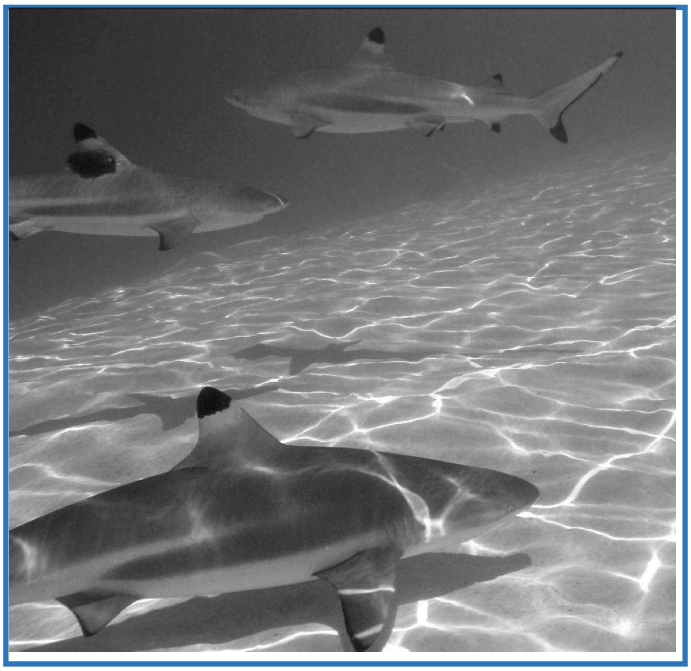

THE SCIENTIFIC BASIS FOR GLOBAL SAFETY GUIDELINES TO REDUCE SHARK BITE RISKS

A review of the latest science

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The scientific basis for global safety guidelines to reduce shark bite risk: a review of the latest science

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Key terminology

Crepuscular: animals that prefer to hunt at dawn and dusk when light levels are low

Fatal shark bite: an encounter between a shark and a human where the human is bitten and dies as a result of the bite

Shark bite: an encounter where a human is bitten by a shark

Shark encounter: An interaction between a shark and a human that results in no injury

Shark sighting: an encounter where a human sees a shark

Negative shark-human interaction: any encounter between a shark and a human that results in a negative outcome (physically or mentally) for the individual

Top predator: a species that once fully grown is positioned near the top of the food web, and has few natural predators.

Abstract

Negative shark-human interactions are relatively unpredictable and ungovernable events which draw significant media attention. The global trend of shark bite frequency is quite variable, with some areas experiencing increases while bite rates in other areas have declined. Historically, government and media responses have framed the story in a way that vilifies sharks, thus further inflaming the negative and emotionally driven public perceptions of sharks. To reduce the risk of negative shark-human interactions, governments and communities around the world have developed extensive shark safety guidelines intended to minimise public risk with sharks. However, workshops and community outreach following shark bite clusters have found that some beach goers may not adhere to such advice, and seek scientific evidence underpinning such guidelines to inform their individual risk assessments and behaviour. To better understand the scientific basis underpinning the shark safety guidelines aimed at minimising the risk of shark bites, this review explored the scientific literature about shark-human interactions, and shark ecology and behaviour, and compared it with 36 shark safety guidelines identified from six regions.

These guidelines were broadly categorised as advice aimed at reducing risk by prompting beach goers to (1) modify their *practices and responses*, or (2) to *observe and adjust* to *environmental conditions or cues*. The ten guidelines most widely used could be considered as general guidelines were largely not supported by current per-reviewed literature about shark behaviour and ecology. The guidelines with the strongest scientific basis tended to be context specific, with the available supporting science focused mainly on predator-prey interactions and shark ecology and behaviour. This review also highlights that some shark safety guidelines could be reframed as 'general water-safety precautions' or 'good practices for beachgoers' to distinguish them from shark-specific guidelines. Additionally, shark safety guidelines may be more applicable if they are tailored towards local shark behaviour and ecology, and local conditions, which could also affect their perceived legitimacy by beachgoers.

1. Introduction

Sharks are predators that have evolved over millions of years for ecological success in marine ecosystems (Bres, 1993). The relatively large size (compared to most other fishes), sharp teeth, and top predator position of species prominent in the media, as well as a long history of negative shark-human interactions has created exceptional global apprehension towards sharks (Peschak, 2006). Evolving knowledge of shark behaviour and biology continues to provide a better understanding of these predators' important role in the marine environment (Heupel et al., 2014) and sharks are valuable tourism resources in many locations (Healy, Hill, Barnett, & Chin, 2020). Sharks and rays are facing increasing pressure around the world with up to ¼ of shark and ray species threatened with extinction (Dulvy, Fowler *et al.* 2014). There is a growing narrative and clear need for action to conserve threatened species of sharks and rays, however, conservation could lead to conflict (Carlson, Heupel *et al.* 2019). Indeed, incidences of fatal and non-fatal shark bites around the world often overshadow narratives about the importance of shark conservation efforts for both the ecosystem and global economies (Sabatier & Huveneers, 2018), as media and government responses to such tragedies tend to frame sharks as 'merciless killers' (Neff, 2015).

Trends in shark bite incidents are extremely variable. While documented shark bites have declined in some parts of the world, some areas, such as Australia and the United States, have shown an increase in shark bites per million people since the 1960s (Midway, Wagner, & Burgess, 2019). However, even within Australia, trends are variable, with an increasing bite rate in 'southern Australia', but an overall stable trend in 'northern Australia' (see Fig 4, Midway, Wagner and Burgess, 2019). Identifying and explaining trends in shark bite rates and patterns is extremely challenging because these occurrences are relatively rare, for example there is less than one incident per 1 per million people per year in Australia (Midway, Wagner, & Burgess, 2019). Regardless of how infrequently they occur, negative shark-human interactions around the world have been dramatically reported in the media for decades (Neff, 2012; Pepin-Neff & Wynter, 2017; Sabatier & Huveneers, 2018). Although increased human populations appear to be a key a driver in shark bite frequency as opposed to sharks 'seeking out' humans to bite (Chapman & McPhee, 2016), the historic labels of sharks as "man-eaters" (Linnaeus, 1758) and as "rogues" (Coppleson, 1950) continue to permeate through society and generate emotional responses from the public (Myrick & Evans, 2014; Neff & Hueter, 2013). As negative shark-human interactions are low probability-high consequence events, this issue has traditionally been difficult for political leaders to manage in a way that reconciles the clash between shark bites and the need for shark conservation (Meeuwig & Ferreira, 2014; Pepin-Neff & Wynter, 2018).

Government responses are particularly complex following a string of negative shark-human interactions over a short-time period. Such clusters of shark bites appear throughout reported history and they have historically been accredited to "rogue sharks" that have a "taste for human flesh" (Coppleson, 1958). While the "rogue shark" theory is unsupported by empirical evidence and global shark bite data (Neff & Hueter, 2013), clusters of shark bites generate extreme apprehension towards participating in marine tourism and recreational activities in the area (Neff, 2015). Shark bite clusters also tend to prompt acute government interventions as a response to better alleviate public anxiety and fulfill their duty to maintain public safety (Neff, 2012). With little empirical knowledge about why clusters of shark bites occur, information about shark biology and behaviour is needed to inform the public about the likelihood and nature of potential shark encounters under varying conditions. This information will help beachgoers and water users to individually assess their personal risk when entering the water.

In attempts to mitigate negative shark interactions, governments and communities around the world have developed various guidelines to advise beachgoers and water users to reduce their risk of negative shark encounters (Florida FWC, 2020; NSW DPI, 2020; National Park Service, 2019; Queensland Government, 2020; Shark Spotters, 2020; Western Australia, 2020). The advice is generally tailored towards large iconic shark species often associated with negative shark-human interactions: *Carcharodon carcharias* (white sharks), *Galeocerdo cuvier* (tiger sharks), and *Carcharhinus leucas* (bull sharks; McPhee 2012a). The focus on these three species is particularly evident around Australia.

Many beachgoers are ill-informed about shark bite risk and overestimate the likelihood of such low probability-high consequence interactions occurring (Crossley et al., 2014).

Additionally, there are low levels of confidence in governments' ability to prevent shark bites, however these attitudes may also indicate that some people understand that shark bites are relatively ungovernable events (Pepin-Neff & Wynter, 2017). Recent social science research in the Whitsundays (Queensland), and Ballina and Byron Bay (Northern New South Wales) have indicated that there is public desire for more information about the scientific basis supporting the advice so individuals can make their own risk assessments and decisions (McClean et al., 2020). This research also revealed that if an individual does not believe there is reputable science surrounding the shark safety guidelines, a wide range of guidelines may be ignored or assumed as flawed and fictitious (McClean et al., 2020). Coincidentally, a workshop on Australian shark bite mitigation measures held in February 2020 at Flinders University, Australia, also highlighted the need to assess and document the scientific basis of shark safety guidelines.

The extent to which government shark safety guidelines are based on scientific knowledge about shark behaviour has yet to be assessed, raising the question of the origin and applicability of these guidelines. The aims of this review are to (1) collate existing shark safety advice and guidelines from several regions around the world; (2) locate and review the scientific information relating to each of these guidelines; and (3) using a systematic and transparent assessment process, clearly identify the extent to which these public safety guidelines align with the available science. The overall intention is to help the general public understand the evidence behind shark safety so that beach goers and managers can make informed decisions about how to best prevent negative shark-human interactions.

2. Methods

Shark safety guidelines were compiled from six regions: Queensland, New South Wales, and Western Australia (Australia), South Africa, and Florida and Cape Cod, Massachusetts (USA). Queensland and New South Wales guidelines were located on state government SharkSmart websites. Western Australian guidelines were compiled from the Surf Life Saving – Western Australia website, as the government SharkSmart page identified this information source as the “state’s peak coastal safety and rescue organisation”. Specific government advice was also unavailable for South Africa, so guidelines from Cape Town’s primary shark safety strategy group “Shark Spotters” were used. Florida guidelines were compiled from the Florida Fish and Wildlife Conservation Commission website, and Cape Cod guidelines were found on the United States National Park Service website. The French Republic, Reunion Island was omitted from the compilation, as swimming in the open ocean around the island is completely banned apart from the “shark free” net protected beaches, and no shark safety advice could be found (Chapman & McPhee 2016).

The primary literature search was conducted using the Web of Science™ and Google Scholar™ databases filtered to include peer-reviewed journal articles, government reports, and books. Searches consisted of 2–3 terms chosen to obtain ecological and behavioural information about sharks relevant to the guidelines (Table 1). Secondary searches were conducted by examining the references cited in the articles found through the primary search. This search process continued until triangulation (at least three articles) refuting or supporting a guideline was found through the primary search, or until no new publications emerged from continued searches.

Table 1: Search terms used for literature search. Searches consisted of 2-3 search terms, using a phrase from term one and term two, with the addition of term 3 when more specific searches were necessary

		Term 2						
Term 1	**AND**	*Negative Interactions*	*Ecology*	*Sensory*	*Prey*	*Humans*	**AND**	**Term 3**
Bull shark		Attack	Crepuscular	Attraction to blood	Bait fish	Baiting		Australia
Shark		Attack mitigation	Crepuscular predator	Blood	Baitball	Berleying		Cape Cod
Tiger shark		Control	Diel	Deterrent	Dogs	Boats		Florida
White shark		Safety nets	Diel predator	Learning	Dolphin competition	Conditioning		GBR
			Drop off	Olfaction	Dolphin distribution	Conditioning		New South Wales
			Feeding conditions	Olfactory	Dolphin interaction	Depredation		Queensland
			Habitat use	Provoke	Pets	Fisheries interaction		South Africa
			Kelp forest	Repellent	Pinnipeds	Groups of people		Western Australia
			Migration patterns	Sensory biology	Prey behavioural response	Sewage runoff		
			Movements	Touch	Seals			
			Predation					
			Sandbar					
			Temporal hunting					
			Temporal movements					
			Trophic ecology					
			Turbid					

Once the compilation of shark safety guidelines was fully assembled and compared with the available scientific literature, a criteria system was used to provide a systematic 'weight of evidence' for each shark safety guideline. This criteria system (Table 2) assessed each guideline against three criteria:

1) *Likelihood of accuracy* - the extent to which the guideline is consistent with theoretical understanding of factors and behaviours that could increase risk,
2) *Level of supporting evidence* - the extent of existing scientific evidence from studies of shark behavior and ecology that support the guideline; and
3) *Level of congruence and consensus* – the level of agreement, disagreement, debate, and variability in the scientific evidence relating to each guideline.

Guidelines which may not **directly** influence an individual's risk of shark bite *in or on the water* were not assessed using these criteria, and instead were identified as ***Generic Safety Precautions***.

For example: guidelines encouraging beach goers to "find out about beach safety", or to "swim between the flags" may not **directly** affect an individual's risk of shark bites *while in or on the water*. Instead, these are considered here as general guidelines that apply to all manner of swimmer safety scenarios, or may help beach goers find out about more specific behaviours (e.g. guidelines encouraging people to download a smartphone app). Additionally, some of these *Generic Safety Precautions* are also intended to minimise risks from other factors, such as preventing deaths and injuries from other risk factors such as rip currents and drowning.

Table 2: Criteria ranking system used to systematically assess scientific support of the 36 shark safety guidelines. Red indicates low support, yellow indicates moderate support, and green indicates high support

Criteria	Ranking		
	Low	Moderate	High
Likelihood of being accurate	**Implausible**: Does not align with ecological theory AND/OR contradicts known species' biology, ecology, and behaviour. L	**Plausible**: Some aspects align with ecological theory AND with understanding of species' biology, ecology, and behaviour. L	**Highly plausible**: Congruent with ecological theory and understanding of species' biology, ecology, and behaviour. L
Level of supporting evidence	**Limited Evidence**: Evidence limited to a single study on a single species and location. E	**Moderate Evidence**: Two to three studies on several species and in multiple locations. E	**Strong Evidence**: Four or more studies involving multiple studies and locations. E
Level of Congruency	**Limited Congruity**: Guideline has minimal consistency across contexts and species. C	**Some Congruency**: Guideline is moderately applicable across contexts and species but is not universal. C	**Broadly Congruent**: Guideline is widely consistent across contexts and species. C

3. Results

3.1 Safety guidelines

In total, 36 different guidelines were found that are currently provided to the public by six regions as part of shark safety messaging (Table 4). Guidelines were grouped into three categories:

(1) **Generic safety precautions:** These are guidelines which may not **directly** influence an individual's risk of shark bite in or on the water. For example, "Swim between flags" is considered a generic safety precaution as it is applicable to a broad range of swimmer scenarios and does not directly reduce an individual's chance of being bitten.

(2) **Practices and responses:** These are guidelines that are aimed at changing an individual's behaviour in or on the water to directly reduce the risk of shark bites to themselves or to others. For example, "Minimise splashing/noise if a shark is sighted" is considered a behavioural response that an individual could initiate to reduce their risk of attracting unwanted shark attention.

(3) **Observing and adjusting to environmental cues:** These are guidelines that prompt users to reduce their risk exposure by observing *environmental conditions or cues* that may indicate the potential for increased shark bite risk, and adjusting their behaviour based on those cues. For example, "Don't swim near schools of baitfish" is a response based on an environmental cue that potentially could increase the likelihood of unwanted shark interactions.

Of the 36 guidelines identified, 14 relate to beachgoer **practices and responses**, 12 relate to observing and adjusting to **environmental cues**, and 10 were considered **generic safety precautions**.

Twenty-six guidelines were identified from Australia, with New South Wales having the most extensive list of SharkSmart advice with 23 guidelines split into those for swimming/surfing and for diving, snorkeling, and spearfishing (NSW DPI, 2020).
Queensland had six SharkSmart guidelines (Queensland Government, 2020), which for this

review were split into eight guidelines to align better with other agencies and facilitate comparison across the spectrum of advice given. Western Australia's Surf Life Saving advice promoted eleven guidelines (Western Australia, 2020). Shark Spotters from South Africa had five broad safety guidelines split into specific guidelines for scuba divers, free divers/ snorkelers, surfers/bodyboarders, surf skiers/kayakers, and spearfishers (Shark Spotters, 2020). Florida Fish and Wildlife Conservation Commission promoted 15 safety guidelines, which were split into 16 for better comparison (Florida FWC, 2020). The US National Park Service in Cape Cod recommended eight shark smart guidelines (National Park Service, 2019).

Of the 36 shark safety guidelines, only one was used by all six regions whilst ten were used by at least three regions. New South Wales was the only location to use all ten of these widely applied guidelines. The other 26 guidelines were more sparsely used and appear to address more state-specific and location-specific situations.

3.2 Literature assembled and alignment with guidelines

Overall, the literature search identified 98 peer-reviewed articles and books related to the compiled guidelines and shark behaviour or ecology. The literature included directly related to studies of shark bite and/or directly explored shark behaviours and ecology that could be directly related to shark bite risks. This body of literature included publications ranging from 1958 to 2020.

The assembled literature was used to assess the alignment of each of the 36 guidelines against the accuracy, level of supporting evidence, and level of congruence and consensus as described in (Table 2). The extent of alignment varied greatly (Table 3), with some guidelines appearing to have little to no scientific basis, while other guidelines had substantial supporting scientific evidence. However, while all the guidelines are framed as steps that reduce the risk of negative shark encounters, the guidelines that are *generic safety precautions* do not directly relate to reducing shark bites in or on the water. As such, while these *generic safety precautions* are included in Table 3, they were not specifically assessed for their alignment with scientific evidence.

Table 3: Shark safety guidelines and alignment with scientific evidence. Criteria ranking (see Table 2) indicates the extent to which each guideline aligns with scientific evidence: Red = low, yellow = moderate, green = high. Comments provide rationale for weight of evidence ranking. Guidelines are ordered by the number of regions which present them from high to low.

Guideline	Queensland	New South Wales	Western Australia	South Africa	Florida	Cape Cod	Contrary scientific evidence	Supporting scientific evidence	Generic Safety Precaution	Guideline Category	Criteria: Accuracy Likelihood	Criteria: Supporting Evidence	Criteria: Congruency	Comments
Swim, surf, snorkel, dive w/ buddy	x	x	x	x	x	x		(Martin, 2007; Martin & Hammerschlag, 2012)	x	Practices/ Responses	L	E	C	Swimming with a buddy could be classified as a *Generic Safety Precaution*, however it may also have specific shark safety application and hence is assessed here as *Activity/Response based*. Empirical information about this advice is lacking. While it is possible that swimming with a buddy may assist in sighting sharks in the area and aid with quicker post-incident response, it is unclear to what extent swimming with a buddy reduces the risk of being bitten. This guideline would likely be context specific, as shark response to groups may have inter- and intra-species variations or vary depending on location.
Swim in clear water	x	x		x	x	x	**White sharks** (Kock et al., 2006; Wintner & Kerwath, 2018) **Tiger sharks** (Wintner & Kerwath, 2018)	**Bull sharks** (Cliff & Dudley, 1991; Compagno et al., 2005; Lagabrielle et al., 2018; Simpfendorfer et al., 2005; Taglioni et al., 2019; Werry et al., 2018; Wintner & Kerwath, 2018)		Environ-mental Cue	L	E	C	This guideline does not apply to all shark species. It is known that bull sharks frequent areas of higher turbidity, however, there is also evidence suggesting that other species frequent clear water. Habitat use may also change between life stages. As such, swimming in clear water may not always reduce exposure to sharks, but it could prove more useful as in specific situations, or framed as a generic safety guideline as it is easier for beachgoers to be aware of their surroundings and may help in sighting a shark.

Minimise splashing/noise if shark sighted		x	x	x	x	x	(Chapuis et al., 2019)	(Bres, 1993; Chapuis et al., 2019; Hart & Collin, 2015; Klimley et al., 1992; Nelson & Gruber, 1963)		Practices/ Responses	L	E	C	Some evidence supports this claim, but splashing may elicit mixed responses from different individuals or species of shark. Some sharks are attracted to it, while it may scare others away if they are already in the vicinity. However, it is generally accepted that larger predatory sharks are attracted to splashing as it may sound like struggling prey.
Avoid areas with signs of bait fish or feeding activity	x	x	x		x	x		**Bull sharks** (Carlson et al., 2010; Hammerschlage t al., 2012) **White sharks** (Bruce et al., 2006; Colefax et al., 2020; Dudley & Simpfendorfer, 2006)		Environ-mental Cue	L	E	C	This guideline is likely accurate, is widely supported by empirical evidence, and accepted by marine scientists. Bait fish activity indicates high productivity, which is usually associated with higher trophic level predation. More prey in an area provides a greater chance of sharks being present. This attraction to bait fish activity is well documented and agreed upon by empirical data.
Don't swim too far from shore		x	x		x	x	**White sharks** (Colefax et al., 2020; Klimley, 1994; Klimley et al., 2001; Weltz et al., 2013; Weng et al., 2007) **Tiger sharks** (Afonso & Hazin, 2015; Andrzejaczek et al., 2019;	**White sharks** (Weng et al., 2007)	x	Environ-mental Cue	L	E	C	This guideline does not apply to all shark species, and particularly not the species which the guidelines intend to protect people from and may require more specific distances or depths to be truly effective advice. White sharks, tiger sharks, and bull sharks move along coastlines and have frequently been tracked coming in closer than the surf break. Many historic shark bites have occurred in shallow water, so defining "shallow" more specifically related to depth is suggested. This may serve better as a *Generic Safety Precaution* as the closer an individual is to shore, the quicker medical attention and action can be received.

							Dicken et al., 2016) **Bull sharks** (Carlson et al., 2010)							
Don’t swim at dawn/dusk	**x**	**x**		**x**	**x**		**White sharks** (Bruce et al., 2005; Colefax et al., 2020; Klimley, 1994; Klimley et al., 2001; Weng et al., 2007) **Bull sharks** (Curtis et al., 2014)	**Tiger sharks** (Afonso & Hazin, 2015) **White sharks** (Colefax, Kelaher, et al., 2020) (Hammerschlag et al., 2016)	**x**	Environ-mental Cue	**L**	**E**	**C**	This guideline does not apply to all shark species and there is notable intraspecific variation. The high amount of conflicting empirical evidence suggesting that the target sharks are crepuscular predators proves that this guideline is contested by scientific evidence. However, this may serve as a *Generic Safety Precaution* as it is easier to assess risk of being in the water at higher light levels.
Tell on-duty lifeguard if you spot a shark		**x**		**x**	**x**	**x**			**x**	*Generic Safety Precaution*				This guideline does not directly relate to an individual’s in or on water risk, or shark ecology or behaviour in terms of shark safety. It is therefore considered general precautionary advice. This advice could potentially be expanded to include recording the sighting on a shark watch app.

Don't swim with bleeding cuts/wounds or while menstruating		x	x		x		(Maillaud & Van Grevelynghe, 2005)	**Tiger sharks** (Bres, 1993; Tester, 1963; Yopak et al., 2015) **White sharks** (Kara E Yopak et al., 2015)		Practices/ Responses	L	E	C	While it is well known that sharks have a keen sense of smell, attraction to fish blood is different than attraction to human blood. Very few scientific studies empirically test this, and much of the evidence available to back this claim is mainly suggestive based on olfactory bulb sizes or historically outdated studies. The concentration of blood necessary to attract a large shark is high and rarely reached unless an individual has a large injury.
Avoid swimming between sandbars or near steep drop offs		x	x		x			**Tiger sharks** (Heithaus & Dill, 2006; Heithaus et al., 2006; Lee et al. 2018) **White sharks** (Colefax, Kelaher, et al., 2020)		Environ-mental Cue	L	E	C	This guideline is likely accurate, as steep drop offs and areas between sandbars provide sharks ample opportunity to encounter both deep- and shallow-dwelling prey. Large sharks have been widely recorded to patrol such areas, but other species may not be as prevalent.
Follow local signage and flags	x			x		x			x	*Generic Safety Precaution*				This guideline does not directly relate to shark ecology or behaviour in terms of shark safety and is therefore considered general precautionary advice.
Do not feed/touch/harass /provoke sharks		x			x			(Bres, 1993; Clua & Torrente, 2015; Curtis et al., 2012; Maillaud & Van Grevelynghe, 2005; Martin, 2007)		Practices/ Responses	L	E	C	This guideline is likely accurate, but few studies have explicitly tested this. Studies which do explain that by touching or harassing a shark, many sharks may flee, but some may get agitated and respond accordingly. Feeding sharks proves problematic as the sharks' behavior shifts to feeding behavior.

Don't swim where fish are being cleaned	**x**		**x**				**White sharks** (Bruce et al., 2005)	**Bull sharks** (Brunnschweiler & Barnett, 2013) **White sharks** (Laroche et al., 2007)		Practices/ Responses	**L**	**E**	**C**	This guideline is likely accurate, as cleaning fish effectively serves as berleying the water. There are some debates about what concentration of fish guts actually attract large predators, but it is generally agreed upon that fish remains have the capacity to attract sharks. Fish remains may attract sharks to the general area (bay, beach, etc.) rather than just specifically where fish are being cleaned.
Be aware of surrounding fish behavior		**x**	**x**					(Laroche et al., 2008; Wirsing & Ripple, 2011)		Environ-mental Cue	**L**	**E**	**C**	This guideline is likely good practice, but few studies have empirically tested this with large coastal predatory sharks. However, the evidence available suggests that shark presence can increase the vigilance and refugia seeking of prey. Specific indication of which behavior is suggestive of shark presence may better assist in minimising shark bite risk. Further research on this topic could develop a better understanding of coastal prey responses to shark presence.
Do not attach speared fish to your body		**x**	**x**					(Lippmann, 2018; Maillaud & Van Grevelynghe, 2005)		Practices/ Responses	**L**	**E**	**C**	This guideline is likely accurate, as having a dead fish attached on your person while spearfishing may likely attract predatory sharks, and historic fatal shark bites have occurred to spearfishers. However, there is little empirical behavioural literature specifically showing this. Nevertheless, when comparing with depredation on line fishers, it seems likely that the same principle applies for spearfishing.
Swim between flags	**x**	**x**							**x**	*Generic Safety Precaution*				This guideline does not directly relate to shark ecology or behaviour in terms of shark safety and is therefore considered general precautionary advice.

Avoid swimming in canals, river/harbour mouths	**x**	**x**						**Bull sharks** (Simpfendorfer et al., 2005; Heithaus et al., 2009; Heupel & Simpfendorfer, 2008; Matich & Heithaus, 2014; Lee et al. 2018) **White sharks** (Ryan et al. 2019; Colefax, Kelaher, et al., 2020)		Environ-mental Cue	**L**	**E**	**C**	This guideline is likely accurate, specifically for bull sharks, but white shark activity has also shown an increase around river mouths. This is not necessarily true for ALL sharks, however. However, the scientific consensus on this guideline indicates that river mouths are known shark foraging areas.
Avoid having pets in water with you		**x**			**x**			(Bres, 1993; Caldicott et al., 2001; Chapuis et al., 2019; Hart & Collin, 2015; Myrberg et al., 1972; Nelson & Gruber, 1963)		Practices/ Responses	**L**	**E**	**C**	This guideline could be accurate. While there are no empirical studies directly assessing shark attraction to pets, the primary concern is the splashing and noise pets make while swimming in the ocean. As sharks are attracted to sounds of struggling prey splashing around, the noise and disturbance that pets cause in the water may have the same effect as humans splashing. However, it is important to note that there is interspecific variation in shark responses, and it is highly dependent on the shark's proximity from swimming pets.
Don't rely on dolphin sightings to indicate shark absence		**x**			**x**			(Cockcroft et al. 1989; Mollomo 1998, Heithaus 2001, Heithaus & Dill 2006, Curtis et al. 2014; Smith et al. 2017)		Environ-mental Cue	**L**	**E**	**C**	This guideline is likely accurate. Dolphins and some species of large sharks compete for the same prey. Many large shark species also prey on dolphins, so in some areas, dolphin presence may also correlate with shark presence. Some studies indicated that dolphins may hunt in 'safer' areas when large sharks are present, but not exclusively.

Observe and respond calmly to antagonistic changes in shark behaviour		x		x				(Martin, 2007)	x	Practices/ Responses	L	E	C	This guideline is likely accurate. There are very few empirical studies assessing human response to aggressive shark behaviour. However, based on sharks' attraction to splashing and quick movements, it is likely better to remain calm and maintain visual contact with the agitated shark while exiting the vicinity.
Avoid areas used by recreational or commercial fishers	x	x						(Curtis et al., 2014; Gilman et al., 2008; Guttridge et al., 2009; McCord & Lamberth, 2009; Mitchell et al., 2019, 2018; Rosa & Secchi, 2007)		Practices/ Responses	L	E	C	This guideline is likely accurate, as depredation of recreational and commercial fisher catch by large sharks is frequently reported. Positive reinforcement from a low labor-cost food source, like hooked or discarded fish, may explain this noted association of sharks with fishing vessels. There is general consensus that this is an issue fishers face, so swimming in an area without fishers is recommended.
Follow SharkSmart website/app		x	x						x	*Generic Safety Precaution*				This guideline does not directly relate to shark ecology or behaviour in terms of shark safety and is therefore considered general precautionary advice.
Don't throw food scraps or fish waste overboard	x						**Tiger sharks** (Hammerschlag et al., 2012) **White sharks** (Bruce et al., 2005)	**White sharks** (Laroche et al., 2007); **Bull sharks** (Brunnschweiler & Barnett, 2013)		Practices/ Responses	L	E	C	It is unclear what concentration of fish waste attracts large sharks. Many marine tourism activities use feeding events to attract fish. Yet, there is mixed evidence indicating how attractive these activities may be for large shark species like tiger sharks and white sharks, or how previous activities (e.g. dumping of food waste) may have conditioned sharks to frequent certain locations. However, it is recommended that ocean users should avoid discarding any waste overboard.

Don't swim/surf near shark nets		x					(Guttridge et al., 2009)	(Hart & Collin, 2015; McPhee et al., 2019; McPhee, 2012; Wetherbee et al. 1994)		Practices/ Responses	L	E	C	This guideline is likely accurate, as sharks are attracted to the sounds of struggling prey. Shark nets are intended to capture large sharks, however captured animals may attract large sharks to protective nets. Increased net capture has shown correlation to shark attraction to nets. There is also a risk of swimmer entanglement in the nets, and therefore it seems like good precautionary advice to warn against swimming close to shark nets. However, this is not to suggest not swimming at protected beaches, but rather to better define what constitutes "near."
Consider using personal deterrent		x					**White sharks** (Huveneers et al., 2018; Ryan et al., 2017) **Bull sharks** (Gauthier et al., 2020)	**White sharks** (Egeberg et al., 2019; Huveneers et al., 2013, 2018) **Bull sharks** (Gauthier et al., 2020)		Practices/ Responses	L	E	C	While shark deterrents have seen a major increase in popularity and diversity, empirical evidence suggests that many of the personal deterrents are not effective at repelling large sharks. However, the personal deterrent SharkShield® has shown to effectively reduce white sharks' interactions with bait, suggesting this specific deterrent may be useful for individual use. It has been noted that reduction of the risk may be context specific and vary among species sensitivity to the deterrent or according to sharks' primary investigative motivation. So, while they may not be 100% effective every time, they may significantly reduce the risk of negative shark-human interactions.
Research likely shark species and what behavior to expect		x							x	*Generic Safety Precaution*				This guideline does not directly relate to specific shark ecology or behaviour in terms of shark safety. While it may be useful for the public to have a greater knowledge of shark behaviour, it likely will not affect an individual's in or on water risk of a shark bite.

Look carefully before jumping into the water			**x**						**x**	*Generic Safety Precaution*				This guideline may not directly relate to shark ecology or behaviour in terms of shark safety and is therefore considered general precautionary advice.
Don't swim in the ocean if you're not aware of the risks				**x**					**x**	*Generic Safety Precaution*				This guideline does not directly relate to shark ecology or behaviour in terms of shark safety and is therefore considered general precautionary advice.
Stay in the kelp beds in the Western Cape				**x**			**White sharks** (Jewell et al. 2014, O'Connell et al. 2019, Jewell et al. 2019)	**White sharks** (O'Connell et al., 2019) **Bull sharks** (O'Connell et al., 2014)		Environ-mental Cue	**L**	**E**	**C**	Kelp forests are important foraging grounds for fur seals, primary prey of white sharks, in South Africa. Research shows that large predatory sharks, namely white sharks and bull sharks, may avoid entering dense kelp forests and show preference for patrolling adjacent to the forest edge. However recent evidence proves that white sharks both patrol adjacent to and within kelp forests.
Don't wear shiny jewellery					**x**			(Hart et al. 2011, Hart & Collin 2015)		Practices/ Responses	**L**	**E**	**C**	This guideline is likely accurate, as sharks, and other predatory fish, can best see stark color contrasts underwater. Shiny jewelry often catches light underwater and can attract attention of predatory fish. However, few studies specifically indicate that shiny jewelry attracts shark attention, and just because a shark can better see a swimmer does not necessarily increase the risk of an aggressive response.

Don't swim in sewage waters					**x**			(James, 2015; Mollomo, 1998)		Environ-mental Cue	**L**	**E**	**C**	This guideline is likely accurate, as increased nutrient input from the land is often associated with increased fish activity. Large predatory sharks tend to follow increased prey activity, and therefore are more likely to patrol such waters. Historical shark interactions have occurred in such areas, helping to validate this advice besides general sanitary practices.
Don't enter water if sharks are present					**x**				**x**	*Generic Safety Precaution*				This guideline does not directly relate to shark ecology or behaviour in terms of shark safety and is therefore considered general precautionary advice as it is the most risk averse approach.
Avoid areas where seals are present						**x**		(Bruce et al., 2005; Curtis et al., 2014; Martin et al., 2009; Mollomo, 1998; Skomal et al., 2012)		Environ-mental Cue	**L**	**E**	**C**	In many areas of the world, seals are primary prey for white sharks. Seal abundance has often been positively correlated with white shark abundance. This is highly agreed upon by scientists, as white sharks prefer prey with higher fat content for greater energy consumption.
Be aware sharks hunt for seals in shallow water						**x**	(Martin et al., 2009)	(Bruce et al., 2005; Curtis et al., 2014; Martin et al., 2009; Skomal et al., 2012)		Environ-mental Cue	**L**	**E**	**C**	In many areas of the world, seals are primary prey for white sharks. Seal abundance has often been positively correlated with white shark abundance. However, depending on the location, sharks may not solely hunt for seals in the shallows and may prefer to attack from the depths. This guideline should be more specific and provide information about what constitutes "shallow."

Uneven tans and bright clothing may draw sharks attention					x			(Hart & Collin 2015, Ryan et al. 2017)	x	Practices/ Responses	**L**	**E**	**C**	This guideline follows the knowledge that sharks can discern contrasting colors more easily. Bright colors and stark tan lines may provide such contrast, but there is little empirical evidence to suggest that sharks are more attracted to certain colors. However, a shark's ability to best see a swimmer does not necessarily increase the risk of antagonistic behaviour.
Discuss dive logistics and contingency plans with partner before entering the water		x							x	*Generic Safety Precaution*				This guideline does not directly relate to shark ecology or behaviour in terms of shark safety and is therefore considered general precautionary advice.
Alert ocean users around you if you see a shark				x					x	*Generic Safety Precaution*				This guideline does not directly relate to shark ecology or behaviour in terms of shark safety and is therefore considered general advice.

3.3. Ten Most Commonly Promoted Guidelines

Due to the wide array of advice presented to the public, much of which was generic safety advice (see Table 3), only the ten most widely used guidelines are described in detail here. One of the key findings from this review is that the ten most universally promoted guidelines vary widely in their extent of alignment with scientific evidence (Table 4). Indeed, the only guideline ranked with a high likelihood of accuracy, strong supporting evidence, and applicability was “Avoid areas with signs of bait fish or feeding activity.” Another two of the top ten guidelines proved to not directly relate to reducing a person’s risk of being bitten by a shark: “Tell on-duty lifeguard if you spot a shark” and “Follow local signage and flags.”

The remaining seven of the top ten guidelines showed low levels of evidence and/or congruence between studies and supporting empirical evidence. “Swim/surf/snorkel/dive with a buddy” was the only piece of advice presented in all six regions, however this guideline was assessed to have minimal scientific support with respect to reducing unwanted shark encounters and is better considered as a *Generic Safety Precaution* given the wide applicability of this advice. This last example highlights the issue of how to frame guidelines. While there is little scientific evidence to suggest that “Swim/surf/snorkel/dive with a buddy” will reduce the risk of a negative shark-human interaction, this guideline may be very useful for general water safety, including improving the outcome of a shark bite. Therefore, guidelines that lack strong direct supporting scientific should not be automatically disregarded, but may benefit from reframing them as general water safety guidelines.

Detailed descriptions of the supporting evidence and alignment for these top ten guidelines are outlined below.

Table 4. Most commonly promoted guidelines with their assigned categories and weight of evidence rankings. Criteria ranking indicates the extent to which each guideline aligns with scientific evidence. Red = low, orange = moderate, green = high.

Guideline	# of Regions	Category	Ranking		
			Likelihood of Accuracy	Level of Supporting Evidence	Level of Congruity
Swim, surf, snorkel, or dive with a buddy	6	Practices/Responses	[red]	[red]	[red]
Swim in clear water	5	Environmental Cue	[orange]	[orange]	[orange]
Minimise splashing and noise	5	Practices/Responses	[orange]	[green]	[orange]
Avoid areas with signs of bait fish or feeding activity	5	Environmental Cue	[green]	[green]	[green]
Do not swim too far from shore	4	Practices/Responses	[orange]	[red]	[red]
Don't swim at dawn or dusk	4	Environmental Cue	[orange]	[orange]	[red]
Tell a lifeguard if a shark is sighted	4	Generic Safety Advice	N/A	N/A	N/A
Don't swim while bleeding/with open cuts or wounds, or while menstruating	3	Practices/Responses	[orange]	[red]	
Avoid swimming between sandbars or near steep drop-offs	3	Environmental Cue	[green]	[green]	[orange]
Follow local signage and flags	3	Generic Safety Advice	N/A	N/A	N/A

3.3.1. Swim, surf, snorkel, dive with a buddy

Partaking in marine recreational activities with a buddy was the only guideline present in all six states. Nevertheless, there is little empirical evidence available to directly support that this guideline will actively mitigate shark bite risk. Martin (2007) found that many shark bites on scuba divers tended to be defensive behaviour, as larger groups elicited a stressed response from the encountered and cornered sharks. However, this may reflect more on the reaction of a cornered shark than a response to different group sizes. Meanwhile, white sharks off South Africa have been found to primarily target small groups of young-of-the-year seals that are not as vigilant and tire more easily (Martin & Hammerschlag, 2012), indicating that in some circumstances, groupings of in-water objects may not deter sharks. Sharks naturally tend to avoid humans, but some species like white sharks are very "curious" about foreign objects in the water (Hammerschlag et al., 2012b). Such behaviour may increase the risk of negative shark-human interactions, regardless of the number of people present. One could argue that swimming or surfing within a group may reduce an individual's chance of being bitten as the risk is spread amongst the group, but overall does not reduce the risk of a bite occurring. Given the assessed limited scientific basis underpinning this guideline, but it's potential utility for general water safety (e.g. increasing the chance of sighting a shark if present and further aid in a quicker response should any negative shark-human interaction occur), managers could consider reframing this guideline as a *generic safety* precaution instead of its current framing of advice that individuals should practice to reduce unwanted shark encounters.

3.3.2. Swim in clear water

Swimming in clear water or avoiding murky water was a guideline in five of the six assessed regions. It is widely accepted that some large sharks, like bull sharks inhabit and hunt in turbid waters (Cliff & Dudley, 1991; Simpfendorfer et al., 2005; Wintner & Kerwath, 2018), and may be more frequently encountered after large rainfall events associated with higher turbidity (Ryan et al., 2019; Werry et al., 2018). As bull sharks are known to inhabit estuarine environments (Heithaus et al., 2009), their senses give them particular predatory advantage in murky water (Martin, 2005). Bull sharks off Reunion Island have shown a higher incidence of shark bites in moderately high turbidity (Taglioni et al., 2019), but confusingly, also seem to commonly occur in clear waters (Lagabrielle et al., 2018). Turbidity may also affect white sharks. Research in South Africa found that white sharks were significantly more active when turbidity was higher than average (Cliff et al., 1989), but the relationship between turbidity and shark bite risk remains unclear. An analysis of shark bites off the Western Cape indicate that turbidity is unlikely to play a major role in negative white shark-human interactions (Kock et al., 2006). Furthermore, not all species of shark historically responsible for shark bites primarily rely on turbid waters to ambush their prey. Both white sharks and tiger sharks have been found to actively hunt in clearer waters. Wintner & Kerwath (2018) found that along the east South African coast, both species were more likely to be found in less turbid waters (>4 m visibility), while bull sharks were more frequently encountered in <2 m visibility. This may be due to the different hunting strategies used between these species. White sharks are believed to primarily rely on visual detection of prey (Yopak & Lisney, 2012), suggesting that murky waters may partially hinder hunting success. Overall, while this guideline may prove useful for some shark species in some locations, it is by no means universally applicable. Thus, it is not necessarily "safer" to swim in clear water, apart from having a higher likelihood of seeing a shark before a negative interaction may occur.

3.3.3. Minimise splashing/noise if shark sighted

Keeping splashing and other excessive noise to a minimum was a guideline present in five of the six assessed regions. This guideline is generally supported by historical and recent scientific knowledge of shark biology and behaviour. Specialised lateral lines present in all fish help detect vibrations in the water (Montgomery et al., 1995), which assists sharks in locating prey (J. Gardiner & Atema, 2014; J. Gardiner, Atema, Hueter, & Motta, 2016; J. M. Gardiner, Atema, Hueter, & Motta, 2014). As such, splashing and noise sends vibrations through the water column for all fish, including large sharks, to hear within about 100 meters (Myrberg, 2001). However, the way that sharks respond to acoustic stimuli, such as splashing, differs between species, as some species like oceanic whitetip sharks may be attracted to sudden acoustic changes while it may deter other species such as lemon sharks and silky sharks (Bres, 1993). Chapuis et al. (2019) indicated that in South Africa, white sharks were the most inquisitive species tested and investigated a sound generating acoustic rig significantly more than reef-associated species, but that white sharks had shorter interaction times. However, this same study noted that individual responses could also vary, with chaotic noises with variations in intensity and frequency generating both investigative and aversive responses from individual sharks. Sharks proved to be more attracted to low frequency level stimuli, which aligns with the majority of anthropogenic marine noise (Slabbekoorn et al., 2010), further suggesting that splashing and noise should subside when a shark is seen in the vicinity. However, further research is necessary to fully understand the effect of noise stimuli on large sharks.

3.3.4. Avoid areas with signs of bait fish or feeding activity

Avoiding swimming in areas of bait fish and feeding activity was found as a guideline provided in five of the assessed regions. This guideline is largely based on the knowledge that large sharks are often attracted to schools of fish present in productive waters (Letessier et al., 2013). Fine-scale estuarine movements of bull sharks indicated that bull sharks primarily follow prey movements in areas of higher productivity (Carlson et al., 2010; Heupel & Simpfendorfer, 2008), and their abundance and distribution are largely determined by prey availability (Hammerschlag et al., 2012a). Seasonal variation in prey availability was shown to affect bull shark distribution in a Florida estuary (Matich & Heithaus, 2014), indicative of the link between shark and prey abundance. Behavioural and movement studies of tiger sharks in Shark Bay, Western Australia (M. R. Heithaus et al., 2007; M Heithaus, Dill, Marshall, & Buhleier, 2002; A. J. Wirsing, Heithaus, & Dill, 2011) and Raine Island, Queensland (Hammerschlag, Bell, et al., 2016) have demonstrated that the sharks are frequently found patrolling areas of higher prey densities. Bull shark and white shark abundance has also been found to be significantly influenced by the presence of sardine runs off South Africa (Dudley & Simpfendorfer, 2006). Drone analysis of white shark activity on the east Australian coast indicated that the presence of schooling bait fish generated faster swim speeds and was one of the primary drivers for white sharks to swim into/beyond the surf zone (Colefax, Kelaher, et al., 2020). Many other species of shark have also been shown to be attracted to pelagic fish assemblages (Letessier et al., 2013). As such, there is ample scientific evidence to suggest that sharks are associated with bait fish aggregations and consequently, avoiding such aggregations could reduce a swimmer's exposure.

3.3.5. Don't swim too far from shore

Swimming close to shore is a guideline provided to the public in two thirds of the assessed locations. Behavioural knowledge of the three large shark species indicated that this guideline may have limited scientific support. White sharks, tiger sharks, and bull sharks are all known to inhabit and use coastal habitats for foraging (Afonso & Hazin, 2015; Carlson et al., 2010; Weng et al., 2007). White sharks on the East Australian coast have been shown to consistently migrate following finfish migrations along the continental shelf, and may even take up temporary residency in shallow waters adjacent to beaches before moving along (Bruce et al., 2006). Multiple studies indicated that white sharks frequently hunt nearshore, particularly in shallow water near seal colonies (Klimley et al., 2001; Kock et al., 2013). Drone footage also indicated that white sharks patrol the coastlines, including the shallows past the surf break (Colefax, Kelaher, et al., 2020). Tiger sharks can spend considerable time in coastal areas (Daly et al., 2018; Heithaus et al., 2009; Meyer et al., 2018) and forage in shallow habitats (Andrzejaczek et al., 2019; Heithaus et al., 2006; Heithaus, Wirsing, Dill, & Heithaus, 2007; A. Wirsing & Heithaus, 2012). Off Hawaii, tiger sharks showed a preference for inshore habitats near highly frequented beaches (Meyer et al., 2018), and in Southern Africa, tiger sharks were strongly associated with coastal habitats (Daly et al., 2018). One study of bull sharks along the Australian southeast coast suggested higher presence in mid-shelf depths and less frequently along the shallow coastline (Lee et al., 2019), providing some support for this guideline. Bull sharks are also widely known to inhabit riverine, estuarine, and coastal habitats throughout their life cycle (Werry, Lee, Otway, Hu, & Sumpton, 2011), and have been responsible for several shark bites in shallow coastal waters around the world (Hazin, Burgess, & Carvalho, 2008; Lippmann, 2018; Taglioni et al., 2019). As shallow coastal waters are vital for primary production, higher density and diversity of planktivorous fish draw in larger predators, which in turn attracts large sharks (Dicken et al., 2016; Heithaus et al., 2007; Matich & Heithaus, 2014; Weltz et al., 2013). Historic patterns of shark bites in shallow coastal waters (West, 2011) also suggest that swimming close to shore may not effectively mitigate negative shark-human interactions. Such empirical and historical evidence suggests that this guideline has moderate alignment with scientific evidence, and its limited applicability across all scenarios suggests that it may be more appropriately framed as a Generic Safety Precaution. The closer to shore an individual is located, the faster the individual can receive medical attention should a negative interaction occur. Furthermore, in shallow water a swimmer may be able to stand up and thus, take action to fend off an aggressive sharks (G. Cliff *pers comm*). This guideline would also benefit from more specificity regarding what constitutes “far” or change to use depth instead of distance from shore.

3.3.6. Don't swim at dawn or dusk

Avoiding activities such as swimming or surfing at dawn or dusk was a guideline provided by two thirds of the assessed regions. This guideline is based on the common assumption that sharks take advantage of low light conditions at dusk and dawn to hunt, as they are less likely to be detected by diurnal and nocturnal prey (Papastamatiou et al., 2015). However, this is not an accurate assumption for all shark species, and there was varying evidence for this assumption reported in the literature. For tiger sharks, a study from Brazil indicated that they were recorded twice as frequently near the surface (0-10 m) at night than during the day, (Afonso & Hazin, 2015). However, a similar study off the Bahamas found no significant diel differences in tiger shark habitat use in monitored areas (Hammerschlag et al., 2017), suggesting that tiger shark behaviours may differ depending on their habitat. White sharks along the East Australian coast have been found to increase swimming speed, a behaviour associated with foraging, in the morning and afternoons (Colefax, Kelaher, et al., 2020), but diving deep at dawn/dusk, consistent with dolphin hunting tactics (Bruce et al., 2006). Meanwhile, studies from the Eastern Pacific (Weng et al., 2007) and South Africa (Klimley et al., 2001) showed that white sharks had no strong diel movement or hunting patterns. However, another study showed that white sharks' hunting frequency and success at dawn in South Africa significantly increased during nights with low lunar illumination (Fallows, Fallows, & Hammerschlag, 2016), which may be indicative of a predatory advantage at lower light conditions (Martin & Hammerschlag, 2012). As for bull sharks, studies off Florida have shown different diel movements between individuals (Ortega, Heupel, Beynen, & Motta, 2009), while in Southern Africa they are more resident in the day, and then have a broader habitat use at night (Daly, Smale, Cowley, & Froneman, 2014). In Sydney Harbour, satellite tagged bull sharks did not show significant changes during crepuscular periods but did exhibit strong diel patterns in habitat use with sharks using shallower water at night, potentially linked to prey distribution (Smoothey et al., 2019). These studies do not provide consistent evidence that sharks prefer to hunt at dawn and duck, a finding that is consistent with a recent review of crepuscular and diel elasmobranch behaviour (Hammerschlag et al., 2016). What is clear is that crepuscular foraging is not ubiquitous for all shark species and may vary depending on prey and the specific location. Additionally, shark bites have historically occurred at all hours of the day (Global Shark Attack File, 2016). Overall, this guideline was assessed as having arelatively low scientific basis due to the variability in hunting behaviours within and between species. Nevertheless, human eyesight is not as well adjusted to low light, making it more difficult to notice sharks in the vicinity or to spot a person in trouble in the water and this guideline could perhaps be reframed as a general safety precaution.

3.3.7. Tell on-duty lifeguard if you spot a shark

This shark safety guideline was provided in two thirds of the assessed regions; however, it does not specifically mitigate an individual's in or on-water risk. By notifying an on-duty lifeguard about the potential risk for recreational users in the water, swimmers and surfers may vacate the waters which thus reduces risk. However, since this is an action based on human caution and not on shark behaviour or ecology, it was not assessed against scientific evidence and is better suited as a Generic Safety Precaution in relation to shark safety.

3.3.8. Don't swim with bleeding cuts/wounds or while menstruating

Avoiding swimming with open wounds or while bleeding or menstruating was found as a guideline provided in half of the assessed regions. This guideline is based on the principle that sharks have an acute sense of smell and can detect trace amounts of blood in the water from a distance (Bres, 1993), which if used in conjunction with lateral lines and mechanosensory can aid in locating prey (Gardiner, 2012). However, empirical evidence testing the attractiveness of human blood to sharks is relatively infrequent or outdated. Tester (1963) studied the behavioural response of different shark species to various types of blood, which indicated that sharks could sense human blood at 0.1-0.01 ppm concentration in the water. Mixed behavioural responses to the blood stimuli were found, and sharks showed more aggressive responses to "fresh" blood than "stale" blood. Yet, the concentration of blood necessary to attract a large shark is high (Gardiner & Atema, 2010) and unlikely reached from superficial wounds. More recent studies on shark olfaction found that large coastal sharks, like white sharks and tiger sharks, have enlarged olfactory bulbs, indicative that their olfactory system may be more sensitive than other species (Yopak et al., 2015). Such sensitivity likely assists in migration and for location of prey. Yet the sensitivity and attraction of large sharks to human blood has not been adequately tested beyond suggestive biological and historical evidence. As human blood and fish blood are intrinsically different in terms of amino acid and hemoglobin content (Larsen & Snieszko, 1961), it is likely that differences in shark attraction to different types of blood may be found. This was particularly evident in an analysis of shark bites during tourism provisioning dives, which found that human blood did not seem to further aggravate or affect shark behaviour, even if the wounded person remained in the water (Maillaud & Van Grevelynghe, 2005). Chemoreception studies on reef sharks indicated that they are more attracted to fish amino acids than blood (Klimley, 2013). However, since mature white sharks and tiger sharks prey on marine mammals and reptiles with different blood and amino acid content, they may respond differently than piscivorous sharks (Meredith & Kajiura, 2010). Overall, research on shark sensory biology is underrepresented in current scientific literature and more information is needed to better understand the effect of human blood and fluids on shark behaviour.

3.3.9. Avoid swimming between sandbars or near steep drop offs

Avoiding swimming near steep drop offs and between sandbars was a guideline provided in half of the assessed regions. Steep drop offs and edge habitats can be primary shark patrolling grounds, as they potentially allow sharks to access a broader range of both pelagic and shallow-dwelling prey (Heithaus et al., 2006). Tiger sharks in Australia have been found to show a preference for such edge habitats (M. R. Heithaus & Dill, 2006; A. Wirsing & Heithaus, 2012; A. J. Wirsing et al., 2011) and steep drop offs (Hammerschlag, Bell, et al., 2016). In Hawaii, tiger sharks have shown to occur more frequently at depths between 50 and 100 m along the reef slope (Meyer et al., 2018), and have been found to use deep channels to travel between steep coastal environments and shallow seamounts (Holland, Wetherbee, Lowe, & Meyer, 1999). Off South Africa, white sharks have shown preferential seal hunting in waters with the most abrupt changes in depth (Martin et al., 2009). White sharks along the east Australian coast have shown distinct and often predictable patterns of nearshore movement beyond the surf break (Colefax, Kelaher, et al., 2020), with similar but less predictable patterns near the surf for bull sharks and tiger sharks (Colefax, Butcher, Pagendam, & Kelaher, 2020). Off Brazil, historic bull shark bites have been predominantly in areas near channels and steep drop offs (Hazin et al., 2008). Given the scientific evidence available on shark movement and behaviour, this shark safety guideline is generally supported by scientific evidence and there were several studies suggesting this may apply for some large shark species. However, it may not be applicable to all coastal shark species.

3.3.10. Follow local signage and flags

This shark safety guideline was provided in half of the assessed locations. However, it does not specifically mitigate an individuals in or on water risk of a shark bite. While signage *may* inform an individual of a specific behaviour for specific risks, in itself, it is not a behavior an individual would use in or on the water. Additionally, local signage and flag colors are meant to notify the public about potential hazards in the water, prohibited activities, and overall beach conditions (Surf Life Saving Australia, 2020). These are important to follow, as the ocean is an unpredictable environment that is reassessed daily at beaches where lifesavers are present. As such, this guideline was categorised as a *Generic Safety Precaution* and was not assessed for its alignment with the scientific literature.

3.4 Guidelines with highest alignment with scientific evidence

This review also identified that some shark safety guidelines appeared to have relatively high alignment with scientific evidence and are described in more detail here. These ten guidelines had high rankings in at least two of the three categories assessed but were evenly split between the categories of **environmental cues/conditions** and **practices/ responses**. The scientific evidence supporting these guidelines was based mainly on studies of shark behaviour and ecology (Table 3). The only guideline found to overlap with the top ten most common guidelines was "avoid areas with signs of baitfish or feeding activity."

These guidelines tended to focus on responses that aligned with knowledge about the three target shark species' predator-prey interactions in areas of high shark activity (e.g. Colefax, Kelaher, Pagendam, & Butcher, 2020; Heithaus & Dill, 2006; Heithaus, Wirsing, & Dill, 2012; Matich & Heithaus, 2014; Mitchell, McLean, & Collin, 2019; A. Wirsing & Heithaus, 2012). These patterns of overlap between shark abundance and predatory behaviour and prey density are also well documented for other species (e.g. Barnett and Semmens 2012). Humans entering situations and scenarios which are associated with known stimuli for shark feeding and predatory behaviour, or actions that can provoke aggressive responses by sharks, increase their risks of negative shark-human interactions.

Table 5: Top ten guidelines assessed with high scientific support for reducing risk of negative shark-human interactions. Colors indicate the assessment applied using the criteria in Table 2.

Guideline	# of Regions	Category	Ranking		
			Likelihood of Accuracy	Level of Supporting Evidence	Level of Congruity
Avoid areas with signs of baitfish or feeding activity	5	Environmental Cue			
Do not rely on dolphin sightings to indicate shark absence	2	Environmental Cue			
Do not feed/touch/harass/provoke sharks	2	Practices/ Responses			
Avoid areas where seals are present	1	Environmental Cue			
Avoid swimming in canals or river/harbour mouths	2	Environmental Cue			
Do not swim where fish are being cleaned	2	Practices/ Responses			
Do not attach speared fish to your body	2	Practices/ Responses			
Avoid swimming near recreational or commercial fishers	2	Practices/ Responses			
Do not swim or surf near shark nets	1	Practices/ Responses			
Consider using a personal deterrent	1	Practices/ Responses			

The scientific evidence supporting these guidelines is described in more detail below.

3.4.1. Avoid areas with signs of bait fish or feeding activity

Large sharks can be associated with schools of baitfish and their migration patterns (Barnett and Semmens 2012; Letessier et al., 2013). Bait fish activity is indicative of high productivity, which is often associated with predation by higher trophic levels (Carlson, Ribera, Conrath, Heupel, & Burgess, 2010), so areas with higher prey density likely increase the potential for large predator presence (Matich & Heithaus, 2014). Drone footage analysis of white sharks in Australia has also corroborated this advice (Colefax, Kelaher, et al., 2020). Overall, there is good evidence showing the overlap between sharks and their prey, indicating strong support for guidelines suggesting that swimmers avoid bait fish and feeding activity.

3.4.2. Avoid areas used by recreational or commercial fishers

Large shark depredation on commercial and recreational fishing catches are frequently reported (Gilman et al., 2008), with global depredation rates ranging between 0.9–26% (Mitchell et al., 2018). Positive reinforcement may be learnt by large sharks from successful interactions with fishing lines or discarded catch, which provide sharks with low energetic-cost prey (Guttridge et al., 2009). Even in instances void of depredation, sharks have been shown to frequently investigate baited lines (Mitchell et al., 2019).

3.4.3. Do not rely on dolphin sightings to indicate shark absence

Large sharks are known to compete with (Heithaus, 2001) and prey on dolphins (Barnett et al., 2010; Cockcraft et al., 1988; Curtis et al., 2012; Mollomo, 1998). In some areas, dolphin presence may actually correlate with shark presence, as sharks may be attracted to dolphins as both prey and as indicators of other potential prey (Heithaus, 2001). While some studies have indicated that dolphins actively avoid areas of higher prey density when large sharks are present, dolphins do not exclusively exhibit shark avoidance behaviour (Heithaus & Dill, 2006).

3.4.4. Avoid areas where seals are present

In many areas around the world, mature white sharks prey on seals (Laroche, Kock, Dill, & Oosthuizen, 2008) and sea lions (Shaughnessy, Berris, & Dennis, 2007). However, there is some debate around the importance of seals in white shark diets throughout their life cycles, as their diets may be more reliant on fish than previously thought (Grainger, Peddemors, Raubenheimer, & Machovsky-Capuska, 2020). Even so, seal abundance in some areas has often been correlated with white shark abundance (Skomal et al., 2012) and predation on seals showed a strong relationship to seal colony density (Martin et al., 2009).

3.4.5. Do not feed, touch, harass, or provoke sharks

Touching or harassing a shark may elicit various responses from individual sharks: Where many may flee, others may get agitated and respond aggressively (Bres, 1993; Curtis et al., 2012; Martin, 2007). Feeding sharks in uncontrolled environments as opposed to managed tourism activities (see Healy, Hill *et al.* 2020) becomes problematic as the shark's behaviour changes to feeding behaviour (Clua & Torrente, 2015). This behaviour change can prove dangerous to individuals in the water and may result in negative shark-human interactions (Maillaud & Van Grevelynghe, 2005).

3.4.6. Avoid swimming in canals or river/harbour mouths

Many large sharks show increased activity around river or harbour mouths, as the areas are highly productive and provide reduced visibility for stealth hunting tactics of high density prey (Heupel & Simpfendorfer, 2008). In particular, bull sharks are known to inhabit turbid estuarine habitats given their physiological tolerance to lower saline environments (Carlson et al., 2010; Werry et al., 2018; Yates, Heupel, Tobin, & Simpfendorfer, 2015). The use of river mouths and associated habitats by large bull sharks (Heithaus, Delius, Wirsing, & Dunphy-Daly, 2009; McCord & Lamberth, 2009) and white sharks (Colefax et al., 2020) has been recorded around the world.

3.4.7. Do not swim where fish are being cleaned

Waters where fish are being cleaned effectively serve as chummed or berleyed areas. Berleying is a tactic used to draw in particular species to enhance fishing or tourism operations (Techera & Klein, 2013). It is generally accepted that fish remains have a large potential to attract sharks to the general vicinity (Brunnschweiler & Barnett, 2013; Laroche et al., 2007) and to affect their behaviours (Bruce & Bradford, 2011).

3.4.8. Do not attach speared fish to your body

Having a speared fish attached on your person while spearfishing is likely to attract large sharks searching for struggling prey (Bres, 1993). Historical evidence of shark bites on spear fishers also supports this guideline and suggests that it is unwise (Global Shark Attack File, 2016; Maillaud & Van Grevelynghe, 2005). Spearfishing has been found to largely increase the risk of negative shark-human interactions (Lippmann, 2018), and there is anecdotal evidence that the sounds of a speargun being fired can attract sharks (A. Barnett *pers comm*), and studies in the 1960s and 1970s have shown that the sounds of struggling prey can attract sharks struggling prey (Myrberg, Ha, Walewski, & Banbury, 1972; Nelson & Gruber, 1963). While there is little empirical evidence specifically assessing the attractiveness of a speared fish to sharks compared to shark depredation and high attraction rates on fishing lines (Mitchell et al., 2018), speared fish likely have a similar effect.

3.4.9. Do not swim or surf near shark nets

Sharks are known to respond to and be attracted to the sounds of struggling prey (Myrberg, Ha, Walewski, & Banbury, 1972; Nelson & Gruber, 1963). Shark nets are placed with the intention of capturing large "dangerous" sharks (McPhee et al., 2019), but the catch of any marine animals may attract large sharks to these gears (Wetherbee et al., 1994). Increased shark activity near nets has the potential to increase negative shark-human interactions, so avoiding waters close to the nets is recommended. The potential for swimmer entanglement within the net is also of concern, so this guideline may be better reframed as a *Generic Safety Precaution*.

3.4.10. Consider using a personal deterrent

Various shark deterrents have been empirically tested in recent years to assess their efficacy (Huveneers et al., 2018; Kempster et al., 2016; Ryan et al., 2017). Analysis of such deterrents indicated that several of these may not be widely successful at deterring large shark species, however the personal deterrent SharkShield®, which emits a localized electric field, has been proven effective against white sharks (Huveneers et al., 2013, 2018; Kempster et al., 2016) and moderately effective for bull sharks (Gauthier et al., 2020). Yet, reduction of the risk of a negative interaction with a shark may be context specific and vary depending on the shark's initial motivation or investigation strategy (Huveneers et al., 2013). While they may not be perfectly effective every single time, certain personal deterrents may prove useful to reduce the risk of negative shark-human interactions (Huveneers et al., 2018), and it is crucial to inform the public which devices may be more effective.

4. Discussion: scientific consensus and alignment between shark safety guidelines

The large variation in supporting evidence prompts the question as to why some guidelines are promoted if they have limited alignment with scientific evidence and/or consensus. Exploring the historical basis for these guidelines is beyond the scope of this review, however some may in part have arisen from historical generalisations and narratives based on assumptions of what drives aggressive shark behaviour (Coppleson & Goadby, 1988). Nevertheless, scientific knowledge of shark behaviour and ecology has greatly increased in the last decade and this review suggests that there are opportunities to update and/or reframe shark safety guidance so that it better reflects current knowledge.

This review also found that the lesser presented 26 guidelines that were only used in certain locations generally ranked higher in terms of alignment with, and congruence of scientific evidence. This may in part be due to higher specificity of the advice tailored towards individual locations. This finding also highlights the potential value of developing more context specific guidelines that specifically consider the species and locality. This process could also allow for the inclusion of local ecological knowledge, as there are ongoing studies in Australia (New South Wales, Whitsundays in QLD) aiming to better understand shark occurrence and behaviour patterns (e.g. Barnett, Abrantes *et al.* 2019) which could provide high resolution information on factors that affect beachgoer risk. There would also be an opportunity to engage with local communities to develop co-owned and co-managed safety approaches. Local engagement in the process could in-turn, help develop trust and promote community compliance with guidelines (Viteri & Chávez, 2007).

The review distinguished between guidelines that aim to reduce the likelihood of shark bite by **modifying specific beachgoer practices and responses** and guidelines that aim to minimise exposure to shark bite risks based on **environmental cues and conditions** that may indicate greater likelihood of shark presence. A third category was also identified: *generic safety guidelines* that may or may not relate to shark bite risk but are likely to increase swimmer safety. Reframing shark safety messaging to distinguish between these types of guidelines could help communities better understand the rationale underpinning these guidelines, which in turn could improve community trust and willingness to comply.

4.1 Future research

Given the poor congruence and sometimes contradicting evidence for most of the shark safety guidelines, future research on factors affecting shark bite risks should focus on commonly used guidelines that have low scientific support and/or consensus to assess their applicability. One primary direction should be to focus on assessing crepuscular behaviour of shark species commonly associated with shark bites, as that is such a widely used guideline. Few studies directly assessed crepuscular shark activity, but rather focused more on diel patterns. Therefore, it may prove productive to evaluate dusk and dawn activity more closely in future research to better assess the shark specific utility of this guideline, especially given that many beach users visit the beach during these times. Future research should also examine the potential efficacy of guidelines, that is, how much risk would be mitigated by adhering to a specific guideline.

More research is also needed on the sensory biology of sharks, and the environmental cues that and stimuli that initiate feeding behaviours. For example, the notion that sharks have an affinity for human blood is widely assumed but lacks current empirical evidence. Consequently, it is also recommended that further studies be undertaken to explore shark sensory biology, such as the affinity for blood which appears to be a widely held public belief.

Given the variability indicated between species and locations, more social research should be conducted to better explore local knowledge about shark behaviours, how beachgoers perceive risks, and how these perceptions influence behaviour. Information about how beachgoers perceive risk and modify their behaviours (e.g. McClean, van Putten *et al.* 2020) can then be used in conjunction with scientific information to design more effective shark safety awareness campaigns, and develop guidelines that have community support. Furthermore, an updated and in-depth examination of Australian and global shark bite records could provide a current account of patterns in shark bites such as time of day, depths, and activities occurring when the incident occurred.

Lastly, new guidelines could also be explored and developed based on empirical evidence about shark behaviour and ecology that is widely missing from global shark safety guidelines. Environmental conditions have proved significant in affecting the risk of shark bites (Ryan et al., 2019), which could create opportunities to provide further guidance about conditions that may increase risks of shark bites. For example, many studies have shown significant influence of water temperature on shark distribution for various species (Lee et al., 2019; Ortega et al., 2009; Payne et al., 2018; Yates et al., 2015), but no guidelines have been presented that consider this information. Similarly, lunar phase has been shown to affect different shark species' behaviour and coastal distribution (Weltz et al., 2013; Wintner & Kerwath, 2018), findings that are corroborated with anecdotal information received from commercial fishers in Queensland (Chin, pers. comm). Similarly, there are many tagging studies that have revealed spatio-temporal variations in shark abundance along global coastlines. However, this information has not been included in shark safety advice.

5. Conclusions

The findings of this review suggest that existing shark safety guidelines tend to be more generic advice that while potentially increasing swimmer safety, have poor alignment with specific scientific knowledge about shark ecology and behaviour. Many of the widely promoted guidelines were broad generalisations that should be assessed to determine if they should be reframed as generic advice. Similarly, some guidelines require further research to assess their applicability. In contrast, guidelines that were tailored to more specific locations and/or scenarios had greater alignment with scientific information. Specifically, some of the guidelines based on environmental cues and conditions, like those associated with prey availability, appear to have the highest scientific basis, and thus could be the most effective credible predictors of shark presence in an area. However, it should also be noted that the link between the number of sharks in an area and the frequency of shark bites remains unclear and highly contested. Meanwhile, more general guidelines that may not directly relate to sharks should not be ignored. However, thought should be given as to whether these should be reframed as general safety precautions and/or good beachgoer practices to clarify the basis and rationale behind these guidelines for communities.

This review argues there is an opportunity to revise and reframe guidelines to ensure empirically-based information is available to the public in efforts to provide shark safety advice. There is also the opportunity to co-develop higher resolution and more specific shark safety advice within different parts of Queensland. While revised guidelines may not assure a halt in negative shark-human interactions – shark bites are relatively unpredictable events – clearer explanations of the rationale behind these guidelines (e.g. identifying that a guideline applies to a specific species or location) could help to build community trust and compliance in the advice provided. Overall, it is recommended that shark safety advice should be explicit about the rationale and basis for the advice, and as locally-specific as possible to best inform the public of potential risks in their area. Doing so may help an individual more adequately make their own risk assessment and modify their behaviours when partaking in marine recreational activities for the sake of both their own and others' safety.

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