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A global review of elasmobranch tourism activities, management and risk

Teleah Joy Healy [a,*], Nicholas James Hill [b], Adam Barnett [a], Andrew Chin [a]

[a] Centre for Sustainable Fisheries and Aquaculture & College of Science and Engineering, James Cook University, Townsville, Queensland, Australia
[b] Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 49, Hobart, Tasmania, 7001, Australia

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ABSTRACT

Elasmobranch tourism is a rapidly expanding global industry. While this industry can provide community and conservation benefits, it presents risks to target species, environments and humans when inappropriately managed. To ensure appropriate management is implemented, there is a need to identify the prevalence of elasmobranch tourism globally, the types of operations occurring and the controls used to mitigate risk. This study undertook a global literature review to develop an industry activity typology and establish the types of management controls present across elasmobranch tourism operations. In total, 151 unique species-activity-location conditions were identified, with four broad activity types categorised: diving, snorkelling, provisioning and cage diving. Spanning 42 countries and 49 different species, 32% of conditions identified lacked evidence of management. Further to this, many of the prevailing management controls in place (e.g. MPAs, shark sanctuaries, protected species status), were secondary in nature, having not been designed or implemented to manage elasmobranch tourism explicitly. Therefore, avoidable risks are likely widespread throughout the industry. Encouragingly, the application of activity specific management controls is likely to be effective at reducing risks across activity types. The theoretical case studies and management tools investigated herein provide operators and industry managers with guidance on how to reduce risk and safeguard industry benefits. With the elasmobranch tourism industry likely to continue expanding, it is important that appropriate management and regulatory frameworks are in place so that marine wildlife tourism can continue in a beneficial and sustainable manner.

1. Introduction

Wildlife tourism is a rapidly expanding industry globally [1]. When conducted responsibly, wildlife tourism can provide benefits that range from economic development [2,3] to strengthened conservation awareness and action [4–6]. However, when management is absent or sub-optimal, wildlife tourism can also negatively impact focal [7–9] and non-focal species [10,11], ecosystems [12–15] and communities [16–18]. Effective risk mitigation strategies must be identified to ensure that the positive benefits of wildlife tourism outweigh the potential negative impacts [9,19,20].

Management controls currently applied to wildlife tourism can be largely divided into either formal or voluntary arrangements [4,21-28]. Formal regulations refer to the government implementation of mandatory management controls such as permits and licences, policies (e.g. management plans, codes of conduct and protected species status) and spatial restrictions (e.g. Marine Protected Areas (MPAs) and zoning plans) [21,28–31]. When applied accordingly, licensing can create a controlled market where licensed operators receive a form of property rights over a particular resource [21,32]. Operators become liable and can be penalized where non-compliance occurs [21,33]. Formal regulations are considered the most effective mechanism in providing environmental protection and societal benefits where a single resource is shared amongst numerous stakeholders (e.g. the Great Barrier Reef Marine Park) [21]. While strict, this form of management must also be flexible enough to allow incorporation of improved practices and understanding of effects [21,32,34].

Voluntary management involves the informal implementation of management controls by operators wishing to protect their individual needs where formal regulation is lacking, or where pro-active management that incorporates conservation goals can attract increased popularity [29,34,35]. Voluntary management controls such as codes of conduct and eco certification, can both fill the void of and complement formal management controls [29,34–36]. For example, voluntary codes of conduct that outline operator (e.g. vessel approach speeds, noise and distance) and participant behaviour (e.g. approach distance, flash

* Corresponding author. 11A Quamby Avenue, Sandy Bay, Tasmania, 7005, Australia.
E-mail address: Teleah.healy@gmail.com (T.J. Healy).

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photography, no touching) are a prominent management tool for cetacean watching [29,35–37]. However, the quality and detail of the management controls self-imposed by operators are variable and unlikely to appropriately manage industries in isolation [35,38].

Elasmobranch tourism has experienced burgeoning growth globally [8,39]. Recent estimates suggest that 590, 000 tourists participate in a variety of elasmobranch viewing activities, expending $US314 million annually across 20 different countries [2]. Whilst elasmobranch tourism can include activities such as fishing, diving or viewing elasmobranchs from a boat, the definition of elasmobranch tourism herein encompasses any tourist activity that focuses on the in-water observation of sharks and/or rays in their natural habitat.

Elasmobranch tourism can provide an opportunity for tourism to act as an alternate source of income, and may replace income traditionally gained from commercial and artisanal fishing [4]. In French Polynesia, the individual economic value of sicklefin lemon sharks (*Negaprion acutidens*) as a tourism commodity far outweighs the one-off payment fishers traditionally received for their harvest [40,41]. The economic potential of elasmobranch tourism is particularly evident for communities within developing countries such as Palau, where elasmobranch tourism contributed over $US18 million to the economy and accounted for 8% of the nation's Gross Domestic Product (GDP) in 2012 [41]. The successful transition from fisheries to tourism revenue requires appropriate management controls to lessen the potential for exploitive and unsafe practices [42,43].

When poorly managed, the potential economic and social benefits of elasmobranch tourism can be overshadowed by ecological consequences [10,44–46]. To date research on the topic has mainly focused on identifying tourism driven changes in elasmobranch behaviour (e.g. avoidance behaviour of whale sharks in Mexico [47]; altered movement and spatial patterns of southern stingrays in Cayman Islands [48]), species composition and abundance (e.g. bull sharks in Fiji [49]; Galapagos, sandbar and tiger sharks in Hawaii [50]), and physiology (e.g. haematological changes in stingrays in Cayman Islands [51]); increased metabolic rate of whitetip reef sharks in Australia [46]). Often the effects of these changes are poorly understood, variable between species and locations, and dependent on operator methods and the regulations in place. Such variability is highlighted by the contrasting effects from provisioning elasmobranchs at two of the best-studied tourism sites. Tourism activities at Grand Cayman Island are very intensive and have resulted in a number of long-term negative behavioural and physiological effects on the stingray species, *Hypanus americanus* [48,51]. In contrast, the strict self-imposed management actions and limited number of shark feeding operators at Shark Reef in Fiji, has resulted in minimal long-term effects on bull shark (*Carcharhinus leucas*) behaviour and diet, and is likely to have had no effects on health and fitness [45,52,53].

The growth of the elasmobranch tourism industry has been rapid, outpacing efforts to implement appropriate management in many instances, leaving target species and participants of elasmobranch tourism activities at risk of unsafe and unsustainable practices (e.g. shark tourism in The Bahamas [54]). To further complicate matters, the variability and lack of information available on industry practices has hindered the development of informed decision making processes [8,38]. Operators are often not required or incentivised to record fundamental information on operation types, behaviour and the types of risk mitigation practices in place. Without this information, managers are unable to develop appropriate management controls. Greater emphasis on understanding industry practices and effects is required to aid the development of evidence-based management controls that mitigate the potential for adverse impacts.

To begin addressing this challenge, this study aims to: (i) collate and synthesise information on the scale and diversity of elasmobranch tourism operations and create a typology of common activity types; (ii) review prevailing management controls; and (iii) apply a standard risk assessment framework to a number of theoretical activity specific case

Table 1
Elasmobranch tourism species, activity (S: snorkel, D: dive, P: provision, C: cage dive) and location conditions identified in this study. See supplementary material B.1 for list of operators (websites) retrieved and C.1 for attributes of each activity type.

Species	Activities				Locations
	S	D	P	C	
Sharks					
Alopias pelagicus (pelagic thresher)		✓			Philippines
Carcharhinus brevipinna (spinner)	✓				South Africa
Carcharodon carcharias (white)				✓	Australia, Mexico, New Zealand, South Africa, United States of America (U.S.A.)
Carcharhinus falciformis (silky)		✓			U.S.A.
Carcharhinus galapagensis (Galapagos)				✓	U.S.A.
Carcharhinus leucas (bull)		✓			Costa Rica, Mauritius
			✓		Cuba, Fiji, Mexico, Mozambique, South Africa
Carcharhinus limbatus (blacktip)	✓		✓	✓	South Africa
		✓			U.S.A., Belize
Carcharhinus longimanus (oceanic whitetip)		✓			Egypt
			✓		The Bahamas
Cetorhinus maximus (basking)	✓				Scotland, England, Isle of Man
Carcharhinus obscurus (dusky)		✓			U.S.A.
Carcharhinus perezi (Caribbean reef)		✓			Turks and Caicos
			✓		Netherland Antilles, The Bahamas, Honduras
Carcharhinus plumbeus (sandbar)				✓	U.S.A.
Carcharias taurus (sand tiger)		✓			Australia, Lebanon, South Africa, U.S.A.
Cephaloscyllium umbratile (blotchy swellshark)		✓			Japan
Notorynchus cepedianus (broadnose sevengill)		✓			U.S.A., South Africa
Heterodontus japonicus (Japanese bullhead)		✓			Japan
Hexanchus griseus (bluntnose sixgill)		✓			Canada
Galeocerdo cuvier (tiger)			✓		Fiji, South Africa, The Bahamas
				✓	Australia, The Bahamas
Ginglymostoma cirratum (nurse)		✓			Turks and Caicos, U.S.A.
			✓		Belize, The Bahamas
Isurus oxyrinchus (shortfin mako)			✓		Portugal, South Africa, U.S.A.
				✓	U.S.A.
Lamna ditropis (salmon)			✓		U.S.A.
Negaprion acutidens (sicklefin lemon)			✓		Fiji
Negaprion brevirostris (lemon)		✓			U.S.A.
			✓		Fiji, French Polynesia
Nebrius ferrugineus (tawny nurse)			✓		Fiji
Prionace glauca (blue)			✓		U.S.A., South Africa, Portugal
				✓	U.S.A.
Rhincodon typus (whale)	✓				Australia, Belize, Honduras, Kenya, Madagascar, Mexico, Mozambique, Papua New Guinea (P.N.G), Philippines, South Africa, Tanzania, Thailand, Maldives, Republic of Djibouti, Seychelles, Indonesia
		✓			Belize, Ecuador, Japan, Thailand, Maldives, Seychelles, Indonesia
			✓		Philippines
Sphyrna lewini (scallop)		✓			Costa Rica, Ecuador, Japan, Malaysia, Mexico, Mozambique, P.N.G, South Africa, Sudan, Maldives, U.S.A.
		✓			P.N.G., The Bahamas

(*continued on next page*)

Table 1 (*continued*)

Species	Activities				Locations
	S	D	P	C	
Sphyrna mokarran (great)			✓		The Bahamas, French Polynesia
Squatina squatina (angelsharks)		✓			Spain
Triakis scyllium (banded houndshark)		✓			Japan
Triakis semifasciata (leopard)	✓				U.S.A.
		✓			Australia, Thailand
Reef ***spp.*** * *Carcharhinus tilstoni* (Australian blacktip), *Carcharhinus melanopterus* (blacktip reef), *Carcharhinus amblyrhynchos* (grey reef), *Carcharhinus albimarginatus* (silvertip), *Triaenodon obesus* (whitetip reef)		✓			Belize, Egypt, Kenya, Mauritius, Micronesia, P.N.G, Solomon Islands, South Africa, Sudan, Turks and Caicos
			✓		Australia, Fiji, French Polynesia, The Bahamas
Rays					
Manta alfredi (reef manta)	✓				Australia, Maldives, U.S.A.
		✓			Australia, Mozambique, Philippines, Maldives, U.S.A.
Manta birostris (giant manta)	✓				Indonesia, P.N.G
		✓			Ecuador, Indonesia, Japan, Kenya, Mexico, Micronesia, Mozambique, Thailand
Pristis pectinata (smalltooth sawfish)		✓			The Bahamas
Mobula ***spp.***	✓				Portugal
Mobula mobular (giant devil ray), *Mobula tarpacana* (sicklefin devil ray), *Mobula japonica* (spinetail devil ray).		✓			Portugal, Costa Rica
Ray ***spp.*** * *Dasyatis pastinaca* (common stingray), *Himantura fai* (pink whipray), *Dasyatis centroura* (roughtail stingray), *Dasyatis brevicaudata* (short-tail stingray), *Dasyastis Americana* (southern stingray), *Aetobatus narinari* (spotted eagle ray), *Dasyatis thetidis* (thorntail stingray)			✓		Antigua, Australia, Belize, Cayman Islands, French Polynesia, New Zealand, Spain

*The distribution of species listed may not occur across all identified nations.

studies to test the effectiveness of existing management strategies to mitigate industry hazards. Activity specific management recommendations are also included as an illustration of the potential mechanisms to consider when developing controls to mitigate identified risks within elasmobranch tourism. The outcomes of this study will aid managers in developing context appropriate risk mitigation controls for elasmobranch tourism operators, maximising the potential for conservation and associated benefits.

2. Methods

2.1. Identifying industry activities and practices

Research was conducted from August 2015 to November 2017 using a four-stage process. First, peer reviewed literature and broader web searches were carried out in search engines Google Scholar and Web of Science. Given the focus on in-water tourism activities, search terms used were derived from a combination of the terms 'shark', 'stingray' or 'manta', paired with one of several expressions of in-water tourism that included 'dive', 'snorkel', 'encounter', 'swim with', 'feeding' and 'tourism'. Additional elasmobranch tourism activities identified from those referenced in the literature were also included where relevant.

Retrieved websites were only included in the study if they met the following criteria: (1) the operators homepage featured an image of an elasmobranch and/or in text marketing of an in-water tourist activity to encounter elasmobranchs in their natural environment (i.e. wild) and/or; (2) the operator endorsed a specific elasmobranch tourism experience (i.e. tour/experience). Operations offering chance encounters with elasmobranchs were omitted from the study as, elasmobranch encounters were not the primary objective of the tourism activity. Information gathered from relevant sources included:

1. Target species
2. Operation location
3. Key attributes of the operation (i.e. activity description)
4. Presence of management controls, both formal and informal
5. Any identified environmental or social effects and/or potential hazards
6. Additional management controls to mitigate effects and hazards (i.e. those not widely applied or emerging).

Operators offering multiple activities (i.e. snorkelling and diving) or encounters featuring numerous target species were recorded separately, as the purpose of the study is not to quantify the number of operators, but to quantify the diversity of species and locations present within the industry.

The descriptive terms used to describe or market elasmobranch tourism operations were thematically categorised to create a typology. This approach uses the identification of recurring 'key' terms and attributes from one elasmobranch tourism operation and recognises those same marketing terms and attributes in another even though the wording may not be identical.

Unique species-location-activity specific 'conditions' (i.e. codes) were derived from the operator information (i.e. species, location) and typology (i.e. activity type). Duplicate species-location-activity conditions were screened and removed before analysis.

2.2. Identification of management controls

Management controls and policies present were retrieved from government, non-governmental organisations, peer-reviewed literature and operator websites. Keyword search terms were formulated using a combination of the species-location-activity conditions and the terms; 'management', 'licensing', 'policy', 'permit', 'code of conduct', 'zoning plan', 'shark sanctuary', 'marine protected area', 'legislation', 'protected species' and 'conservation actions'.

To minimise complexity, five management control types were defined and recorded for each species-location-activity combination:

1. Protected status: Species listed are protected by federal, state, or local legislation, within the respective country. International legislation/policies (i.e. International Union for Conservation of Nature) were not considered.
2. Operator licensing: Legal permissions (i.e. permit or license) required by an operator to conduct a commercial tourism operation. Inherent within these permissions, it is assumed that operators meet the minimum management and reporting conditions (i.e. be appropriately qualified for the activity and possess necessary maritime licenses), as set by the governing body.
3. Marine Protected Areas (MPAs) and zoning plans: Applies where the government or state has created MPAs or defined activity zones that

Table 2
Consequence criteria used to assess the level of impact associated with elasmobranch tourism activities (adapted from AS/NZS ISO 31000:2009 Risk Management – Principles and Guidelines).

Consequence	Target Species	Ecological		Human	
		Broad scale	Local Scale	Health and safety	Social
Catastrophic	Impact is, or would be, extremely serious and possibly irreversible to a sensitive target species population at a local level. Broader scale population recovery periods of greater than 10 years likely.	Impact is clearly affecting, or would clearly affect, the nature of the ecosystem over a wide area. Recovery periods greater than 20 years likely.	Impact is, or would be, extremely serious and possibly irreversible to a sensitive population or community. Condition of an affected part of the ecosystem possible irretrievably compromised.	Impact is, or would be, significant, causing death or permanent disablement.	–
Major	Impact is, or would be, extremely serious to target species at a local scale. Broader scale population impacts apparent. Recovery periods of five to 10 years likely.	Impact is, or would be, significant at a wider scale. Recovery periods of 10–20 years likely.	Impact is, or would be, significant to a sensitive population or community at a local level. Recover periods of 10–20 years likely.	Impact is, or would be, serious; causing serious bodily injury or illness that requires tertiary medical treatment. Recovery period of months to years likely.	Impact is, or would be, very serious in severely failing to meet the person's expectations and satisfaction of the service provided. Wider reputational damage (i.e. beyond the individual). Would not reuse or recommend business to others.
Moderate	Impact is, or would be, serious to target species at a local level. Recovery period of one to five years likely.	Impact is, or would be, serious, affecting some component of the ecosystem. Recovery periods of five to 10 years.	Impact is, or would be, serious and possible irreversible over a small area. Recovery periods of five to 10 years likely.	Impact is, or would, cause injury or illness that requires tertiary medical treatment. Recovery period of weeks to months likely.	Impact is, or would be, clearly affecting the person's expectations and satisfaction of the service provided. Minor reputational damage (i.e. negative reviews). Unlikely to reuse or recommend business (i.e. loss of business).
Minor	Impact is, or would be, clearly affect to target species at a local level. Recovery periods of weeks to months.	Impact is, or would be, evident but not to the extent that it impairs the overall condition of the broader scale ecosystem or community populations. Recovery periods one to five years likely.	Impact is, or would be, evident but not to the extent that it impairs the overall condition of the local ecosystem or community populations. Recovery periods one to five years likely.	Impact is, or would, cause injury or illness requiring first aid only. Does not require tertiary medical treatment. Recovery time of days to weeks likely.	Impact is, or would be, evident only to the extent that it has little impact on the persons expectations and satisfaction of the service provided. No reputational damage. Likely to reuse or recommend service.
Insignificant	No impact; or if impact is present, then only to the extent that it has no discernible effect on the overall condition of the target species. Recovery periods of hours to weeks likely.	No impact; or if impact is present, then only to the extent that it has no discernible effect on the overall condition of the ecosystem. Recovery periods of minutes to hours likely.	No impact; or if impact is present, then only to the extent that it has no discernible effect on the overall condition of the ecosystem. Recovery periods of minutes to hours likely.	No impact; or impact is present, than only to the extent that it has no discernible effect on the person impacted (no treatment required).	No impact; of if the impact is present then only to the extent that it has no discernible impact on the persons expectations and satisfaction of the service provided. No reputational damage. Likely to reuse or recommend service.

restrict or permit certain recreational and commercial activities but does not include shark sanctuaries.

4. Shark sanctuaries: Geographically defined area that prohibits shark fishing.
5. Code of conduct: Species-specific set of guidelines that stipulate how vessels and participants will interact with the target species. Both formal (i.e. regulated) and informal (i.e. voluntary) codes of conduct were recorded.

Presence of these management controls was recorded for each species-activity-location combination. This information was then collated, and percentage calculations performed to estimate the prevalence of different management controls, at both a global and activity specific scales.

2.3. Risk assessment

Four theoretical elasmobranch tourism case studies were developed from the literature as examples to be evaluated under this risk assessment framework (see supp. material A.1). Case studies developed covered each activity type and assessed a range of common elasmobranch species. Case studies assessed included:

1. SCUBA diving with reef sharks
2. Snorkelling with whale sharks
3. Bull shark provisioning dive
4. Cage diving with white sharks

The risk calculations for each case study were repeated twice: 1) in the absence of any management control (i.e. inherent risk) and, 2) after the implementation of management controls (i.e. residual risk).

The risk assessment methods applied herein were based on the Australian and New Zealand Standard Risk Assessment (AS/NZS ISO 31000:2009) [55], which were adapted for use in the context of elasmobranch tourism. This process involves scoring three components:

- Hazard – Hazards identified from the literature were collated for each elasmobranch tourism industry type. Identified hazards included effects to the target species, ecological impacts and human safety.
- Consequence – Consequence of each hazard is ranked from insignificant to catastrophic across the three criteria identified under hazards: target species, ecological and human (Table 1).
- Likelihood – The likelihood of each hazard occurring was ranked from rare to certain (Table 2).

Using a risk assessment matrix, the application of the consequence and likelihood criteria was used to estimate the risk rating of each hazard (Fig. 1, Tables 1 and 2). Risk ratings were given a value of 1 (low risk) to 4 (very high risk). The risk rating for each activity-specific hazard was first assessed in isolation, than an average calculated to determine the level of risk for each elasmobranch tourism activity type. Hazards where evidence of impact could not be found for each particular activity type were left blank.

As the purpose of the theoretical case studies is to demonstrate the process and utility of risk assessments, the calculations, while informed by the literature, were conducted and reviewed by the authors of this paper. Given the uncertainty of some industry impacts and likely under-reporting of elasmobranch tourism incidents (e.g. bites, 'troublesome behaviour' [38]), the precautionary principal was applied [56]. Calculations are therefore likely to have a bias to overestimating risk but this was deemed appropriate, as doing so reduces the likelihood of assigning a lower risk rating that might actually be present for the given context.

Finally, it is important to emphasize that these theoretical risk assessments are not suitable replacements for the context specific risks associated with the diversity of elasmobranch tourism activity conditions occurring globally. Instead, industry managers and operators are strongly advised to examine the risk assessment process within the context of their operations. Additional steps within the broader risk management process (i.e. risk communication and consultation; risk monitoring and review) are beyond the scope of this research but need be applied for risk mitigation to be successful (refer to AS/NZS ISO 31000:2009 for details).

3. Results

3.1. Scale and diversity

This research identified 151 unique elasmobranch tourism conditions, across 42 countries and 49 target species Table 3). Operations were predominately found within the tropical and subtropical regions throughout Africa, Oceania, Asia and the Caribbean. Established elasmobranch tourism activities were also identified in temperate locations such as Canada, England, Scotland, Japan and New Zealand. Elasmobranch tourism operations primarily focused on species that displayed predictable spatial and temporal aggregations, namely: whale sharks (*Rhincodon typus*, 57%), *Reef spp.* (33%) and scalloped hammerhead sharks (*Sphyrna lewini*, 26%). Of the 49 individual species identified, three categories were created for species (*spp.*) commonly grouped under a generic term (i.e. reef shark) or unidentifiable at a species level (i.e. mobula rays). These categories were: *Reef spp., Ray spp.* and *Mobula spp.*

Consequence					
Catastrophic	High	High	Very High	Very High	Very High
Major	Medium	Medium	High	High	Very High
Moderate	Low	Low	Medium	High	High
Minor	Low	Low	Low	Medium	Medium
Insignificant	Low	Low	Low	Low	Low
	Rare	Unlikely	Possible	Likely	Almost Certain
	Likelihood				

Fig. 1. Risk assessment matrix that applies the mathematical product of consequence and likelihood, to calculate a risk value for each identified hazard (i.e. low = 1, medium = 2, high = 3, very high = 4).

3.2. Elasmobranch tourism activities

Elasmobranch tourism is highly diverse with a number of attributes identified that describe and differentiate industry activities (supp. material C.1). The thematic assessment of these activity attributes revealed four broad elasmobranch tourism activity types, by prevalence these were: (1) diving, (2) snorkelling, (3) provisioning and (4) cage diving. Each activity type is described below:

1. Diving: Tourist activities that utilise SCUBA equipment to view elasmobranchs. Activity does not involve the use of attractants or a shark cage.
2. Snorkelling: Tourist activities involving the use of snorkel equipment to view elasmobranchs. Species will typically occur in close proximity to the surface. Activity does not involve use of attractants or a shark cage.
3. Provisioning: Snorkelling, diving or swimming tourist activities that use an attractant, bait or food rewards for the purpose of aggregating and/or positively reinforcing elasmobranchs to remain in close proximity. Activity occurs outside of or in the absence of a shark cage.
4. Cage Diving: Tourist activities that involve the underwater observation of elasmobranchs from a cage. Typically attractants such as berley and baits are used to attract target species towards the cage. Activity is not restricted to SCUBA diving and may occur on snorkel or through the use of a surface line.

Diving was both the most widely available (n = 28 countries) and species diverse (n = 25 species) elasmobranch tourism activity (Table 3). Snorkelling was also popular, with tours available in 50% of countries. Both activities showed a preference for species that display relatively predictable temporal movements. In particular, scalloped hammerhead shark and whale shark interactions were identified in 39% of diving and 76% of snorkelling nations, respectively. Provisioning activities were identified across 18 countries and involved 16 different species; the most widely encountered being *Ray spp.* (33%). Cage diving was the least prevalent activity with operations established across 6 countries. This activity was also the least species diverse (n = 8) with 83% of countries offering dedicated white shark (*Carcharodon carcharias*) encounters.

Table 3
Likelihood criteria used to assess the likelihood (i.e. probability) of the predicted level of consequence actually occurring (adapted from AS/NZS ISO 31000:2009 Risk Management – Principles and Guidelines).

Likelihood	Guiding measure	Guiding frequency
Almost certain	There is a 95% chance the risk will occur	Risk expected to occur in most circumstances, more or less continuously throughout the year.
Likely	There is a 75% chance the risk will occur	Risk not expected to be continuous but to occur most of the time (i.e. multiple times through out the year).
Possible	There is a 50% chance the risk will occur	Risk not expected to occur annually but expected to occur at some time within a two to five year period.
Unlikely	There is a 20% chance the risk will occur	Risk not expected to occur within a two to five year period but expected to occur every five to 10 years.
Rare	There is a 5% chance the risk will occur	Risk not expected to occur within only under exceptional circumstances. Periods of every 10 years and upwards.

3.3. Management controls

Evidence of management was retrieved for 68% of the 151 unique species-location-activity conditions identified in this study (supp. material Table C.1-4). Management controls ranged from unrestricted access (no management), to complex regulatory frameworks involving legal policies (e.g. protected species status, species/activity specific management plans), operator licensing (e.g. commercial charter), permits (i.e. tourism and/or activity specific) and partnerships (i.e. government, NGO, industry and researchers).

Of the 103 managed conditions, 47% only had a single management control in place (e.g. shark sanctuary or protected species status). Shark sanctuaries occurred in 40%, protected species 25%, operator licensing 15%, MPAs 15% and codes of conduct 6% of conditions where a single management control was identified (supp. material Table D1-4). External regulatory mechanisms including protected species status and presence of MPAs/zoning plans were most prevalent, occurring in 49% and 47% of all managed conditions. Codes of conduct and operator licensing were present across 39% and 36% of managed conditions, respectively. However, the implementation of codes of conduct was largely self-regulated with 78% of identified codes of conduct voluntarily applied by operators. The least prevalent management control was shark sanctuaries, which were present in 29% of managed conditions. Management evidence was not present for a number of locations and it remains unclear if control mechanisms are lacking or if other factors are contributing to the absence of this information (e.g. language, unwritten law).

Of the four elasmobranch tourism activity types, cage diving was found to be the most regulated activity with all countries enforcing licencing conditions (supp. material Table C.1). Robust multi-strategy management controls including codes of conduct, spatial zoning, and berley restrictions were identified for white shark specific cage dive operations in Australia, New Zealand and South Africa. Management was evident for 86% of snorkelling and 74% of provisioning nations (supp. material Table C.2, C.3). Protected species status and codes of conduct were widely prevalent management tools for snorkelling (75% and 67%, respectively), while MPAs/zoning plans were the most common management tool for provisioning activities (59%, supp. material Table C.2, C.3). Codes of conduct were also moderately prevalent for provisioning elasmobranchs; however, 92% were voluntarily (supp. material Table C.3). The most common elasmobranch tourism activity, diving, reported the least uptake of management with 48% of the 71 conditions lacking evidence of management (supp. material Table C.4).

3.4. Risk assessment

A total of 18 hazards relevant to the conduct of an elasmobranch tourism activity were identified which included risks to the target species (e.g. physiology, behaviour), associated ecosystems (e.g. ecological) and humans (e.g. safety, social) (Fig. 2, supp. material Table D.1). Provisioning was the only activity specific case study to contain all 18 hazards. Cage diving followed with 16 hazards and, diving and snorkelling each had 12. Additional hazards present for provisioning and cage diving activities involved the use of attractants and included: 'local-scale ecological impacts', 'shifts in local- and broad-scale population dynamics', 'conditioning' and, 'competitive interference' (Fig. 2, supp. material Table D.1).

When unmanaged, both provisioning ($\overline{x} = 2.9$) and cage diving ($\overline{x} = 2.5$) reported high mean risk scores. For provisioning, very high risk hazards included 'staff competence' and 'participant competence', with 72% of all hazards listed assessed as high risk. For cage diving, only 'equipment failure' had a very high risk score, with a further 50% of hazards assessed as high risk. Diving and snorkelling had medium risk scores, however 33% of hazards still presented as high risk such as 'emergency response factors', 'equipment failure' and 'tourist crowding'.

Presence of management reduced risk across all activity types (Fig. 2, supp. material Table E.1-4). Overall, the mean risk score of provisioning

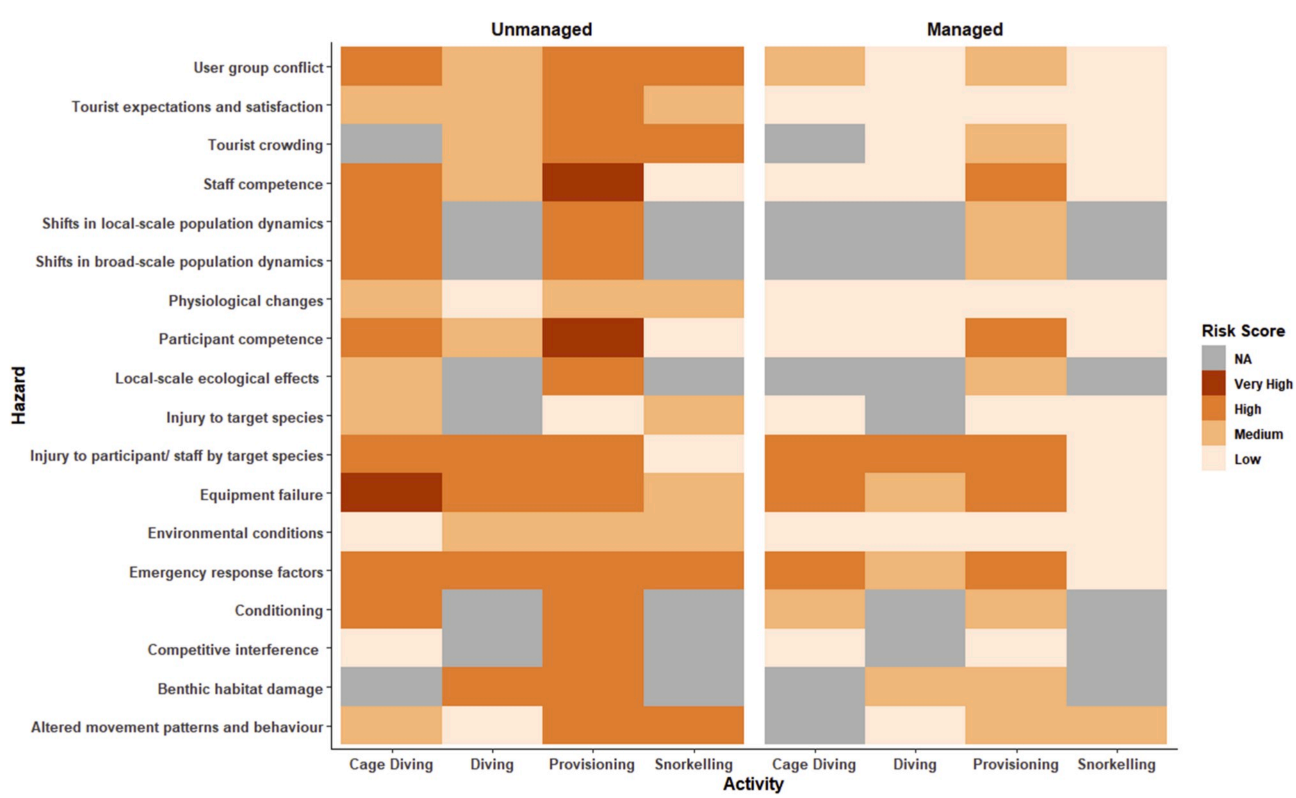

Fig. 2. Risk assessment scores for each elasmobranch tourism activity-hazard combination under unmanaged (i.e. inherent) and managed (i.e. residual) management conditions.

declined from high ($\bar{x} = 2.9$) to medium risk ($\bar{x} = 1.9$), cage diving from high ($\bar{x} = 2.5$) to low ($\bar{x} = 1.4$) and, diving and snorkeling from medium ($\bar{x} = 2.2$, $\bar{x} = 2.1$ respectively) to low risk ($\bar{x} = 1.4$, $\bar{x} = 1.1$ respectively). Provisioning hazards that remained high risk included staff competence, participant competence, and injury to participant/staff by target species. For cage diving and divine, the risk of 'Injury to participant/staff by target species' was also high. The most frequently applied management controls to reduce risk included activity specific zoning plans, licenses/permits, codes of conduct, appropriate accreditation and training (for both participants and staff) and the implementation of safety policies and procedures (supp. material Table F.1).

4. Discussion

The findings of this study show that management of elasmobranch tourism globally is often absent or ad-hoc in its design and implementation. Of the 151 unique species-location-activity combinations identified, 32% lacked evidence of management and a further 47% had only a single management control in place. Further to this, many of the management controls in place (e.g. MPAs, shark sanctuaries, protected species status), are secondary in nature, having not been designed or implemented to manage elasmobranch tourism explicitly. Considering the inherent risk elasmobranch tourism activities pose to target species [44,47,57,58], the surrounding environment [14,59–61], and the humans taking part [62,63], and the rate at which this industry is growing [2,13,64,65], development and implementation of improved management is needed.

With the broad-scale absence of deliberate elasmobranch tourism management, avoidable risk is likely to be widespread. A number of potential hazards are shared across activity types including: human disturbance (e.g. interference causing altered movement patterns), human competence (e.g. staff and participants training and experience), safety policies and social factors (e.g. participant expectations and stakeholder conflict). In many instances, these risks are not mitigated against, despite the range of management controls available. The example risk assessments applied herein indicate that irrespective of the activity attributes and potential hazards, the application of management controls, particularly those that limit the frequency and duration of human disturbance (e.g. tourism permits/licenses, zoning plans, codes of conduct), are likely able to reduce common risks present across activity types. Provisioning elasmobranchs, the activity deemed to have the most risk associated with it, can be effectively undertaken if appropriate management is in place (e.g. bull shark feeding at Shark Reef Reserve, Fiji) [4,52,53].

At present, many of the management controls in place to regulate elasmobranch tourism are secondary in nature (e.g. protected species sanctions, MPAs, shark sanctuaries). These controls, which have primarily been implemented as fisheries or conservation management tools (e.g. Ref. [26,66,67]), have limited ability to reduce activity specific hazards present throughout elasmobranch tourism [68]. For example, shark sanctuaries were the only management strategy present for 40% of the elasmobranch tourism conditions that applied a single management control. Given that the purpose of a shark sanctuary is to prohibit shark fishing, this management control has little to no effect on mitigating tourism impacts [22]. These indirect management controls are limited in scope when applied to elasmobranch tourism activities as they do not provide specific guidance to manage the practices that influence hazards and effects, and often neglect the value of elasmobranch tourism activities, including potential economic, societal and conservation benefits [6,8,41].

Encouragingly, there are examples of effective, activity and species specific management controls in place that can be used for guidance [24,31,32,69]. The iconic nature of whale and white sharks has meant that these species have attracted a disproportionate amount of public interest that has driven greater research and management attention [6,39]. For example, studies investigating the effects of cage diving tourism on the behaviour [38,70,71], movement [39,70,72] and physiology [73] of white sharks have contributed to the development of species and tourism specific management policies [24,74]. Inherent in the risk management process, ongoing research not only continues to improve understanding of cage diving tourism interactions with white shark tourism (e.g. target species, associated ecosystem), but also contributes to monitoring and evaluation.

Another form of management that is becoming increasingly prevalent is voluntary or self-management [35,38]. For example, codes of conduct were present for 35% of managed conditions, of which most were voluntarily [38]. This likely reflects the inherent lack of regulatory enforcement, and the need for operators to be seen to be active and aware of responsible practices for their clientele [38]. However, the quality, detail and compliance of codes of conduct varies widely suggesting that self-regulation alone may be inadequate [38,75]. Government intervention would be more appropriate in an area where there are a number of operators sharing access to a particular site, aggregation or most importantly, where sensitive environments or species are involved.

While we have endeavoured to provide a comprehensive overview of global elasmobranch tourism management, it is almost certain that many tourism operators and associated documentation will have been undetected due to the dynamic growth of the industry and limitations of the search terms, and reliance on English language references. Resolving this complex network of tourism businesses and managing authorities is beyond the scope of this review. We emphasize that management strategies should be developed cooperatively by industry, communities, managers, and other stakeholders on a case-by-case basis. We also stress that the impacts of shark tourism needs to be placed within the context of the full risk spectrum facing elasmobranchs. Globally, fishing and habitat loss are the major drivers of elasmobranch declines and the potential impacts of tourism should be considered alongside other threats when allocating resources and prioritising conservation efforts [76].

This study has created a typology of common activity types and associated hazards, allowing for the streamlined development of activity specific management. The risk assessment undertaken identified a range of hazards and potential management controls that can minimise the risks present across different elasmobranch tourism activities. These tools, together with the risk assessment case studies, provide a foundation from which operators, managers, and policy makers can develop informed management decisions that will help to maximise the potential conservation and economic benefits of elasmobranch tourism.

Declaration of competing interest

None.

CRediT authorship contribution statement

Teleah Joy Healy: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Nicholas James Hill:** Validation, Resources, Writing - original draft, Writing - review & editing, Visualization. **Adam Barnett:** Validation, Resources, Writing - review & editing. **Andrew Chin:** Conceptualization, Methodology, Validation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision.

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Appendix A. Supplementary data

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