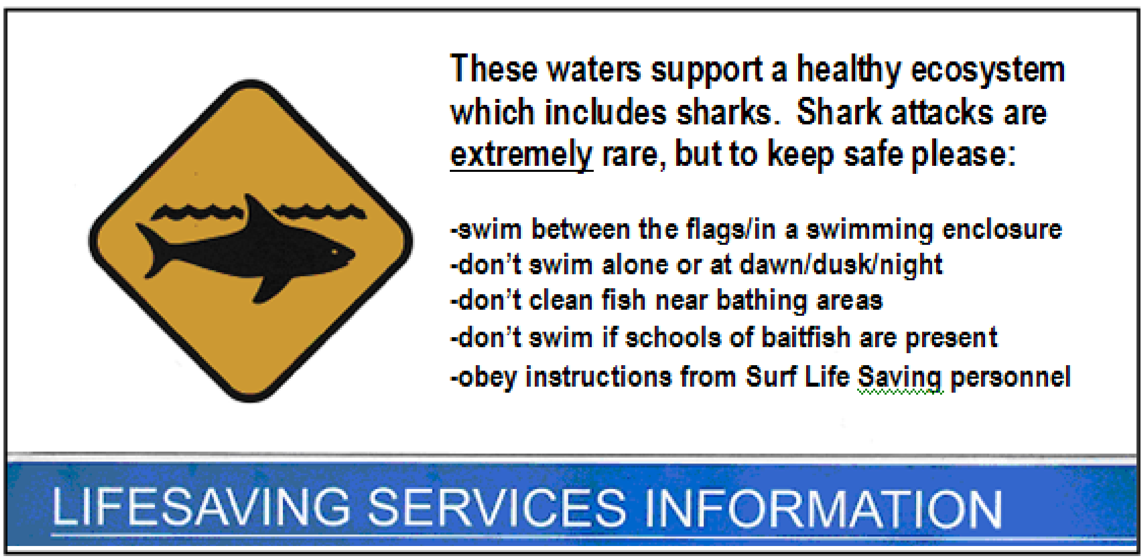

Figure 7: Example of a possible design for new shark safety signage on North Stradbroke

Drumlines are suitable for use off of North Stradbroke Island as they are resilient to damage and effectively remove large sharks that could harm bathers. The four drumlines at Amity Point should be removed, as they do not effectively reduce the local population of sharks at that site, but should be maintained off of Cylinder and Ocean Beaches where conditions are more similar to other parts of the Queensland coast i.e. the Gold Coast, where the drumlines do have a local effect.

The swimming enclosures at Dunwich and Amity should be renovated with more advanced barrier technologies similar to those used in Hong Kong. There will be high initial capital necessary to fund this but the nets will be more resilient to damage and will require less maintenance while guaranteeing bather safety if they are used **See Figure 8.**

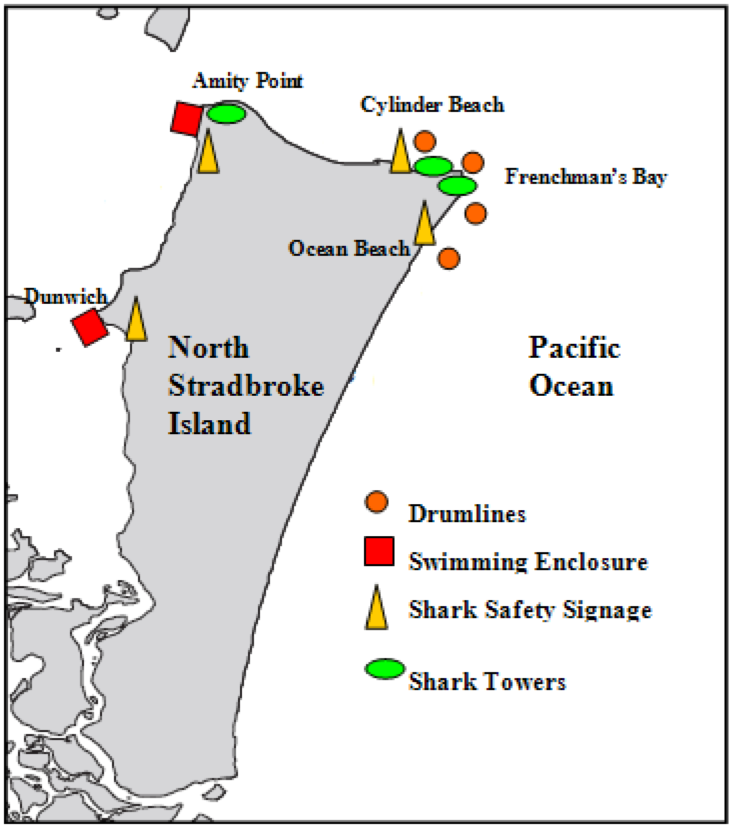

Figure 7: Map of North Stradbroke Island with proposed changes to the Shark Safety Program

This program would be implemented and managed by the Shark Safety Program, in consultation with the local stakeholders. The stakeholders impacted by this new program would include bathers, surfers, fishermen, boaters, the local tourism industry, resort owners, local government, and the indigenous community. The proposed plan represents the shark attack prevention methodologies which were shown to be most supported by the community, and it would therefore encounter relatively low opposition in its implementation. The various approaches to preventing shark attack prevention promoted by this technological review would integrate effectively and there are redundant safety measures at each protected site. The highest costs would be associated with building new swimming enclosures at Amity Point and Dunwich, and the construction/purchase of shark towers for Amity Point, Cylinder Beach, and Frenchman's Bay, could cost approximately $150,000 AU. Both of these new systems will involve maintenance costs including paying SLSQ officials and private contractors to maintain the new infrastructure. The cost of implementing new signs at all sites and increasing SSP advertising on the island would likely be minimal relative to the $100,000 AU directed annually by the SSP to education for the whole of Queensland. Last, the cost of removing the drumlines at Amity Point would likely be negligible.

One problem in implementing this design is the legal issues that could result from changing the current system; should an attack occur at a beach protected by this new system, the parties responsible for the change could possibly be held responsible and sued by the impacted persons (Scientific Shark Protection Summit, 2006). Further research should investigate the legal issues surrounding changing shark attack prevention gear. Also, more technical details on the exact technologies that could be applicable at the North Stradbroke sites should be investigated to better understand if they are feasible from an engineering standpoint, particularly examining developing swimming enclosure technologies. Last, further research should be conducted on the sharks which frequent Moreton Bay, with the hope of making shark forecasting a more viable technique in the future.

The success of this program could only be ascertained through long-term monitoring of certain variables, including attack levels at protected beaches, the number of target and non-target species caught on the drumlines, the number of sharks sighted by SLSQ observers, the maintenance costs associated with each technology, and the community support and usage of each protective measure. The Queensland Shark Safety Program would collect information on each of these topics and compare this data to previously-defined targets for success. If a specific methodology is proven to be unsuitable, then its use must be reevaluated and possibly removed.

Conclusions:

This study demonstrates that there is no perfect solution to end all shark attacks, but there are technologies and methodologies available which can be effective in reducing this risk without simultaneously compromising sustainability goals. Humans and sharks are inextricably linked both through complex ecosystem processes and culture connections. As apex predators, they keep coastal ecosystems in balance, consequentially allowing us to utilize these relatively stable systems for sustenance. At the same time, we culturally value sharks as archetypes of fear and natural power. The QSSP program is playing a game of odds by saying that by reducing the total number of sharks in eastern Australian waters there will be fewer shark attacks. The problem with this strategy is that it is short-sighted in regards to ecosystem health- continuing with the status quo of shark control will inevitably cause shark populations to decline below a level to which they can recover with negligible effects on population structure, and the trophic impacts resulting from this could be catastrophic for many human stakeholders and marine organisms. In this era of increased environmental awareness and understanding of the connectivity between humans and the natural world, this is unacceptable. Acknowledging the basic fact that the ocean will always remain a dangerous environment, we should proceed to mitigate its risks with smarter approaches by pooling scientific, technological, and community resources. We can use our intelligence rather than our shear technological brawn to reduce the odds of shark attack, with the end result of improved ecosystem health and optimal levels of bather safety. This study has voiced rational, more sustainable alternatives to traditional shark attack prevention, and it hopefully has helped to establish a framework from which future technologies can be analyzed for their potential integration into shark management programs.

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Appendix 1 Aerial Survey

Image from an aerial survey of a large white shark off a South African beach (photo by Michael C. Scholl)

Appendix 2 Beach Meshing

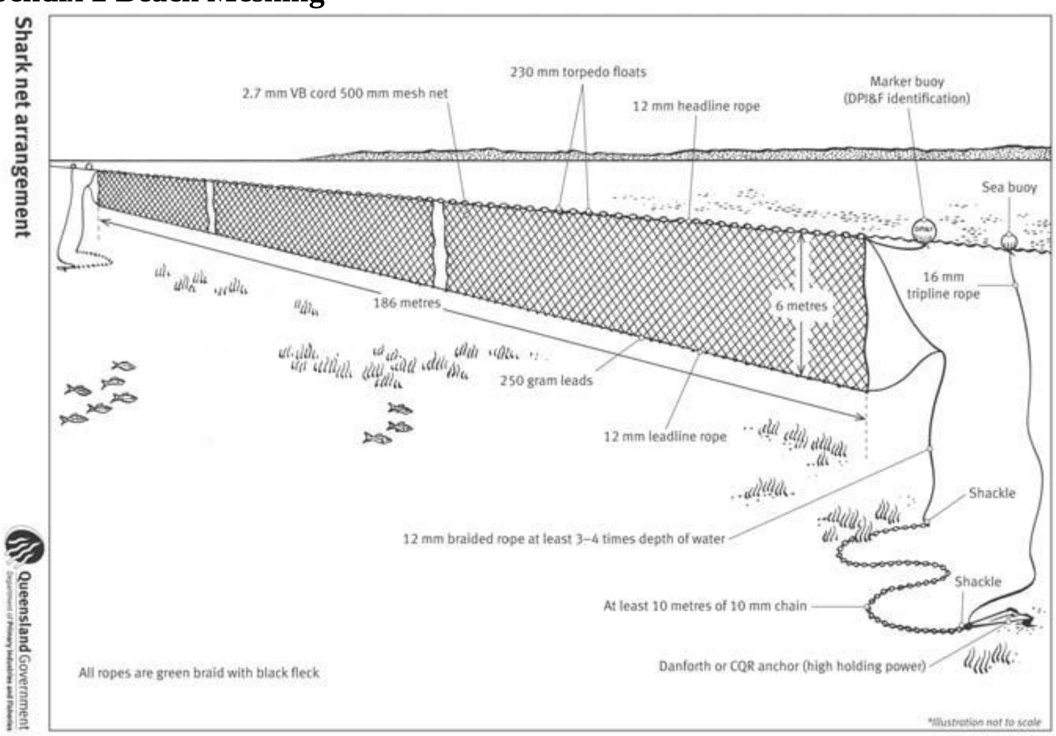


Diagram of a standard gill net used by the QSSP (QDPI&F, *A Report on the QSSP*, 2006)

Appendix 3 Drumlines

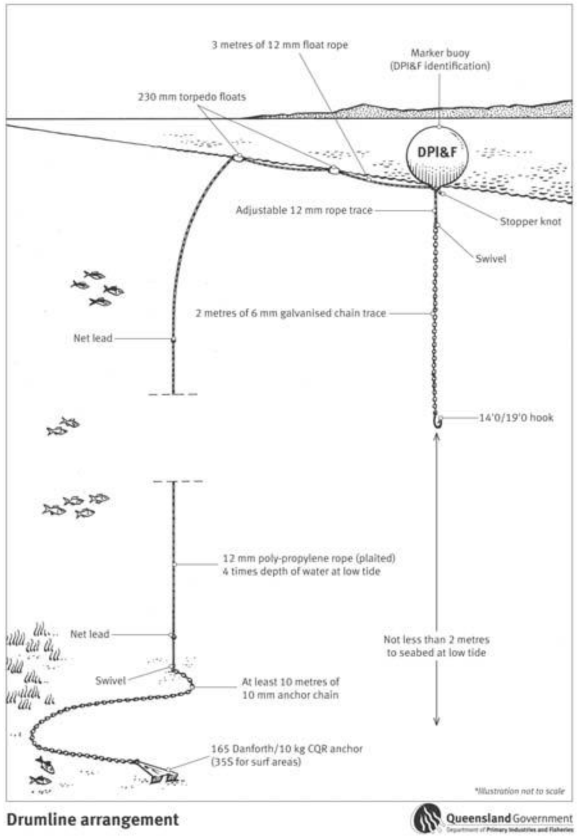
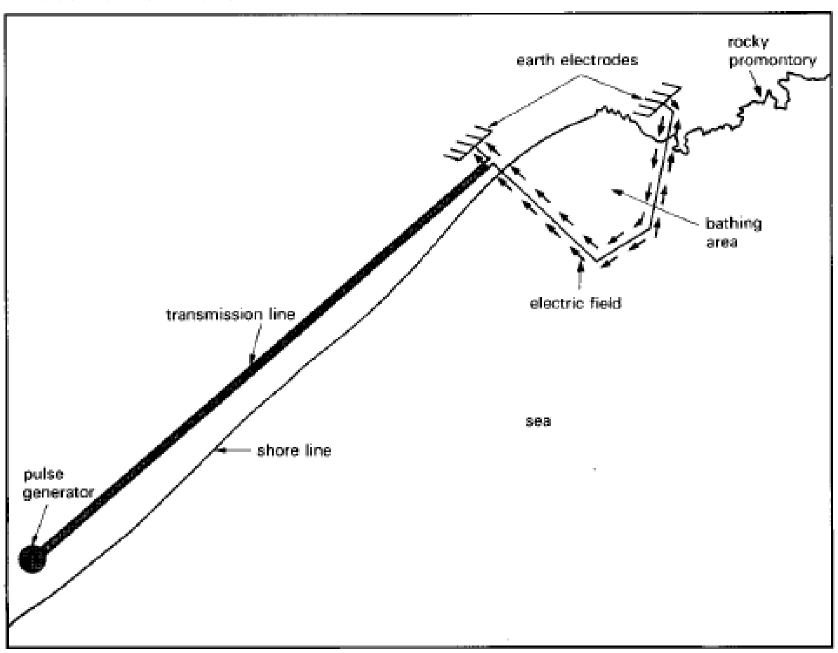


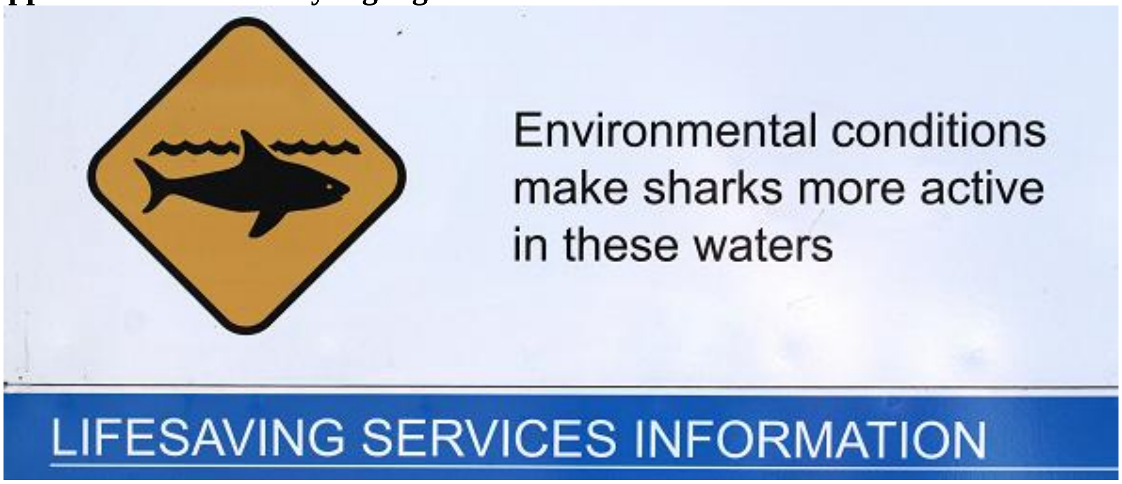
Diagram of a standard drumline used by the QSSP (QDPI&F, *A Report on the QSSP*, 2006)

Appendix 4 Electric Barriers



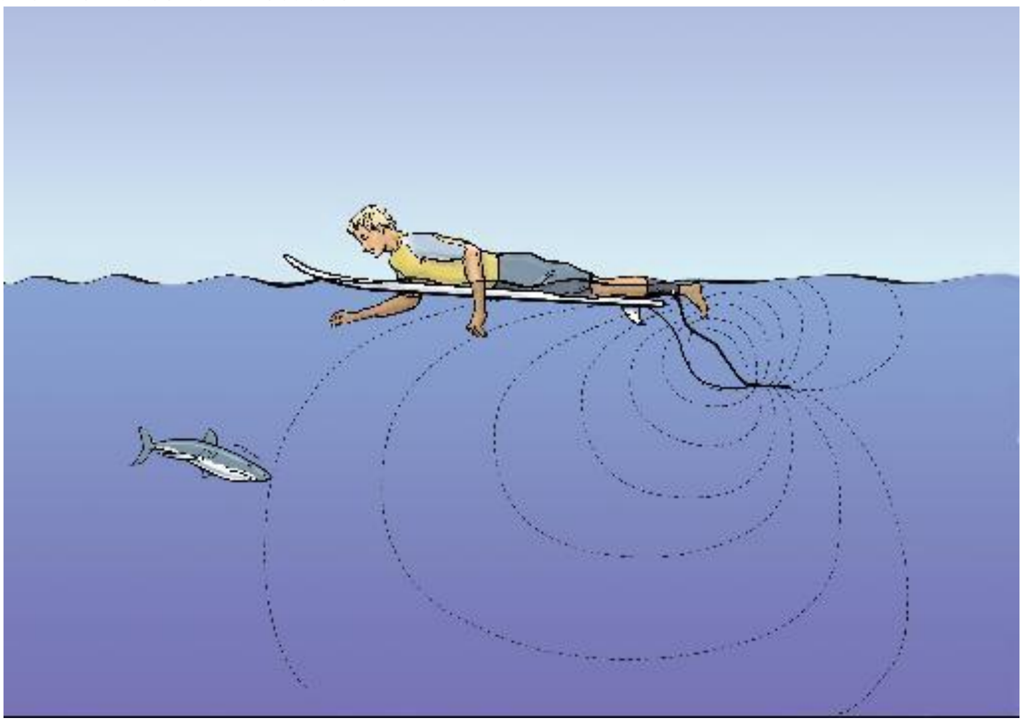
Schematic of a proposed electric shark barrier *Smith* (1989)

Appendix 5 Shark Safety Signage



Current signage in place at Amity Point (photo by author)

Appendix 6 Personal Protection



Cartoon schematic demonstrating the use of a Shark Shield electrical shark deterrent device for surfers (Shark Shield Product Website)

Appendix 7 Seasonality of Shark Catch in Queensland Shark Safety Program

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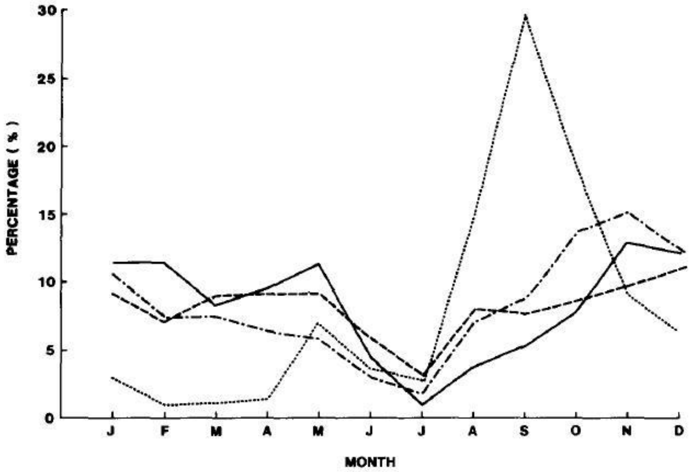

Fig. 4. Monthly catches in percentage terms of *Carcharhinus* spp. (——), *C. carcharias* (·····), *G. cuvieri* (—·—·—) *and Sphyrna* spp. (– – – –) at all regions between 1962 and 1988.

Graph of monthly catches in percentage terms of all target species for the QSSP from 1962-1988, demonstrating the seasonality of shark catches, information that could be integrated into a shark forecasting model *Paterson* (1989)

Appendix 8 Shark Tower

A shark tower located on a hillside above Greenmount Beach on the Gold Coast (photo by author)

Appendix 9 Swimming Enclosure

Photo of the swimming enclosure at Amity Point (photo by author)