Shark Deterrents and Detectors

Review of Bather Protection Technologies

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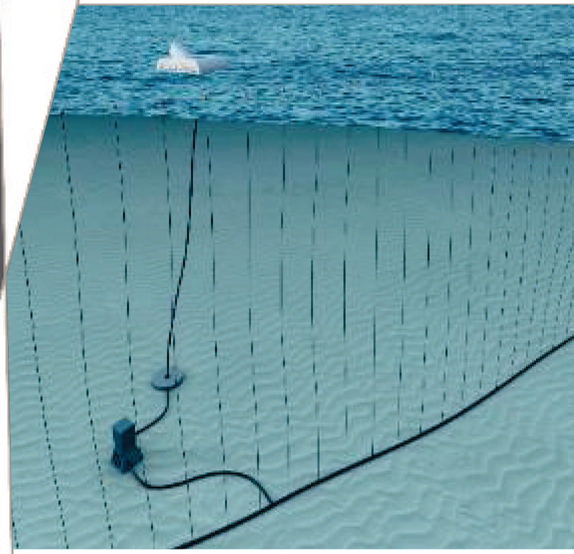

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Glossary of Terms and Abbreviations

Term	Definition
Bather	Any person engaged in in-water recreational activities of surfing, body surfing or swimming in coastal waters
Coastal waters	The immediate nearshore environment out from ocean beaches but not in protected waterways such as estuaries, even if they comprise sea water.
DPI	Department of Primary Industries
Emerging (new) technologies	Technology to deter or detect sharks that has been recently developed or is under development
NSW	The state of New South Wales in Australia
Personnel device	A shark deterrent worn by an individual or that is part of an individual’s water craft
Shark barrier	A device enclosing bathers in part of a beach that physically prevents sharks from gaining entry
Shark detector	A device or activity that is used to detect sharks approaching an area
Shark deterrent	A device or activity that deters or repels sharks from approaching a person or area
Shark meshing program	Deployment and retrieval of mesh nets along 51 high-use beaches in NSW between Wollongong and Stockton (near Newcastle), and including Sydney, between 1 September and 30 April each year. The nets are ‘sunk nets’ set below the surface in about 10 to 12 metres of water, within 500 metres of the shore and made of multifilament flat braid polyethylene with a corkline and leadline, with 160 kg breaking strength. Each net is 150 m long, 6 m high, 50 - 60 cm mesh size and fitted with acoustic warning devices to alert dolphins and whales. The nets do not cover the entire length of most beaches and there is rotation among beaches.
Surfer	Surfboard or bodyboard rider

Executive Summary

Cardno was commissioned by the New South Wales (NSW) Department of Primary Industries (DPI) to undertake an independent review of emerging technologies for bather protection (including swimmers and surfers) to create a ‘short list’ of feasible technologies for possible trial off some NSW ocean beaches. The focus of the review was on technologies that might be effective at the whole-of-beach scale, but aerial survey methods were not considered as part of this review.

Emerging technologies can be separated into two broad groups: shark deterrents and shark detectors. Either of these technologies can theoretically protect bathers. Deterrents aim to keep sharks away from bathers, whereas detectors aim to warn bathers that a shark is nearby.

In evaluating the emerging technologies for potential trial, eight criteria were considered, in order of importance: 1) the practicalities of implementing at a whole-of-beach scale; 2) the potential for adverse effects on human health (particularly interference with pacemakers); 3) the ability to withstand conditions similar to NSW beaches; 4) commercial availability; 5) effectiveness on white, tiger or bull sharks; 6) verification of effectiveness via independent testing; 7) potential for adverse effects on wildlife; and 8) potential to affect other water users. A decision tree was used to rank technologies based on which of the suite of criteria were met by each of the technologies. Shark deterrents and detectors were ranked using separate decision tree processes. Cost of trialling was also considered where this information was available. Technology manufacturers and scientists involved in evaluating technologies were consulted as part of the assessment process.

The overall outcome of the review indicated that shark deterrent and detection technologies are effective in some circumstances, or in the case of physical barriers effectively prevent shark from entering beaches where water users are present. Of the barrier approaches reviewed, the physical barriers ranked highest according to assessment criteria for potential trial in NSW, followed by bubble, visual and magnetic, and electric barriers. Although all of the barrier type approaches were considered to have potential they were also considered to need further refinement before they could be recommended for possible trial at NSW beaches. Despite evidence of effectiveness for some models, all of the personal deterrents did not rank highly for potential trial as a whole-of-beach solution but they would provide a good solution for bathers using remotely located beaches and for surfers that frequent the reefs and headlands between beaches.

Of the shark detectors, the shark spotter program ranked the highest although the cost of labour for the program would need to be closely scrutinised and there are issues associated with its effectiveness on longer beaches, as well as uncertainties regarding the effectiveness at reliably detecting bull and tiger sharks. Given the costs of setting up and running a shark spotter program, possible trials of this program, and for that matter any technology, should consider how existing networks of lifeguards or other organisations could be utilised to make implementation of a program cost-effective. The other three shark detection technologies reviewed each have different issues that would need to be overcome before they were short-listed for trial.

The following recommendations are made:

1. Because the short-listed technologies cannot provide a single, simple solution that would encompass all types of beaches in NSW, consideration should be given as to how best to integrate emerging technologies, were they trialled successfully, into the NSW Government’s overall suite of bather protection measures;
2. Although most of the shark deterrents that operate at large-scales have potential for whole-of-beach protection we consider that they require further refinement before short-listing for potential trial at NSW beaches. We provide advice in the report for each type of emerging shark deterrent technology as to the refinement that is needed to make them ready for trial;
3. The short-list of shark detectors for potential trial on NSW beaches is limited to the shark spotter program but Smart Drumline and Cleverbuoy systems would also be suitable for trial if the following issues can be overcome:
    - (a) Smart Drumline - a suitable means for translocating hooked sharks before mortality occurs is determined, the practicality and cost-effectiveness of effectively tending the fishing gear is addressed, and there is independent scientific verification of effectiveness against white, tiger or bull sharks; and
    - (b) Cleverbuoy - durability is proven, further evaluations are made on its effectiveness at shark detection and negligible potential to have adverse impacts on wildlife including rigorous scientific evaluation.
4. NSW Government should consider including advice in its SharkSmart program regarding the types of personal deterrents that it would recommend as being suitable for bathers to use in remote locations and for surfers to use around headlands.

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1 Introduction

1.1 Background

While shark bite incidents are rare, they are extremely traumatic. To reduce the risk of shark bite incidents and fatalities, the New South Wales (NSW) Government provides a suite of bather protection measures including:

- A shark meshing program along 51 beaches between Wollongong and Stockton;
- The public awareness program 'SharkSmart', designed to inform and educate water sports enthusiasts about ways to reduce the risk of a shark bite incident;
- A Shark Incident Response Plan, which provides a coordinated government response to shark related incidents;
- Grants to assist the construction of observation towers and provide associated shark-spotting equipment; and
- Research to investigate better ways to use aerial surveillance to provide additional bather protection during the peak beach activity season.

The NSW Government is committed to a comprehensive approach to bather protection and is currently investigating emerging technologies for potential use off some ocean beaches in NSW, Australia to further reduce the chances of a shark bite incident. Cardno was commissioned by the NSW Department of Primary Industries (DPI) to undertake the first part of this process: an independent review of technologies currently available. This report presents the findings of the desktop review which was presented at a stakeholder workshop where a 'short list' of feasible technologies was discussed for possible trial off some NSW ocean beaches.

1.2 Scope of Works

To assess the current status and knowledge of technologies to reduce shark encounters with humans, the review encompassed literature published in scientific journals, grey literature, internet information and personal communications with the manufacturers and scientists involved with the technologies. The review was limited to technologies that were commercially available or where prototypes had been developed. Ideas and technologies that were only in the concept stage were not considered. Cardno in association with Bond University used a decision tree to compare and rank technologies for short-listing. A key criteria in this decision making process was an assessment of how technologies would perform in the environmental conditions experienced off NSW ocean beaches.

Unprovoked shark bite occurs in a number of different habitat types (e.g. open water, coral reefs and rocky reefs), but globally, the majority occur on surfers at ocean beaches, with swimmers making up the next highest category (McPhee 2014). In addition to beaches, unprovoked shark bite occurs in a number of different habitat types (e.g. open water, coral reefs and rocky reefs). In addition to surfers and swimmers, it can also occur on users undertaking a diversity of water-based leisure activities (e.g. snorkelling, scuba diving, spearfishing). In this report, however, we focus on the application of emerging technologies to mitigate the hazard of unprovoked shark bites for swimmers and surfers at ocean (surf) beaches with the specific aim of identifying and prioritising options for trials in NSW. A variety of measures will always constitute a government's shark mitigation strategy, and newly emerging technologies can continue to make a contribution. The likely efficacy of options based on current research knowledge, cost effectiveness and commercial availability at an appropriate scale is assessed. In addition to considering options that are specifically designed to act over a large area, novel approaches for the use of personal deterrents and deterrents at a beach-scale context are also considered. Aerial survey methods were not considered in this review, as they have been previously investigated by the NSW DPI (in the case of fixed-wing and helicopter platforms; Robbins et al. 2012) or recently reviewed for the department (in the case of drones; Bryson and Williams 2015). However the role of surveillance methods in general, whether beach-based, aerial or other, needs to be considered as part of an overall assessment of shark bite mitigation strategies.

2 Review of Existing Information

2.1 Occurrence of Unprovoked Shark Bite

Unprovoked shark bite incidents have the widest footprint of geographic human-wildlife interactions and represent a complex challenge for managers, scientists, policymakers and conservationists. Globally, the frequency of unprovoked shark bite has been increasing (McPhee 2014). The reasons for this increase are complex. While a greater number of water users over time contribute to this trend, it does not explain it entirely, with a number of natural and anthropogenic factors contributing (Amin et al. 2012; McPhee 2014). Over the last 30 years unprovoked shark bite has been recorded from 56 countries and territories, with the majority (84%) having occurred in the United States, South Africa, Australia, Brazil, the Bahamas and Reunion Island (McPhee 2014). While the probability of an unprovoked shark bite remains low, the vivid nature of a shark bite ensures a high degree of media reporting and public concern (Zillman et al. 2004; Neff 2012), even though globally, most shark bites result in very minor injuries only (Woolgar and Cliff 2001). When a number of unprovoked shark bites occur at a single location or region over a short period of time, it potentially becomes a societal problem which might require government intervention (or additional intervention) at that locality or region.

Globally there are a large number of shark species implicated in unprovoked shark bite. However, where a species is reliably assigned to an incident, white sharks (*Carcharodon carcharias*), tiger sharks (*Galeocerdo cuvier*) and bull sharks (*Carcharhinus leucas*) account for 55.6% of all bites over a thirty year period (McPhee 2014). During the same period these three species account for all but three fatalities which were reliably attributed to the oceanic white tip shark (*Carcharhinus longimanus*). In Australian waters tiger, bull and white sharks occur over a relatively wide geographic area. In Western Australia in 2011/12 and currently on beaches of the NSW north coast most recent unprovoked bites have been attributed to white sharks. There are also some unprovoked shark bites where the species of shark is not identified with certainty due to the shark not being seen clearly, eyewitness reports being of a generic nature (e.g. “large shark”, “whaler”) or conflicting, or failure to confirm the species responsible from assessments of wounds or damage to water craft.

2.2 Responses to Unprovoked Shark Bite

Responses to unprovoked shark bite involve public policies and management approaches that contend with the needs of public safety, and the responsibility to protect native species in their natural environment, particularly threatened species. The white shark itself is a listed threatened species. Government agencies may implement measures that attempt to reduce the risk posed, placate the public, or provide information aimed at identifying the presence of sharks at a beach in real-time and allowing water users to make more informed decisions about utilising a particular area at a particular time. No single mitigation measure is 100% effective in all circumstances. Responses to unprovoked shark bite needs to consider how the various water users utilise a beach area. Bathers may be happy to congregate in a relatively small area on a beach very close to shore (e.g. between the flags), whereas surfers often seek out less crowded areas where good surfing waves can be found and their activities place them in deeper water for longer periods of time.

2.2.1 Traditional Responses

In two Australian states (Queensland and New South Wales) and South Africa, methods that aim to capture and kill large sharks (using nets and drumlines) adjacent to popular beaches are a long standing approach aimed at reducing the probability of an unprovoked shark bite. These traditional intervention measures have become highly controversial (Meeuwig and Ferreira 2014; Gibbs and Warren 2015). This is in part due to a realisation of the conservation status of some shark species and the role of sharks in the marine ecosystem as apex predators, and the recognition of the need to reduce the overall anthropogenic mortality on shark species from various sources (Simpfendorfer et al. 2011; O’Connell and deJong 2014; Gibbs and Warren 2015). There is also ongoing concern about the bycatch captured using these methods (e.g. Paterson 1990; Krogh and Reid 1996; Dudley 1997; Gribble et al. 1998; Brazier et al. 2012), despite the best efforts at reducing bycatch through gear modifications and the timing of deployment (e.g. Sumpton et al. 2010). Another traditional approach has been the use of nets to physically separate sharks and bathers (termed ‘exclusion’ nets), and such approaches are still deployed successfully in a few protected environments (e.g. Sydney Harbour), although their use in exposed surf environments can be difficult due to the likelihood of wave damage and high maintenance costs (Cliff and Dudley 1992).

2.2.2 Research into Shark Deterrents and Detectors

As well as the traditional methods of shark nets, drumlines and exclusion nets, there has been a history of research aimed at developing a diversity of shark deterrents. Much of this work has focussed on methods that can be used by an individual water user (personal deterrents). Shark deterrents have generally been based on an understanding of the sensory biology and the behavioural ecology of sharks. This has included approaches based on chemical deterrents, visual deterrents, acoustic deterrents, and electrical and magnetic deterrents (**Table 2-1**). Some of these approaches have been adapted from other purposes, such as the development of approaches to reduce shark bycatch in commercial fisheries. A particular challenge is that there can be substantial inter-species variation in shark responses to the various methods, even to the extent that what deters one species of shark, may act as an apparent attractant to others (Hart and Collin 2015). No shark deterrent can be guaranteed to be 100% effective in all circumstances for all shark species. Building on the initial body of research, further recent research efforts have been catalysed (in part) by a series of unprovoked shark bites in Western Australia, Egypt and Brazil. In addition, there have been advances in remote detection methods in the marine environment (e.g. sonar technologies and acoustic tagging and tracking) that have applicability to sharks, as well as a fuller understanding of the potential role of community-based shark monitoring such as the Cape Town Shark Spotters Program (Oelofse and Kamp 2006; Weltz et al. 2013) (**Table 2-2**).

Table 2-1 Types of emerging shark deterrent technologies

Scale	Type	Product / Group
Large - scale Deterrents	Physical barriers	Temporary net
		Eco Shark barrier
		Bionic barrier
		Aquarius barrier
	Visual barrier	Bubble curtain
	Visual and Magnetic barrier	Sharksafe barrier
	Electric barrier	Shark repellent cable
		Shark Repelling System
		Underwater rubberized electric fence
Personal Deterrents	Chemical	Repel sharks
	Shark vision disruptor/camouflaging	SAMS (camouflage wetsuits and surfboards)
	Electric	Shark Shield
		Surf safe
		Sharkbanz (electropositive metals)
	Magnetic	Sharkbanz (permanent magnets)

Table 2-2 Types of emerging shark detection technologies

Type	Product
Sonar	Cleverbuoy
Dedicated land-based observers	Cape Town Shark Spotters Program
Acoustic tagging and tracking	Various

2.3 Effectiveness of Emerging Technologies for Bather Protection

With the technological advancements in shark detection methods and deterrents and advances in the understanding of shark biology and ecology, a review of emerging methods that are applicable at a whole-of-beach scale is warranted. As indicated in **Section 1.2**, unprovoked shark bite occurs in a number of different habitat types and on users of various water-based leisure activities. In this review, however we focus on the application of emerging technologies to mitigate the hazard of unprovoked shark bites for bathers and surfers at ocean (surf) beaches with the specific aim of identifying and prioritising options for use in NSW. In addition to considering options that are specifically designed to act over a large area, novel approaches for the use of personal deterrents and repellents at a beach scale context are also discussed.

2.3.1 Electrical Deterrent Barriers

The aim of electric deterrent barriers is to provide an electric field that can potentially provide protection for an area (a beach or part of a beach), as opposed to personal protection devices based on the same principles. Electric barriers are based on an exploitation of shark sensory biology. Elasmobranchs (sharks and rays) have a specialised set of receptors (ampullae of Lorenzini) that enable them to detect extremely weak electrical potentials generated by other animals as well as inanimate objects, and these are used principally for locating prey. The electrical receptors of sharks are highly sensitive at short distances (0.5 m), and a corollary of this high sensitivity is that it is easily saturated by intense stimulation, and this is the basis of electrical shark repellents (Hart and Collin 2015). The deployment of electric barriers in the physically harsh and dynamic surf environment is a potential challenge for effective operation. This challenge though is not considered to be insurmountable. All of the three electric barriers considered in this review are very much in the research and development phase and are not yet commercially available.

2.3.1.1 Shark Repellent Cable (KwaZulu Natal Sharks Board)

Research on electric deterrents for beach protection was first initiated in South Africa in the 1960s. Cliff and Dudley (1992) summarise the results of the early work and raised a number of practical challenges in terms of effectively maintaining the equipment, as well as experimental challenges in determining its effectiveness. They reported that the first cable deployed in 1972 malfunctioned and a second cable deployed in 1982 was inadvertently laid on top of a section of buried reef, which, once the sand had been scoured away caused irreparable damage. A third deployment was successful in 1985, but difficulties arose in experimental designs to test its effectiveness, and also it was found that the electric field around the cable was weaker in the surf zone environment compared to that obtained in tank trials and in calm water.

In 2010, research in South Africa resumed on overcoming the practical challenges encountered previously with deployment. The South African National Space Agency (SANSA) undertook consolidation of available knowledge and modelling of electrical field distribution in seawater under different environmental conditions. In 2012, the South African Institute of Maritime Safety was commissioned to confirm the modelling, develop a prototype cable and then construct a full cable. The full cable was installed at Glencairn Beach in October 2014. Glencairn Beach is a small beach between two headlands and is exposed to prevailing wind and waves. However, given it is in False Bay there would be some protection from large ocean swells and as such, conditions are not directly comparable to those at NSW beaches. Fish Hoek was the preferred location for testing as it was calmer, but concerns were raised there about the impacts of the physical structures on the commercial trek net (beach seine) fishery. The trial period ran until March 2015. There was a requirement for trialling to be undertaken outside the migration period of the southern right whale to avoid any entanglements.

The recent deployment consisted of a large chain weighing down the cable with wave action covering the cable with sand (G. Cliff, pers. comm.). Electrodes vertically rose towards the surface from a depth of approximately six metres (**Figure 2-1**). The cable was powered by a pack of large truck batteries and driven by the electronic controls housed in a small trailer which was driven on site and connected each day. While there were some teething problems, once these were solved, the cable was reported to function well in terms of maintain its position on the seabed with no damage to the cable occurring. Very large detached kelp plants caused entanglement issues with the rising electrodes. The sizes of the kelp plants encountered were generally much larger than those generally occurring in most of NSW. While the cable was successfully deployed, no white sharks were recorded approaching it – either by the resident Shark Spotters or by dedicated automated photography (a photo of the cable area taken every 7 seconds). Therefore, the ability of the barrier to effectively deter white sharks could not be determined, despite substantial efforts.

Further redesign, trialling and monitoring of the shark repellent cable is proposed by the KwaZulu-Natal Sharks Board (G. Cliff, pers. comm.). The redesigning includes development of a cable that is floating with electrodes dropping down, as opposed to the previously trialled approach of having the cable on the seabed with electrodes rising up. This new approach will potentially have the advantage of being able to be deployed on a temporary basis and can this can potentially alleviate interactions with the commercial trek net (beach seine netting) fishery.

Figure 2-1 Shark Repellent Cable. Left: cable leaving shoreline, Right: cable floats and controls. Source: Geremy Cliff.

2.3.1.2 Rubber Guard Electric Fencing (Resen Energy)

Resen Energy is a Danish company that focuses principally on wave energy technology, but also has expertise and interests in engineering other products. One product is the Rubber Guard fencing, a new type of fencing which is mainly used for difficult applications where there is a requirement for electric fencing that cannot be short circuited by wet vegetation. The typical application is either to keep expensive stock inside or predators like wild dogs, wolves and bears outside. This product has since been modified for use as a seal deterrent for commercial fishing activities, but a further alternative use as a shark barrier has been flagged by the manufacturers (P. Resen Steenstrup, pers. comm.).

The Rubber Guard fencing consists of an electric cable which is heavy enough to stay on the seabed and a number of flexible vertical Rubber Fence wires which are distributed along the electric cable with a 1 to 1.5 m spacing (**Figure 2-2**). The fence is energized with 100 to 200 Volt electric pulses, using a technology similar to the standard electrical fences above water. However the voltage level is so low that it is only noticed as a slight prickly feeling on human beings. The small red floats at the end of the Rubber Fence wire will keep the wires vertical and the wires will sway forth and back with the passing waves, which makes the curtain lively. The barrier can either be energized with a special water proof battery operated energizer designed for the purpose or with a combination of photovoltaic power or wave power modules.

This barrier has not yet been tested on sharks and is not currently commercially available, although trials are planned (P. Resen Steenstrup, pers. comm.).

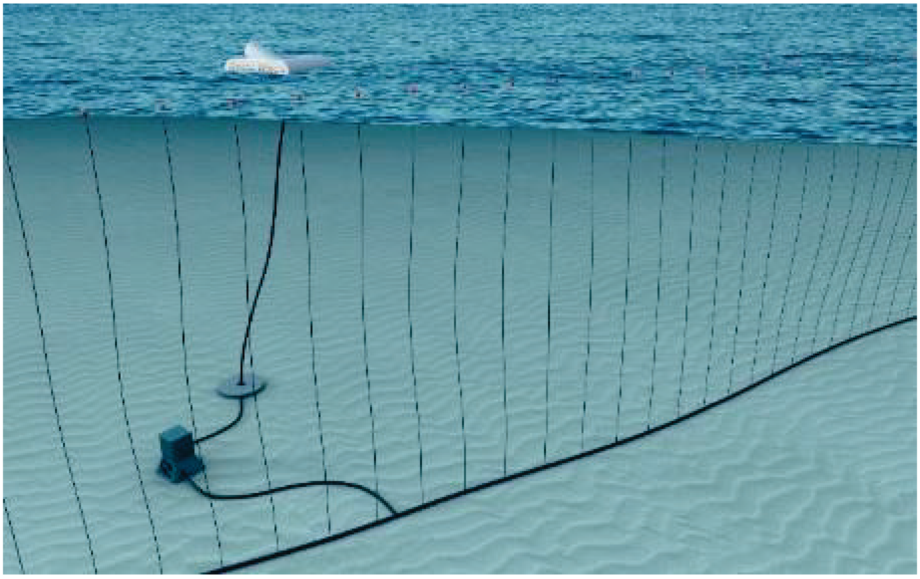

Figure 2-2 Rubber Guard Electric Fencing (Resen Energy). Source: Per Resen Steenstrup.

2.3.1.3 Shark Repelling System (Aquatek Technology)

Following the series of unprovoked shark bites in Egypt in 2009, the Belgian company Aquatek Technology was formed to focus on developing an electric shark barrier. Underwater gates produce an electromagnetic field and each unit of the gate is provided with a backup power supply and an alarm that provides notification of any power failures. The approach has been reportedly trialled[1] on various shark species (including bull sharks, white sharks and tiger sharks) in tanks and in the field (reef environment rather than surf beaches), but these trials do not at this stage constitute rigorous scientific experiments. They do however demonstrate proof of concept. However, the practicality and durability of the Shark Repelling System does not appear to have been tested yet in surf zone conditions. The Shark Repelling System will be tested at Reunion Island for the purpose of protecting professional divers that will be in the water for the purpose of constructing a coastal road, with the timeframe for this testing to occur being six to twelve months (Y. Eeckhout pers. comm.).

2.3.2 Physical and Visual Barriers

Physical barriers either wholly, or in part, aim to separate sharks from water users such as bathers. They do not aim to capture sharks or other marine life. Physical barriers principally aim to protect bathers, but there is no reason that a number of the products could not be placed at a specific location to provide protection for surfers. For barrier nets that wholly enclose an area, provided the net is intact it will effectively exclude sharks. As such, scientific trials to determine shark behavioural responses to barriers are not required. However, permanent physical barriers need to be designed to withstand the surf conditions at the location where they are deployed, and trialled to ensure that in practice they do. This ability to withstand the surf conditions must be tested over a relatively long period of time (e.g. years). Biofouling is also a potential issue that can greatly limit the cost-effectiveness of the approach. The potential for biofouling will be geographically variable and transferability of information on biofouling from one location to another requires caution. The potential for interactions with the NSW Ocean Haul Fishery may be a consideration for the placement of physical barriers in the surf zone at some NSW locations.

While there is obviously a visual component to the physical barriers in as much that sharks see them, the physical barrier obviously prevents a shark from access to an area. Visual barriers can also be deployed that aim to deter a shark from entering an area, but do not physically prevent it from doing so. An example of this would be a bubble curtain where an animal could swim through it if it wanted to, but which creates a visual profile which may reduce the probability of it doing so.

2.3.2.1 Eco Shark Barrier Net

The Eco Shark Barrier Net was designed in Western Australia. It consists of thousands of small modules made of the polymer nylon 6 or polycaprolactam (used to make cable ties) to form a barrier that allows water to pass through 295 mm diameter squares (**Figure 2-3**). The modular design has a 450 kg breaking strain,

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[1] http://www.sharkrepellingsystem.eu/presentation.asp? (Accessed 23/9/15).

or 12 tonne breaking strain when the support ropes are attached. It is held upright by floats on a surface rope spaced 100 mm apart. Chain and anchors hold the bottom of the barrier to the seabed and it can be setup with pylons on the corners or along its length. The Eco Shark Barrier Net has been successfully deployed at Coogee Beach (Western Australia), which is a beach largely protected from oceanic swells by Garden and Rottnest Islands. The initial trial was for four months (December 2013 - March 2014), and following that trial the design was improved and it was redeployed for an ongoing three year trial which commenced in November 2014[2] It has been reported by the manufacturer to have withstood waves of 1.5 metres. Cleaning of marine growth is possibly required every couple of years, although this may vary depending on the location where it is deployed as the potentially for biofouling will differ geographically as mentioned previously. At Coogee Beach, no entanglements of fauna have been recorded, although it does act as a fish aggregating device. It is reported that the manufacturers clean the currently deployed barrier themselves (N. Hart pers. comm.).

Figure 2-3 Eco Shark Barrier Net. Left: long view of Barrier at Coogee Beach, WA. Right: floats and barrier material. Source: Eco Shark Barrier Pty Ltd

2.3.2.2 *Bionic Barrier and Aquarius Barrier Nets*

The Bionic Barrier and Aquarius Nets are also designed in Western Australia. They both evolved from the Eco Shark Barrier Net, but are designed and manufactured by a different company (Global Marine Enclosures). The advancements are aimed at providing a barrier that is better able to withstand more wave energy and drag, and also to reduce the costs. In the event of an extreme weather event, the floats are easily removed from the barrier which will allow the frame panels to fold and drop down and rest on the seabed. In the event that part of the barrier gets damaged, the barrier features an ability to be repaired quickly in situ. The unique connection method allows damaged frame panels to be easily removed and replaced with new panels (**Figure 2-4).** The Bionic Barrier is commercially available, while the more recently designed Aquarius Barrier is due to be commercially available in October 2015 (E. Khoury, pers. comm.).

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[2] http://www.ecosharkbarrier.com.au/about-us/ (Accessed 23/9/15)

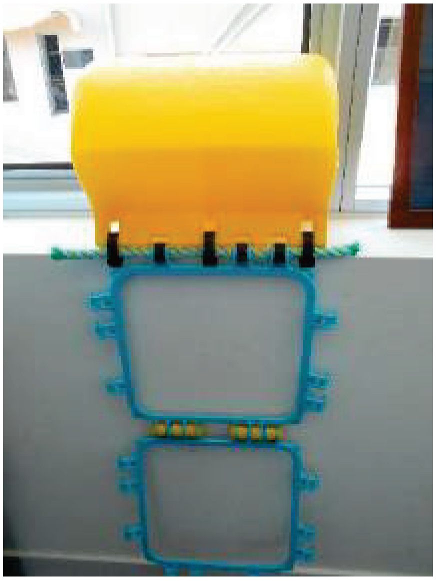

Figure 2-4 Bionic Barrier and Aquarius Barrier Net material and float. Source: Global Marine Enclosures.

2.3.2.3 Temporary Barrier Net

At Fish Hoek Bay in South Africa, a temporary net (4 x 4 cm mesh size) is deployed to act as a shark barrier at one part of the beach. The deployed net is suitable for protecting bathers only due to it being deployed at a relatively protected part of the beach (**Figure 2-5**). Deploying the net is a labour intensive operation, and the net has been modified a number of times (e.g. adding additional floats to increase buoyancy and vertical positioning in water column and improving the fastening system). These modifications have improved the efficiency of the daily operations and further reduced any risk of entanglements of any animals. Even with these modifications deployment and retrieval of the temporary net remains difficult and labour intensive.

The advantage of using a temporary net is that the need for it to be designed to withstand all surf conditions is eliminated. However, it is of course only effective when it is deployed and this will depend on the limitations in surf of the vessels required to deploy it. Despite the best design efforts, the potential for the net to entangle wildlife exists, in particular fish. The probability of entanglement will vary according to location and would need to be assessed accordingly. The transferability of the approach to NSW beaches overall is generally limited, however the approach may be applicable for very protected parts of beaches that are in the lee of prevailing wind and waves by rocky headlands.

Figure 2-5 Temporary Barrier Net deployed at a beach in South Africa. Source: Alison Kock.

2.3.2.4 *Bubble Curtains*

Bubble curtains create a visual barrier and this approach showed early promise in tank trials (McCormick 1963), however subsequent trialling identified only very limited deterrent abilities. A bubble curtain works by generating air (e.g. through a compressor) along a submerged perforated hose which escapes from the perforations and rises to the surface resembling a curtain. There are practical challenges in efficiently generating enough air over a length of hose necessary to provide a suitably large barrier, and challenge in maintaining the hose in position in the surf zone. Additionally, the surf zone itself already can contain a large number of air bubbles due to turbulence, and this includes areas that sharks utilise as habitat, so the type stimuli is generally not novel, although the pattern of its delivery will be. No commercially available bubble curtains to mitigate the risk of unprovoked shark bites were identified. As well as being a visual barrier, they may create hydrodynamic cues that sharks respond to through their auditory or lateral line systems. Bubble curtains are also used to mask anthropogenic underwater noise such as from pile drivers and their potential impacts on dolphins (Würsig et al. 2000). The deployment of bubble curtains at a location over an extended period of time may potentially interrupt dolphin communication and effect habitat use by these animals, although as previously identified bubbles are a natural feature of the surf zone water column. The impact may not be ecologically meaningful but it is still an impact that needs to be considered.

Additional recent work on the potential of bubble curtains as a shark barrier have been undertaken at the University of Western Australia, and while the publication of the results are imminent, they were not available at the time for inclusion in this report.

2.3.2.5 *Sharksafe Barrier*

The Sharksafe barrier consists of two key stimuli: grade C9 barium-ferrite permanent magnets and PVC piping to mimic kelp as visual barriers. The piping while anchored to the seafloor moves with waves and currents. Unlike the limitations on the size of permanent magnets for use as personal deterrents which is discussed later in this report, the magnets that can be practically used in the Sharksafe barrier can be large enough to create a larger deterrent field. The rationale of using both the visual and magnetic components in the barrier is that it may maximise the performance of the barrier across circumstances where turbidity may vary as it produces two distinct stimuli detected by two of the sharks sensory systems. That said, from the trials undertaken the importance of the magnetic component of the barrier is uncertain (O'Connell et al. 2014a). Overall, trials of the Sharksafe Barrier have been undertaken using a rigorous experimental design and the findings published in the scientific literature. The size of the barrier constructed and trialled to date was 15 m x 15 m (C. O'Connell pers. comm.). The results of these trials identified that the Sharksafe barrier is effective at modifying the behaviour of both white and bull sharks with the animals being effectively excluded from the area where they are deployed (O'Connell et al. 2014a and b). The Sharksafe barrier that incorporated kelp as a visual barrier additionally provided artificial habitat for a range of invertebrates and the Cape fur seal (*Arctocephalus pusillus pusillus*). The Sharksafe barrier has not been tested in surf zone conditions. Biofouling is also an important consideration and future published work on the effectiveness of the barrier will consider this issue (C. O'Connell pers. comm.). The transferability of the results obtained to date in habitats are very different to those encountered at NSW beaches is an important caveat that needs to be considered.

2.3.3 Personal Deterrents

As the name suggests, personal deterrents are designed to protect an individual who is using the deterrent rather than collective protection of a number of people at a location. While the focus of this report is on methods that can be deployed at a beach for collective protection of bathers and surfers, a review of the main approaches is relevant as there is substantial independent research undertaken on a number of deterrents, much of which is relevant to understanding deterrents and shark behaviour more generally. Owing to many surfers frequently seeking less crowded surfing locations at dawn and dusk, personal deterrents should remain at the forefront of strategies for protecting surfers. However, the use of an individual deterrent is a personal choice, as is the type of a deterrent that an individual may choose to use. A surfer though should potentially focus on choosing a personal deterrent that has undergone independent scientific trialling and weigh up whether they consider the effective area that a deterrent operates over provides them with sufficient piece of mind. Personal deterrent methods are diverse and include: electrical deterrents, magnetic deterrents (permanent magnets and electropositive metals), chemical deterrents, and visual deterrents. Individual deterrents come with relevant caveats from the manufacturers that they are not 100% effective all the time in all situations.

2.3.3.1 Electrical Deterrents

Electrical deterrents work by creating an electric field around a person in the water that sharks can detect and potentially respond to by ceasing their movements towards a person. The review has considered two such deterrents – the Shark Shield and the Surf Safe device. Electrical deterrents for individuals can vary in terms of the area of the field generated, as well as the exact nature of the field (e.g. pulse rate). Electrical deterrents require a power source. There is a limit to the extent the electrical deterrents can be miniaturised while still generating an electrical field of sufficient size to potentially deter a shark.

2.3.3.1.1 Shark Shield

The company Shark Shield makes a range of personal deterrents with models designed for diving, swimming and surfing (**Figure 2-6**). The current model for surf boards the Surf 7 TM attaches to the back of the surfboard. A new model for surfboards is currently in the final stages of development and is based on the generating device being incorporated into the grip pad of the surfboard (L. Lyon, pers. comm.). It is reported by the manufacturer (L. Lyon pers. comm) that the new design will reduce the drag through the water which has been a potential impediment for uptake of the device by high performance surfers. The deterrents produce an electrical field around a person in the water that sharks can detect and potentially respond to by moving away.

There have been two studies that have focussed on the shark shield and the predecessor of the current devices - the shark PoD. Smit and Peddemors (2003) compared the probability of an attack on a bait fitted with a shark PoD in both the power -on and power-off mode. They concluded that the probability of an attack in at most five minutes was reduced from 0.70 in power-off mode to about 0.08 in power-on mode and in a period of at most 10 minutes from 0.90 to 0.16. Huveneers et al. (2012) undertook independent testing of the Shark Shield Freedom7TM on white sharks using trials to determine its effectiveness on static baits and towed seal decoys. They found that the deterrent increased the time it took to take a static bait and the number of interactions per approach. On average sharks did not approach as close when the deterrent was activated. Tows of a seal decoy showed that the deterrent reduced the number of breaches, surface interactions, and the total number of interactions. Importantly, there was individual variation in behavioural responses to the deterrent. While the results of Huveneers et al. (2012) showed that the deterrent had an effect on white shark behaviour, it did not repel or deter them in all situations and for all individual sharks. This is an important point because although Smit and Peddemors (2003) and Huveneers et al. (2012) document statistically significant changes in shark behaviour which can be interpreted as reducing the risk of a bite on a person wearing a device when it is switched on, it does not translate into 100% protection. Importantly, and contrary to the opinion of some members of the surfing community, there is no evidence that the Shark Shield attracts sharks (Collin 2010). Additional work has been undertaken by the University of Western Australia of the effectiveness of the Shark Shield and this includes filling the important information gap on the response of sharks to the device when they are in close proximity to it.

In terms of impacts on fish assemblages from the Shark Shield, substantial effects of the electrical field on shallow-reef fish assemblages were not detected (Broad et al. 2010).

Figure 2-6 Shark Shield devices. Left: surfboard device fitted to rear of the board. Right: attached around the leg of a snorkeler. Source: Lindsay Lyon.

2.3.3.1.2 Surf Safe

The Surf Safe shark deterrent consists of electronics providing an electric field that are integrated into the surfboard - one electrode at front, one at rear, and a cable through the centre of the board (**Figure 2-7**). To date, in comparison to the Shark Shield, the Surf Safe shark deterrent has not had the same level of testing under controlled experimental conditions.

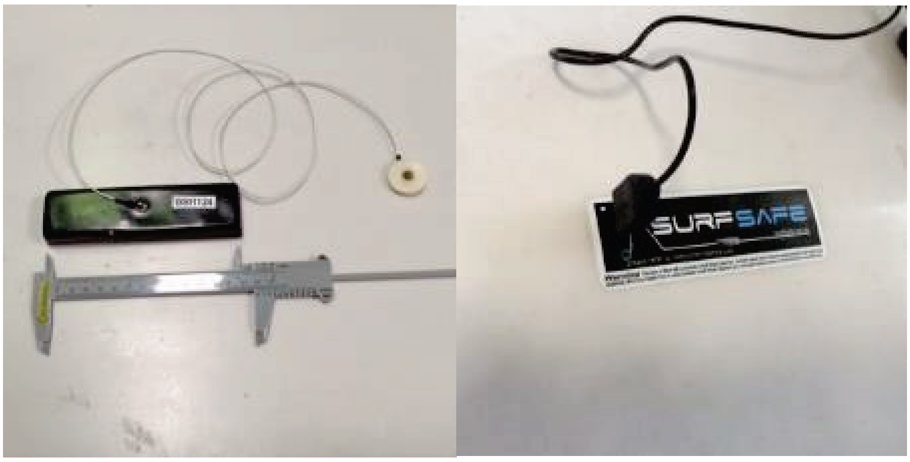

Figure 2-7 Surf Safe surfboard device. Left: prior to fitting, WA. Right: fitted in a surfboard. Source: Dave Smith.

2.3.3.2 Magnetic Deterrents

Magnetic deterrents can be divided into those based on the use of either electropositive metals or permanent magnets, although both can be combined. Unlike the electrical deterrents discussed in the previous section, magnetic deterrents do not require a power source. The use of both electropositive metals and permanent magnets as a shark deterrent had their origins in efforts to reduce the bycatch of sharks in commercial fisheries (e.g. O'Connell et al. 2011). The advantage of both these approaches for use as personal shark deterrents is that they can be incorporated into devices that are small, lightweight and wearable. The disadvantage is that the fields generated from them are typically very small in area. Research on the effectiveness of electropositive metals and permanent magnets as a shark deterrent has clearly been equivocal and strongly influenced by the species of shark, the level of food deprivation when captive animals have been used in trials, the presence of conspecifics, and the details of the metals and magnets used (reviewed in Hart and Collin 2015).

Electropositive metals are metals such as magnesium and rare-earth lanthanide metals (e.g. neodymium) which react vigorously with sea water when immersed which generates a small electrical current. Thus this means that the metals corrode and need to be replaced on a fairly regular basis. The fields generated have a very small effective range (e.g. <85 cm) (Hart and Collin 2015). Overall in terms of the role of electropositive metals in reducing elasmobranch by-catch in commercial long-line fisheries, Favaro and Cole (2013) determined through meta-analysis that a reduction did not occur statistically, which does not provide confidence that the approach has clear potential for use as a shark deterrent or repellent to protect water users. Permanent magnets are thought to act on the electrosensory system of sharks indirectly through electromagnetic induction which is thought to be the same physical mechanism that is thought to allow sharks to detect the Earth's magnetic field. (O'Connell et al. 2014a). The actual sensory processes by which sharks detect magnetic fields is not yet elucidated. Like electropositive metals, the effective range of permanent magnets is very small. The field strength of the magnetic dipole falls off approximately as inverse cube of the distance from the magnetic source.

2.3.3.2.1 Sharkbanz

Sharkbanz incorporate strong magnets in a wrist or ankle band-personal device. As discussed for personal magnetic deterrents in general, the effective range of the device is likely very limited. The manufacturer identifies that the device is likely to be effective at deterring "hit and run" bites in murky water from sharks such as bull sharks, but this is of only limited effectiveness at deterring an ambush predator such as the white shark. However, taking into consideration the limited size of the field that is likely to be generated, it is questionable as to whether a shark would react quick enough in order to cease biting a person. The general approach of using permanent magnets to deter sharks was discussed in the preceding section. Overall, specific independent testing of the Sharkbanz device using appropriately controlled experiments appears lacking.

2.3.3.3 Chemical Deterrents

The development of chemical deterrents can be dated back to at least 1942 with the U.S military being an important driver of this research in response to the fear servicemen had of sharks (Baldridge Jr. 1990; Stroud et al. 2014; Hart and Collin 2015). An early chemical deterrent - the Shark Chaser (using cupric acetate as an active ingredient) was discontinued for military use as it was shown to be ineffective at repelling sharks, although it may have been useful as a “psychological crutch” (Baldridge Jr. 1990; Smith Jr. 1991). In addition to actually deterring a shark, any chemical deterrent needs to be: a) non-lethal to sharks and also not negatively impact other marine animals (e.g. bony fish); b) able to be synthesised and stored without denaturing for a sufficient period of time; and, c) be effective in relatively small volumes to allow for practical use. When these three factors are considered a number of chemicals which elicit avoidance responses in sharks are not suitable as a deterrent or repellent. Pardaxin and pavonin are naturally occurring toxins derived from certain soles (*Pardachirus* spp.) which can repel sharks, but are not suitable as a shark deterrent or repellent as they lose potency when freeze-dried for long periods of time (Hart and Collin 2015). Chemicals such as sodium dodecyl sulphate (SDS) generally require the release of a volume of chemical that is too large for practical use in the field and may have broader environmental impacts (Baldridge 1990). Surfactants such as sodium lauryl sulphate which is used in many common household goods (e.g. shampoos and laundry detergent) can elicit a response if delivered directly to the mouth of a shark (e.g. via a squirt gun), but is not effective as a repellent when released into the water at low concentrations (Smith Jr. 1991; Sisneros and Nelson 2001). More recent chemical deterrents have focussed on biologically relevant compounds (semiochemicals) rather than those that are an irritant to shark senses (Hart and Collin 2015).

2.3.3.3.1 RepelSharks

RepelSharks is a personal chemical deterrent available in aerosol cans that when released covers a broad area, at least for a short period of time until it disperses. It is a manufactured chemical that is based on necromones in decomposing shark tissue which contains high concentrations of acetic acid in addition to a large array of amino acids, short chain and fatty carboxylic acids, amines and short chain lipid oxidations products (Stroud et al. 2014). The chemical deterrent has been trialled and shown to disperse competitively feeding Caribbean reef sharks (*Carcharhinus perezi and C. acronotus*). It is plausible that for shark species that scavenge on conspecifics, necromones may be a feeding stimulant. This potentially includes white and tiger sharks, both of which occur in NSW and are responsible for unprovoked bites there. It is imperative that testing of RepelSharks be undertaken on these two species before their use as a repellent in NSW is considered.

2.3.3.4 Visual Deterrents

Visual deterrents are based on current understanding of the shark visual system which operates over a medium-range, which, depending on light and water clarity, can be up to 100 m (Jerlov 1976). The science of shark vision is dynamic and continually advancing, but a lot of unknowns still exist (Lisney et al. 2012). Present knowledge indicates that sharks possess monochromatic vision, lacking the neural machinery for true colour vision (Hart et al. 2011). For this reason, sharks are unlikely to respond specifically to colour (spectral reflectance). Instead, sharks most likely rely heavily on brightness contrast and variation in light intensity to visually distinguish shapes and patterns (Hart and Collin 2015). Various wetsuit designs have been developed to either ‘hide’ humans from the view of sharks or to portray humans as ‘unpalatable’ through patterns based on the surface reflective spectra and the visual acuity of sharks. The use of illumination to disguise a person against the lighter background of the sky is a further avenue of visual deterrence which shows promise (Hart and Collin 2015) but research is still in the relatively early phase of development and no commercial available deterrents of this type are available.

2.3.3.4.1 SAMS Warning ™ and SAMS Cryptic ™ Wetsuits

There are two wetsuit patterns currently marketed by Shark Attack Mitigation Systems (SAMS) - the SAMS Warning ™ and the SAMS Cryptic ™ (**Figure 2-8**). These designs are also utilised in products other than wetsuits including surfboard stickers and underlays, and swimwear. The SAMS Cryptic design is purported to make it difficult for the shark to see the wearer in the water column by using disruptive coloration and shaping from the visual perspective of a shark. The pattern is not only purported to be difficult for the shark to see, but is also designed to blend in with the background colours. The SAMS warning design is intended to overtly present the wearer as unlike any shark prey, or even as an unpalatable or dangerous food option.

While the wetsuit designs are based on knowledge of the shark visual system, the patterns designed to hide humans from sharks’ view may reduce contrast, it is unlikely that a silhouette would disappear completely. Further the importance of visual cues and how sharks perceive such cues is likely to vary based on turbidity and in areas where turbidity is relatively high bull sharks can occur. Overall, both wetsuits designs have not been subjected to rigorous published experimental trials that can support their efficacy as a deterrent. In terms of the SAMS Warning ™ design wetsuit designs based on the concept of animals considered to be dangerous to sharks are also questionable. A black and white banding pattern, meant to mimic a venomous sea snake, would only be useful to predators that are in some way affected by the potentially dangerous prey. The venom and venom apparatus of sea snakes is designed to capture prey and not deter predators (the animal is venomous not poisonous). In fact, sea snakes were the most commonly represented prey item in stomach content analysis of tiger sharks in Shark Bay, Western Australia (Heithaus 2001). Wetsuits of this design have been tested previously on smaller reef sharks with equivocal results (Nelson 1983).

Figure 2-8 The SAMS Warning ™ (left) and the SAMS Cryptic ™ (right) wetsuits. Source: Craig Anderson.

2.3.4 Detection Methods

There are three main methods (excluding aerial surveys) of detecting potentially dangerous sharks that can contribute to beach goers making a more informed decision about entering the water at a specific time and location. They are: sighting sharks by dedicated land-based observers; detecting them by sonar; and detecting the presence of an acoustically tagged animal. The use of these methods over time can potentially provide information on the patterns of movement and habitat use of potentially dangerous sharks. No detection methods are 100% effective under all conditions, but overall they can contribute to providing objective information which the public can use to determine their pattern of beach usage. It should also be noted that sonar detection technologies in particular are advancing rapidly and technical solutions to existing limitations may be solved within a three to five year timeframe. It should also be noted that approaches are not mutually exclusive, and indeed there may be benefit in terms of validation by using more than one approach at a location.

2.3.4.1 Shark Spotters Program

In response to a series of unprovoked shark bites in South African waters a Shark Spotters Program was developed and trialled in the Cape Town region (Oelofse and Kamp 2006). The program is an early warning initiative that provides information in real time on the presence or absence of dangerous shark species to beach goers. The information can allow beach goers to make a more informed decision regarding entering or remaining in the water, and when a dangerous species of shark is spotted a clear directive that beach goers should leave the water is provided. The guiding principles of the program are:

1. Find a balance between people's safety & white shark conservation;
2. Reduce the spatial overlap between people & sharks; and
3. Take into account socio-economics, public safety and environment/ wildlife.

The program relies on a series of flags to communicate to beach goers the presence or absence of sharks and the reliability of spotting given the conditions at the time (**Figure 2-9**). There are four flags:

- Green flag: Spotting conditions good, no sharks seen;
- Black flag: Spotting conditions poor, no sharks seen;
- Red flag: Either a shark has been seen in the last two hours, or there is an increased risk of a shark being in the area; and
- White flag (with black shark): Shark has been spotted – siren will sound. Leave water immediately.

The programs commenced in 2004 and since that time over 1,700 shark sighting have been recorded. The program operates throughout the year at five beaches and seasonally at another three. Shark Spotters are positioned at strategic points along the Cape Peninsula, primarily along the False Bay coastline. A spotter is placed on the mountain with polarised sunglasses and binoculars. This spotter is in radio contact with another spotter on the beach. If a shark is seen the beach spotter sounds a siren and raises a white flag with a black shark. When the siren sounds the water users are requested to leave the water and only return when the appropriate all clear signal is given. Shark sightings are also provided in real time via Facebook and Twitter. The program has been successful in restoring a significant degree of public confidence, however it has not completely eliminated shark bites occurring at beaches where the program has been operating.

For effective operation, vantage points with substantial elevation are required (> 40 metres). The elevation needed is above that normally afforded by surf patrol towers. The program is obviously only effective when spotters are in place (8:00AM to 6:00PM in South Africa). While sea state and weather condition impact the likelihood of sighting a shark that is present, this limitation is in effect incorporated into the warning system by virtue of the black flag which identifies that spotting conditions are poor. A difficulty encountered by the program in South Africa is ensuring that all people clear the water when a shark is sighted. This is no different to the challenge that surf life savers have in clearing the waters at patrolled beaches in Australia. A Shark Spotters program could augment and coordinate with surf life savers at patrolled beaches, or be a standalone approach at unpatrolled beaches. The South African Program has an element of human error as spotters undertake long shifts in difficult conditions (little shelter from the elements: rain, wind, heat), and it is unrealistic to expect spotters to maintain the same level of attentiveness for an entire 8-10 hour day, at times going months without a sighting (Oelofse and Kamp 2006). If a Shark Spotters Program was trialled in NSW, consideration should be given to having spotters operate in shifts (e.g. four hours) to partly alleviate fatigue. Observers in the Shark Spotters Program are also trained in first aid and can identify a swimmer at risk or drowning, but this service would largely be redundant at patrolled beaches in NSW. A Shark Spotters program would require a coordinator whose initial role would include the design of reporting requirements, assist with developing appropriate training and its implementation, as well as have overall responsibility for the program. In the first instance in a limited trial (e.g. at one beach), the coordination role is unlikely to be onerous and may be incorporated with current beach authority duties. There is scope to integrate dedicated Shark Spotting activities within existing life-saving and life-guard activities at patrolled beaches and this will influence the cost of the program. Any implementation of a Shark Spotters program at a locality should involve consultation with local beach users and Surf Life Saving clubs and this will aid determining the best position for any spotters.

The South African Program has principally focussed on the spotting of white sharks. As such, the efficacy of spotting the other two main shark species of concern (bull and tiger sharks) in NSW has not been tested. While the effectiveness of the approach has been the focus of published material (e.g. Kock et al. 2006; Oelofse and Yang 2006), not all sharks will be detected. Currently, information to determine the proportion of sharks that occur in the surf zone where spotting is being undertaken that are actually sighted by the observers is lacking. While incorporated into the system of flags in the program is a delineation between "good" and "bad" spotting days, there must be a sufficient number of good spotting days in order for the program to be effective and to build public confidence. In theory at least good spotting should coincide with sunny and relatively calm days and this is likely to be times of peak beach usage by the public.

Figure 2-9 Shark Spotters in South Africa . Left: spotter checking beach, Right: flag indicating potential shark risk. Source: Alison Kock.

2.3.4.2 Acoustic and Satellite Tagging

The use of acoustic and satellite tagging for assessing movement patterns and habitat use of a range marine animals (including sharks) is well established (**Figure 2-10**). The contemporary approach involves the use of arrays of fixed receivers to detect tagged animals. There is an Ocean Tracking Network (OTN) which is a $168-million ocean research and technology development platform headquartered at Dalhousie University (Nova Scotia). The OTN has receivers stationed in Western Australia and off Tasmania. There is also a series of receivers on the Australian east coast that are part of the Animal Tracking and Monitoring System (AATAMS), part of a much broader national marine monitoring initiative: the Integrated Marine Observing System (IMOS)[3].

Acoustic and satellite tagging of sharks is used in Western Australia to provide an early warning system of when a shark was close to popular beaches. The information collected from tagged sharks is also augmented with sightings by the public that are reported via a dedicated phone number. Information on tagged sharks that are detected by the receivers are communicated to the public via Twitter and a dedicated website[4]. Potentially a text message could be sent a lifeguard to alert them to the presence of a shark. Information on the activity of tagged sharks; together with sightings by the public, the capture of a relatively large number of sharks in a short period of time for tagging, or other factors which are known to attract sharks to a specific region (e.g. the presence of a whale carcass) is integrated into shark alerts and warnings. The approach in Western Australia involves the deployment of satellite-linked (VR4G) acoustic receivers, and data-recording acoustic receivers (VR2W) on the sea floor. Detections by VR2W receivers are not transmitted via satellite but are stored in the receiver's on-board memory.

The ability of acoustic and satellite tagging to identify the presence of dangerous shark species at beaches where acoustic receivers are in place is a function of the number of sharks that have been captured tagged and released. The more sharks that are utilising the coastal area that have been tagged the greater the likelihood that a shark occurring at a beach where a receiver is present will be detected. There may also be location specific factors which influence the spatial range the performance of the tag and the ability of the receiver to detect it. Mitigating this may require the placement of receivers closer together in the array to ensure a continuous line of detection. Satellite-linked (VR4G) receivers need fresh batteries and a major service of their buoys and moorings. Data-recording (VR2W) receivers need to be recovered annually by divers so that the stored data can be downloaded and receivers serviced.

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[3] http://www.imos.org.au/ (Accessed 23/9/15)
[4] http://www.sharksmart.com.au/shark-activity/ (Accessed 23/9/15)

Figure 2-10 Shark tagging. Left: A captured white shark in preparation for being fitted with an acoustic tag, Right: a satellite tag in a shark's dorsal fin. Source: NSW Fisheries.

2.3.4.3 Cleverbuoy

Cleverbuoy is an acoustic detection method designed to detect sharks at beaches where an array of buoys are deployed (**Figure 2-11**). Cleverbuoy uses multi-beam sonar to identify underwater objects. This type of technology was previously only used by the navy and the oil and gas industry, but is now in more general use due to reduced costs. Sonar data is transmitted via a closed system (i.e. CPU on buoy with modem connected to Optus 3G network with redundancy back to dedicated Optus satellite) to a server where software (made by Tritek) aims to distinguish sharks from other objects (i.e. sharks are identified as objects > 2 m that are self-propelled). The software has a set level of probability to provide a shark alert to an end user who can be located anywhere. Potentially a text message could be sent a lifeguard to alert them to the presence of a shark. The alert will tell the end user which buoy has a shark nearby and specifies the GPS location of the buoy. A Cleverbuoy unit consists of a buoy anchored to the seabed. The sonar transducer is attached to the base mounting on the seabed (an anchor system) and there is an antenna on the surface of the buoy which transmits the sonar data. The transducer is reported by the manufacturer to emit sonar to a maximum distance of 85 m in a wedge that covers 120 degrees.

Currently, Cleverbuoy is constructed from a number of off the shelf components. Cleverbuoy has been trialled in the Abrolhos Islands (Western Australia) and trialled for a single day at both Bronte and Bondi beaches (C. Anderson pers. comm.). The results from these trials have not been published. According to the manufacturer, a 30 day commercial viability trial is planned in the Sydney region this coming summer (December 2015 – February 2016). Such a trial, however, is unlikely to encounter significant shark numbers in the Sydney region at that time for rigorous testing of the efficacy of Cleverbuoy, but it will provide information on the durability of the units under NSW beach conditions. Currently, it is unclear if turbulence and suspended sediment will affect the range of Cleverbuoy or its ability to detect and accurately classify an object. If the range is affected it may require the installation of a greater number of units per area. It is also possible that boat traffic may influence the performance of Cleverbuoy. A Cleverbuoy can also be fitted with a VR2C receiver and thus contribute to the collection of data on the movement of tagged sharks. This can also provide additional validation for Cleverbuoy's detection ability.

Parsons et al. (2015) assessed the ability of the Tritech Gemini imaging sonar to detect sharks. They specifically assessed the ability of the technology to observe sharks of 1.4 to 2.7 m in length at ranges from 1 to 50 m. They found that within 5 m range shark shape, length and swimming action were readily discernible; however beyond this range, and unless swimming pattern could be clearly discerned, reliable identification of a shark was problematic. They identified that for a given frequency and noise level, maximum detection and identification ranges are reliant on system source level, beam pattern, bathymetry, object target size and acoustic reflectivity. In terms of the deployment of a vertical array of sonars to cover an area, Parsons et al. (2015) identified that issues of interference where beams from more than one unit overlap is an important consideration. Overall, they concluded that a vertical array in shallow waters (< 15 m) may not provide suitable benefits at ranges greater than 75 m.

Figure 2-11 A Cleverbuoy unit deployed for testing at Bondi Beach, NSW. Source: Craig Anderson.

2.3.5 Other Methods

2.3.5.1 Smart Drumlines

An additional method to mitigate the risk of unprovoked shark bite is deployment of the Smart Drumline in an area. This approach differs from those discussed elsewhere in this report in that it is not a deterrent or a barrier, but rather it is a method of capture with the aim of relocating the shark through a system designed specifically to substantially reduce the mortality of animals captured by a drumline. The fishing gear is composed of classical material used for a standard drumline, however the mooring buoy itself is designed to detect when an animal such as a shark has been captured on the drumline and relay a message to shore that a capture has occurred in real time. There is then the opportunity for a shark contractor to immediately attend to the drumline and release the captured animal. The mooring buoy is solar powered. Data recorders (VR2W) can also be deployed with buoys and therefore simultaneously collect information on the presence of tagged sharks that are not captured.

Smart Drumlines have been trialled at Reunion in depths of 10 to 30 metres including directly behind the surf break. A constraint with the approach is that it can only be effective if sea conditions do not prevent a contractor immediately attending the drumline to deal with the captured animal. There may also be practical challenges of requiring a contractor to be on standby and be able to rapidly deploy to tend the drumline when a capture occurs. While the number of animals currently captured by Smart Drumline is relatively low, **Table 2-3** identifies that the survival of captured animals is considerably higher than that recorded in Queensland using standard drumlines.

Table 2-3 A comparison of survival rates of animals caught on Smart Drumline in Reunion with those caught by standard drumlines in Queensland. Source: David Guyomard (Reunion Island Regional Committee for Sea Fisheries and Aquaculture).

Species	Number of individuals caught		Survival rate (% of individuals found alive on the hook when retrieved)	
	Queensland (Sumpton et al. 2011)	Reunion – Smart Drumline	Queensland (Sumpton et al. 2011)	Reunion - Smart Drumline
Bull shark *(Carcharhinus leucas)*	79	9	25.9 %	100 %
Sandbar shark *(Carcharhinus plumbeus)*	28	2	10.7 %	50 %
Tiger shark *(Galeocerdo cuvier)*	485	16	31.0 %	100 %
Scalloped hammerhead *(Sphyrna lewini)*	11	4	0.0 %	50 %
Stingray (*Dasyatis sp.*)	-	15	-	100 %
Other unidentified rays	8	-	50.0 %	-

3 Choosing an Emerging Technology for Bather Protection in NSW

3.1 Assessment Criteria

Many factors need to be considered in choosing an emerging technology for bather protection for potential trialling on NSW beaches including: the practicalities of deploying equipment in the exposed coastline of NSW, durability and longevity, human heath, stakeholder opinion, expense and the efficacy of the technology at either deterring or detecting sharks. Some factors have greater importance than others. For example, it would be pointless trialling a technology that could not cope with 3 to 4 m swell events, given these occur regularly along the NSW coast, along with more occasional swell events where the swell can be even larger. Factors requiring less consideration are those that have potential to be more easily managed. For example, consider that some deterrents would presumably affect other species of shark besides white, tiger and bull sharks, and potentially impact the use of critical habitat (known aggregation sites) of the critically endangered grey nurse shark (*Carcharias taurus*). Grey nurse sharks are of very little concern to bathers but some of the known aggregation sites for this species occur near ocean beaches. The potential risk of a deterrent affecting this species could be minimised if the deterrent was not used on beaches close to the known aggregation sites. The order of importance of the assessment criteria was considered carefully given it had a bearing on how technologies were ranked against each other for potential consideration for short-listing for trial.

Descriptions of the criteria, in order of their importance, used to assess the technologies for consideration for potential trial, are given below, along with a justification of their importance:

1. *Practically able to implemented at a whole-of-beach scale?*

The practicality of applying the technology in a whole-of-beach approach was considered to be the most important of the assessment criteria. Technologies were considered to be impractical if there were logistical or engineering challenges at a whole-of-beach scale that were unlikely to be overcome in the short-term.

2. *No potential to affect human health (e.g. pacemakers)?*

From a precautionary perspective, this criteria was considered to be the next most important factor given that technologies would potentially be trialled at public beaches. This criteria is most relevant to the technologies that generate an electric or magnetic field. Some of the manufacturers of these technologies recommended that people with pacemakers, or indeed many other heart conditions, do not use, or swim near, operating devices.

3. *Ability to withstand conditions similar to NSW beaches?*

Third, it was considered very important that the technology was proven to be able to withstand the oceanographic conditions at beaches in NSW where the coastal swells and seas can often be large (i.e. >3 m).

4. *Currently commercially available?*

Fourth, it was important that technologies were available for immediate trial at the whole-of-beach scale in NSW, or could become available in the short-term. Technologies where only a prototype had been developed or which were still under development were considered not to be commercially available.

5. *Effectiveness tested on white, tiger or bull shark, or is technology a physical barrier?*

It is possible that some technologies may not be effective on all shark species. Hence, it was important that technologies were considered to be effective against the species most responsible for unprovoked shark bite (i.e. white, tiger or bull sharks). For physical barriers, the default answer to this question was ‘yes’ given these barriers are all purportedly made of material strong enough to stop sharks from breaking through.

6. *Has independent testing been undertaken and/or have results of testing been published in the peer reviewed literature that verified effectiveness against white, tiger or bull sharks, or technology is a physical barrier?*

The verification of a technology’s effectiveness against white, tiger or bull sharks through independent testing (i.e. in a scientific experiment conducted by scientists with no commercial interest in the sale of the technology) was a further means of discriminating effectiveness among technologies that were reported to work on at least some shark species. For physical barriers, the default answer to this question was ‘yes’ (see above).

7. *No potential for adverse impacts on wildlife?*

As indicate above, this criterion was considered to be less important than many of the others given that for most technologies, potentially adverse impacts on wildlife could probably be managed to a level where they would not occur or be negligible. This includes the potential for entanglement with marine mammals or reptiles.

8. *No potential to affect other water users (e.g. commercial fishers)?*

Commercial ocean haulers operating in NSW shoot their fishing nets in an arc that extends from the beach to beyond the breakers, hence their fishing grounds would potentially overlap with the placement of some technologies. The transit of lifeguard vessels and operators of other surfcraft in and out of the surf zone may also have potential to be impeded by some technologies. These issues, however, have potential to be managed.

9. *Cost*

Costs of technologies were based on indicative setup and maintenance costs for trialling at a 1km-long NSW beach. It should be stressed that the costs are indicative only, and more precise estimates of costs can only be determined when a specific beach location is confirmed for trialling, along with other considerations. For personal deterrents, the costs given were for a single unit.

Each technology was assessed against each of the criteria according to the current research knowledge of the technology and from the results of direct consultation with manufacturers of technologies and scientists that had evaluated technologies. Consultation involved asking respondents a standard list of questions (**Appendix A**) via email or telephone. Each criterion (apart from cost) was in the format of a question where the answer could be one of either ‘yes’, ‘no’ or ‘uncertain’.

A summary of the assessment of technologies against criteria is given in **Table 3-1**.

Table 3-1 Summary of the assessment of technologies against evaluation criteria

	EVALUATION CRITERIA								
TECHNOLOGY	1. Can be implemented at a whole of beach scale?	2. No potential to affect human health (e.g. pacemakers)?	3. Can withstand conditions at NSW beaches?	4. Currently commercially available?	5. Effectiveness tested on white, tiger or bull sharks, or Technology is a physical barrier?	6. Has been independently tested and/or Results have been published in peer-reviewed literature or Technology is a physical barrier?	7. No potential for adverse impacts on wildlife?	8. No potential for impacts on water users(e.g. commercial fishers)?	9. Are the likely costs (including capital costs, maintenance costs, replacement costs) known? What are costs for 1 km beach deployment?
Electric Deterrent Barriers									
Shark Repellent Cable	**Yes**	**Uncertain** Electromagn-etic fields could affect people with pacemakers or other heart conditions.	**Uncertain**	**No**	**No** Electrical field generated has been independently tested for use as an individual deterrent for white sharks. Further work planned to test the cable in surf environment. No relevant shark species encountered in field trials to date.	**No**	**Uncertain**	**No** Cable on seabed could affect beach seine fisheries at some beaches during fishing seasons.	**Uncertain** Cable in research and development phase. Costs not known.
Underwater Rubberised Electric Fence	**Yes**	**Uncertain** Electromagnetic fields could affect people with pacemakers or other heart conditions.	**Uncertain**	**No**	**No**	**No**	**Uncertain** For most wildlife. Could modify habitat used by seals as it was specifically designed to exclude seals from coastal infrastructure.	**No** Cable on seabed could affect beach seine fisheries at some beaches during fishing seasons.	**Yes** Deployment of a 1 km long device would be ~US$465,000

TECHNOLOGY	EVALUATION CRITERIA 1. Can be implemented at a whole of beach scale?	2. No potential to affect human health (e.g. pacemakers)?	3. Can withstand conditions at NSW beaches?	4. Currently commercially available?	5. Effectiveness tested on white, tiger or bull sharks, or Technology is a physical barrier?	6. Has been independently tested and/or Results have been published in peer-reviewed literature or Technology is a physical barrier?	7. No potential for adverse impacts on wildlife?	8. No potential for impacts on water users(e.g. commercial fishers)?	9. Are the likely costs (including capital costs, maintenance costs, replacement costs) known? What are costs for 1 km beach deployment?
Aquatek Technology Shark Repelling System	Yes	Uncertain Electromagn-etic fields could affect people with pacemakers or other heart conditions	Uncertain	No But still in the development and trialling phase.	Yes All three key species as well as others.	No Details of trials and results could not be ascertained.	Uncertain Potential for whale entanglements for some beaches during whale migration. The electric field may deter other elasmobranchs from utilising habitat. Impacts to teleosts unlikely but not tested.	No The cable on the seabed could impact beach seine fisheries for some beaches during fishing.	Uncertain
Physical and Visual Barriers									
Eco Shark Barrier	Yes	Yes	Uncertain Trialled at Coogee Beach in WA, protected from large oceanic swells. Waves up to 1.5 m waves did not damage barrier, but beach morphodynamic state different from typical NSW beaches.	Yes	Yes Will exclude sharks provided it is not damaged.	Yes Physical barrier.	Yes No entanglements with fauna recorded. Can act as an aggregating device for fish.	No The barrier could impact beach seine fisheries on some beaches during fishing seasons. May also assist in preventing drowning by providing emergency support	Yes Capital costs for Bionic Barrier and Aquarius Barrier ~AU$1.0 million. Cleaning of marine growth possibly every couple of years. Option to lease for 3 years at AU$470,000

EVALUATION CRITERIA

TECHNOLOGY	1. Can be implemented at a whole of beach scale?	2. No potential to affect human health (e.g. pacemakers)?	3. Can withstand conditions at NSW beaches?	4. Currently commercially available?	5. Effectiveness tested on white, tiger or bull sharks, or Technology is a physical barrier?	6. Has been independently tested and/or Results have been published in peer-reviewed literature or Technology is a physical barrier?	7. No potential for adverse impacts on wildlife?	8. No potential for impacts on water users(e.g. commercial fishers)?	9. Are the likely costs (including capital costs, maintenance costs, replacement costs) known? What are costs for 1 km beach deployment?
Bionic Barrier / Aquarius Barrier	**Yes**	**Yes**	**Uncertain** Both products designed to improve performance and reduce costs compared to Eco Shark barrier antecedent.	**Yes** For Bionic Barrier Aquarius Barrier; estimated be available after Oct 15 2015.	**Yes** Will exclude sharks provided it is not damaged.	**Yes** Physical barrier.	**Yes** No entanglements with fauna recorded. Can act as an aggregating device for fish.	**No** The barrier could impact beach seine fisheries on some beaches during fishing seasons. May also assist in preventing drowning by providing emergency support.	**Yes** Capital costs for Bionic Barrier and Aquarius Barrier ~AU$1.0 million. Cleaning of marine growth possibly every couple of years.
Temporary barrier net	**Yes**	**Yes**	**Uncertain** Trialled at Fish Hoek Beach in South Africa which is an ocean beach exposed as some Sydney beaches.	**Yes** Appropriate net could be sourced from existing commercial sources.	**Yes** Will exclude sharks provided it is not damaged.	**Yes** Physical barrier.	**Uncertain**, Consideration would be needed to ensure it is of a type and design that does not mesh animals.	**No** The net could impact beach seine fisheries on some beaches during fishing seasons.	**Yes** Net R500,000 (~AU$50,000). Deployment costs but could be incorporated into standard SLS procedures at patrolled beaches.
Bubble curtain	**Yes**	**Yes**	**Uncertain**	**No**	**Uncertain**	**No**	**Yes**	**Yes**	**Uncertain**
Sharksafe magnetic barrier	**Yes**	**Uncertain**	**Uncertain**	**No**	**Yes** Tested on whites and bull sharks but uncertain for tiger sharks	**Yes**	**Yes**	**No** Could impact beach seine fisheries on some beaches.	**Uncertain**

EVALUATION CRITERIA

TECHNOLOGY	1. Can be implemented at a whole of beach scale?	2. No potential to affect human health (e.g. pacemakers)?	3. Can withstand conditions at NSW beaches?	4. Currently commercially available?	5. Effectiveness tested on white, tiger or bull sharks, or Technology is a physical barrier?	6. Has been independently tested and/or Results have been published in peer-reviewed literature or Technology is a physical barrier?	7. No potential for adverse impacts on wildlife?	8. No potential for impacts on water users(e.g. commercial fishers)?	9. Are the likely costs (including capital costs, maintenance costs, replacement costs) known? What are costs for 1 km beach deployment?
Personal Deterrents									
Shark Shield	**No** Impractical to distribute to all bathers at all times at all beaches.	**No** Electromagn-etic fields could affect people with pacemakers or other heart conditions.	**Yes** Extensive field trials conducted but not in surf zone. Trial results highly likely to be transferable to the surf environment. A device specifically for surfers is available.	**Yes**	**Yes** Focus of testing on white sharks	**Yes** For the diver based model.	**Yes**	**Yes**	**Yes** Current surf unit is AU$649. A new design is due for release, expected retail approximately AU$500.
Surf Safe	**No** Impractical to distribute to all bathers at all times at all beaches.	**No** Electromagn-etic fields could affect people with pacemakers or other heart conditions.	**Yes** A device specifically for use by surfers is available.	**Yes**	**No** No effective trials undertaken, but are planned.	**No**	**Yes**	**Yes**	**Yes** AU$294 per unit plus fitting costs

EVALUATION CRITERIA

TECHNOLOGY	1. Can be implemented at a whole of beach scale?	2. No potential to affect human health (e.g. pacemakers)?	3. Can withstand conditions at NSW beaches?	4. Currently commercially available?	5. Effectiveness tested on white, tiger or bull sharks, or Technology is a physical barrier?	6. Has been independently tested and/or Results have been published in peer-reviewed literature or Technology is a physical barrier?	7. No potential for adverse impacts on wildlife?	8. No potential for impacts on water users(e.g. commercial fishers)?	9. Are the likely costs (including capital costs, maintenance costs, replacement costs) known? What are costs for 1 km beach deployment?
Sharkbanz (permanent magnets)	**No** Impractical to distribute to all bathers at all times at all beaches.	**No** Electromagn-etic fields could potentially affect people with pacemakers or other heart conditions.	**Yes**. All trails done in open water environments. However, the trial results are highly likely to be transferable to the surf environment.	**Yes**	**Yes,** but mostly tested on reef sharks only.	**Uncertain** Independent testing with highly variable results have been undertaken on magnetic deterrents for individual use and the Sharkbanz is one example of such a device	**Yes**	**Yes**	**Yes** AU$110 per unit
Sharkbanz (electropositive metals)	**No** Impractical to distribute to all bathers at all times at all beaches.	**No** Electromagn-etic fields could potentially affect people with pacemakers	**Uncertain**	**No**	**No**	**No**	**Uncertain**	**Yes**	**Uncertain**
Repel Sharks	**No** Impractical to distribute to all bathers at all times.	**Yes**	**Yes.** All trials done in open water but no reason that the technology is not directly transferable to NSW beaches..	**Yes**	**Yes** Tiger and bull sharks.	**Yes**	**Yes** Likely to affect elasmobranchs in general, but impacts not likely to persist when the chemical has dissipated.	**Yes**	**Yes** US$29.95 per aerosol can.
SAMS - Camouflage wetsuits	**No**	**Yes**	**Yes**	**Yes**	**No**	**No**	**Yes**	**Yes**	**Yes** Variable. Wetsuits range between ~$300-$700

	EVALUATION CRITERIA								
TECHNOLOGY	1. Can be implemented at a whole of beach scale?	2. No potential to affect human health (e.g. pacemakers)?	3. Can withstand conditions at NSW beaches?	4. Currently commercially available?	5. Effectiveness tested on white, tiger or bull sharks, or Technology is a physical barrier?	6. Has been independently tested and/or Results have been published in peer-reviewed literature or Technology is a physical barrier?	7. No potential for adverse impacts on wildlife?	8. No potential for impacts on water users(e.g. commercial fishers)?	9. Are the likely costs (including capital costs, maintenance costs, replacement costs) known? What are costs for 1 km beach deployment?
Detection Methods									
Shark Spotter Program	**Yes**	**Yes**	**Yes** At a number of locations in South Africa.	**Yes**	**Yes** Focus has been on white sharks.	**Yes**	**Yes**	**Yes**	**Yes** The cost of the program is approximately R2,000,000 (~AU200,000). Additional start-up costs likely for Australia, and higher operational costs likely due to substantially higher wage structure.
CleverBuoy	**Yes**	**Yes**	**Uncertain.** Very short trial of prototype done and knowledge of durability very limited at this stage.	**No**	**No**. No effective field tests at this stage.	**No**	**Uncertain** The potential for impacts on cetaceans and teleosts that vocalise (e.g. Sciaenids) requires assessment.	**No**. An array of buoys could impact beach seine fisheries on some beaches during fishing seasons.	**Yes** Approximately $70,000 per unit with approximately 5 units needed for a 1 km stretch of beach, but site-specific characteristics could alter the number of units required.

EVALUATION CRITERIA									
TECHNOLOGY	1. Can be implemented at a whole of beach scale?	2. No potential to affect human health (e.g. pacemakers)?	3. Can withstand conditions at NSW beaches?	4. Currently commercially available?	5. Effectiveness tested on white, tiger or bull sharks, or Technology is a physical barrier?	6. Has been independently tested and/or Results have been published in peer-reviewed literature or Technology is a physical barrier?	7. No potential for adverse impacts on wildlife?	8. No potential for impacts on water users(e.g. commercial fishers)?	9. Are the likely costs (including capital costs, maintenance costs, replacement costs) known? What are costs for 1 km beach deployment?
Tagging and real time tracking of tagged sharks	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes** $350 / acoustic tag; $17,000 / VR4G receiver
Other Methods									
Smart Buoys	**Yes**	**Yes**	**Yes** Tested in a different environment, but technology directly transferable to NSW beaches.	**Yes**	**Yes** Will catch the same suite of shark species as standard drumlines. Survival rates of captured tigers and bull sharks only assessed to date.	**No**	**No** Could impact the same suite of species as standard drumlines, but improvements to survival rates for most species are plausible. May have high initial capture rates when deployed in new locations.	**No** Despite potentially reducing the environmental impacts of standard drumlines, may be community concerns. An array of buoys could impact beach seine fisheries on some beaches during fishing seasons.	**Uncertain**

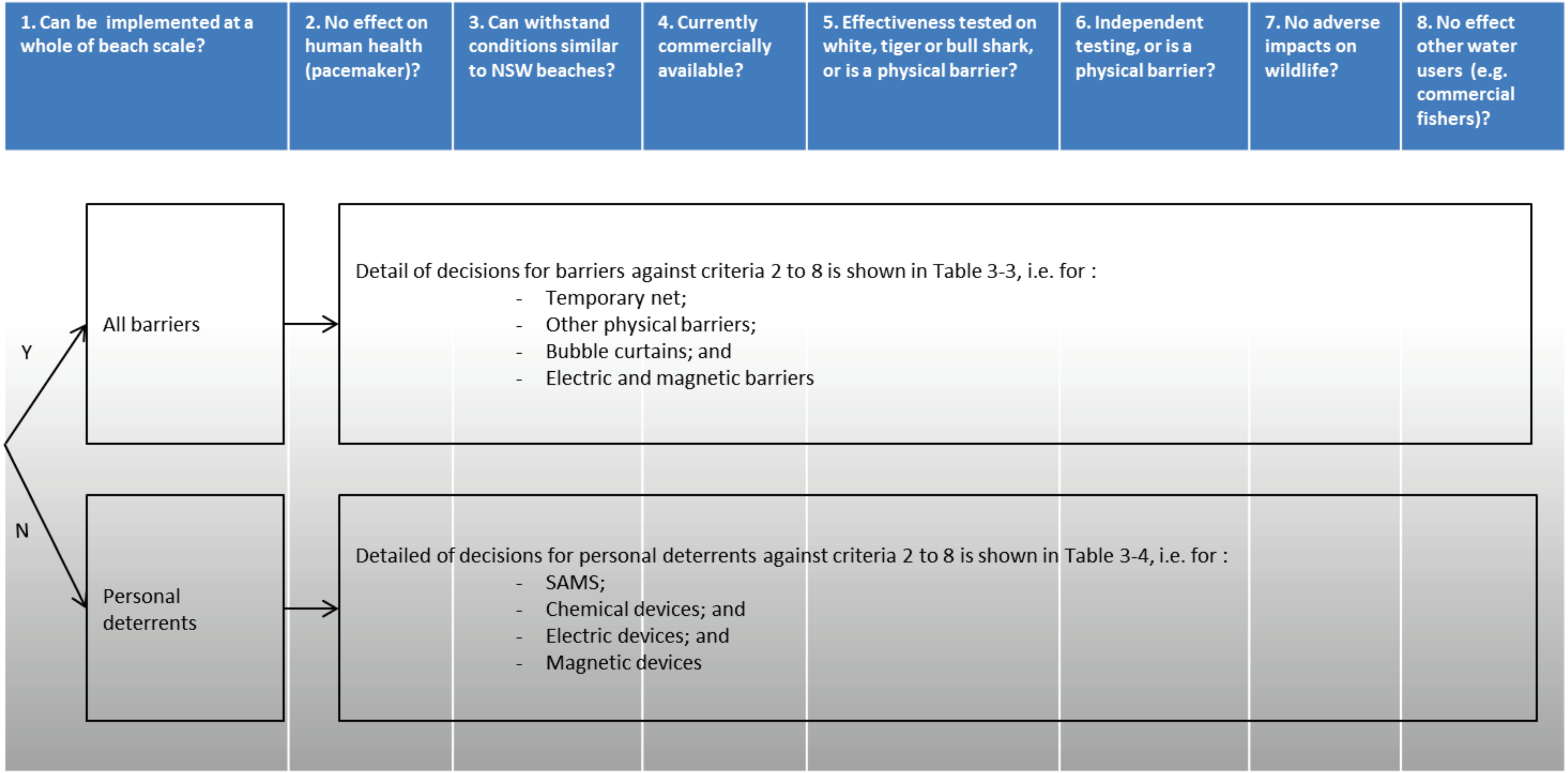
3.2 Decision Analysis

Ideally, to be recommended for trial on NSW beaches, the technologies would have met all of the assessment criteria. As none of the technologies, however, currently met all criteria a decision tree was used to compare, contrast and rank technologies based on which of the suite of criteria they did meet. The decision tree was used to rank shark deterrents (**Table 3-2** to **Table 3-4**) and detectors (**Table 3-5**) separately. As Smart Drumline has elements of a detector given its potential for capture and release of sharks at beaches it was assessed within the group of detectors.

In all decisions in the tree, an answer of ‘yes’ to an assessment criterion would rank a technology in a higher group than an answer of ‘uncertain’ followed by an answer of ‘no’. As decisions were made (from left to right) along the tree, each decision allocated the technologies into higher or lower sub groups within major groups. The decision tree was designed so that the key decisions for determining broad differences in rankings among deterrents or detectors were determined by responses to the more important assessment criteria.

In deciding on the short-lists for trial, the costs of trialling the deterrent and detection technologies was considered along with the decision tree rankings.

Table 3-2 First step in decision tree for ranking shark deterrents for trial on NSW beaches. Y = yes, N = no, U = uncertain



1. Can be implemented at a whole of beach scale?	2. No effect on human health (pacemaker)?	3. Can withstand conditions similar to NSW beaches?	4. Currently commercially available?	5. Effectiveness tested on white, tiger or bull shark, or is a physical barrier?	6. Independent testing, or is a physical barrier?	7. No adverse impacts on wildlife?	8. No effect other water users (e.g. commercial fishers)?

All barriers

Detail of decisions for barriers against criteria 2 to 8 is shown in Table 3-3, i.e. for :

- Temporary net;
- Other physical barriers;
- Bubble curtains; and
- Electric and magnetic barriers

Personal deterrents

Detailed of decisions for personal deterrents against criteria 2 to 8 is shown in Table 3-4, i.e. for :

- SAMS;
- Chemical devices; and
- Electric devices; and
- Magnetic devices

Table 3-3 Steps 2-8 in decision tree for ranking shark deterrent barriers for trial on NSW beaches. Y = yes, N = no, U = uncertain

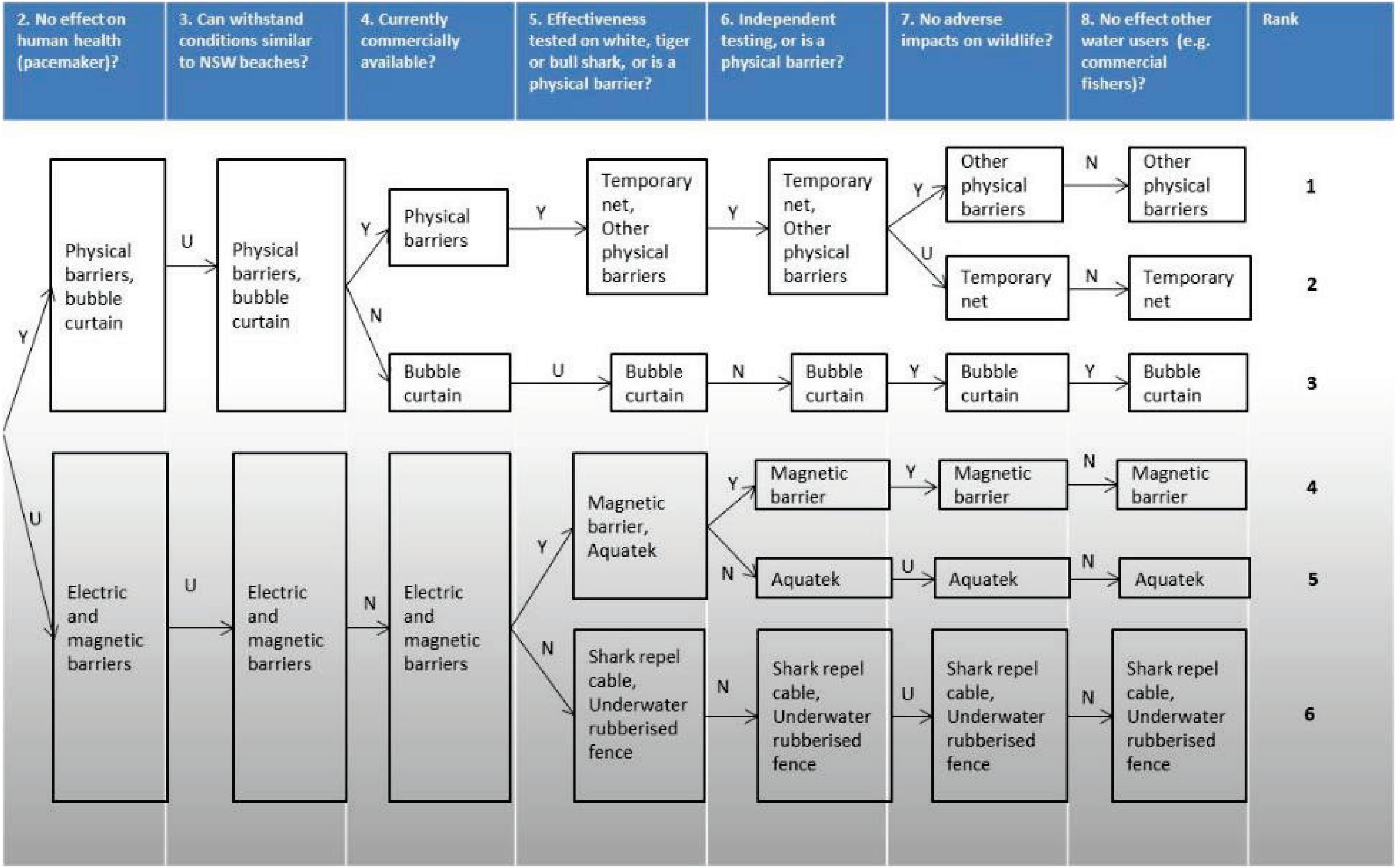


Table 3-4 Steps 2-8 in decision tree for ranking personal deterrents for trial on NSW beaches. Y = yes, N = no, U = uncertain

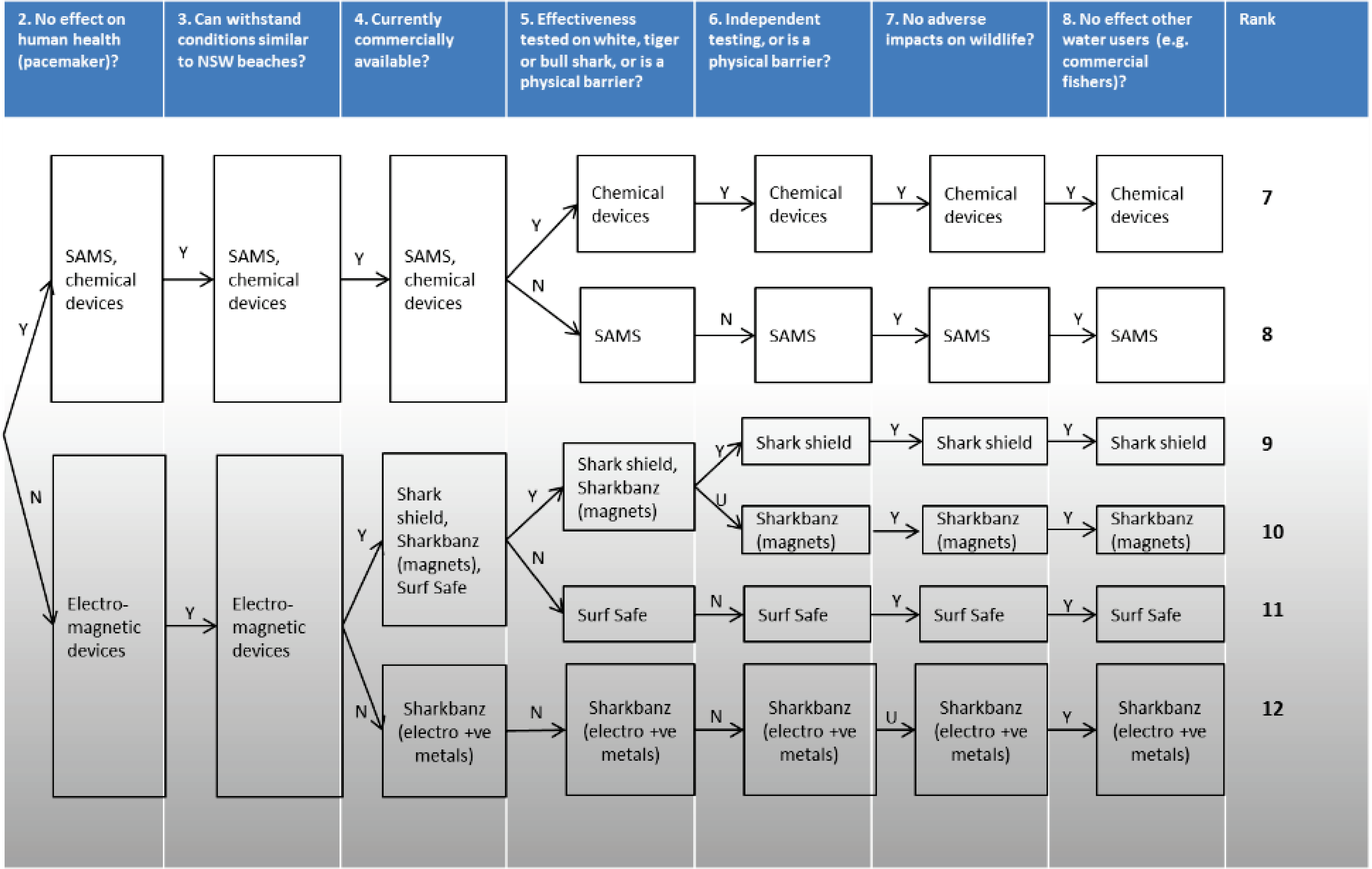


Table 3-5 Decision tree for ranking shark detectors for trial on NSW beaches. Y = yes, N = no, U = uncertain

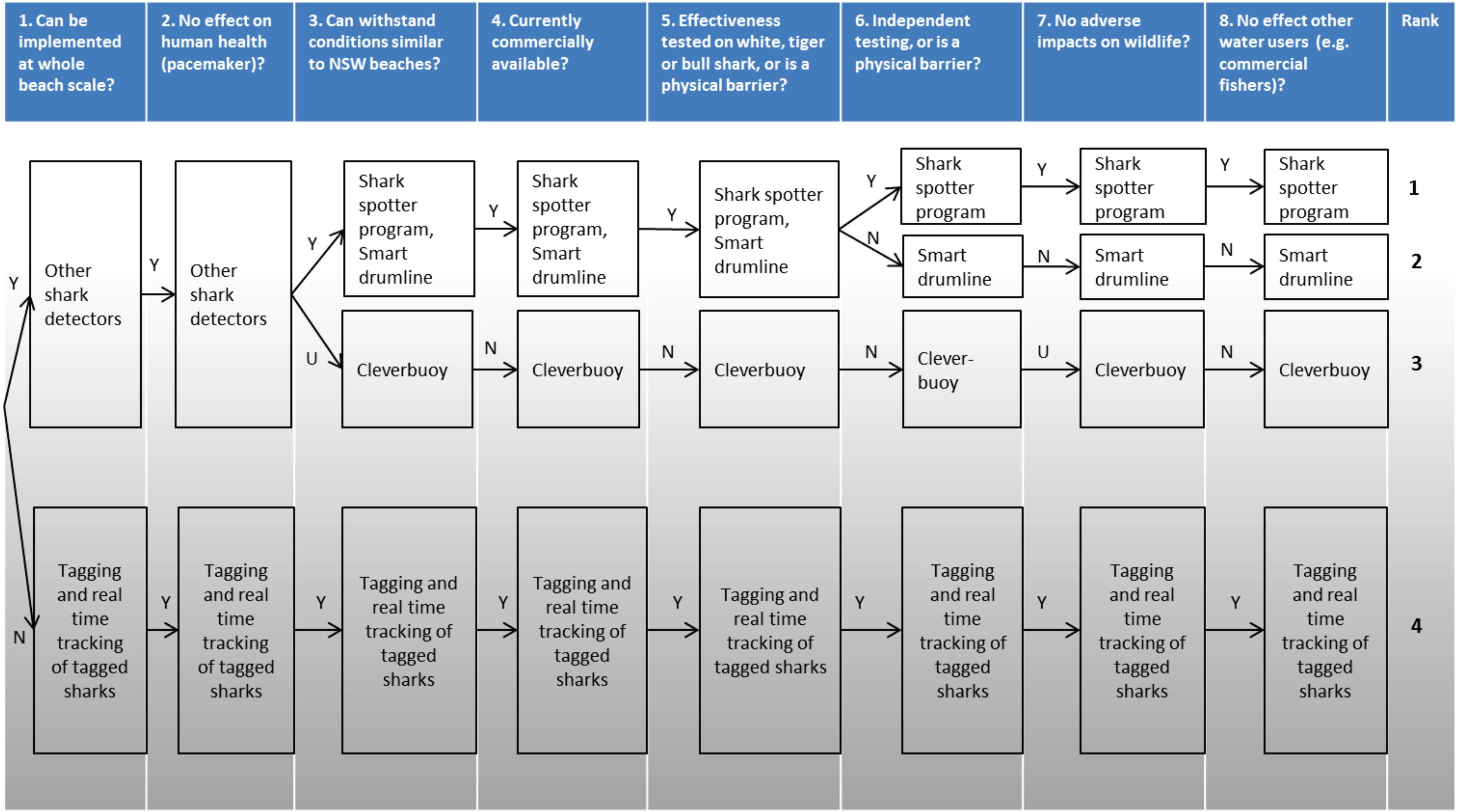


Table 3-6 Indicative cost of trialling shark deterrent technologies on a 1 km NSW beach.

Rank	Shark Deterrent	Type	Approximate Cost of Trial
1	Aquarius barrier	Physical barrier	~AU$1.0 million
1	Eco Shark Barrier	Physical barrier	~AU$1.0 million + maintenance costs, option to lease for 3 years at AU$470,000
1	Bionic barrier	Physical barrier	~AU$1.0 million
2	Temporary net	Physical barrier	AU$50,000 (cost of net) plus labour for daily deployment & retrieval
3	Bubble curtain	Visual barrier	Uncertain
4	Sharksafe barrier	Magnetic (and visual) barrier	Uncertain
5	Aquatek	Electric barrier	Uncertain
6	Shark repellent cable	Electric barrier	Uncertain
6	Underwater rubberized electric fence	Electric barrier	US$465,000
7	Repel sharks	Chemical personal deterrent	US$29.99 for a standard aerosol can, and US$19.99 for a mini aerosol can.
8	SAMS (camouflage wetsuits)	Shark vision disruptor/camouflaging personal deterrent	Variable. Wetsuits range between ~ AU$300- AU$700/unit
9	Shark Shield	Electric barrier	AU$649/surf unit
10	Sharkbanz (permanent magnets)	Magnetic personal deterrent	AU$110/surf unit
11	Surf safe	Electric barrier personal deterrent	AU$294/surf unit
12	Sharkbanz (electropositive metals)	Electric barrier personal deterrent	Cost not available

Table 3-7 Indicative cost of trialling shark detector technologies on a 1 km NSW beach

Rank	Shark Detector	Cost of Trial
1	Shark spotter program	AU$200,000 (equivalent costs to run in South Africa), plus additional startup costs
2	Smart Drumline	Uncertain
3	Clever Buoy	AU$350,000 for 5 units
4	Tagging and real time tracking of tagged sharks	AU$350 / acoustic tag AU $17,000 / VR4G receiver

The decision analysis indicated that physical barriers ranked highest among the deterrents (**Table 3-2**). The bubble barrier was the next highest ranked deterrent, followed by the electric and magnetic barriers largely because the effect of electric and magnetic fields on people with pace makers or a heart condition was uncertain. That said, the Sharksafe barrier could also act solely as a visual barrier minus the permanent magnets.

Although all of the physical barriers ranked highly (Eco Shark Barrier, Bionic and Aquarius Barriers and the temporary net barrier) (**Table 3-2, Table 3-3**) are currently used, or have potential to be used, on ocean beaches in other jurisdictions, they have not been trialled effectively over a sufficient period of time in conditions similar to what would be expected on a NSW beach and so there remains some uncertainty as to their durability. The temporary barrier net has much lower setup costs than the other physical barriers (**Table 3-6**) although it has the practical challenge to overcome of requiring efficient deployment and retrieval, as well as the need to design the need to minimise the entanglement of fish.

Of all the deterrents, personal deterrents generally were considered to have the lowest rankings primarily due to logistical issues associated with operating effectively at a whole-of-beach scale (**Table 3-4)**. This is not surprising given these personal deterrents are not designed for providing protection over an area.

The shark spotter program was the highest ranked of the four detectors assessed and indeed, was the only technology (across both deterrents and detectors) to meet all eight assessment criteria (**Table 3-5**). It would also be one of the least expensive shark detection programs to run, although it is unclear what the capital and running costs of Smart Drumline would be (**Table 3-7**). Unlike the highest ranked technology, the Smart Drumline has not been verified through independent testing, has potential to affect other sharks, and an array of the apparatus would potentially impede ocean haulers. Nonetheless it met all of the first five most important assessment criteria. The next highest ranked detector, Cleverbuoy, only met the first two assessment criteria. Tagging and real time tracking of sharks was the lowest ranked detection technology given it would be impractical to tag enough sharks to have surety that a significant proportion of the dangerous sharks would be monitored.

4 Discussion

4.1 What are the Best Technologies to Trial?

The decision tree approach based on a list of assessment criteria was just one of many ways that could have been used to rank technologies. Regardless of whether the decision tree, or an alternative approach had been used, the way in which criteria had been weighted would determine the ranking process. Given the high costs of potentially trialling some of the technologies, we considered that it was of critical importance that the technologies were not going to fail due to logistical constraints or commercial availability issues. Under this approach, the eventual trial of short-listed technologies would be a direct test of the effectiveness of shark deterrence or detection at a NSW beach, rather than a test of the durability and logistical issues of deploying a device.

There is evidence that all of the technologies reviewed generally showed proof of concept that they would deter or detect sharks at some level and in our view, it was more difficult to separate technologies in terms of their effectiveness at deterring or detecting sharks than it was to separate them according to the practicalities of deployment. Early in the decision making process, it was important to discriminate practical technologies from those that could fail due to engineering or logistical issues. In addition, as many of the technologies would be directly interacting with the public, we considered it important that the technologies selected for possible trial had no potential to affect human health. This was particularly relevant to the technologies that generate electric or magnetic fields as their potential to affect people with pacemakers or heart conditions is unclear. We also recognise that the choice of swimming or surfing at a beach if an electric deterrent was present is a personal one, and the risk of doing so can be communicated to the public (including those with pacemakers and heart conditions). It remains, however, an important consideration.

The rankings we give in this report are relevant only to the time this report was written. Despite our best efforts to review all currently emerging technologies, there may be others that eluded our search, or there may be additional data for those we have reviewed. Additionally, some of the technologies that currently do not meet some of our assessment criteria could possibly be developed further in the future so that they met these criteria. In the future, the importance (weightings) we gave to each assessment criteria could also change for many reasons. Were this the case, the ranking and short-listing process could be repeated easily with updated data. It is also important to understand that we have considered technologies with regards to their ability to protect bathers (swimmers and surfers) on beaches rather than those undertaking activities around the headlands between the beaches (but see **Section 4.3.1**).

As indicated, costs were not used in the rankings of technologies due to limited data for many, however the setup costs of a program as well as the longer term running and maintenance costs need consideration. The physical barriers ranked highest on the short-list of deterrents for possible trial. Of these, the temporary barrier net would also be the least expensive to trial due to the cost of material. Its use, however, would be limited to beaches where there was manpower stationed to deploy and retrieve it (such as lifeguards with vessels), and beaches that are relatively calm. Some of the other physical barriers may be more appropriate for unpatrolled beaches, assuming they could be engineered for durability, given their potential to be deployed and left for long periods, although setup costs for these devices would be expensive given the cost of material and anchoring. A more comprehensive estimate of costs based on deployment at a specific location would need to be undertaken if barriers (or for that manner, any emerging technology) were chosen for trial.

Of all the deterrents, personal deterrents were the lowest ranked due to logistical issues that are likely to be associated with them operating effectively at a whole-of-beach scale. On any day, thousands of bathers can be present on Sydney beaches for example, and the development of a system to cater for these numbers effectively so that all of the bathers were equally ‘protected’ would be challenging. In theory, if a large number of water users were using a deterrent simultaneously at one beach, this could be interpreted as providing a level of protection over a large area. In reality however, the effective area for an individual deterrent is small and as such water users would need to be spaced very closely together (e.g. one to two metres). Even in highly crowded beaches there would be areas where the effects of a deterrent would not be detected by sharks. Therefore, it is concluded that a large number of people using an individual deterrent at a beach is highly unlikely to provide protection to those that are not wearing an individual deterrent. Notwithstanding this, personal deterrents have potential to play an important role in bather protection at many of the more remote locations in NSW (see **Section 4.3.1**).

We identified issues with all deterrents as to their suitability for trial for protection of bathers at a whole-of-beach scale. This is not surprising given they are, indeed, ‘emerging’ technologies and many manufacturers are currently working through operational issues and/or are in the process of scientifically proving their credibility at deterring sharks. Although most of the deterrents that operate at large-scales have great potential it may be wise for NSW government to delay trialling these types of deterrents at NSW beaches until they are refined further. We provide advice in **Section 4.3.2** as to what type of refinement is potentially needed before NSW government considers a short-list of deterrent devices for trial at NSW beaches.

There were noticeably fewer shark detectors to review than deterrents. Of these, the tagging and real time monitoring of tagged sharks represents an approach that can make a contribution in the long-term to the knowledge of sharks and the presence of sharks at popular beach locations, once a sufficient large number of relevant shark species are tagged and sufficient receivers deployed. However it was not considered a feasible ‘protection program’ given only a small proportion of the population of dangerous sharks could be tagged. Cleverbuoy, although having good potential, is in a very early stage of development. There are also some key issues with the technology that would need to be overcome with Smart Drumline. Dangerous sharks that were hooked by Smart Drumline would either have to be killed or transported to a place away from the capture location. There would be challenges relocating very large captured sharks and with moving ‘the problem’ elsewhere. It is also worth noting that a previous review for DPI identified significant potential for cameras suspended under tethered balloons as a potential detection technique (Bryson and Williams 2015).

There are also some issues with the highest ranked shark detector, the shark spotter program. This program is used successfully in one part of South Africa but labour costs in Australia are much higher. It is also likely that a spotter would have difficulty seeing sharks at long distances from his observation point on a headland meaning there would be a threshold in the length of a beach beyond which the program would not be effective. This could be problematic on the northern coast of NSW where beach length is much longer, on average, than in the south of the state.

The issues with the shark spotter program highlight the point that ‘one type will not fit all’ in NSW. A trial of a single technology is likely to be only applicable for rollout only to beaches of a particular length and morphodynamic as the trial beach. If technologies to be trialled are to have broader geographic deployment in the longer-term, then more than one technology may need to be trialled on different beach types.

4.2 Issues for Consideration in Trialling Emerging Technologies

4.2.1 Habituation to Deterrents

A challenge with the use of deterrents, particularly those that are fixed in place is the potential for animals to habituate to the deterrent over time rendering to less effective or completely ineffective. Permanent deterrents are likely at greater risk of habituation than those that are used as personal deterrents as they will be spatially and temporally predictable and hence a shark may encounter the deterrent more than once at the same location. Future field trials to test the efficacy of deterrents need to test habituation over a suitable period of time (e.g. months).

4.2.2 Using Combined Methods

There is no one universally applicable approach to mitigating the risk of unprovoked shark bite. There is considerable merit in simultaneously trialling more than one approach as this can provide additional information on the effectiveness of trialled approaches. For example acoustic receivers could be stationed to detect acoustically tagged sharks at beaches where observers from a Shark Spotter Program are stationed. Over time, this would potentially provide a measure of accuracy of the observers by way of the number of acoustically tagged sharks that were detected by the receivers and were also sighted by the observers. Likewise, Cleverbuoy could also be deployed directly adjacent to acoustic receivers deployed to detect acoustically tagged sharks, which would give additional verification of the effectiveness of Cleverbuoy.

Further as demonstrated in this report, mitigation approaches have developed and evolved independently in a number of instances.

4.3 Other Issues to Consider

4.3.1 Further Opportunities for Individual Deterrents

It is not possible for NSW Government to protect bathers (swimmers and surfers) from unprovoked shark bite at all of the 900 or so beaches in NSW. The capital expense and maintenance costs of rolling out most of the whole-of-beach protection systems reviewed in this report at many beaches would be unaffordable. Further, were any of the emerging technologies found to be suitably effective after a trial it is likely that they would only be used on some of the more highly-frequented beaches and would become one of the many approaches used by the NSW Government in its suite of bather protection measures (see **Section 1.1**). For the more infrequently used beaches a more cost-effective solution is required. Personal deterrents are best placed to provide this solution.

Some of the personal deterrents efficacy against sharks are independently tested and as long as the manufacturers guidelines are followed regarding their use (e.g. they are not to be used by people with pacemakers or with heart conditions), they provide a good solution for bathers in some of the more remote beaches. By extension, they are also a good solution for bathers, particularly surfers, that frequent the reefs and headlands between beaches where a whole-of-beach technology would be impractical to deploy. Further, personal deterrents are potentially more suitable for surfers generally than an approach that protects a specific area. As mentioned earlier in this report, this is due to surfers not being confined to a small location (e.g. tens or hundreds of metres) in very shallow water as many swimmers are.

It is reiterated here that the decision to use an individual deterrent and the exact nature of that deterrent is a personal decision. It is not a decision for government at any level. Notwithstanding this, there is scope for NSW Government to include advice in its SharkSmart program regarding the types of personal deterrents that it recommends are appropriate for bathers to use in remote locations and for surfers to use around headlands.

While individual deterrents are obviously designed to be purchased and used by an individual, there is also potential scope at patrolled beaches to use personal deterrents to disperse a dangerous shark when it is spotted. Currently, when a dangerous shark is spotted at a patrolled beach water users are directed to leave the water immediately, but in reality this takes time and people will still be at risk until they completely leave the water. Augmenting the directive for people to leave the water can be the deployment of a deterrent. A chemical deterrent such as RepelSharks is a good candidate to use for this purpose because it can be very quickly deployed, can cover a relatively large area at least for a short period time, and has been demonstrated to work effectively through published experimental trials.

4.3.2 The Focus of Further Research on Emerging Technologies

This review has identified that a diversity of research activity in a number of countries is underway, and is at various stages of completion. While the focus of this review is on approaches that are ready to be trialled in NSW conditions, a number of emerging technologies can be considered in the future provided further specific research and testing of durability in NSW conditions is undertaken (see **Table 4-1**). In the case of the three permanent physical barriers identified and discussed in this report, the issue that needs to be addressed is their durability over a period of years in NSW conditions. If their durability can be clearly demonstrated then they represent an option for physically separating sharks from water users. The temporary barrier net avoids the need for a structure to be durable under all weather conditions, however the most appropriate material for avoiding the capture of an animal as well as the development of appropriate deployment and retrieval protocols need to be assessed.

In the case of electric and magnetic barriers, testing of their durability over a period of years in NSW conditions is also required but in addition, there needs to be rigorous research which clearly demonstrates that they can effectively repel sharks in surf conditions. Provided enough sharks are encountered the additional trialling of the Shark Repellent Cable planned by the KwaZulu-Natal Shark Board represents just such an opportunity for that particular device. The issue of the potential human health impacts of electrical barriers on people with pacemakers or heart conditions needs further consideration. The feasibility of powering electric barriers with small-scale wave energy generators should be assessed as this will potentially eliminate the need for onshore power generation facilities. The efficacy of the Sharksafe barrier has been successfully demonstrated on white and bull sharks, and the focus of research on this barrier should be on modifying the approach to best suit NSW surf conditions. The potentially impacts of habituation to barriers such as the electric barriers and the Sharksafe barriers requires assessment over an appropriate timeframe.

In terms of detectors, Cleverbuoy represents a technology with potential however a number of issues need to be considered by rigorous and appropriately designed independent controlled field experiments in the surf zone (**Table 4-2**). This field experimentation should focus on verifying the effective detection range of a Cleverbuoy in surf conditions, which would identify the number of Cleverbuoy's required for deployed per area of beach. It should also focus on verifying the ability of Cleverbuoy to reliably detect large sharks in the surf zone. Additional work also needs to be undertaken to determine the durability of the device in the surf zone conditions of NSW over a suitable period of time. In the case of the SmartBuoy, the issue is not specifically with the efficacy of the technology itself, but rather the practicality of utilising the approach specifically related to being able to rapidly deploy to attend to a captured animal (**Table 4-2**).

Table 4-1 Key aspects of shark deterrents with potential to operate at the whole-of-beach scale that if addressed, would make them suitable for possible future trialling at a NSW beach.

Shark Deterrent	Type	Independent scientific verification of no effect on people with pace makers or a heart condition	Trials proving long-term durability and continuous operation (if powered) in conditions similar to those expected at a NSW beach	Commercial availability	Independent scientific verification of potential for capture of other wildlife	Independent scientific verification of effectiveness against white, tiger or bull sharks
Temporary barrier net	Physical barrier		Needed		Needed	
Eco Shark Barrier	Physical barrier		Needed			
Bionic barrier	Physical barrier		Needed			
Aquarius barrier	Physical barrier		Needed			
Bubble curtain	Visual barrier		Needed	Needed		Needed
Sharksafe barrier	Magnetic (and visual) barrier	Needed	Needed	Needed		
Shark repellent cable	Electric barrier	Needed	Needed	Needed		Needed
Aquatek	Electric barrier	Needed	Needed	Needed		Needed
Underwater rubberized electric fence	Electric barrier	Needed	Needed	Needed		Needed

Table 4-2 Key aspects of shark detectors that if addressed, would make them suitable for possible future trialling at a NSW beach.

Shark Detector	Trials proving long-term durability and continuous operation (if powered) in conditions similar to those expected at NSW beaches	Commercial availability	Independent scientific verification of effectiveness against white, tiger or bull sharks	Independent scientific verification of no adverse impacts on wildlife
Shark spotter program				
Smart Drumline			Needed	Needed
Clever Buoy	Needed	Needed	Needed	Needed
Tagging and real time tracking of tagged sharks				

5 Conclusions and Recommendations

Effectively mitigating the risk of an unprovoked shark bite remains a substantial and diverse research field. The focus of this report was on identifying an approach or approaches that was ready to be trialled at a whole-of-beach scale in NSW. There is some basis that all of the technologies reviewed potentially deter or detect sharks in some circumstances, or in the case of physical barriers prevent a shark entering a beach where water users are present. Of the many barrier approaches reviewed, the physical barriers ranked highest according to assessment criteria for potential trial in NSW, followed by bubble, visual and magnetic, and electric barriers. Although all of the barrier type approaches were considered to have potential they were also considered to need further refinement before they could be recommended for possible trial at NSW beaches. All of the personal deterrents did not rank well as a whole-of-beach solution although they provide a good solution for bathers using remotely located beaches and surfers that frequent the reefs and headlands between beaches. The decision to use an individual deterrent, however, is a personal decision and not a decision for government at any level.

Fewer emerging technologies for shark detection were reviewed than shark deterrents. The shark spotter program ranked the highest although the cost of labour for the program would need to be closely scrutinised and there are issues associated with its effectiveness on longer beaches, as well as uncertainties regarding the effectiveness at reliably detecting bull and tiger sharks. Given the costs of setting up and running a shark spotter program, possible trials of this program, and for that matter any technology, should consider how existing networks of lifeguards or other organisations could be utilised to make implementation of a program cost-effective.

The other three shark detection technologies each have different issues that would need to be overcome before they were short-listed for trial. The Smart Drumline system would need to determine a suitable means for translocating hooked sharks (or other animals) before mortality occurs, and consideration of the practicality (including costs) of a contractor on standby to rapidly respond to a captured shark when required. The Cleverbuoy system’s durability in the challenging environment of NSW beaches is not yet proven, and its effectiveness at shark detection at a relevant spatial scale has not been the subject of rigorous scientific testing. Were these issues overcome, then Smart Drumline and Cleverbuoy have great potential. Although tagging and real time monitoring of tagged sharks can contribute substantially over time to knowledge of movement patterns and behaviour of tagged sharks its effectiveness at detecting sharks for the purpose of identifying a threat to water users is proportional to the number of sharks tagged. It will take a substantial period of time to tag a suitably large number of sharks, and this approach will potentially contribute to mitigating the risk of unprovoked shark bite only in the longer term.

The following recommendations are made:

1. Because the short-listed technologies cannot provide a single, simple solution that would encompass all types of beaches in NSW, consideration should be given as to how best to integrate emerging technologies, were they trialled successfully, into the NSW Government’s overall suite of bather protection measures;
2. Although most of the shark deterrents that operate at large-scales have great potential for whole-of-beach protection we consider that they require further refinement before short-listing for potential trial at a NSW beach. We provide advice in **Section 4.3.2** for each type of emerging shark deterrent technology as to the refinement that is needed to make them ready for trial;
3. The short-list of shark detectors for potential trial on NSW beaches is limited to the shark spotter program but Smart Drumline and Cleverbuoy systems would also be suitable for trial if the following issues can be overcome:
   (a) Smart Drumline - a suitable means for translocating hooked sharks before mortality occurs is determined, the practicality and cost-effectiveness of effectively tending the fishing gear is addressed, and there is independent scientific verification of effectiveness against white, tiger or bull sharks; and
   (b) Cleverbuoy - durability is proven, further evaluations are made on its effectiveness at shark detection and negligible potential to have adverse impacts on wildlife including rigorous scientific evaluation.
4. NSW Government should consider including advice in its SharkSmart program regarding the types of personal deterrents that it would recommend as being suitable for bathers to use in remote locations and for surfers to use around headlands.

6 References

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Appendix A – Consultation Documents