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Are marine reserves and non-consumptive activities compatible? A global analysis of marine reserve regulations

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ABSTRACT

Marine reserves are places where wildlife and habitats are protected from extractive and depositional uses of the sea. Although considered to be the pinnacle in marine conservation, many permit non-consumptive activities with little or no regulation. This paper examines the potential impacts of 16 non-consumptive activities including scuba diving, sailing, scientific research and motor boating, and how they might compromise the conservation objectives of marine reserves. Examination of 91 marine reserves from 36 countries found little agreement or consistency in what non-consumptive activities are permitted in marine reserves and how they are regulated. The two most common activities allowed without regulation were swimming (mentioned in 80% of marine reserves and allowed in 63% of these) and kayaking (mentioned in 85%, allowed in 53%). Scuba diving was mentioned in 91% and allowed without regulation in 41%. A risk score for the likely level of threat to wildlife and/or habitats that each activity could produce was then assigned based on effects reported in the literature. The risk analysis suggests that motor boating and activities which include or require it have a high potential to negatively impact wildlife and habitats if inadequately managed. Hence protection against extractive or depositional activities alone is insufficient to secure the high standard of protection usually assumed in marine reserves. For this to be achieved activities typically considered as benign must receive appropriate management, especially with increasing recreational use.

1. Introduction

Marine habitats and species are affected by a multitude of human impacts including fishing, pollution, habitat destruction and introduced species, among others [1]. As a result, in many places species have declined in abundance, diversity has decreased and habitat complexity has been reduced [2]. Marine reserves, sites that are protected from extractive and depositional activities, are increasingly seen as a way to help address many of these impacts [3,4] and have been shown to effectively protect biodiversity and enable ecosystem recovery [5–7]. Currently, marine reserves protect just a fraction of the world's oceans, calculated at 0.1% in 2007 [8], whilst wider, multiple-use marine protected areas cover 1.6% of the global ocean surface [9]. Yet despite their limited extent, marine reserves are widely seen as the 'pinnacle of protection' for marine life and as a way to provide resilience against future stressors such as climate change [10].

Marine reserves have been variously defined [11,12], but their usual aim is to prohibit extractive or depositional activities and to maintain or recover the ecosystem(s) to a natural state in which marine life can thrive and natural processes dominate ecosystem dynamics [13–15]. Ballantine [11] states that the aim of marine reserves is to "maintain (or restore) the intrinsic biodiversity and natural processes [within the marine environment]. No fishing is permitted or any removal of material. No dredging, dumping, construction or any other direct disturbance is allowed". Lubchenco et al. [16] defined fully protected marine reserves as "areas of the ocean completely protected from all extractive and destructive activities". In New Zealand marine reserves are "specified areas of the sea and foreshore that are managed to preserve them in their natural state as the habitat of marine life for scientific study [...]. Within a marine reserve, all marine life is protected and fishing and the removal or disturbance of any living or non-living marine resource is prohibited, except as necessary for permitted monitoring or research. This includes dredging, dumping or discharging any matter or building structures" [13]. In Australia the term 'marine reserve' is used to define "an area of sea especially dedicated to the protection and maintenance of biological diversity and of natural and associated cultural resources, and managed through legal or other effective means" [14]. In Wales in the United Kingdom, the establishment of

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marine reserves which will be known as 'highly protected marine conservation zones' is currently underway. These are defined as "sites that are protected from extraction and deposition of living and non-living resources, and all other damaging or disturbing activities" [17]. Damaging activities are defined as "acts that potentially result in permanent or temporary physical harm or injury to species, or cause permanent or temporary alteration to natural features within the marine environment". Disturbing activities are defined as "acts that interfere with the normal functioning of populations beyond the natural variability of the ecosystem" [17].

Some marine reserve equivalents, such as IUCN Strict Nature Reserves and Wilderness Areas, and the Australian Great Barrier Reef Marine Park Preservation Zones restrict public access. However, the scope for creating such 'no use' zones is extremely limited, so it has generally been taken for granted that non-consumptive activities be allowed (i.e. activities which do not result in extraction of a resource or deposition of materials). Many marine reserves positively encourage such uses, which are often recreational or educational, and so many marine reserves play an important economic and social role. However, this creates a potential problem in that, unless suitably managed, some non-consumptive activities have the potential to cause significant environmental damage, especially in marine reserves with high visitation and/or highly sensitive features [18]. To determine which non-consumptive activities are compatible with the goal of complete ecosystem protection a better understanding of the potential impacts of non-consumptive activities is required. This would allow marine managers to make decisions as to whether marine reserves that allow certain non-consumptive uses are protected enough to deliver demanding conservation objectives.

This study examines what non-consumptive activities or uses are prohibited or allowed within marine reserves or their equivalents from across the world, and how permitted activities are regulated. Risks to wildlife associated with the various managed or unmanaged activities are assessed across a spectrum of intensity of use, and management options to improve compatibility with full ecosystem protection are discussed.

2. Methods

2.1. Non-consumptive activities in marine reserves

Ninety-one marine reserves or their equivalent (i.e. protected areas offering a high degree of protection from exploitation) from thirty-six countries were examined to investigate management approaches in use. Sixteen activities were identified as commonly receiving or being in need of management: catch and release angling, diving, snorkelling, swimming, boat mooring, anchoring, scientific research, jet skiing, kayaking, wildlife observation, motorised boating, water skiing, surfing, wind surfing, sailing and kite surfing. For all marine reserves examined each activity was then categorised as being either prohibited, allowed or regulated. If a marine reserve did not mention an activity, it was not included in the analysis for that activity. Doing this required the following assumptions: catch and release fishing was assumed to be prohibited alongside other forms of fishing unless it was explicitly stated as allowed, while boating was assumed to be allowed in cases where it was not specifically mentioned, but where anchoring and mooring were listed as permitted or regulated activities. Where boating or watercraft activities were mentioned but specific activities were not detailed, it was assumed that this included sailing, motor boating and kayaking. If regulations included a category termed 'motorised watersports' then jet skiing and water skiing were assumed to be covered by that unless stated otherwise. The assumption that the non-mention of an activity in a marine reserve management plan means that the activity does not occur is a critical one. However, we attempted to address this problem by using the best available information from the Internet and available literature, in addition to making the assumptions detailed above for each of the marine reserves analysed.

For the sixteen activities, 'high' and 'low' impact versions of each were then assessed to consider their potential to negatively impact upon species or habitats within the marine reserve and to provide a range of intensity of impact for each activity (see Table 1). In classifying an activity as high impact it was assumed that no-take regulations would be adhered to but that otherwise it was unregulated. Classification of high and low impact versions of activities were based on effects reported in the scientific literature (see Supplementary Materials A for literature reviewed) and personal knowledge.

2.2. Risk analysis

A risk analysis was performed to identify the level of threat for high and low impact versions of each activity. This was done by assessing each activity against the six criteria listed in Table 2. The criteria were established by review of the scientific literature to determine the range of potential impacts likely to occur as a result of recreational activities [18,19], [Supplementary Materials A]. A risk score for each activity was attributed under each criterion and an overall risk score calculated by averaging across the six criteria. Averaging was performed so that impacts of different activities could be compared and ranked.

To evaluate whether the riskier activities identified were typically excluded from marine reserves, the average level of risk for each activity was plotted against the percentage of marine reserves sampled that either allowed or regulated that activity.

3. Results

3.1. Activities in marine reserves

A summary of the 91 marine reserves reviewed and which of the 16 non-consumptive activities they prohibit, regulate or allow is provided in Appendix A and summarised in Fig. 1. The most commonly prohibited activity (in addition to those extractive or depositional activities mentioned earlier as being fundamental to marine reserve status, such as fishing or dumping, and excluding reserves where the activity was not mentioned) was catch and release angling which was prohibited in 98% of marine reserves and permitted with regulation in 2%. Kite surfing and jet skiing were also commonly prohibited in marine reserves where these activities were mentioned, the figures being 63% and 61% respectively. However, kite surfing was only mentioned in 18% of marine reserves and jet skiing in 34%.

Activities most commonly permitted with regulation were scientific research (68%), mooring (62%), wildlife observation (52%) and motorised boating (51%). Mention of management for these was made in 82%, 49%, 32% and 92% of marine reserves sampled. Activities most commonly permitted without apparent regulation were swimming (63%), snorkelling (58%), kayaking (53%) and surfing (52%). These activities were mentioned in 80%, 81%, 85% and 27% of marine reserves sampled.

3.2. Risk assessment of non-consumptive uses

Table 3 shows results of the risk analysis. By considering each activity as either high or low impact the risk scores presented

Table 1
Conditions under which different activities are considered to be "High" or "Low" impact. Asterisk indicates that potential damage could also arise from boat use, which is described under the section on motorised boating. References from which examples of high and low impact versions of activities have been drawn can be found in Supplementary Materials[a].

Activity	Description
Motor boating	High impact: Activity occurs within a restricted area at high intensity of use. Inappropriate behaviour occurs, for example users drive faster than designated speed limits, or if no limits are set, users drive at speeds that are likely to reduce ability of animals to avoid boats or to cause damage to soft-sediment habitats from wash/wake effects. Noise is generated to the extent that it may impact upon feeding or breeding activities of wildlife present or may inhibit communication among animals. Low impact: Users keep to any speed regulations and remain at distances from wildlife and/or habitats that either meet with regulations or do not obviously impact upon animals' normal behaviour. If no speed limits are defined, users keep to a speed that either minimises wash or reduces the chances of disturbing or colliding with wildlife in the immediate area. Noise is kept to a minimum.
Catch and release angling*	High impact: Fish caught are not handled with care and not returned promptly to the sea. Low impact: As for low impact motor boating or shore-based angling at low intensity that avoids wildlife sensitive areas. Care is taken to minimise fish injury i.e. use of barbless hooks and artificial lures, minimising air exposure and angling time.
Scuba diving and snorkelling*	High impact: Divers disregard any codes of conduct and underwater, direct contact with marine organisms and considerable sediment disturbance occurs. Low impact: As for low impact motor boating or careful access from shore. Sensitive areas are avoided and codes of conduct followed.
Wildlife observation*	High impact: Observers disregard any codes of conduct, are noisy, and crowd or harass wildlife. Low impact: Sensitive areas are avoided and codes of conduct followed.
Anchoring	High impact: Anchoring allowed without restriction, or anchor zones contain fragile habitat. High intensity of use occurs, and use of over-long chains increases impacts. Low impact: Designated anchoring zones in areas of mobile sediment are well advertised and marked, levels of use are monitored and controlled and regulations are in force on chain length.
Mooring	High impact: Mooring blocks are not properly fixed and placement occurs among fragile habitats, over-long chain used. Low impact: Appropriate fixings are used for the habitats present and chain buoyed to lift from bottom, levels of use monitored and controlled.
Scientific research*	High impact: Destructive sampling permitted and high intensity of use occurs. Research is performed in fragile habitats/sensitive breeding areas without adequate precautions and no monitoring of use is undertaken. Low impact: Opposite of high impact attributes.
Non-motorised watersports, personal watercraft and swimming.	High impact: High intensity of use, presence of intertidal/subtidal habitats that are vulnerable to trampling, scouring or erosion. Lack of demarcated access points and code of conduct signs. Presence of populations of megafauna, birds or breeding populations. Low impact: Low intensity of use among habitats that are robust to trampling, scouring or erosion. Marked access points and codes of conduct in place. Vulnerable marine wildlife populations rarely present or not dependent upon area for resting, feeding or breeding activities.

[a] It is recognised that high and low intensities of use will differ depending upon the nature of the habitats and species present within the marine reserve, as well as the stated objective of the marine reserve. Hence these categories are not defined precisely and will be subject to interpretation depending upon habitats and species present.

bracket both the upper and lower extremes of possible risk that an activity might pose, depending on how it is conducted. Scores for activities ranged between a low of 0.3 and a high of 3.7. The ranking of activities in this way makes intuitive sense, with low impact variants of most activities in the bottom half of scores and high impact variants in the top half. On the basis of the risk assessment, 'low impact' versions of swimming (risk score 0.3), surfing (risk score 0.3), wildlife observation (risk score 0.5), kayaking (risk score 0.5), scientific research (risk score 0.8), wind surfing (risk score 0.8), kite surfing (risk score 0.8) and sailing (risk score 0.8) were the activities least likely to cause environmental impact to marine reserves. By contrast, high impact versions of commonly permitted activities such as scuba diving (risk score 3.5), snorkelling (risk score 3.5) and motor boating (risk score 3.3), involving reckless and inappropriate use of boats, brought them up to the risk levels of activities more commonly associated with high threat to wildlife, i.e. jet skiing (risk score 3.7) and water skiing (risk score 3.7).

Fig. 2 plots risk scores for activities against the degree that each activity was allowed to take place in the marine reserves examined without any apparent regulation. Jet skiing and water skiing are high risk-scoring activities that, as noted above, were generally excluded or regulated within marine reserves but many other activities requiring potentially risky boat access were commonly allowed. Clearly these activities have the potential to cause serious problems for habitats and/or wildlife if not managed appropriately.

4. Discussion

It is generally recognised that a purpose of marine reserves in addition to wildlife and habitat protection is to provide places for recreation and inspiration [16,20]. Consequently advocates have been quick to point out that exclusion of extractive and depositional uses does not mean that marine reserves are off limits to people [16]. Indeed, as this study confirmed, most marine reserves embrace a wide variety of non-consumptive uses. For many it is a key part of their business plan as user fees generate a significant fraction of their operating budget [21,22]. However, the risk analysis also revealed that many non-consumptive activities that are typically considered to be benign carry significant risks to habitats and species within protected areas. Thereby allowing certain non-consumptive activities to continue may jeopardise the stated goals of marine reserves, i.e. that of complete ecosystem protection to achieve recovery to a quasi-unimpacted state. The potential problems can be particularly severe in highly popular and/or very sensitive marine reserves and poorly managed activities can cause significant damage [23–25]. As this research showed, marine reserves that protect particularly sensitive conservation features, such as aggregations of whale sharks (e.g. Gladden Spit, Belize [26]) or manta rays (Hanifaru Reef, Maldives, Guy Stevens, Maldivian Manta Ray Project personal communication) are at heightened risk of harm. However, on the whole the most risky activities (i.e. the high impact versions of most activities) involve use of motorised boats

Table 2
Scoring scheme for criteria against which non-consumptive activities were assessed in the risk analysis. Scores 0 to 4 correspond to a gradient of risk, where 0=no risk and 4=very high risk.

***Criterion* (i): Potential to change animal behaviour**	***Risk score***
Permanent avoidance of important feeding/resting/breeding areas AND/OR Permanent masking of communication and/or echolocation AND/OR Long-term change in parental behaviour	4
Temporary avoidance of important feeding/resting/breeding areas AND/OR Temporary masking of communication and/or echolocation AND/OR Temporary alteration of group cohesion AND/OR Short-term change in parental behaviour	3
Temporarily affects group dynamics of a species AND/OR Short-term change in parental behaviour BUT Does not mask communication or cause an area to be avoided	2
Any disturbance is very temporary with behaviour returning to normal shortly after the activity stops	1
No behavioural change	0
***Criterion* (ii): Potential to cause injury/stress to animals or habitats**	
Severe and long lasting injury or stress i.e. permanent tissue damage, haemorrhages to vital organs, mass stranding events, permanent auditory damage AND/OR Death to individual animals AND/OR Irreversible or long-term degradation to an area of habitat	4
Serious but temporary injury or stress i.e. physiological damage that may be life threatening but can be recovered from over time	3
Moderate and temporary injury or stress i.e. non-life threatening physiological damage or raised stress levels. Limited and reversible degradation to a habitat	2
Slight and temporary injury or stress, i.e. activity is unlikely to cause physiological damage, but high levels of activity may increase levels of stress over time	1
No physiological damage occurs	0
***Criterion* (iii): Likelihood of collision with wildlife**	
As part of activity, vessels frequently move at high speeds (i.e. a speed faster than wildlife present can easily move to avoid) AND in an area where marine megafauna are known to frequent at any time of year	4
As part of activity, vessels frequently move at high speeds AND/OR megafauna known to frequent at certain periods of the year	3
As part of activity, vessels sometimes move at high speeds AND/OR manoeuvrability of vessels in area is limited AND/OR megafauna are present at certain periods of the year	2
Speed of vessel is limited and is able to manoeuvre with ease to avoid obstacles	1
Low speed maintained and megafauna rarely seen in area	0
***Criteria* (iv): Potential to create pollution**	
Pollution includes any of the following: deterioration of water quality; addition of solid waste, wastewater, fuel leaks and exhaust emissions, invasive species, litter and oil spills. The degree of impact is a combination of lethality, area affected and duration of effects. High probability of pollution event due to high number of vessels. Pollutants likely to persist in the environment AND/OR affect a wide area. Pollutants are potentially lethal	4
Moderate to high probability of pollution event. Pollutants likely to persist but only affect a limited area	3
As above, but pollutants unlikely to persist within the environment and only impact upon a limited area	2
Low probably of pollution event, short-term impacts only	1
No pollution effects	0
***Criteria* (v): Potential to cause scouring or erosion damage**	
High likelihood of scouring e.g. shallow waters (standing depth/canoe paddling depth, within reach of outboard engine propwash) or erosion e.g. soft sediment (near-shore activities) AND where vulnerable habitats such as coral or seagrass occur that may not recover quickly upon damage	4
High to moderate likelihood of scouring or erosion e.g. shallow waters occur but the majority of vulnerable habitats present beyond standing/propwash depth OR less vulnerable habitats are present in shallow waters	3
Moderate likelihood of scouring or erosion BUT habitat type robust to low levels of damage	2
Low probability of scouring or erosion OR habitat type robust to low levels of scouring/erosion, short-term impacts only	1
No scouring or erosion effects e.g. deep water	0
***Criteria* (vi): Potential to result in trampling damage or sediment disturbance**	
High likelihood of trampling damage or sediment disturbance e.g. shallow, standing depth waters where vulnerable habitats such as coral or seagrass occur that may not recover quickly upon damage OR easily accessed intertidal populations present	4
High to moderate likelihood of trampling damage or sediment disturbance e.g. shallow waters occur but the majority of vulnerable habitats present beyond standing depth OR less vulnerable habitats present but prolonged sedimentation disturbance may occur	3
Moderate likelihood of trampling BUT habitat type robust to low levels of trampling damage	2
Low probability of trampling OR habitat type robust to low levels of trampling, short-term impacts only	1
No breakage or sediment disturbance e.g. deep water	0

so there are many ways in which the impacts of these activities can be controlled.

This paper shows the vital importance of providing appropriate management for high impact variants of pursuits commonly allowed within marine reserves. For high scoring activities identified by the risk analysis, the section below explores how compatible they are with marine reserve goals, and whether or not mitigation measures such as those listed in Table 4 can help keep impacts to an acceptable level. Further discussion of lower scoring activities is also provided in Supplementary Materials B.

4.1. Implications of permitting high-risk non-consumptive activities within marine reserves

Jet skiing, water skiing, and the high impact variants of scuba diving, snorkelling, motorised boating, scientific research, catch and release angling and wildlife observation activities were ranked as having the highest levels of risk to species and/or habitats within marine reserves. However, with the exception of jet and water skiing, the risks to wildlife and habitats for all these activities could be reduced to low levels (see Fig. 2) with appropriate management

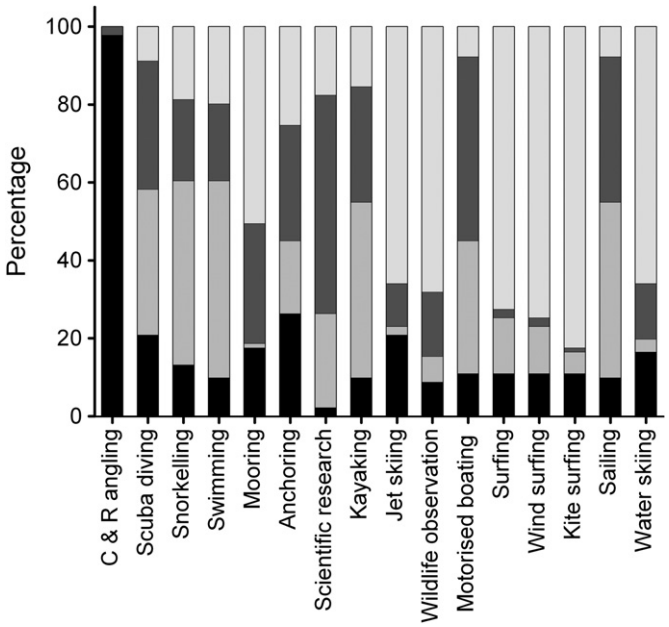

Fig. 1. Management approaches taken by 91 marine reserves for 16 activities that are allowed or allowed with regulation within at least one marine reserve. C&R angling=catch and release angling. Black bars represent percentage of marine reserves that prohibited an activity, medium grey bars represent percentage of marine reserves that allowed an activity, dark grey bars represent percentage that allowed activities with some form of regulation, and light grey bars represent percentage of marine reserves that did not mention an activity.

so that if regulated they could be compatible with the high protection standards of marine reserves.

The nature of jet skiing and water skiing means that participants inevitably travel at high speeds often in shallow water where a variety of sensitive marine habitats and species occur [27]. Consequently these activities pose a serious risk of collision to marine megafauna such as cetaceans, seals, sirenians and turtles [19,28], and to people in the water [29]. Disturbance from jet skis to wildlife in marine reserves has severe consequences for animals' resting, feeding and breeding behaviour, potentially for prolonged periods of time [19,28,30]. Marine life can also be harmed by launch of jet skis from undesignated access points and by the pollution they emit. Burger [31] recommends that jet skis be halted within 100 m of nesting bird colonies, and that their speed be restricted beyond this point. However, given that speed and erratic movement form an inherent part of both jet and water skiing it is unreasonable to assume that either could be compatible with the goals of marine reserves even at low intensities of use. This view is supported by the low percentage of sampled marine reserves that allowed personal watercraft without regulation (Figs. 1 and 2).

It is now widely recognised that scuba diving and snorkelling can detrimentally affect marine life, particularly in sensitive habitats such as coral reefs [19,32–34]. Divers and snorkellers can break corals directly by trampling, touching or accidentally kicking them and can also cause physiological stress through raising sediment [34–36]. Novice divers with poor buoyancy control and underwater photographers can be particularly destructive [37]. Ecological consequences of diving and snorkelling include a reduction in the diversity of corals and structural complexity of reefs [38], which has implications for reef resilience [39,40]. Reduced reef complexity can also affect the number of fish species that a reef can sustain [41]. Divers and snorkellers can also disturb reef creatures by approaching, touching or riding them [42].

The great majority of marine reserves permit recreational scuba diving and snorkelling, although a few include areas that are off limits to diving e.g. Ashmore Reef Reserve and Cartier Reserve in Australia [43]. For tropical coral reefs, several scientists have concluded that the carrying capacity for diving is around 5,000 to 6,000 dives per site per year [23,44,45]. However, higher diving intensities are acknowledged for reefs whose biological and physical characteristics make them particularly resistant to diver impacts or in places where divers are trained to minimise the damage they might cause [46]. After studying diver impacts in New Zealand MPAs, McCrone [47] concluded that strategies for managing divers need to be determined on an individual site basis and that these should be evaluated through scientific monitoring and adaptive management. One promising strategy for monitoring the effects of non-consumptive activities is the 'Limits of Acceptable Change' (LAC) framework, which was initially developed to support management of recreational uses within protected wilderness areas in the USA [48]. This framework defines acceptable environmental conditions for sites based upon measurable standards, for example, proportion of coral damage as a result of a non-consumptive activity [49]. Thus damage caused by permitted activities can be monitored over time and regulations adapted as necessary. This framework could potentially be applied to non-consumptive activities within marine reserves and other marine protected areas, for example, Dinsdale and Harriott [50] showed that the number of overturned corals was a useful indicator of the effect of different intensities of anchoring upon coral reef condition. The need for regular reassessment of permitted diving activity is also underscored by the fact that sensitive species are likely to increase in marine reserves over time due to protection from exploitation. With appropriate regulation, there is wide support in the scientific literature that diving and snorkelling can be compatible activities within marine reserves if carefully conducted, especially as they are also very beneficial in helping raise public awareness of the need for marine conservation, and for generating funding for marine reserves through user fees [22].

Motor boats are commonly allowed in marine reserves and are required for a number of the 16 activities considered in this paper. However these vessels have been shown to cause stress and disturb animals such as marine mammals, reptiles, fish and birds whilst they are resting or feeding [19,51–53]. In addition they pose a particular risk to marine megafauna through collisions [30] and by affecting echolocation and communication [54]. Mothers and their young can be especially susceptible to collisions if their manoeuvrability is limited [55,56]. Vessel groundings or wake produced by motorised boats can cause damage and erosion of sediments and vegetation [57–59], and boats also have the potential to introduce exotic species [19]. Pollution from motor boats may occur through fuel emissions and leaks and leaching of anti-fouling compounds [60,61].

Given the potential of motor boats to cause adverse impacts it seems appropriate that all marine reserves should regulate their speed and number and what activities they are allowed to perform. Basic elements of such regulation include prohibitions on discharge of litter, organic waste or ballast into marine reserves and permitting mooring only on specified buoys and/or anchor sites where damage to the seabed will be minimal. At times and in places where motor boats are particularly disturbing to wildlife, tighter restrictions on speed limits and distances that boats can approach animals can be brought into play. Since strict regulation of motor boats can ensure minimal impact to wildlife and habitats, then generally speaking, under these circumstances motorised boating is a compatible marine reserve activity. However since the potential for motor boats to impinge upon marine reserve goals are considerable, it would be sensible to assess their impacts on a case-by-case basis depending on the habitats and species present.

Non-extractive scientific research is generally allowed in marine reserves as it is essential for monitoring purposes. However, to be compatible with the 'highly protected' ideology it also needs to be of the 'low impact' version described in this paper. Hence research

Table 3
Risk scores for 16 non-consumptive activities allowed within a sample of 91 marine reserves. Each activity is assessed using the six criteria from Table 2 which are then averaged. Scores 0 to 4 correspond to a gradient of risk, where 0=no risk and 4=very high risk.

Activity	(i) Change in behaviour	(ii) Injury, stress	(iii) Collision risk	(iv) Pollution	(v) Scouring, erosion damage	(vi) Trampling	Average risk score
Jet skiing high impact	3[a]	4	4	3	4	4	3.7
Water skiing high impact	3[a]	4	4	3	4	4	3.7
Scuba diving high impact	3[a]	4	4	3	3	4	3.5
Snorkelling high impact	3[a]	4	4	3	3	4	3.5
Motor boating high impact	3[a]	4	4	3	4	2	3.3
Scientific research high impact	3[a]	4	4	3	3	3	3.3
Catch and release high impact	3[a]	4	4	4	3	2	3.3
Wildlife observation high impact	3[a]	4	4	3	3	2	3.2
Anchoring high impact	1	4	1	0	4	4	2.3
Jet skiing low impact	2	2	3	2	3	2	2.3
Sailing high impact	2	2	2	2	3	2	2.2
Water skiing low impact	2	2	3	2	2	2	2.2
Mooring high impact	1	4	0	0	3	2	1.7
Kite surfing high impact	2	2	2	0	2	2	1.7
Wind surfing high impact	2	2	2	0	2	2	1.7
Kayaking high impact	1	2	1	0	2	4	1.7
Catch and release low impact	1	3	1	3	1	0	1.5
Surfing high impact	1	2	1	0	2	3	1.5
Swimming high impact	1	2	0	0	2	4	1.5
Scuba diving low impact	1	1	1	1	2	2	1.3
Snorkelling low impact	1	1	1	1	2	2	1.3
Mooring low impact	1	1	1	0	2	2	1.2
Anchoring low impact	1	1	1	0	2	2	1.2
Motor boating low impact	1	2	1	2	1	0	1.2
Sailing low impact	1	1	1	1	1	0	0.8
Kite surfing low impact	1	1	1	0	1	1	0.8
Wind surfing low impact	1	1	1	0	1	1	0.8
Scientific research low impact	1	1	1	1	0	1	0.8
Kayaking low impact	0	1	0	0	1	1	0.5
Wildlife observation low impact	1	0	1	0	0	1	0.5
Surfing low impact	0	0	0	0	1	1	0.3
Swimming low impact	0	0	0	0	1	1	0.3

[a] Under extreme circumstances this score could be 4.

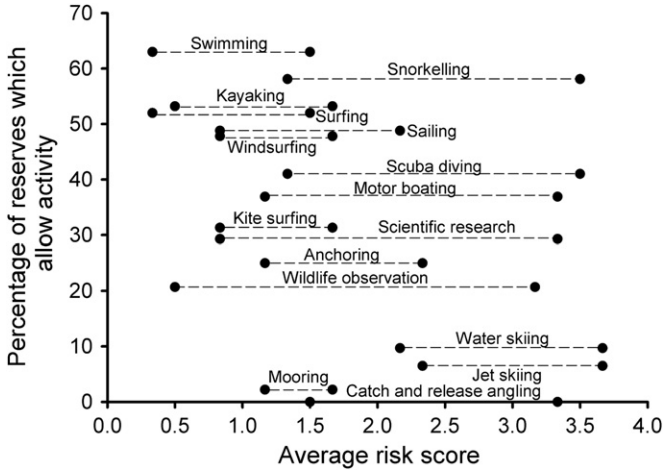

Fig. 2. Average risk score from Table 3 for activities in relation to the percentage of 91 marine reserves examined that allowed the activity in question without any clear form of regulation, and excluding marine reserves that did not mention the activity. Dashed lines indicate the range between risk scores for high and low impact versions of an activity.

should create as little noise, physical and visual disturbance as possible since these can all negatively affect sensitive marine life [62]. Problems from non-extractive research are predominantly associated with boating and scuba diving to collect data, and these can be reduced by targeted regulations. Once these risks are reduced, scientific research should be compatible with marine reserve conservation goals.

The great majority of marine reserves sampled prohibit catch and release angling, a policy supported by the high ranking of the activity in this risk analysis. Whilst some high-risk aspects of catch and release angling can be reduced, e.g. reducing vessel speeds, using moorings, or fishing from shore, there are still aspects of catch and release angling that make it difficult to reconcile it with the goals of marine reserves. Whilst catch and release angling aims to return caught fish to the sea, in reality post-release mortality rates show great variation within and among species, ranging from none to nearly 95% killed [63]. Furthermore, mortality is very difficult to quantify due to the time lag between release and possible death [64]. Even if an animal appears to survive catch and release, the event may still have caused it harm and/or stress which could ultimately reduce its fitness. Schroeder and Love [65] demonstrated that this could be particularly significant for populations of long-lived, relatively sedentary species where individuals can be subjected to numerous hooking events throughout their lives. These factors indicate that catch and release angling would undermine the objectives of marine reserves and as such make it an incompatible activity even in low risk form.

Wildlife observation has become extremely popular [66] and if conducted responsibly can be a powerful tool to raise public awareness of environment and marine conservation issues, in addition to generating funds for marine reserves [22,67]. However, to ensure compatibility with marine reserve conservation goals, it needs careful regulation, in particular relating to use of boats [68]. Studies have shown that boats which take tourists to observe wildlife are generally less disturbing than other forms of motorcraft, particularly jet skis [69]. Nevertheless, underwater noise from vessels such as whale-watching boats has the potential to affect

Table 4
Circumstances under which damage could arise from different activities and possible mitigation measures. Asterisk indicates that potential damage could also arise from boat use, which is described under the section on motorised boating. Adapted from [17].

Activity	Possible mitigation
Motorised boating	Seasonal closures, code of conduct, speed restrictions, permits to regulate user numbers, zoning, provision of moorings.
Scuba diving and snorkelling*	Permits to regulate user numbers, codes of conduct in place, zoning, signs to raise awareness, specified areas for beginners, seasonal closures, briefings and underwater interventions by guides to reduce damage.
Wildlife observation*	Permits to regulate user numbers, codes of conduct in place, special care taken during breeding seasons, distances maintained from animals, noise kept to a minimum, zoning.
Scientific research and education*	Code of conduct, performed only under permit[a].
Swimming	Designated and demarcated access points, code of conduct, zoning.
Non-motorised boating	Designated and demarcated access points, code of conduct, seasonal restrictions.
Anchoring/mooring	Provision of suitable moorings, placement of anchors/moorings away from sensitive habitats, code of conduct in place, permits to limit user numbers/limit on numbers able to use moorings.

[a] Assumes only non-extractive, non-destructive methods used, since extractive sampling would be incompatible with marine reserve status.

echolocation and behaviour of cetaceans by masking communication signals and causing auditory damage [54]. Wildlife watching boats have the potential to disrupt natural behaviour and reduce resting times, potentially affecting animals' long-term health and fitness [51,70]. Collisions with animals may also occur, especially if boats get too close or crowded [71]. Shore-based wildlife observation also has the potential to disrupt natural behaviour, particularly of shore-feeding or nesting birds [72,73].

To reduce impacts of wildlife observation within marine reserves, regulations can define minimum distances, and possibly angle of approach toward animals, particularly those with young. Regulations may also stipulate that boats do not circle wildlife and set speed limits to minimise wash, noise and collision risk. Access to breeding areas can be seasonally restricted. Limits on the number of boats or people in particular areas or within certain distances of particular populations at any one time, can be developed on a site-specific basis. For example in Horoirangi Marine Reserve in New Zealand, no more than three boats at a time are allowed around any marine mammal, and all marine animals have to be approached slowly without sudden boat movements or loud noise [74]. Modern four-stroke engines are also preferable to older two-stroke engines as noise and pollution emissions from modern engines are significantly reduced [75,76]. Boats with older two-stroke engines are banned from some lakes in the United States to reduce negative noise and pollution effects on visitors and wildlife [77,78].

Common ways to mitigate damaging impacts discussed in this paper are shown in Table 4. This table includes all activities considered potentially compatible with the goals of marine reserves. Further details of the impacts of activities not discussed above are given in Supplementary Materials B. The latter activities all scored considerably lower in the risk analysis.

5. Conclusions

Marine reserves are generally assumed to provide the pinnacle of protection against extractive and depositional activities that damage marine life. However, some activities traditionally considered benign have the potential to damage marine reserves yet are commonly allowed with little or no regulation. Most are associated with recreational use and thereby help generate revenue for marine reserves and provide benefits for wider communities [22]. However, if marine reserves are to provide the strong protection they are intended to provide, any allowable activity needs careful management consideration. Without it, simply stopping extractive or depositional activities may be insufficient to achieve demanding marine reserve conservation goals. In this respect, the survey revealed a major disconnect between the intended conservation outcomes of marine reserves and their management. Importantly managers need to consider, and possibly mitigate particularly subtle forms of disturbance or damage that may be caused by human activities. For example, some forms of disturbance described may have effects at spatial scales or over periods of time that are not easily observed by typical research studies. Another possibility is that disturbance could affect an animal's natural behaviour without making it appear stressed [72,79], or affect particularly sensitive organisms or features within a marine reserve. In view of the high standards of protection intended for marine reserves, a precautionary approach is appropriate when making decisions about the level and type of activities that should be allowed or regulated within a marine reserve. Scientific reference areas, where all human activity with the exception of scientific monitoring is banned, could also provide comparison sites by which to judge the changing conditions of features within marine reserves where non-consumptive activities continue to occur, for example, Preservation Zones within the Great Barrier Reef Marine Park [80].

Bearing in mind the caveats discussed in this paper, most non-consumptive activities practised within marine reserves can be compatible if practised in their 'low impact' form, with appropriate management. The exceptions are jet skiing, water skiing and catch and release angling, all of which undermine high levels of protection. To ensure compatibility, operation of motor boats within marine reserves needs careful regulation, including use for scuba diving, snorkelling, wildlife observation and scientific research. Ultimately marine managers have to make difficult decisions about what to allow or not allow in marine reserves and this may include placing limits on visitor numbers for permitted activities and prohibiting some activities altogether—notably the more damaging ones identified in this paper. Such actions may be unpopular, but without them, non-consumptive activities may limit the potential of marine reserves to recover or maintain sensitive ecosystems and wildlife. That said, it is impossible to eliminate all impacts associated with non-consumptive uses. In view of this and the extra conservation benefits of restricting almost all human access (e.g. Robbins et al. [81] found that no-entry zones in the Great Barrier Reef Marine Park were easier to enforce than no-take zones, thereby potentially providing greater protection to reef shark populations), planners may want to consider the inclusion of such strict protection zones in marine protected area networks wherever it is feasible to do so.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2012.03.006.

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