REVIEW

Marine mammal conservation: over the horizon

Sarah E. Nelms1,*, Joanna Alfaro-Shigueto2,3, John P. Y. Arnould4, Isabel C. Avila5, Susan Bengtson Nash6, Elizabeth Campbell1,2, Matt I. D. Carter7, Timothy Collins8, Rohan J. C. Currey9, Camila Domit10, Valentina Franco-Trecu11, Mariana M. P. B. Fuentes12, Eric Gilman13, Robert G. Harcourt14, Ellen M. Hines15, A. Rus Hoelzel16, Sascha K. Hooker7, David W. Johnston17, Nachiket Kelkar18, Jeremy J. Kiszka19, Kristin L. Laird20, Jeffrey C. Mangel1,2, Helene Marsh21, Sara M. Maxwell22, Aubrie B. Onoufriou23,24, Daniel M. Palacios25,26, Graham J. Pierce1,27, Louisa S. Ponnampalam28, Lindsay J. Porter29, Debbie J. F. Russell7,30, Karen A. Stockin31, Dipani Sutaria22, Nina Wambiji32, Caroline R. Wei33, Ben Wilson34, Brendan J. Godley1

1Centre for Ecology and Conservation, University of Exeter, Cornwall, TR10 9EZ, UK

ABSTRACT: Marine mammals can play important ecological roles in aquatic ecosystems, and their presence can be key to community structure and function. Consequently, marine mammals are often considered indicators of ecosystem health and flagship species. Yet, historical population declines caused by exploitation, and additional current threats, such as climate change, fisheries bycatch, pollution and maritime development, continue to impact many marine mammal species, and at least 25% are classified as threatened (Critically Endangered, Endangered or Vulnerable) on the IUCN Red List. Conversely, some species have experienced population increases/recoveries in recent decades, reflecting management interventions, and are heralded as conservation successes. To continue these successes and reverse the downward trajectories of at-risk species, it is necessary to evaluate the threats faced by marine mammals and the conservation mechanisms available to address them. Additionally, there is a need to identify evidence-based priorities of both research and conservation needs across a range of settings and taxa. To that effect we: (1) outline the key threats to marine mammals and their impacts, identify the associated knowledge gaps and recommend actions needed; (2) discuss the merits and downfalls of established and emerging conservation mechanisms; (3) outline the application of research and monitoring techniques; and (4) highlight particular taxa/populations that are in urgent need of focus.

KEY WORDS: Conservation · Marine mammals · Priority setting · Management · Research techniques · Threats

1. INTRODUCTION

Marine mammals, including 126 extant species of cetaceans (whales, porpoises and dolphins), pinnipeds (true seals, fur seals, sea lions and walruses), sirenians (dugongs and manatees), sea otters Enhydra lutris and polar bears Ursus maritimus known to date, can play important ecological roles and are often considered indicators of marine ecosystem health (Bossart 2011, Parsons et al. 2015, Society for Marine Mammalogy 2019). Their typically large body sizes and broad range of diets influence community structure and functioning through processes such as top-down control, nutrient recycling and bioerosion (Estes & Duggins 1995, Bowen 1997, Roman et al. 2014, Kiszka et al. 2015, Albouy et al. 2017). Yet,
historical declines caused by exploitation, and additional current threats, such as climate change, fisheries bycatch, pollution and maritime development, continue to jeopardize many marine mammal species (Kovacs et al. 2012, Magera et al. 2013, Parsons et al. 2015, Albouy et al. 2017, Avila et al. 2018). These stressors, combined with life-history traits such as low reproductive rates and the specificity of the breeding or foraging requirements of some species (Davidson et al. 2012, Maxwell et al. 2013), have led to ~25% (n = 32) of marine mammal species currently being classified as threatened (Critically Endangered, n = 2; Endangered, n = 17; and Vulnerable, n = 13) on the International Union for Conservation of Nature’s (IUCN) Red List of Threatened Species (www.iucn.org; last accessed April 2020). Marine mammals can be difficult to monitor, and changes in their population status are challenging to detect (Kaschner et al. 2011, Lotze et al. 2011, Davidson et al. 2012). As a result, an additional 21% (n = 26) of species are deemed Data Deficient by the IUCN.

Many species and populations of marine mammals are declining, and some have been extirpated from parts of their range (e.g. dugong Dugong dugon and Ganges river dolphin Platanista gangetica) or have gone extinct (e.g. Steller’s sea cow Hydrodamalis gigas, Caribbean monk seal Monachus tropicalis and Yangtze River dolphin or baiji Lipoptyes vexillifer; Turvey et al. 2007, McClenachan & Cooper 2008, Davidson et al. 2012). Yet in some cases, management interventions, such as hunting bans and greater protection, have led to population increases/recoveries in recent decades, and are heralded as conservation successes (e.g. northern elephant seals Mirounga angustirostris, humpback whales Megaptera novaeangliae and Guadalupe fur seals Arctocephalus townsendi; Magera et al. 2013).

With the advent of the Decade of Ocean Science for Sustainable Development beginning in 2021 (United Nations 2019), we sought to bring together a global network of scientists interested in marine mammal conservation to look over the horizon and explore emerging challenges and solutions. In this review, we (1) outline key threats to marine mammals from anthropogenic activities, identify knowledge gaps and recommend responses; (2) discuss the merits and downfalls of existing and future conservation mechanisms; (3) outline the application of research and monitoring techniques; and (4) highlight particular taxa/populations that are in urgent need of focus. Given that they make up the majority of this animal group, we generally focus on cetaceans and pinnipeds.

2. KEY THREATS TO MARINE MAMMALS

The threats posed to marine mammals by anthropogenic activities can be numerous and complex (Avila et al. 2018). Approximately 98% of marine mammal species are at some level of risk in 56% of the ocean, mainly in coastal waters (Avila et al. 2018; Fig. 1). Here, we provide a brief background of the key threats affecting marine mammals around the globe. In Table 1 we summarise knowledge gaps relating to these threats and recommend actions to resolve them.

2.1. Climate change

Specialised diets, restricted ranges, high site fidelity and dependence on specific habitats, which are often reached via extensive migrations, are thought to make many marine mammal species particularly vulnerable to anthropogenic climate change (Würsig et al. 2001, Simmonds & Isaac 2007, Laidre et al. 2015, 2018, Silber et al. 2017). While the full nature and scope of climate-driven effects are uncertain for many species (Schumann et al. 2013, Fuentes et al. 2016a), impacts have already been detected for some and forecasted for others (Schumann et al. 2013, Fuentes et al. 2016a, Regehr et al. 2016, Laidre et al. 2018, Moore & Reeves 2018). These impacts may be geographic (e.g. habitat loss and range shifts) or trophic-related (e.g. variation in food availability, trophic dynamics and competition), with consequences for phenology (e.g. changes to breeding and migration timing) and ultimately, fitness (e.g. effects on reproductive success, health, body condition and population vital rates; Simmonds & Isaac 2007, Burek et al. 2008, Kovacs et al. 2011, Edwards 2013, Ramp et al. 2015, Fuentes et al. 2016b, Silber et al. 2017, Hauser et al. 2018, Boyd et al. 2019, Hamilton et al. 2019, Avila et al. 2020, Laidre et al. 2020a). Marine mammal populations most vulnerable to these influences are likely to be those that (1) are dependent on or associated with sea ice in the polar regions (e.g. polar bears, walruses and ice seals; Moore & Reeves 2018, Bestley et al. 2020); (2) are reliant on upwelling boundary currents (e.g. rorqual whales; Díaz López & Methion 2019); (3) have restricted ranges and small populations (e.g. vaquita Phocoena sinus; Simmonds & Isaac 2007); or (4) are reliant on low-lying islands, atolls and coral reef habitats (e.g. Hawaiian monk seal Neomonachus schauinslandi; Baker et al. 2012).

The capacity of marine mammals to adapt to climate change is poorly understood. Some species may
be able to modify their behaviour in response to changes (e.g. by shifting their range or diet; Moore & Huntington 2008, Evans et al. 2010, Schumann et al. 2013, Ramp et al. 2015). In some cases, the impacts of climate change may be initially positive but later unknown (Moore & Reeves 2018, Laidre et al. 2020b). For example, evidence of a number of positive impacts linked to thinner sea-ice (range expansion, improved body condition and stable reproductive performance) has been identified for a subpopulation of polar bears (Laidre et al. 2020b). However, the rapid pace of climate change and the large number of potential cumulative and synergistic stressors make predicting specific impacts challenging (Laidre & Heide-Jørgensen 2005, Burek et al. 2008, Moore 2008, Patyk et al. 2015).

2.2. Fisheries

2.2.1. Fisheries bycatch

Marine mammal bycatch, i.e. the incidental capture or entanglement of animals in active fishing gear, is a critical yet seemingly intractable problem (Reeves et al. 2013, Brownell et al. 2019), and is currently the threat affecting the greatest number of marine mammal species worldwide (101 species recorded, but likely more; Avila et al. 2018). From small-scale to large commercial fisheries, in national and international waters, developed and developing countries, in urban and isolated areas, marine mammals are being caught in nets and other types of fishing gear (Tulloch et al. 2020b). Gillnet or entangling net fisheries are the greatest global concern (Dawson et al. 2013, Reeves et al. 2013, Brownell et al. 2019), but interactions also occur with other fishing gears such as longlines, purse-seines, trawls and pots/traps (FAO 2018, Hamilton & Baker 2019). Additionally, electric fishing is an emerging threat in freshwater habitats (Turvey et al. 2007).

Several species of cetaceans (e.g. vaquita and North Atlantic right whale *Eubalaena glacialis*; Kennedy 2018, Jaramillo-Legorreta et al. 2019) and pinnipeds (e.g. Mediterranean monk seal *Monachus monachus*; Karamanlidis et al. 2008) have been driven close to extinction due, in part, to fisheries bycatch. The baiji was declared extinct in the Yangtze River in 2006 as a result of unsustainable bycatch and other human activities (Turvey et al. 2007). Other species have also been reduced to critically low levels (e.g. New Zealand sea lion *Phocarctos hookeri*, Australian sea lion *Neophoca cinerea* and some sirenian populations; Hamer et al. 2013, Chilvers & Meyer 2017).
| Key threats                                      | Knowledge gaps                                                                 | Required actions                                                                 |
|-------------------------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Climate change                                   | • Functional responses to environmental change through physiological, phenological and behavioural mechanisms  
• Indirect impacts on prey and habitat availability | • Long-term monitoring  
• Assess tolerance zones of marine mammals and their prey  
• Predictive modelling of species distributions and trophic networks under different climate scenarios  
• Determine cascading effects from impacts of prey and habitat availability |
| Fisheries bycatch                                | • Bycatch rates  
• Fate of animals post-capture and release (e.g. mortality rates)  
• Social and economic consequences of mitigation measures | • Deploy on-board monitoring systems (for bycatch rates and species)  
• Use re-sighting or satellite tagging to gain estimates of post-release mortality  
• Develop more low/no cost mitigation methods  
• Gain perspectives on governance structures, cultural beliefs and perceptions of fishers  
• Create more awareness of the dimension of the problem among seafood consumers and fishers |
| Reduction of prey availability due to overfishing | • Quantitative estimates of the biological interactions between marine mammals and fisheries | • Gain information on key marine mammal diet parameters, such as composition and prey consumption rate, for a greater number of species  
• Expand the use of ecosystem models to assess the competitive interactions between marine mammals and fisheries |
| Commercial and subsistence take                  | • Population impacts of commercial whaling  
• Local drivers and motivators of take  
• Sustainability of subsistence take of sirenians  
• Quantity estimates of illegal take | • Establish mechanisms to regulate commercial whaling  
• Develop mitigation alternatives  
• Create more awareness of the dimension of the problem  
• Work with local communities to obtain data and enable sustainability assessments  
• Encourage governments to implement measures to deter illegal take |
| Use of marine mammals as bait in fisheries       | • Quantity of aquatic mammals targeted or salvaged, particularly in Africa and South America  
• Which marine mammal populations are affected by this practice | • Quantitative assessment of the take and its impact on the local populations  
• Monitor effectiveness of mitigation measures, e.g. campaigns to change local perceptions, alternative livelihoods for fishers, enforced legislation and management of target fisheries |
| Coastal and freshwater development               | • Degree of displacement of the local populations  
• Impact on the population size  
• Consequences of cumulative effects caused by multiple impacts  
• Extent of loss of critical sirenian habitat | • Assess habitat degradation and monitoring  
• Examine the effects in the long term of the overlap between vessel traffic and marine mammals  
• Improve regulation of coastal and riverine construction and development  
• Assess cumulative impact in coastal populations  
• Identify and monitor changes in critical sirenian habitats and their ecosystem services, and work with local communities and managers to protect them |

(continued on next page)
| Key threats                              | Knowledge gaps                                                                 | Required actions                                                                 |
|-----------------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Marine renewable energy installations   | • Occurrence and behaviour of marine mammals using sites targeted for MREIs   | • Investigate the energetic/fitness consequences of disturbance (i.e. population consequences of disturbance) from construction and operation |
| (MREIs)                                 | • Consequences of behavioural impacts of MREIs for marine mammals, in terms of fitness and population dynamics | • Examine if, how and why marine mammals seek out MREIs, and how they serve as attractants |
|                                         | • Impacts from deployment of MREIs                                            | • Investigate device noise, audibility and sound propagation in energetic marine environments |
|                                         | • If and how animals respond spatially to tidal stream turbines in 3D space   |                                                                                  |
|                                         | • Investigate the energetic/fitness consequences of disturbance (i.e. population consequences of disturbance) from construction and operation |                                                                                  |
|                                         | • Examine if, how and why marine mammals seek out MREIs, and how they serve as attractants |                                                                                  |
| Noise                                   | • No audiograms, and therefore no information on hearing sensitivities, exist for some species (particularly baleen whales) | • Validate reliability of frameworks to infer ecologically relevant metrics, such as consequences for individual fitness |
|                                         | • Validity of mitigation measures is incomplete for the diversity of habitats and species to which they are applied | • Scale noise impacts to populations in space using process-based modelling frameworks, such as individual-based models |
|                                         | • What represents healthy or attractive acoustic habitats for marine mammals   | • Study, understand and mitigate new industrial consequences as the ice-cover in the Arctic changes |
|                                         | • Population consequences of disturbance                                       |                                                                                  |
| Plastic pollution                       | • Potential for nanoplastics (sub-micron sized plastic particles) to pass through the gut wall and into the blood stream, and reach organs, such as the liver or the lymphatic system | • Develop methods and technology to detect nanoplastics in biological tissue of wild animals |
|                                         | • Extent to which plastic ingestion exposes marine mammals to chemicals on or within them compared to their usual dietary and environmental input | • Examine concentration of chemical contaminants (e.g. plasticizers such as phthalates) in animal tissue and blood alongside plastic debris in digestive tract and environmental loads |
|                                         | • Effects of plastic ingestion on animal health and exposure to disease        | • Explore global strandings datasets for plastic pollution interactions and pathological information to better understand potential impacts on animal health |
|                                         | • Population-level impacts and global trends of entanglement in plastic debris |                                                                                  |
| Chemical contaminants                   | • Environmental exposure of marine mammal populations to newly listed persistent organic pollutants, such as poly- and perfluoro-alkyl substances and short-chain chlorinated paraffins, as well as chemicals of emerging concern, such as nanoparticles and pharmaceuticals and personal care products | • Examine impacts of emerging contaminants on animal health |
|                                         | • Marine mammal effect assessment                                              | • Improve regulations on chemical disposal and reduce the amount of chemicals entering the environment |
|                                         | • Effect of climate change on transport, late and effects of environmental contaminants and their toxicological impact in populations |                                                                                  |
| Pathogen pollution                      | • Exposure of marine mammals to pathogens from domestic animals (e.g. dogs, cats and livestock) | • Evaluate the impact of domestic animals on health of wild marine mammals and establish protocols to diminish such interactions |
|                                         | • Influence of sea farms on the health of wild animal populations              | • Further explore potential virus transmission routes (e.g. eDNA analysis of wastewater outflows) and examine marine mammals for the presence of human-borne viruses |
|                                         | • Prevalence of reverse zoonosis of human virus (e.g. SARS-CoV-2) from various input pathways (e.g. poorly managed wastewater) | • Evaluate the susceptibility of marine mammals to SARS-CoV-2 and other coronaviruses |
In many regions, fisheries bycatch of marine megafauna is poorly monitored or regulated, especially in international waters (e.g. Anderson et al. 2020), so the population-level impacts are not well understood (Lewison et al. 2014). Where monitoring is carried out, gaps in data on fishing effort, marine mammal encounter frequency, bycatch rates, species identification and the fate of animals post-capture and release limit our ability to assess the risk of fisheries bycatch, understand the cumulative impacts from fisheries that overlap with the distributions of individual populations and constrain management action (Hines et al. 2020).

2.2.2. Reduction of prey availability due to overfishing

Indirect interactions between marine mammals and fisheries are complex, poorly understood and largely unmanaged (Trites et al. 1997). Relatively little is known about exploitative competition between marine mammals and fisheries, i.e. the overlap in resource use between them (e.g. Pauly et al. 1998, Kaschner & Pauly 2005, Machado et al. 2016).

Multiple studies have shown that prey species reduction by fisheries can (at least partially) contribute to the decline of marine mammal populations, particularly small cetaceans and pinnipeds (e.g. Plaganyi & Butterworth 2005). For example, in the Mediterranean Sea, the population decline of short-beaked common dolphins *Delphinus delphis* has been mainly attributed to the decline of small pelagic fish stocks in the Ionian Sea (Bearzi et al. 2006, Piroddi et al. 2011). Along the coast of British Columbia, Canada, and Washington State, USA, the decline of reproductive rates and survival of fish-eating killer whales *Orcinus Orca* has been correlated with the reduced abundance of Chinook salmon *Oncorhynchus tshawytscha*, which is at least partially due to overfishing of salmon stocks (Nehlsen et al. 1991, Ford et al. 2010). Among pinnipeds, population declines due to prey depletion from fisheries have been documented, or strongly suspected, for several species, including harbour seals *Phoca Vitulina* in the western Gulf of Alaska (Pitcher 1990) and southern sea lions *Otaria flavescens* off the coast of Argentina (Koen-Alonso & Yodzis 2005) and Uruguay (Riet-Sapriza et al. 2013). At least 19 species of marine mammals, mainly odontocetes, are currently known to experience biological interactions with fisheries; high-risk areas are mostly in the northern Mediterranean Sea and along the eastern coast of South America (Avila et al. 2018). However, the magnitude of impact on marine mammal populations from fisheries-related prey depletion might be underestimated and requires further investigation. In addition, herbivorous species of marine mammals (e.g. sirenians) may experience depletion of food availability as a result of fishing activities. For example, some fisheries damage the seagrass meadows on which dugongs feed (Marsh et al. 2011).

2.3. Exploitation

2.3.1. Commercial and subsistence take

Many taxa marine mammal taxa are subject to direct human exploitation. For example, Robards & Reeves (2011) estimated that people in 114 countries have consumed meat and other products from ~87 species of marine mammals since 1990. A global moratorium on whaling was enacted in 1983, and no commercial whaling has been permitted under the International Whaling Commission (IWC) in international waters. Commercial whaling within nations’ exclusive economic zones (EEZs) was/is allowed under IWC, and both subsistence and scientific whaling have continued in some countries. For example, in 2019, 360 individuals from 4 baleen whale species were caught by Denmark (Greenland), St Vincent and the Grenadines, Russia and the USA for subsistence purposes (www.iwc.int/table_aboriginal; last accessed 23 September 2020) and 640 individuals from 2 baleen whale species were caught for scientific purposes by Japan in the 2018/19 Antarctic season (www.iwc.int/table_permit; last accessed 23 September 2020).

The take of small cetaceans for food, bait and traditional uses has long been a cause of concern for the IWC as well as other intergovernmental and non-governmental organisations. Most countries have, at some time, used small cetaceans for food, but the scale and extent of such utilization is variable. Present-day artisanal hunting has been identified in some areas, for example, St Vincent and the Grenadines, as an essential source of protein for local communities (Fielding 2014), and subsistence hunting by indigenous residents across the Arctic is a vital part of communities and contributes to economic, cultural and spiritual well-being (Laidre et al. 2015). Few countries regulate small cetacean hunts, and globally, the number of small cetaceans taken, deliberately or otherwise, is unknown.

Pinniped hunting is extensive in the Arctic region and, although controversial, is regulated through a variety of legal frameworks. Canada permits the
largest marine mammal hunt in the world with allowable takes of up to 350,000 ind. yr\(^{-1}\) (Hammill & Stenson 2005), although actual takes vary greatly (www.dfo-mpo.gc.ca/fisheries-peches/seals-phoques/seal-stats-phoques-eng.html; last accessed 23 Sept 2020). Comparable commercial hunts for multiple species of small cetaceans set quotas at approximately 22,000 ind. yr\(^{-1}\) (www.jfa.maff.go.jp/j/whale/w_document/pdf/h17_progress_report.pdf; last accessed 23 Sept 2020).

All 4 species of sirenians are subject to subsistence take (Marsh et al. 2011). In most countries, this harvest is illegal, but in Australia, and some Pacific countries, indigenous people are permitted to hunt dugongs for traditional purposes.

Illegal take likely poses a significant threat to many marine mammal populations but the extent is largely unknown.

2.3.2. Use of marine mammals as bait in fisheries

The use of marine mammals as bait is a geographically extensive activity, affecting at least 42 species in 33 countries, predominantly in Latin America, Asia and West Africa (Cosentino & Fisher 2016, Mintzer et al. 2018). Small cetaceans and pinnipeds are primarily used for shark, crab and lobster fisheries in the marine environment, and riverine dolphins are used for catfish fisheries in freshwater systems (Avila et al. 2008, Quintana-Rizzo 2014, Mintzer et al. 2018, Campbell et al. 2020, Castro et al. 2020). Marine mammals as bait are either (1) deliberately targeted, where animals are the main objective for fishers, (2) non-targeted-deliberate, bycaught or stranded animals are recovered and killed, and (3) non-targeted salvaged acquisition, when an incidentally caught animal is used (Hall 1996, Marsh et al. 2011, Robards & Reeves 2011). The majority of interactions are thought to be deliberately targeted (83% of cases; Mintzer et al. 2018). The general appeal of marine mammal bait to fishers is that it is considered effective (due to its fatty, bloody and durable consistency), and readily available at little or no cost (often being collected en route to fishing grounds; Mangel et al. 2010, Barbosa-Filho et al. 2018).

2.4. Industrial development

2.4.1. Coastal and freshwater development

Many marine mammal species have experienced significant declines due to cumulative impacts of anthropogenic activities in coastal and freshwater environments, especially those with small populations, high site fidelity and reliance on coastal and riverine habitats (Schipper et al. 2008, Pompa et al. 2011, Avila et al. 2018).

The expansion and intensity of anthropogenic activities in these areas generates a wide array of stressors, which may impact marine mammals both directly or indirectly (Aguirre & Tabor 2004, Maxwell et al. 2013). Industrial activities include the construction of infrastructure such as ports and dams, as well as facilities related to aquaculture, energy production and military activity. Human encroachment on breeding and haul-out habitat is thought to have played a contributory role in the decline and extinction of the Caribbean monk seal and Japanese sea lion Zalophus japonicas, and likely threatens other extant pinniped species (Kovacs et al. 2012). For freshwater species, such as river dolphins in South Asia and South America, and manatees in Africa and South America, large-scale diversions of river flows by dams, barrages and canals for irrigation, hydropower generation and urban/industrial water supply have led to habitat loss (with fragmentation of population connectivity and increased pollution), and effects on food abundance and distribution (Smith et al. 2009, Marsh et al. 2011, Choudhary et al. 2012, Braulik et al. 2014, Araújo & Wang 2015, Pavanato et al. 2016, Arraut et al. 2017). Reduced freshwater flows have also negatively affected the productivity of downstream estuarine and coastal habitats for other dolphin species (Smith et al. 2009).

Additionally, the global increase in maritime and riverine vessel traffic is causing greater underwater noise (see Section 2.5.1) and vessel–animal collisions (Laist et al. 2001, Van Waerebeek et al. 2007, Manuel & Ritter 2010, Avila et al. 2018, Dey et al. 2019).

2.4.2. Marine renewable energy installations

Marine renewable energy installations (MREIs; wind, wave and tidal-stream devices), can help reduce hydrocarbon use and therefore mitigate climate change (Magagna & Uihlein 2015). However, installation, operation and decommissioning of these devices can potentially impact wildlife, including marine mammals (Boehlert & Gill 2010). Installation of wind turbines using pile-driving is associated with high sound levels, leading to avoidance or displacement of marine mammals out to considerable ranges (>20 km; Tougaard et al. 2009, Russell et al. 2016). Construction and maintenance of MREIs also results
in increased vessel traffic and increased potential for vessel collision, particularly with whales (Inger et al. 2009, Bailey et al. 2014), as well as noise impacts (David 2006, Graham et al. 2019). Floating wind turbines are an emerging technology that allow for deployment in waters too deep for pile-driven seabed-mounted turbines. Advantages of floating turbines include reduced construction noise, reduced vessel traffic and lower installation costs. However, mid-water column infrastructure (chains and power cables) could pose higher entanglement risk (Harnois et al. 2015), and could snag abandoned fishing gear in the water column, exacerbating this risk (Benjamins et al. 2014). Devices to extract wave energy, although less common than floating wind turbines, are likely to have similar sub-surface risks. Devices that extract energy from tidal streams are effectively submarine versions of wind turbines, although the blades are generally shorter and slower turning. However, marine mammal injury from collision with tidal turbine blades is a significant conservation and consenting concern (Wilson et al. 2007, Onoufriou et al. 2019). Hastie et al. (2018) demonstrated that harbour seals avoid areas during playback of tidal turbine operational noise, but a priority for future research is to determine the avoidance behaviour of marine mammals in relation to actual operating turbines, and the potential for such devices to cause exclusion from foraging areas, or barriers to transit, particularly in multi-device arrays.

2.5. Pollution

2.5.1. Noise

Anthropogenic underwater noise is recognised as a pervasive pollutant impacting marine mammals globally (Williams et al. 2015, Cholewiak et al. 2018). Sources range from the intentionally generated (e.g. seismic exploration, sonar, particularly naval, and acoustic deterrent devices; Elliott et al. 2019) to the incidental (e.g. commercial and private vessels, pile-driving, explosives, icebreaking, dredging and point sources like offshore structures, such as MREIs, as well as coastal roads, bridges and aircraft; Richardson et al. 2013). The consequences for marine mammals depend heavily on the nature of the source, particularly its amplitude, frequency and temporal components (e.g. continuous, impulsive, predictable and familiar). Impacts range from direct tissue trauma, particularly auditory damage (Southall et al. 2008), to behavioural responses and stress (Gómez et al. 2016, Dey et al. 2019) which may themselves lead to significant injury (Jepson et al. 2003), or habitat exclusion and masking of ecologically relevant sounds like communication (Clark et al. 2009).

2.5.2. Plastic

At least 42% of extant marine mammal species have been found to ingest or become entangled in plastic pollution (Senko et al. 2020). Plastic may be consumed via 2 main pathways, direct or indirect ingestion. The former can occur as a result of indiscriminate feeding strategies (e.g. filter feeders; Besseling et al. 2015), mistaken identity (Secchi & Zarzur 1999, de Stephanis et al. 2013) or due to naivety and curiosity, as may be the case in young animals (Baird & Hooker 2000). Indirect ingestion can occur as a result of trophic transfer where prey containing microplastics (plastic <5 mm in size) are consumed (Nelms et al. 2018, 2019a,b). Ingestion of macroplastics (>5 mm) can cause lacerations, ulcerations, obstructions and lesions, and may lead to sub-lethal effects such as dietary dilution, dehydration and starvation (Kastelein & Lavaleije 1992, Stamer et al. 2006, Levy et al. 2009, Alexiadou et al. 2019). Although ingestion of macroplastics can result in mortality, the population-level effects for most species are unknown (Alexiadou et al. 2019, Senko et al. 2020). Some, already vulnerable, species and populations (i.e. those that are of conservation concern due to other stressors) are likely to be most at risk. Foraging ecology and/or habitat use also appear to be a risk factor. For example, deep-diving odontocetes, such as beaked and sperm whales, seem to have the propensity to consume, and become compromised by, plastic pollution (Secchi & Zarzur 1999, Stamer et al. 2006, Jacobsen et al. 2010, Kaladharan et al. 2014, Lusher et al. 2015, Abreo et al. 2016, Alexiadou et al. 2019).

Entanglement in plastic pollution, such as derelict fishing gear (or ‘ghost gear’; i.e. gear that is abandoned, lost or deliberately discarded), packaging and strapping, can lead to lacerations, constriction, higher energetic costs associated with increased drag, an inability to forage and/or escape predators and other threats (such as ship strikes) and drowning (Allen et al. 2012, van der Hoop et al. 2017, Jepsen & de Bruyn 2019). Although cetaceans are known to become entangled in debris (Baulch & Perry 2014), pinnipeds seem to be more susceptible, and 67% of species (n = 22 of 33) have been recorded with entanglements (Laist 1997, Jepsen & de Bruyn 2019).
2.5.3. Chemical contaminants

Contaminants are recognised as significant stressors of marine mammal health worldwide, including in remote polar environments (Brown et al. 2018). Persistent organic pollutants (POPs), heavy metals, and pharmaceuticals and personal care products (Bengtson Nash 2018) represent just a small selection of legacy and emerging contaminants of concern. Genotoxicity, immunosuppression and endocrine disruption are among the toxic effects commonly associated with legacy POPs and heavy metals, but our understanding of how exposure to complex environmental chemical mixtures is expressed in wild marine mammal populations is poor (Desforges et al. 2017). Oil spills from offshore extraction and transportation can negatively affect marine mammals through direct contact with crude oil and damage to foraging areas and prey stocks. For instance, the 1989 ‘Exxon Valdez’ oil spill in Alaska killed tens of killer whales and thousands (1000–2800) of sea otters, and other individuals may have migrated out of the affected area (Helm et al. 2015). Similarly, the 2010 Deepwater Horizon oil spill in the Gulf of Mexico caused a dolphin mortality event (>1000 dead individuals were recorded; www.fisheries.noaa.gov/national/marine-life-distress/sea-turtles-dolphins-and-whales-10-years-after-deepwater-horizon-oil; last accessed 11 December 2020), while surviving animals exhibited moderate to severe lung disease and evidence of hypoadrenocorticism consistent with immunotoxic effects of oil (Daly et al. 2016).

2.5.4. Pathogens

Increased urbanisation of coastal areas, movement of ballast waters and global movement of people have contributed to an increase in detection of terrestrial pathogens in marine life. The term ‘pathogen pollution’ has been coined to describe the emergence of organisms typically considered pathogens of land animals in the ocean ecosystem. Protozoa such as *Giardia*, shed in mammalian faeces, have been detected in marine mammals from the Arctic to Antarctica (Fayer et al. 2004). *Toxoplasma gondii*, a parasite dependent upon cats for sexual reproduction and shed in faeces of felids, is an important cause of mortality in Endangered Hawaiian monk seals and California sea otters in the USA, and for Māui dolphins *Cephalorhynchus hectori maui* in New Zealand (Roe et al. 2013, Barbieri et al. 2016).

The recent outbreak of COVID-19 (SARS-CoV-2 virus) has highlighted concerns of reverse zoonosis, where human-borne viruses are passed to wild animals. Marine mammals may be exposed to the virus via sources such as inadequately managed wastewater and direct human contact (e.g. handling by field researchers), and are potentially highly susceptible to infection (Barbosa et al. 2021, Mathavarajah et al. 2021).

3. CONSERVATION MECHANISMS

The diversity of threats facing marine mammals requires an equally diverse suite of conservation tools to address them. Here we outline a range of established and emerging conservation mechanisms and discuss their merits and downfalls.

3.1. Practical management options

3.1.1. Bycatch mitigation

Many non-technical and technical marine mammal bycatch mitigation methods have been proposed or tested with varying degrees of success and implementation (for detailed reviews, see FAO 2018 and Hamilton & Baker 2019). Non-technical methods include spatial closures (permanent, seasonal or dynamic) to reduce or eliminate the overlap between the fishing activity and at-risk species (Gilman et al. 2006, NMFS 2010, van der Hoop et al. 2013, Hazen et al. 2018); gear switching from high- to low-risk practices (e.g. from gillnets to longlines); binding and non-binding measures (e.g. national legislation, international agreements and consumer campaigns); and Food and Agriculture Organization of the United Nations (FAO) best practice advice.

Technical methods to reduce bycatch come in many forms but their efficacy tends to be species-specific. Acoustic deterrents are perhaps the most tested and include alarms (pingers) applied to fishing nets (Carretta & Barlow 2011, Dawson et al. 2013), playback of predator sounds (Werner et al. 2015) and passive acoustics, such as nets with enhanced acoustic reflectivity (Trippel et al. 2003, Larsen et al. 2007, Bordino et al. 2013). Pingers have had promising results in deterring several species of cetaceans (e.g. Burmeister's porpoises *Phocoena spinipinnis*) from small-scale driftnets (Clay et al. 2018) but have also been shown to attract some pinnipeds (‘dinner bell’ effect; Carretta
3.1.2. Creating alternative livelihoods for fishers

Elimination of human-induced mortality is urgently needed for small isolated populations of marine mammals (Wade 1998, Brownell et al. 2019). This goal is challenging for fisheries in developing countries where extensive multi-gear fisheries are active, some throughout the year. Professional fishing is not only about food security and income generation but is also a source of cultural identity. Successfully changing the behaviour of fishers to new gears and/or areas that reduce bycatch, to not using marine mammals as bait and potentially reducing their dependence on fisheries, requires not only awareness, education and exposure to ecosystem-based thinking, but requires alternative modes of income generation and sources of food. As these processes require a rigorous social and economic assessment of individual situations, providing alternative livelihoods should be considered as a socio-ecological process of transformation, rather than a conservation challenge per se (Mozumder et al. 2018).

Focus on the fishing community to maximise the likelihood of successful transition to alternative livelihoods and economic and sociological expertise is key (Amevenku et al. 2019). Failure to understand and incorporate the needs of the fishers and their community will inevitably lead to suboptimal outcomes in the long term because too few fishers will be able to transition to the new livelihoods needed to achieve required levels of bycatch reduction (Sorice & Donlan 2015). In small-scale fisheries, fishing is often part of a ‘portfolio’ of activities, especially in Asia where fishing is a seasonal activity. Fishers seek other opportunities in off-seasons, indicating that alternatives to fishing may be already available to these communities.

There are a few examples of alternative livelihood programmes that have been specifically designed to protect a species of conservation concern from fishing. The alternative livelihoods programme developed by the National Oceanic and Atmospheric Administration (NOAA) for the vaquita (Vaquita SAFE 2019) is a prominent but unsuccessful example. In some situations, dolphin-watching may provide an alternative livelihood (Sutaria 2009, Beasley et al. 2014, Mustika et al. 2017). Women’s collectives that provide a wide portfolio of income generation at the household level through diverse activities, such as seaweed drying, pond aquaculture, vegetable and fruit farming and handicrafts, along with the education and movement of youth from fishing to different occupations, have been established in several marine fishing communities in India (Patterson et al. 2008, Periyasamy et al. 2014, Kadfak 2020), but the performance of such initiatives has not yet been evaluated.
3.1.3. Spatial management for conservation

Spatial management is one of the most common approaches in marine mammal conservation, varying widely in spatial scope and target, including marine protected areas (MPAs), single-sector spatial management or dynamic management approaches. MPAs are the most well-known spatial management tool, with their goals and protection levels ranging from no-take marine reserves where all extractive activities are prohibited (IUCN Category Ia: Strict Nature Reserve), to MPAs where only a subset of activities are prohibited (IUCN Category VI: Protected areas with sustainable use of natural resources; Day et al. 2019). MPAs may be designed to protect marine mammals either directly by targeting threats, or indirectly through management goals that may reduce impacts on marine mammals, such as prohibition of fisheries that result in bycatch of marine mammals or that compete with their food resources (Peckham et al. 2011).

Since many marine mammals are wide-ranging species, smaller MPAs may not be of sufficient size to encompass critical habitat (Agardy et al. 2011); however, many marine mammal species do aggregate during key life-history stages or during seasonal cycles (e.g., foraging and breeding), and these areas can potentially be effectively encompassed by MPAs (Cordes et al. 2011, Gormley et al. 2012).

Dynamic ocean management, whereby managed boundaries shift over short time scales, or near-real time, in response to changing conditions or animal movements (Maxwell et al. 2015), is an approach that is increasingly being employed, as it is more responsive to highly mobile species and results in less active management of human uses of the ocean (see e.g. Wiley et al. 2013, Dunn et al. 2016, Hazen et al. 2017, 2018). Furthermore, mobile and flexible MPAs may be a critical tool for accommodating shifting marine mammal distributions as a result of climate change (Avila et al. 2018, Maxwell et al. 2020).

A relatively new advance in spatial management for marine mammals is the concept of Important Marine Mammal Areas (IMMAs; Corrigan et al. 2014). IMMAs are defined as discrete portions of habitat, important to marine mammal species that have the potential to be delineated and managed for conservation. How IMMAs concord with existing legislative controls within and across national jurisdictions is still being developed, and IMMAs have the potential to be delineated and managed for conservation by management agencies, whether government, intergovernmental organisations or conservation groups, though this is not mandated.

While spatial management can be effective for marine mammals (Notarbartolo di Sciara et al. 2016), several limitations exist. For example, marine mammals are often impacted by multiple human threats simultaneously, resulting in additive or cumulative impacts on individuals and populations (Maxwell et al. 2013). Additionally, threats that exist within MPAs, such as pollution or climate change, may originate outside of spatial boundaries and may be beyond the jurisdiction or capabilities of management agencies (Maxwell et al. 2014). Furthermore, population-level impacts of management actions can be difficult to assess, given the highly mobile nature and long generation times of some marine mammal species. Determining the efficacy of these management actions requires greater attention (Ashe et al. 2010).

3.1.4. Ex situ conservation

Ex situ management, i.e. the maintenance of a species outside its natural habitat for conservation purposes, has saved species such as the Arabian oryx Oryx leucoryx and the California condor Gymnogyps californianus from extinction. Classically in this approach, individuals are removed from their natural habitat to a safe area, a breeding programme is established, and offspring are returned to the wild after threats there have been reduced or eliminated. Ex situ management can be controversial, because such efforts may be perceived to divert resources from efforts to conserve species in their natural habitats (Bowkett 2009, Ralls & Ballou 2013). In addition, ex situ operations are expensive, logistically challenging, require long-term commitment and are risky for captured individuals. Typically they are only considered when extinction risk is high (Martin et al. 2012, Canessa et al. 2016).

The increasing urgency for actions to tackle the current biodiversity crisis has led to changes in the definition of ex situ conservation, and the distinction between in situ and ex situ has become blurred. The IUCN (IUCN/SSC 2014) now defines ex situ as:

conditions under which individuals are spatially restricted with respect to their natural spatial patterns or those of their progeny, are removed from many of their natural ecological processes, and are managed on some level by humans.

This new approach to ex situ conservation, which includes elements of management by humans within marine mammal habitats (as distinct from ex situ captive breeding), is feasible for some marine mammals,
especially those with terrestrial elements to their life history. Temporary holding of stranded pinnipeds to treat injuries, diseases, malnutrition or impacts from oil with release into their natural range following disease screening now occurs in many parts of the world. For example, in 2012, almost a third (32%) of all living Hawaiian monk seals were alive due to past human interventions, such as disentanglement, translocation, nutritional support and vaccination (Harting et al. 2014). In California, 71% of abandoned sea otter pups reared in captivity by surrogate otter mothers and released at weaning survived to adulthood (Nicholson et al. 2007). In China, Yangtze finless porpoise Neophocaena phocaenoides have been translocated from the mainstream river to protected oxbow pools where they are now reproducing (Wang 2015).

In the future, new approaches will need to combine ex situ conservation with in situ management to prevent the loss of marine mammal diversity. Disentanglement, medical treatment, vaccination and translocation will likely be increasingly integrated into population-level management of pinnipeds in situ. For cetaceans, capture myopathy and captive maintenance remain challenges. For example, attempts to capture Critically Endangered vaquita for temporary protection were halted after the death of an animal from capture myopathy (Rojas-Bracho et al. 2019) but may have potential for more robust species. The scale, size and number of facilities needed to adequately house sufficient animals to maintain genetic diversity in a captive population make captive breeding programmes for reintroduction unlikely for the larger marine mammal species. The successful release of captive-born cetaceans into the wild poses an additional challenge due to their complex patterns of social behaviour. To date, only 1 formal attempt has been described, with unclear results: a group of bottlenose dolphins, including 4 captive-born juveniles, were released from an aquarium in Western Australia in 1992; 1 calf was recaptured due to poor health, 1 is assumed to have died, and the fate of the other 2 is unknown (Gales & Waples 1993).

3.1.5. Animal welfare science and its application to conservation outcomes

It is increasingly acknowledged that conservation efforts for wild marine mammal populations need to be inclusive of animal welfare (McMahon et al. 2012, Dubois & Fraser 2013), and that the welfare science of individuals can inform conservation management of populations (Beausoleil et al. 2018). However, animal welfare can be mistaken for animal rights, and subsequently misunderstood as either morally or emotionally motivated. Papastavrou et al. (2017) demonstrated how conservation and welfare share similarities in their scientific biases and proposed that they should be considered in unison in marine mammal conservation management. These arguments align with international legislations such as the US Marine Mammal Protection Act (1972) and New Zealand Marine Mammal Protection Act (1978) which define disturbance and harm at the individual level (welfare), even though the aim of conservation management is to prevent population impacts. Indeed, the potential benefits of integrating welfare science, including individual health studies, into conservation management efforts are starting to be recognised in marine mammal conservation (Pirotta et al. 2017). While many biologists still appear to be discomforted by the now widespread discussions of welfare in terms of an individual’s subjective experience, i.e. ‘feelings’ (Beausoleil et al. 2018), recent failed attempts to safely live-capture vaquita in an attempt to conserve the species (Rojas-Bracho et al. 2019) serve as a reminder of why welfare must be positioned within scientific discourse, planning and assessment. While some conservationists, veterinarians and welfare scientists still consider their own disciplines in isolation, an increasing need to find commonalities in our language, understanding and application is necessary if we are to positively affect conservation outcomes for marine mammals (Stockin 2019). The recent application of the 5 domains model to assess welfare implications of tourism on a critically endangered whale population is just one example (Nicol et al. 2020).

3.2. Monitoring and sampling

Effective management of marine mammals with diverse habitat ranges depends on the sharing of species- and population-specific data, environmental information and data on local, regional and global threats. Forums such as the IWC have long facilitated data sharing, and there is now strong evidence suggesting data syntheses are effective at identifying research and conservation priorities (Campbell et al. 2015, Nguyen et al. 2017, Hindell et al. 2020). Recommendations for how to achieve this include:

1. Create data management plans that include definitions of the types of data, their source, formats, interfaces, and scientific robustness (e.g. anecdotal records, incidental sightings or systematic monitoring).
(2) Map out potential data sources.
(3) Pool information to produce datasets.
(4) Accompany all datasets with metadata descriptions based on standardised formats and vocabularies, such as MVB (vocab.nerc.ac.uk/collection/MVB) and use the Biodiversity Information Standards to offer online management and sharing of data from multiple sources.
(5) Store and securely back up the data for providers and users.
(6) Provide protection/privacy policies for re-use of the available data and determine whether it should be open access (see Lennox et al. 2020 for issues regarding release of sensitive biological data).
(7) Encourage the use of free apps/platforms to collect citizen science data and map sightings.
(8) Promote pathways by which scientists, students and industry can provide input to any resultant repository database(s).
(9) Enable frameworks for the access and sharing of data with different stakeholders/users in the short and long term, while adhering to the ‘Findable, Accessible, Interoperable, Reusable’ (FAIR) principles for scientific data management and stewardship (Wilkinson et al. 2016).
(10) Provide services that acknowledge or display contributors, in particular the promulgation of data digital object identifiers (DOIs), to encourage data publication.
(11) Promote e-learning platforms for training, especially for remote areas or those with less access to technological resources.

Building the capacity of scientists with skills in Open Science, programming for analysis, research data management, data visualization, information security, machine learning and author carpentry, and computational infrastructures (www.codata.org/) will facilitate data handling required for effective marine mammal research and conservation. To do this effectively, we need to create strong and relevant communication and messaging platforms for all marine mammal scientists. Datasets should be made available within a global repository of metadata (e.g. global databases that can integrate both species and environmental parameters such as the Ocean Biogeographic Information System, OBIS; https://obis.org/), ensuring that existing data can be discovered, accessed and used to support management decisions, such as designating IMMAs (De Pooter et al. 2017). A forum for such a repository could be hosted within an extant international consortium, such as the IWC, Intergovernmental Oceanographic Commission of United Nations Educational, Scientific and Cultural Organisation (IOC-UNESCO; https://ioc.unesco.org/), OBIS, World Register of Marine Species (WoRMS; http://www.marinespecies.org/) or the IUCN, thereby ensuring longevity and that the quality of the data is maintained and linked to other platforms worldwide.

3.3. Policy, guidance and assessment

3.3.1. IUCN Red List

The IUCN Red List (https://www.iucnredlist.org/) is the globally recognised standard for characterizing conservation status of species and ecosystems, and has many strengths. Rigorous application of the clearly defined quantitative Categories and Criteria by recognised experts in the field provides a common currency that a variety of global stakeholders respect, roughly understand and rely upon. Red List classifications are cited in many contexts, including popular media, environmental impact assessments and national and international laws, policies and treaties (Hoffmann et al. 2008). Assignment of a ‘Threatened’ classification status can spur conservation action and lend urgency and credibility to regional recovery programmes, management plans, research projects and funding, to support practical conservation efforts. Furthermore, in many cases, the need to obtain quantitative population data and evaluate threats for either national or international Red List assessments can provide incentive for the expert compilation of unpublished, but reliable, data on certain species or populations, or drive new research which, in turn, informs on-the-ground conservation efforts (Hoffmann et al. 2008).

While the Red List is generally viewed as authoritative, critics argue that its emphasis on robust data on abundance and threats may distract energy and funding away from more practical on-the-ground threat reduction and conservation interventions (e.g. Knight et al. 2010). Furthermore, the utility of global species-level assessments has been questioned on the grounds that they may provide a false sense of security for wide-ranging species with geographically isolated (sub)populations, which themselves are threatened or in decline (Godfrey & Godley 2008, Desforges et al. 2018). Some feel that efforts to address this concern for marine mammals have resulted in a somewhat haphazard collection of (sub)population-level assessments, usually conducted only for those populations that are well studied, are seriously threatened and have a ‘champion’ with the expertise and motivation to prepare and submit an assessment.
Among other perceived limitations, as an assessment tool only, the Red List lacks ‘teeth’ and has no mechanism or power to implement or enforce change at the level of a range state, which is where most of the regulatory capacity lies (Hoffmann et al. 2008). However, from its inception, the Red List has been designed as a widely accepted and practical way to help stakeholders of all types to set priorities for conservation action. Without such a standardised tool, governments, funding bodies, industry and others responsible for allocation of resources or development of conservation policy, would arguably have difficulty sifting through and synthesizing scientific and popular literature to guide their decisions.

The Red List can and should evolve, and complementary tools can make it more effective to achieve conservation aims. Recently, in an effort to move beyond an exclusive reliance on quantitative population and trend data, Red List assessments for cetaceans have included greater consideration of the nature and pervasiveness of threats and their potential population-level impacts (Minton et al. 2017, Wang & Reeves 2017, da Silva et al. 2018, Braulik & Smith 2019), providing a more precautionary and holistic approach. Combined with national assessments, and other complementary tools, such as place-based assessments (e.g. IMMA, Ecologically or Biologically Significant Marine Areas, or Key Biodiversity Areas), the Red List can serve to catalyse and inform legislation, threat-mitigation efforts and management measures that lead to population increase and recovery (Zamin et al. 2010). As the human footprint on our planet expands to include almost every marine mammal habitat, putting more and more populations at risk, the IUCN Red List remains more relevant for marine mammal conservation than ever.

3.3.2. Science outreach and advocacy: international agreements and frameworks

It is frequently argued that the role of science stops with providing the evidence, leaving policy-makers to decide how to act. Many marine mammal scientists are likely guilty of statements such as ‘this research is essential to underpin the implementation of the Marine Strategy Framework Directive’, implicitly assuming that marine mammal conservation is enhanced as a result of research. However, to be effective, scientists must, from the outset, engage with all relevant stakeholders, ranging from policy-makers to the general public: locally, nationally and internationally. Following the precautionary principle, scientific advice should be offered even when data are imperfect (as they usually are), noting that incomplete knowledge does not justify inaction by managers.

An effective approach to successful conservation science is to embed it within the adaptive management framework (McFadden et al. 2011). Adaptive management capitalises on opportunities to improve the effectiveness of management strategies as new knowledge is gained (McCarthy & Possingham 2007) and so extends conservation science into management strategy evaluation and decision-support systems, with feedback and linkages between scientific advice, its implementation (partial or complete) and evaluation and re-evaluation of outcomes. Such systems can propose a range of possible science-based management measures, providing evidence about the likely environmental, social and economic outcomes of their implementation, and critically evaluate the likely nature and extent of non-compliance with measures and its consequences (e.g. the Conservation Evidence assessments: www.conservationevidence.com). However, this requires adaptation by scientists, consent of managers and policy-makers, and support from governments, stakeholders and the general public. It also presupposes a joined-up approach to environmental legislation, for example such that fisheries and conservation management are integrated rather than dependent on different legislation and government departments. An ecosystem-based approach to managing charismatic species is key in order to truly understand and mitigate the impacts of multiple threats on marine mammal populations. This could be supported by a risk-based approach, which explicitly recognises the monetary and cultural values attached to marine mammals as a component of healthy marine ecosystems, objectively measures the likelihood and extent of costs and benefits, to identify how and where resources can be most effectively deployed using a return-on-investment approach to achieve conservation objectives (Tulloch et al. 2020b). This can help to avoid focussing conservation actions on a few charismatic species or a few protected areas while the wider ecosystems on which they depend continue to be degraded.

3.3.3. Regulatory versus incentive-based approaches

The marine mammal conservation science community has historically focussed on documenting the
status of, and threats to, various taxa (Read et al. 2006, Avila et al. 2018) and recommending potential regulatory or management solutions to the many conservation concerns. This approach has often not resulted in the uptake of the solutions proposed, even in nations where the conservation priority is codified in legal and policy instruments (Reeves et al. 2003). There are relatively few examples of demonstrated impact from uptake of science-based recommendations into regulation or management (although see Gormley et al. 2012). The potential socio-economic and resultant political impact associated with regulating activities is often deemed unacceptable by decision makers, and so a zero-sum trade-off results. While good governance may be necessary for marine mammal conservation, it may not always be sufficient.

Faced with similar challenges in other sectors, civil society actors (e.g. non-government organisations and progressive companies) have sought to create positive incentives via markets to recognise and reward those who act in a sustainable or responsible manner. These actors leveraged increasing societal expectations for sustainability, coupled with increasing market demand for secure supply chains, and eventually led to the development of a suite of voluntary sustainability certification and labelling programmes for products, including timber, coffee, palm oil and fish (e.g. Agnew et al. 2014). Such organisations develop standards that entities who wish to be certified need to meet in order to access the potential benefits of certification (e.g. access to new markets or price premiums). When these potential benefits exceed the marginal cost of actions that result in more sustainable outcomes, organisations who seek certification are incentivised to implement such solutions. For example, implementing harvest-control rules to restrict fishing effort as the stock approaches the target level, increasing levels of observer coverage to assess bycatch species and conducting benthic surveys to improve assessments of habitat impacts.

We suggest that the uptake of marine mammal conservation-focused recommendations may benefit from considering how market (or indeed other) incentives could aid in addressing the socio-economic impacts of regulatory or other measures whose consequences may impede conservation outcomes. However, in situations where individuals in small populations of marine mammals are killed incidentally, the time required to implement incentive-based mechanisms is likely to be too long to prevent local extinction. For example, all 11 examples of Critically Endangered small cetacean populations impacted by gill netting identified by Brownell et al. (2019) have such small populations that even 1 human-caused mortality will increase the risk of extinction (see International Whaling Commission 2018). In such cases, incentives alone are unlikely to prevent extinction although they may be a component of a more comprehensive approach. Interdisciplinary research to identify the scenarios under which either regulatory or incentive-based measures, or both in combination, may yield successful outcomes would be valuable. Such research should be undertaken well before emergency conservation actions are required. Additionally, improved communication between scientists and the general public may enhance awareness of conservation issues, improve support for proposed solutions and result in greater conservation success.

4. RESEARCH AND MONITORING TECHNIQUES

In recent decades, the range of methods used to observe and understand marine mammals has evolved rapidly. Here we outline examples of key technological, molecular and social techniques and discuss their future application and priorities for development.

4.1. Technology

4.1.1. Satellite and drone imagery

Over the past 5 decades, the use of earth observation satellites and other emerging technologies has grown exponentially. Decreasing costs, increasing resolution of sensors, expanding global coverage, and the availability of public archives of imagery (e.g. Google Earth) now make it possible for researchers to use remote sensing tools to safely and efficiently study marine mammals (Moxley et al. 2017, Johnston 2019, Schofield et al. 2019).

Earth observation satellites: Several studies have successfully employed satellite data to investigate marine mammal distribution and density. WorldView imagery has been used to study distributions of Weddell seals *Leptonychotes weddelli* (LaRue et al. 2011) and polar bears (LaRue & Stapleton 2018), and to detect and count mysticete whales in several locations around the world (Fretwell et al. 2014, Cubaynes et al. 2019, Bamford et al. 2020). Deep learning methods to automate detection and enumeration in satellite data are in development (Guirado et al. 2019).
The capacity for studying and conserving marine mammals via satellites will continue to grow, due to the continued launch of large earth observation satellites (>50 kg) to support habitat and conservation studies (Probst et al. 2017), as well as the proliferation of small satellites (<50 kg; i.e. cubeSats, microSats and nanoSats, see Spaceworks, https://www.spaceworks.aero/nano-microsatellite-forecast-8th-edition-2018/). These efforts will provide improved imaging and increased coverage for purposes of tracking animals with the Argos System (Bille et al. 2018).

**Unoccupied aircraft systems:** At present, unoccupied aircraft systems (UASs or ‘drones’) are used to detect and count marine mammals in shore-based colonies, on sea ice and at sea (Moreland et al. 2015, Seymour et al. 2017, Angliss et al. 2018, McIntosh et al. 2018), assess size and body condition (Durban et al. 2015, Sweeney et al. 2015, Christiansen et al. 2018, Allan et al. 2019), monitor vital signs (Horton et al. 2019), study respiratory microbiomes and virology (Apprill et al. 2017, Pirotta et al. 2017, Geoghegan et al. 2018), document behaviour (Torres et al. 2018) and detect and assess injury rates (Martins et al. 2019). These on-demand sampling approaches are increasingly coupled with automated approaches for analysis (e.g. Fearnbach et al. 2018, Burnett et al. 2019), including deep learning techniques (Gray et al. 2019). Alongside these biological and ecological applications, efforts focussed on understanding and mitigating disturbance of marine mammals by aerial and underwater drones are underway (Smith et al. 2016, Arona et al. 2018, Thaler et al. 2019). Finally, there is a growing interest in using drones to study human interactions with marine spaces and species, although key privacy and security concerns must be addressed (Nowlin et al. 2019).

Drones provide on-demand remote sensing at incredibly high resolutions, overcoming many challenges presented by satellite remote sensing (Johnston 2019). Furthermore, UAS surveys can be cheaper and less logistically challenging than occupied aircraft surveys, and may present opportunities to reduce risk to researchers and study subjects (Johnston 2019). As costs decline further and platform and sensor capacities rise, UAS technology represents a dramatic democratization of remote sensing in marine mammal research and conservation. Unfortunately, at present, the legal rules associated with the use of UAS in marine mammal research are complicated, constantly in flux, and in some locations, their use is prohibited. This ever-changing legal landscape is one of the major factors that limits adoption of UAS technology in marine mammal research.

### 4.1.2. Biologging and telemetry

Biologging is the use of animal-borne electronic tags to record data about individuals and their environment (Rutz & Hays 2009; Fig. 2). Biotelemetry refers to the remote transmission of such data when tags cannot be recovered (Hart & Hyrenbach 2009, Hussey et al. 2015). Biologging was pioneered on marine mammals over 50 yr ago (Kooyman 1966), and the field has since developed to facilitate data collection from all marine mammal taxa around the globe (McIntyre 2014). We are in a ‘Golden Age’ of biologging science, with rapid advances in technology and analytical approaches (Ropert-Coudert et al. 2009, Wilmers et al. 2015). Besides the long-established location and dive sensors, an array of additional sensors, including conductivity, temperature, depth (Boehme et al. 2009); accelerometers (Ydesen et al. 2014); magnetometers (Mate et al. 2017) and jaw movement (Liebsch et al. 2007); video (Goldbogen et al. 2013); stomach temperature (Andrews 1998); sound level (Johnson & Tyack 2003); active acoustics (Lawson et al. 2015); and, most recently, near-infrared spectroscopy to measure haemodynamics (McKnight et al. 2019), can be incorporated into biologging devices. Such data and associated analytical tools have provided key information for marine mammal conservation, including inference of important foraging areas (Hindell et al. 2020), and how individuals respond to anthropogenic disturbance (Russell et al. 2016, Isojunno et al. 2017) and environmental change (Hindell et al. 2017, Harcourt et al. 2019b).

As biologging technology and analytical approaches continue to develop, 5 key areas are essential to maximise progress for marine mammal conservation:

1. Improved on-board compression and abstraction techniques for high-resolution data to optimise transmission (Photopoulou et al. 2015, Cox et al. 2018). This will reduce reliance on archival tags, which are currently only appropriate for certain life stages and species that can be easily re-encountered, generating demographic bias in the literature (McIntyre 2014).

2. Improved tag hydrodynamics and bio-compatibility with minimally invasive attachments to limit energetic consequences of carrying a tag (Kyte et al. 2019), thus helping to mitigate tag effects in biologging data and welfare concerns (Wilson & McMahon 2006, Horning et al. 2017).

3. Development of long-lasting miniature tags, allowing individuals to be tracked over multiple years, facilitating estimation of vital rates including survival and recruitment age to improve our understanding of population dynamics (Horning & Hill 2005).
(4) Integration of physiological sensors alongside simultaneous collection of behavioural and environmental data to allow estimation of the true impacts of anthropogenic disturbance on marine mammals at sea (Hays et al. 2016, Pirotta et al. 2018).

(5) Improved integration of biologging and biotelemetry data into international marine policy frameworks for effective conservation (Dunn et al. 2019).

4.1.3. Habitat preference modelling

Habitat preference modelling (HPM) aims to quantify the link between species presence or abundance and environmental covariates (Fig. 3). For marine mammals, modelled relationships are often used to predict the at-sea distribution of populations (Gregor et al. 2013). For pinnipeds, HPM can also be used to predict distributions on land (Dendrinos et al. 2007). Predicted distributions are used to identify priority areas for conservation management (Bailey & Thompson 2009, Embling et al. 2010). Although traditionally such models are based on census or visual survey data (Baumgartner et al. 2003), advances in ecological modelling techniques have facilitated HPM for acoustic survey (Marques et al. 2009, Pirotta et al. 2011, Stanistreet et al. 2018, Merkens et al. 2019) and individual tracking data (Aarts et al. 2008, Wilson et al. 2018).

To maximise the potential of HPM for marine mammal conservation, we identify 4 general (1–4), and 2 data-specific (5–6), challenges, and suggest priorities for future work:

(1) Climate change increases the challenges associated with HPM but also its necessity (Hazen et al. 2013, Silber et al. 2017). Such modelling often involves extrapolating predictions beyond the environmental parameter space in which the model was fitted (Bouchet et al. 2020). Researchers should highlight areas of extrapolation and use multiple climate scenarios to assess the robustness of predictions.

(2) To enhance our ability to predict distributions, we must improve our understanding of the mechanistic relationships between species and the physical (e.g. water depth) and biological (e.g. drivers of prey/predator distributions) processes that shape habitats (Palacios et al. 2013). This shift towards ecosystem-level modelling requires data on diet composition and flexibility (Smout & Lindstrom 2007) but could facilitate more dynamic management strategies (Maxwell et al. 2015).

(3) Where possible, HPM should be activity-specific (Palacios et al. 2019). Not accounting for activity-specific (e.g. foraging, resting and breeding) preferences may result in inaccurate overall preference

Fig. 2. Biologging devices provide a suite of data useful for marine mammal conservation. For example, satellite telemetry devices deployed on grey seals in the southern North Sea record and transmit data on their location, dive activity and haul-out behaviour, which can be used to answer a range of questions relevant to conservation management. Photo and tracks credit: Sea Mammal Research Unit
relationships and inadequate protection (Tyne et al. 2015).

(4) Future research should aim to improve the interface between population models and HPM to directly link population dynamics and habitat trends with species distributions (Hindell et al. 2017).

(5) Models using survey data should propagate uncertainty in detection probabilities to inform uncertainty surrounding predictions (Marques et al. 2009).

(6) HPM for presence-only (i.e. tracking) data often requires various subjective assumptions. More robust predictions depend on understanding the impacts of such assumptions and would benefit from combining multiple data sources to evaluate methods (Mikkelsen et al. 2016, Woodman et al. 2019), and linking inference from the typical HPM landscape-scale models with models of individual movement paths (Signer et al. 2017, Michelot et al. 2019).

4.1.4. Real-time acoustic data

In contrast to light, sound travels well underwater and has become a key source of information on marine mammal species presence, system attributes and harmful anthropogenic activities. Options for deploying acoustic monitoring sensors into appropriate locations are diverse (Van Parijs et al. 2009) and typically rely on passive-acoustic monitoring using hydrophones. The simplest approach is to suspend one or multiple hydrophones in the water, using any platform, from canoes to ships. Vessels can be expensive, however, and impractical for long-term use. Continuous monitoring can be achieved if hydrophones can be cabled to shore. Though more convenient, cables are costly and vulnerable to damage from storms or fishing activities, and require substantial, often military, infrastructure (e.g. Tyack et al. 2011). With the advent of small, low-power electronics, miniaturisation has revolutionised acoustic monitoring, and

Fig. 3. (a) Locations of 104 blue whales {Balaenoptera musculus} were tracked using satellite-monitored radio tags off the US West Coast between 1994 and 2008, with colour shading indicating the number of tagged whales occurring inside 25 km grid cells to highlight the hotspots of highest observed aggregation. Red circles indicate the 3 areas where the tags were deployed (see Bailey & Thompson 2009 for details). Tracks credit: Oregon State University (OSU). (b) Prediction of the likelihood of blue whale occurrence (% chance) based on habitat preference modelling of static and dynamic habitat variables in the California Current ecosystem for September 2019, on a 25 km resolution grid, from the WhaleWatch model available from NOAA at https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/whalewatch (see Hazen et al. 2016 for details)
many options are now available to remotely capture and archive sound without vessels or cables (Sousa-Lima et al. 2013). Hydrophones and recorders are commonly packaged as free-standing units and left alone in the water to record for days, months or longer and can be stationed at any depth by using acoustic release mechanisms (Mellinger et al. 2007). Memory size, battery life, desired sampling rate and duty cycling determine device duration. Units are most often left at sea moored or drifting, alone or in arrays (Van Parijs et al. 2009, Wilson et al. 2014). Further miniaturisation has even made it possible to attach them to the animals themselves (Johnson & Tyack 2003, Fregosi et al. 2016). Passive acoustic monitoring is not suitable for species such as pinnipeds that do not reliably indicate their presence through vocalisations. For these species, active sonar is emerging as a potentially useful monitoring technique (Hastie et al. 2019).

There are a number of situations where stored sound is insufficient and real-time information is needed. Examples include those where animal presence and location are used to observe how they respond to the presentation of particular signals (Tyack et al. 2011) or where industrial activities need be curtailed when animals are present (Verfuss et al. 2016). For such applications, real-time sound might be transferred through cables or via satellite or cellular networks (Lee et al. 2018). Real-time acoustic monitoring of right whales on the east coast of the USA is used to notify mariners of their location, thus reducing the risk of ship strikes (Soldevilla et al. 2014). The high-frequency and cryptic nature of many marine mammal signals, however, mean that sophisticated data compression and automated detectors are required (Gillespie et al. 2009). Here, the ongoing artificial intelligence revolution in signal detection and species classification methods has exciting potential for marine mammal studies. The proliferation of above- and below-water unmanned vehicles has meant that acoustic sensors can be attached and manoeuvred into and through a wide variety of challenging habitats at less cost than traditional approaches (Verfuss et al. 2019). Especially exciting is the possibility of communication and responsive sampling or movement between unmanned vehicles so that all the benefits of applications like arrays can be harnessed without the limitations of being fixed in space. At such a point, listening to marine mammals could be as mobile as the animals themselves. An operational challenge for the marine research community will be to keep abreast of the ever-changing tools long enough to apply, test, debug, validate and optimise them so that they can be used to usefully answer urgent questions required for marine mammal conservation and management.

4.1.5. Electronic monitoring of fisheries

Electronic monitoring (EM) systems are increasingly being used to complement conventional human on-board observer programmes and to initiate at-sea monitoring of fishing practices where none previously existed, and can produce estimates of marine mammal bycatch with high precision and possibly higher accuracy than estimates derived from conventional at-sea observer programmes (Kindt-Larsen et al. 2012, Bartholomew et al. 2018). EM systems typically use on-board cameras, global positioning systems, sensors and data loggers to collect information on fishing, trans-shipment and supply vessels (Restrepo et al. 2018). Properly designed EM systems have several advantages over conventional human observer programmes, in particular, greatly reducing 3 main sources of statistical sampling bias (Monteagudo et al. 2015, Kennelly & Hager 2018, Gilman et al. 2019):

1. Observer effect: Fishers may alter their fishing practices and gear in response to the presence of a human observer or EM system. The higher the observer and EM coverage rate, the lower the bias from an observer effect, where 100% observer coverage would eliminate this source of bias. Having all vessels outfitted with EM equipment and analysing a random sample or all of the EM imagery could eliminate this source of bias.

2. Observer displacement effect: Management authorities may not place observers on vessels that are too small to accommodate an additional person, or because they are unsafe, or it may be logistically challenging for placement. Vessel specification requirements for EM systems are much lower than for a human observer. EM therefore enables avoiding an observer displacement effect so that sampling is random and balanced proportionately across ports and vessel categories.

3. Coercion and corruption: At-sea observers collect sensitive information, and the vessel captain and crew may hinder the observer from properly conducting their monitoring activities, threaten the observer’s safety or attempt to bribe the observer to not report damaging information. Some observers may deliberately misreport sensitive data fields due to friendships with fishers.
EM also provides more accurate data by enabling multiple areas of vessels to be monitored simultaneously and near-continuously, allowing questionable data to be audited. Logbook data self-reported by fishers can be much less reliable than EM data, in particular for discards and bycatch of species of conservation concern, as fishers may have economic or regulatory disincentives to record accurate data, or may be inattentive (e.g. Walsh et al. 2002). Camera set-up, however, can be a weakness for EM systems, as areas on deck or water where crew handle and release non-retained catch may not be within EM camera fields of view (Monteagudo et al. 2015, Larcombe et al. 2016, Bartholomew et al. 2018, Briand et al. 2018). For marine mammals, and other species that crew release, blind spots may prevent EM analysts from determining the species, condition, handling and release methods employed by crew, or what gear remained attached to the animal upon release (McElderry et al. 2010, 2011, Gilman et al. 2020). Minor modifications, such as adding a dedicated camera on the outboard side of the rail near the hauling station (Gilman et al. 2019), obtaining crew cooperation to bring bycatch into the EM camera field of view prior to release, and, if needed, adjusting deck lighting to ensure that areas within the EM cameras' fields of view are adequately lit, could all help address the issues of visibility and detection by cameras (Gilman et al. 2019).

4.1.6. Spatial Monitoring and Reporting Tool patrols

Spatial Monitoring and Reporting Tool (SMART) is a suite of best practices and a free, user-friendly software program (https://smartconservationtools.org/) used by protected-area managers and local communities to document, adaptively manage and evaluate the performance of wildlife enforcement and monitoring patrols. The software can also integrate data collected from other sources, such as informant networks and vessel monitoring systems. Although SMART has been used mostly for terrestrial wildlife enforcement and monitoring patrols, it is also becoming a valuable conservation tool in the marine environment (Cronin et al. 2019). SMART is being pioneered for marine mammal conservation in the waterways of the Sundarbans mangrove forest of Bangladesh which support populations of Ganges river dolphins *Platanista gangetica* and Irrawaddy dolphins *Orcaella brevirostris* (Smith et al. 2006), both considered Endangered on the IUCN Red List (Minton et al. 2017, Braulik & Smith 2019). Between January and September 2018, the Bangladesh Forest Department conducted 63 SMART patrols lasting 10–12 d each and covering more than 68 000 km. A total of 322 offenders were arrested, more than half for illegal fishing that threatened dolphins. In addition, 292 vessels and 312 illegal fishing gears were seized, and 962 georeferenced sightings were made of Ganges river dolphins and 296 of Irrawaddy dolphins.

SMART is also being deployed in the Mekong River, which supports a genetically distinct Irrawaddy dolphin population (Krützen et al. 2018) considered Critically Endangered on the IUCN Red List (Smith & Beasley 2004). Sixty-eight river guards were recruited from local communities and stationed at 16 outposts throughout the 190 km long distribution of Irrawaddy dolphins in the Mekong. SMART patrols resulted in a dramatic increase, from 998 in 2014 to 2596 in 2016, in confiscation of illegal gillnets that bycatch Irrawaddy dolphins and certainly contributed to a reduction in mortality and an increase in dolphin abundance (Thomas & Gulland 2017).

As SMART is adaptable to use in different situations in different environments, it is ideal for guiding effective conservation management and promoting accountability using both top-down (e.g. government led) and bottom-up (e.g. community led) approaches. Information collected on marine mammals during SMART patrols, including geo-referenced sightings and mortalities, can be especially valuable in areas where dedicated studies and local capacity for conducting marine mammal research is lacking. A key factor in the success of SMART is intensive training and mentoring for field-level practitioners and data managers.

4.2. Molecular techniques

The rapid advancement and decreasing cost of DNA sequencing technology provides an ever-expanding suite of tools to assist in marine mammal conservation (Cammen et al. 2016). For example, the investigation of genetic data can highlight vulnerabilities from reduced genetic diversity, examine resilience and plasticity, assess susceptibilities to environmental and anthropogenic stressors, develop necessary management strategies associated with population differentiation and cryptic species, and help to understand the mechanisms that determine these factors. Marine mammal distributions vary from local endemics to global species inhabiting all major ocean
basins (Kaschner et al. 2006). Many species with large ranges are sub-divided among insular regional populations that are genetically differentiated (Hoelzel 2009, Vianna et al. 2010). The identification of these groups can help effective management by defining populations to protect and therefore conserving the evolutionary potential for the species as a whole (Barlow et al. 2018). It is also useful to compare patterns of genetic diversity and demography within and between distinct populations, as local adaptation and differing levels of diversity may reflect different sensitivities to exploitation and disturbance. For example, low genetic diversity in small populations or species increases the risk of inbreeding depression, a loss of evolutionary potential in a changing environment and increased risk of disease (Hoffman et al. 2014, Leroy et al. 2018).

One of the earliest, and still widely used, applications of genetics in marine mammal conservation is the forensic identification of animals to species, and sometimes population, of origin (Ogden & Linacre 2015, Baker & Steel 2018). Sequence data (such as the control region of mitochondrial DNA) from the sample in question is compared to a database of validated species (e.g. Ross et al. 2003), and can reveal illegal harvest and trade (Baker et al. 1996), and quantify the prevalence of a particular species in bycatch (Henshaw et al. 1997) or strandings (Alfonsi et al. 2013). They can even result in the discovery of new species when the samples have no database match (Dalebout et al. 2002). Advancements of these methods have allowed for the identification of specific individuals in genetic monitoring programmes, a particularly useful method to estimate vital life history parameters and connectivity when the recapture of individuals is possible (Carroll et al. 2018).

Future directions in conservation genetics will involve improving new sequencing technologies (Amarasinghe et al. 2020), expanding the use of ‘-omics’ technologies in non-model species, refining methods to extract genomic material from minimally invasive material (i.e. seawater, faeces, exhaled breath, ancient samples; Carroll et al. 2018), combining genetic data with those of other monitoring technologies (e.g. telemetry or demographic) to inform meta-population dynamics (Carroll et al. 2020) and developing tools for storing and analysing vast quantities of genetic data for Big Data analyses (Siepel 2019).

Harnessing the power of advanced gene editing technology may also become an option in the wildlife conservation toolkit, with methods such as clustered regularly interspaced short palindromic repeats (CRISPR/Cas; Cong et al. 2013) and gene drives (Esvelt et al. 2014) opening the doors to de-extinction, more effective and/or humane eradication of pests/invasive species/pathogens, vaccine development and fitness improvements by increasing genetic diversity in the face of accelerating pathogen and climate change threats (Shapiro 2015, Novak et al. 2018).

4.3. Societal engagement

‘Citizen science’ can be defined as the collection or collation and processing of data by members of the public who may not necessarily have scientific credentials, but whose contribution can aid in ongoing scientific research (Bonney et al. 2014, Wood et al. 2015). The ever-increasing popularity of portable electronic devices gives users online accessibility to websites and social media platforms, and enables them to contribute data on subjects such as species occurrence and distribution (Wood et al. 2015) as well as incidents of injury or mortality (e.g. entanglement in plastic pollution; Donnelly-Greenan et al. 2019).

With quality checks, citizen science can be especially useful in gathering information on data-deficient, elusive and difficult to study marine mammal species, particularly in regions of the world where carrying out extensive surveys is logistically and financially challenging (Stafford & Baumgartner 2014, Olson et al. 2018). Information from social media posts can be a source of data where no other data exist and can be mined retrospectively, after citizens have shared their observations (Parton et al. 2019).

In India, a marine mammal data-deficient country, an increase in the number of annual marine mammal sighting/stranding records appeared after 2012 (www.marinemammals.in), when this open access database was first advertised widely, resulting in greater participation from the public and increased information. In Vietnam, another marine mammal data-deficient country, species occurrence and diversity were investigated by data mining social media and other online entries for sightings and stranding events along the entire coastline of the country over a 14 yr period. This yielded 166 events with at least 15 species of cetaceans, including 1 new species record (Vu & Ponnampalam 2018). Citizen science has also been used for more complex investigations. For example, in Australia, data collected by non-specialist volunteers has contributed to understanding local habitat use by migrating humpback whales (Bruce et al. 2014) and enabled scientists to monitor their rate of recovery (Pirotta et al. 2019). Similarly, in New Caledonia, Derville et al. (2018) found that citi-
zen science data were a valuable tool in describing cetacean habitat in a study of humpback whale distribution.

The development of mobile applications, or ‘apps’, has led to the creation of various marine mammal reporting apps that are locality specific, such as Whale Alert, Dolphin and Whale 911, Beach Track, SEAFARI, Whale Track, Happywhale and SIREN. These enable the public to easily report any marine mammal sighting or stranding in a standardised manner that provides researchers with key information. Apps are also an opportunity for the public to become more informed, interested and involved in marine conservation issues (Edwards 2015). Investigating the effectiveness and limitations of mobile apps, as well as citizen science programmes, can improve those platforms and so ensure the quality of the data and enhance the sustenance of these programmes (Thiel et al. 2014, Hann et al. 2018). One caveat, however, is that citizen science programmes are not a panacea and are most valuable when a scientifically robust design is implemented at the outset (Bird et al. 2014, Embling et al. 2015).

5. PARTICULAR TAXA/POPULATIONS THAT ARE IN URGENT NEED OF FOCUS

Despite the great strides made by researchers and conservationists towards finding ways to monitor and protect marine mammals and their habitats, species and populations continue to be lost. The baiji was declared likely extinct in 2006 (Turvey et al. 2007), and the vaquita is close behind. Here, we highlight selected examples of species for which additional focus might yet turn the tide of their fortunes. The North Pacific and the North Atlantic right whales (*Eubalaena* spp.) were driven to near-extinction by whaling by the early 20th century (nearly 30 000 were taken in the North Pacific during 1840–1849 alone; Scarff 2001, Reeves et al. 2007), and the populations have languished since then, even in the absence of whaling (Cooke & Clapham 2018). Right whales remain extremely rare throughout their historical range in the North Pacific, with few recent signs of successful reproduction and recruitment. The main threats to both species are ship strikes and entanglement in fishing gear (Harcourt et al. 2019a). However, climate change may be exacerbating problems by pushing whales further north. Every individual lost lessens the chances of recovery, and research effort focussing on solutions to mitigate these threats is urgently needed.

Similar to the plight of baleen whales, all monk seal species (genera *Monachus* and *Neomonachus*) experienced overhunting by sealers. Of the 3 species, the Caribbean monk seal is extinct, while the Hawaiian and Mediterranean monk seals are IUCN Red-listed as Endangered. After a long history of decline, Hawaiian monk seals managed to stabilize at around 1300 individuals in 2013–2015 (Baker et al. 2016). However, they have particularly low genetic diversity (following a population bottleneck) and have one of the highest documented rates of entanglement of any pinniped (Antonelis et al. 2006). For the Mediterranean monk seal, strong conservation efforts, in Madeira (Portugal), Greece and Mauritania, have enabled seals to persist in a few parts of their now highly fragmented range, but the entire meta-population comprises less than 500 mature individuals (Karamanlidis & Dendrinos 2015). Habitat loss, entanglement in fishing gear, deliberate persecution by fishermen, reduced genetic diversity and a litany of other stressors continue to threaten these seals.

All 4 sirenian species (genera *Dugong* and *Trichechus*) are classified as Vulnerable (Marsh et al. 2011). However, some populations (e.g. West Indian manatees *T. manatus*) are likely to be secure given their location in highly developed countries with advanced conservation practices. In contrast, the future of African manatees *T. senegalensis* is particularly concerning because of the high levels of poverty throughout most of their range, an issue that will be exacerbated by climate change. Similarly, local extinctions of very small, isolated populations of dugongs are likely in East Africa, the South Asian sub-continent, Palau and Japan (Marsh & Sobtzick 2017).

The Critically Endangered Atlantic humpback dolphin *Sousa teuszii*, endemic to nearshore waters between Western Sahara and Angola (Weir & Collins 2015), has a discontinuous distribution, with small remnant populations (typically 10s to low 100s) isolated by hundreds of kilometres. This likely reflects the distribution and relative intensity of several anthropogenic stressors, for example, habitat loss, gillnet fisheries and local consumption as marine bush meat (Collins et al. 2017). Although the conservation prospects in some areas appear ‘intractable’ (Ayissi et al. 2014), with stringent measures, the species’ status could yet improve. An urgent focus is required on known strongholds with explicit measures to reduce bycatch, protect habitat (e.g. through MPA designation) and prevent hunting. To date, however, conservation has been limited by an absence of resources and capacity to conduct much-needed work (Van Waerebeek et al. 2004, Weir et al. 2011, Ayissi et al. 2014).
In southern Asia, small coastal, lagoonal and riverine populations of river dolphins (*Platanista*), Irrawaddy dolphins (*Orcaella spp.*), Indo-Pacific humpback dolphins (*Sousa spp.*) and finless porpoises (*Neophocaena spp.*) are threatened primarily by entanglement in gillnets and other fishing gear, and secondarily by chemical and noise pollution, loss and degradation of habitat as a result of water management policies and structures, competition with fisheries, inland shipping and low levels of hunting (Sutaria 2009, Sutaria et al. 2015, Khanal et al. 2016, Minton et al. 2017, Sule et al. 2017, Braulik & Smith 2019, Dey et al. 2019). The risk of losing local populations rises as their numbers become smaller over time in a region that is under immense development pressure, with ever-increasing human population densities and little or no evident political will to protect biodiversity and natural habitat.

The maritime fur trade of the 18th and 19th centuries caused a significant decline in sea otter populations, reducing their numbers from approximately ~300 000 to less than ~2000 individuals (Davis et al. 2019). Although some populations are now recovering due to the implementation of multi-national management measures, the pre-exploitation range of this species is highly fragmented, and some populations remain in decline due to issues such as habitat degradation and loss, oil spills, potential fisheries interactions, predation and disease events (Doroff & Burdin 2015).

Although some sub-populations of polar bears may initially benefit from the effects of climate change on sea-ice thickness (Laidre et al. 2020b), rising temperatures pose severe risks to the species as a whole. A reduction in sea-ice leads to diminished access to prey and lower reproductive success (Laidre et al. 2020a), as well as increased disturbance from humans due to the opening up of new shipping routes (Gross 2018). Accurate population estimates for polar bears are limited, and the current population trend for the species is unknown. Large reductions in the global polar bear population are predicted, however, if sea-ice loss continues as forecasted by climate models (Wiig et al. 2015).

### 6. CONCLUSION

Marine mammals are a diverse group, inhabiting marine, estuarine and many riverine environments globally. While very few marine mammal species have been driven to extinction in modern times, continued increases in anthropogenic pressures on our marine and freshwater ecosystems are placing new and powerful stressors on many species and populations. As we begin the Decade of Ocean Science for Sustainable Development, we have taken a renewed synthetic view of these key threats, discussed existing and future conservation mechanisms and outlined emerging research and monitoring techniques that can be engaged to help safeguard marine mammals over the horizon.

Acknowledgements. We thank Gill Braulik, Frances Gulland, Gianna Minton, Andrew Read, Randall Reeves, Brian Smith, 3 anonymous reviewers and the Editor for their valuable and insightful comments that improved the manuscript. S.E.N. acknowledges funding from the Natural Environment Research Council (NE/L002434/1). S.E.N. and B.J.G. also acknowledge support from the European Union (INDI CTT; EU grant agreement no. 110661/2018/794561/SUB/ ENV.C2). E.C. has a doctoral fellowship from the World Wildlife Foundation - Education for Nature. M.I.D.C. was supported by the UK Department for Business and Industrial Strategy (BEIS; project number OESEA-16-78). D.J.F.R. was supported by National Capability funding from the UK Natural Environment Research Council (NERC) to the Sea Mammal Research Unit (SMRU) (grant no. SMRU1001). A.B.O. acknowledges funding from the Office of Naval Research (award no. N0001416113017). D.M.P. was supported by the Whale Habitat Professorship Endowment Fund, Marine Mammal Institute, Oregon State University. K.A.S. was supported by a Royal Society of New Zealand Te Aparangi Rutherford Discovery Fellowship.

**LITERATURE CITED**

- Aarts G, Mackenzie M, McConnell B, Fedak M, Matthiopoulos J (2008) Estimating space-use and habitat preference from wildlife telemetry data. Ecography 31:140–160
- Abreo NAS, Macusi ED, Blatchley DD, Cuenca-Ocay G (2016) First evidence of plastic ingestion by the rare Deraniyagala’s beaked whale (*Mesoplodon hotaula*). IAMURE Int J Ecol Conserv 19:16–36
- Agardy T, Notarbortolo di Scia G, Christie P (2011) Mind the gap: addressing the shortcomings of marine protected areas through large scale marine spatial planning. Mar Policy 35:226–232
- Agnew DJ, Gutiérrez NL, Stern-Pirlot A, Hoggarth DD (2014) The MSC experience: developing an operational certification standard and a market incentive to improve fishery sustainability. ICES J Mar Sci 71:216–225
- Aguirre AA, Tabor GM (2004) Introduction: marine vertebrates as sentinels of marine ecosystem health. EcoHealth 1:236–238
- Albouy C, Delattre VL, Mérigot B, Meynard CN, Leprieur F (2017) Multifaceted biodiversity hotspots of marine mammals for conservation priorities. Divers Distrib 23:615–626
- Alexiadou P, Foskoulos I, Frantzis A (2019) Ingestion of macroplastics by odontocetes of the Greek Seas, Eastern Mediterranean: often deadly! Mar Pollut Bull 146:67–75
- Alfonso E, Méheust E, Fuchs S, Carpentier FG and others (2013) The use of DNA barcoding to monitor the marine mammal biodiversity along the French Atlantic coast. ZooKeys 365:5–24
Allen BM, Ierodiaconou D, Hoskins AJ, Arnould JPY (2019) A rapid UAV method for assessing body condition in fur seals. Drones 3:24

Allen R, Jarvis D, Sayer S, Mills C (2012) Entanglement of grey seals Halichoerus grypus at a haul out site in Cornwall, UK. Mar Pollut Bull 64:2815−2819

Amarasinghe SL, Su S, Dong X, Zappia L, Ritchie ME, Gouil ALLAN BM, Ierodiaconou D, Hoskins AJ, Arnould JPY (2019) A comparison of baleen whale density estimates associated uncertainty. Endang Species Res 31:317−324

Arraut EM, Arraut JL, Marmontel M, Mantovani JE, de Solano, Chocó, Colombia. J Cetacean Res Manag 10:196−203

Avila IC, Garcia C, Bastidas JC (2008) A note on the use of dolphins as bait in the artisanal fisheries off Bahía Solano, Chocó, Colombia. J Cetacean Res Manag 10:179−182

Avila IC, Kaschner K, Dorrnann CF (2018) Current global risks to marine mammals: taking stock of the threats. Biol Conserv 221:44−58

Avila IC, Dorrnann CF, García C, Payán LF, Zorrilla MX (2020) Humpback whales extend their stay in a breeding ground in the Tropical Eastern Pacific. ICES J Mar Sci 77:109−118

Ayissi I, Segniagbeto GH, Van Waerebeek K (2014) Rediscovery of Cameroon dolphin, the Gulf of Guinea population of Sousa teuszii (Kükenthal, 1892). I. SSRN Biodivers 2014:819827

Bailey H, Thompson PM (2009) Using marine mammal habitat modelling to identify priority conservation zones within a marine protected area. Mar Ecol Prog Ser 378:279−287

Bailey H, Brookes KL, Thompson PM (2014) Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquat Biosyst 10:8

Baird RW, Hooker SK (2000) Ingestion of plastic and unusual prey by a juvenile harbour porpoise. Mar Pollut Bull 40:719−720

Baker CS, Steel D (2018) Genetics, forensics. In: Würsig B, Thewissen JGM, Kovacs KM (eds) Encyclopedia of marine mammals, 3rd edn. Academic Press, San Diego, CA, p 406−410

Baker CS, Cipriano F, Palumbi SR (1996) Molecular genetic identification of whale and dolphin products from commercial markets in Korea and Japan. Mol Ecol 5:671−685

Baker JD, Howell EA, Polovina JJ (2012) Relative influence of climate variability and direct anthropogenic impact on a sub-tropical Pacific top predator, the Hawaiian monk seal. Mar Ecol Prog Ser 469:175−189

Baker JD, Harting AL, Johanos TC, Littnan CL (2016) Estimating Hawaiian monk seal range-wide abundance and associated uncertainty. Endang Species Res 31:317−324

Bamford CCG, Kelly N, Dalla Rosa L, Cade DE and others (2020) A comparison of baleen whale density estimates derived from overlapping satellite imagery and a shipborne survey. Sci Rep 10:12985

Barbieri MM, Kashinsky L, Rolstein DS, Colegrove KM and others (2016) Protozoal-related mortalities in endangered Hawaiian monk seals Neomonachus schauinslandi. Dis Aquat Org 121:85−95

Barbosa A, Varsani A, Morandini V, Grimaldi W and others (2021) Risk assessment of SARS-CoV-2 in Antarctic wildlife. Sci Total Environ 755:143352

Barbosa-Filho MLV, Barreto RMF, Siciliano S, Seminara CI, Costa-Neto EM (2018) Use of cetaceans as bait in southern Bahia, Brazil, by expert fishermen that market shark fins. Ethnobiol Lett 9:12−18

Barlow DR, Torres LG, Hodge KB, Steel D and others (2018) Documentation of a New Zealand blue whale population based on multiple lines of evidence. Endang Species Res 36:27−40

Bartholomew DC, Mangel JC, Alfaro-Shigueto J, Pingo S, Jimenez A, Godley BJ (2018) Remote electronic monitoring as a potential alternative to on-board observers in small-scale fisheries. Biol Conserv 219:35−45

Baulch S, Perry C (2014) Evaluating the impacts of marine debris on cetaceans. Mar Pollut Bull 80:210−221

Baumgartner MF, Cole TVN, Clapham PJ, Mate BR (2003) North Atlantic right whale habitat in the lower Bay of Fundy and on the SW Scotian Shelf during 1999−2001. Mar Ecol Prog Ser 264:137−154

Bearzi G, Politi E, Agazzi S, Azzellino A (2006) Prey depletion caused by overfishing and the decline of marine megafauna in eastern Ionian Sea coastal waters (central Mediterranean). Biol Conserv 127:373−382

Beasley I, Bejder L, Marsh H (2014) Cetacean-watching in developing countries. In: Higham J, Bejder L, Williams R (eds) Whale-watching: sustainable tourism and ecological management. Cambridge University Press, Cambridge, p 307−321

Beausoleil NJ, Mellor DJ, Baker L, Baker SE and others (2018) ‘Feelings and fitness’ not ‘feelings or fitness’—the raison d’être of conservation welfare, which aligns con-
Bengtson Nash S (2018) Toxicological risks and considerations associated with lipophilic contaminant burdens of Southern Ocean mysticetes. In: Fossi C, Panti C (eds) Marine mammal ecotoxicology: impacts of multiple stressors on population health. Academic Press, p 381–401

Benjamins S, Hamois V, Smith HCM, Johanning L, Greenhill L, Carter C, Wilson B (2014) Understanding the potential for marine megafauna entanglement risk from marine renewable energy developments. Scottish Natural Heritage Commissioned Report No. 791. https://www.nature.scot/naturescot-commissioned-report-791-understanding-potential-marine-megafauna-entanglement-risk

Besseling E, Foekema EM, Van Franeker JA, Leopold MF and others (2015) Microplastic in a macro filter feeder: humpback whale Megaptera novaeangliae. Mar Pollut Bull 95:248–252

Bestley S, Ropert-Coudert Y, Bengtson Nash S, Brooks CM and others (2020) Marine ecosystem assessment for the Southern Ocean: birds and marine mammals in a changing climate. Front Ecol Evol 8:566936

Bielli A, Alfaro-Shigueto J, Doherty PD, Godley BJ and others (2020) An illuminating idea to reduce bycatch in the Peruvian small-scale gillnet fishery. Biol Conserv 241:108277

Bille M, Dendiu R, Borne K, Baker L, Brune S, Byrnes I, Round C (2018) Microsats and Moby Dick: microsatellite support to whale science and conservation. SCC18-V-07. 32nd Annual AIAA/USU Conference on Small Satellites. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=4098&context=smallsat

Bird TJ, Bates AE, Lefcheck JS, Hill NA and others (2014) Statistical solutions for error and bias in global citizen science datasets. Biol Conserv 173:144–154

Boehlert GW, Gill AB (2010) Environmental and ecological effects of ocean renewable energy development. Oceanography 23:68–81

Boehme L, Lovell P, Biuw M, Roquet F and others (2009) Animal-borne CTD-Satellite Relay Data Loggers for real-time oceanographic data collection. Ocean Sci 5:685–695

Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ, Parrish JK (2014) Next steps for citizen science. Science 343:1436–1437

Bordino P, Mackay AI, Wener TB, Northridge SP, Read AJ (2013) Francisca bycatch is not reduced by acoustically reflective or physically stiffened gillnets. Endang Species Res 21:1–12

Bossart GD (2011) Marine mammals as sentinel species for oceans and human health. Vet Pathol 48:676–690

Bouchet P, Miller D, Roberts J, Mannocci L, Harris C, Thomas L (2020) Dsmextra: Extrapolation assessment tools for density surface models. Methods Ecol Evol 11:1464–1469

Bowen WD (1997) Role of marine mammals in aquatic ecosystems. Mar Ecol Prog Ser 158:267–274

Bowkett AE (2009) Recent captive-breeding proposals and the return of the ark concept to global species conservation. Conserv Biol 23:773–776

Boyd I, Hanson N, Tynan CT (2019) Effects of climate change on marine mammals. In: Cochrane JK, Bokuniewicz HJ, Yager PL (eds) Encyclopedia of ocean sciences, 3rd edn. Academic Press, p 416–419

Braulik GT, Smith B (2019) South Asian river dolphin Platanista gangetica (amended version of 2017 assessment). The IUCN Red List of Threatened Species 2019: e.T41758A151913336. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T41758A151913336.en

Braulik GT, Arshad M, Noureen U, Northridge SP (2014) Habitat fragmentation and species extirpation in freshwater ecosystems: causes of range decline of the Indus river dolphin (Platanista gangetica minor). PLOS ONE 9: e101657

Briand K, Bonieux A, Le Dantec W, Le Couls S and others (2018) Comparing electronic monitoring system with observer data for estimating non-target species and discards on French tropical tuna purse seine vessels. Collect Vol Sci Pap ICCAT 74:3813–3831

Brown TM, Macdonald RW, Muir DCG, Letcher RJ (2018) The distribution and trends of persistent organic pollutants and mercury in marine mammals from Canada’s Eastern Arctic. Sci Total Environ 618:500–517

Brownell RL Jr, Reeves RR, Read AJ, Smith BD and others (2019) Bycatch in gillnet fisheries threatens Critically Endangered small cetaceans and other aquatic megafauna. Endang Species Res 40:285–296

Bruce E, Albright L, Sheehan S, Blewitt M (2014) Distribution patterns of migrating humpback whales (Megaptera novaeangliae) in Jervis Bay, Australia: a spatial analysis using geographical citizen science data. Appl Geogr 54:83–95

Burek KA, Gulland FMD, O’Hara TM (2008) Effects of climate change on Arctic marine mammal health. Ecol Appl 18:S126–S134

Burnett JD, Lemos L, Barlow D, Wing MG, Chandler T, Torres LG (2019) Estimating morphometric attributes of baleen whales with photogrammetry from small UASs: a case study with blue and gray whales. Mar Mamm Sci 35:108–139

Cammen KM, Andrews KR, Carroll EL, Foote AD and others (2016) Genomic methods take the plunge: recent advances in high-throughput sequencing of marine mammals. J Hered 107:481–495

Campbell E, Mangel JC, Alfaro-Shigueto J, Mena JL, Thurstan RH, Godley BJ (2020) Coexisting in the Peruvian Amazon: interactions between fisheries and river dolphins. J Nat Conserv 56:125839

Carrell HA, Beyer HL, Dennis TE, Dwyer RG and others (2015) Finding our way: on the sharing and reuse of animal telemetry data in Australasia. Sci Total Environ 534:79–84

Canessa S, Converse SJ, West M, Clemann N and others (2016) Planning for ex situ conservation in the face of uncertainty. Conserv Biol 30:599–609

Carretta JV, Barlow J (2011) Long-term effectiveness, failure rates, and ‘dinner bell’ properties of acoustic pingers in a gillnet fishery. Mar Technol Soc J 45:7–19

Carroll EL, Bruford MW, DeWoody JA, Leroy G, Strand A, Waits L, Wang J (2018) Genetic and genomic monitoring using minimally invasive sampling methods. Evol Appl 11:1094–1119

Carroll EL, Hall A, Olsen MT, Onoufriou AB, Gaggiotti OE, Russell DJ (2020) Perturbation drives changing metapopulation dynamics in a top marine predator. Proc R Soc B 287:20200318

Castro C, Van Waerebeek K, Cárdenas D, Alava JJ (2020) Marine mammals used as bait for improvised fish aggre-
gating devices in marine waters of Ecuador, eastern tropical Pacific. Endang Species Res 41:289–302

Chilvers BL, Meyer S (2017) Conservation needs for the endangered New Zealand sea lion, Phocarctos hookeri. Aquat Conserv 27:846–855

Cholewiak D, Clark CW, Pomirakis D, Franken A and others (2018) Communicating amidst the noise: modeling the aggregate influence of ambient and vessel noise on baleen whale communication space in a national marine sanctuary. Endang Species Res 36:59–75

Choudhary S, Dey S, Dey S, Sagar V, Nair T, Kelkar N (2012) River dolphin distribution in regulated river systems: implications for dry-season flow regimes in the Gangetic basin. Aquat Conserv 22:11–25

Christiansen F, Vivier F, Charlton C, Ward R, Amerson A, Burnell S, Bejder L (2018) Maternal body size and condition determine calf growth rates in southern right whales. Mar Ecol Prog Ser 592:267–281

Clark CW, Ellision WT, Southall BL, Hatch L, Van Parijs SM, Franken A, Pomirakis D (2009) Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Mar Ecol Prog Ser 395:201–222

Clay TA, Mangel JC, Alfaro-Shigueto J, Hodgson DJ, Godley BJ (2018) Distribution and habitat use of a cryptic small cetacean, the Burmeister’s porpoise, monitored from a small-scale fishery platform. Front Mar Sci 5:220

Collins T, Braulik GT, Perrin W (2017) Atlantic humpback dolphin Sousa teuszii (errata version published in 2018). The IUCN Red List of Threatened Species 2017: e.T20425A123792373.e. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T20425A123792373.en

Cong L, Ran FA, Cox D, Lin S and others (2013) Multiplex genome engineering using CRISPR/Cas systems. Science 339:819–823

Cooke JG, Clapham PJ (2018) North Pacific right whale Eubalaena japonica. The IUCN Red List of Threatened Species 2018: e.T41711A50380694. https://dx.doi.org/10.2305/IUCN.UK.2018-1.RLTS.T41711A50380694.en

Cordes LS, Duck CD, Mackey BL, Hall AJ, Thompson PM (2011) Long-term patterns in harbour seal site-use and the consequences for managing protected areas. Anim Conserv 14:430–438

Corrigan CM, Ardron JA, Comeros-Raynal MT, Hoyt E, Notarbartolo Di Sciara G, Carpenter KE (2014) Developing important marine mammal area criteria: learning from ecologically or biologically significant areas and key biodiversity areas. Aquat Conserv 24:166–183

Cosentino AM, Fisher S (2016) The utilization of aquatic bushmeat from small cetaceans and manatees in South America and West Africa. Front Mar Sci 3:163

Cox SL, Orgeret F, Gesta M, Rodde C, Heizer I, Weimerskirch H, Guinet C (2018) Processing of acceleration and orientation data from a small-scale fishery platform. Front Mar Sci 5:220

Cronin DT, Holmes K, Buddo D (2019) Marine protected areas are getting SMART (commentary). https://news.mongabay.com/2019/03/marine-protected-areas-are-getting-smart-commentary

Crawford HC, Newton PT, Bamford C, Gerrish L, Jackson JA (2019) Whales from space: four mysticete species described using new VHR satellite imagery. Mar Mamm Sci 35:466–491

da Silva V, Trujillo F, Martin A, Zerbini AN, Crespo E, Aliaga-Rossel E, Reeves R (2018) Amazon river dolphin Inia geoffrensis. The IUCN Red List of Threatened Species 2018: e.T10831A50358152. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T10831A50358152.en

Dalebout ML, Mead JG, Baker CS, Baker AN, Van Helden AL (2002) A new species of beaked whale Mesoplodon perrini sp. n. (Cetacea: Ziphiidae) discovered through phylogenetic analyses of mitochondrial DNA sequences. Mar Mamm Sci 18:577–608

Daly KL, Passow U, Chanton J, Hollander D (2016) Assessing the impacts of oil-associated marine snow formation and sedimentation during and after the Deepwater Horizon oil spill. Anthropocene 13:18–33

David JA (2006) Likely sensitivity of bottlenose dolphins to pile-driving noise. Water Environ J 20:48–54

Davidson AD, Boyer AG, Kim H, Pompa-Mansilla S and others (2012) Drivers and hotspots of extinction risk in marine mammals. Proc Natl Acad Sci USA 109:3395–3400

Davis RW, Bodkin JL, Coletti HA, Monson DH, Larson SE, Carswell LP, Nichol LM (2019) Future directions in sea otter research and management. Front Mar Sci 5:510

Dawson SM, Northbridge S, Waples D, Read AJ (2013) To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. Endang Species Res 19:201–221

Day J, Dudley N, Hockings M, Holmes G and others (2019) Guidelines for applying the IUCN protected area management categories to marine protected areas, 2nd edn. https://portals.iucn.org/library/node/48887

De Pooter D, Appelants W, Bailly N, Bristol S and others (2017) Toward a new data standard for combined marine biological and environmental datasets—expanding OBIS beyond species occurrences. Biodivers Data J 5:e10989

d.de Stephanis R, Giménez J, Carpinelli E, Gutierrez-Exposito C, Cañadas A (2013) As main meal for sperm whales: plastics debris. Mar Pollut Bull 69:206–214

DeAlteris J (1999) Design, testing, and evaluation of an acoustic release system for offshore lobster pot buoy lines. NMFS Project No. 40EANF800065, submitted to the NMFS Fisheries Engineering Group. https://www.bycatch.org/sites/default/files/DeAlteris_1999.pdf

Dendrinos P, Karamanlidis AA, Kotomatas S, Legakis A, Tounta E, Matthiopoulos J (2007) Pupping habitat use in the Mediterranean monk seal: a long-term study. Mar Mamm Sci 23:615–628

Derville S, Torres LG, Iovan C, Garrigue C (2018) Finding the right fit: comparative cetacean distribution models using multiple data sources and statistical approaches. Divers Distrib 24:1657–1673

Desforges JP, Levin M, Jaspere L, De Guise S and others (2017) Effects of polar bear and killer whale derived contaminant cocktails on marine mammal immunity. Environ Sci Technol 51:11431–11439

Desforges JP, Hall A, McConnell B, Rosing-Asvid A and others (2018) Predicting global killer whale population collapse from PCB pollution. Science 361:1373–1376

Dey M, Krishnaswamy J, Morisaka T, Kelkar N (2019) Interacting effects of vessel noise and shallow river depth elevate metabolic stress in Ganges river dolphins. Sci Rep 9:15426

Diaz López B, Methion S (2019) Habitat drivers of endangerment for humpback whales in a highly impacted upwelling region. Ecol Indic 103:610–616

Donnelly-Greenan EL, Nevins HM, Harvey JT (2019) Entangled seabird and marine mammal reports from citizen science surveys from coastal California (1997–2017). Mar Pollut Bull 149:110557
Karamanlidis AA, Androukaki E, Adamantopoulou S, Kaschner K, Tittensor DP, Ready J, Gerrodette T, Worm B, Kenney RD (2018) What if there were no fishing? North Kastelein RA, Lavaleije MSS (1992) Foreign bodies in the Kasten R, Watson R, Trites AW, Pauly D (2006) Mapping KADFak A (2020) More than just fishing: the formation of Johnston DW (2019) Unoccupied aircraft systems in marine mammal conservation: over the horizon.
impacts and solutions. Springer-Verlag, New York, NY, p 99–139

Laist DW, Knowlton AR, Mead JG, Collet AS, Podesta M (2001) Collisions between ships and whales. Mar Mamm Sci 17:35–75

Larcombe J, Noriega R, Timmiss T (2016) Catch reporting under e-monitoring in the Australian Pacific longline fishery. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra

Larsen F, Engaard OR, Tougaard J (2007) Reduction of harbour porpoise (Phocoena phocoena) bycatch by iron-oxide gillnets. Fish Res 85:270–278

LaRue MA, Stapleton S (2018) Estimating the abundance of polar bears on Wrangel Island during late summer using high-resolution satellite imagery: a pilot study. Polar Biol 41:2621–2626

LaRue MA, Rotella JJ, Garrott RA, Siniß DB and others (2011) Satellite imagery can be used to detect variation in abundance of Weddell seals (Leptonychotes weddellii) in Erebos Bay, Antarctica. Polar Biol 34:1727

Lawson GL, Hückstädt LA, Lavery AC, Jaﬀré FM and others (2015) Development of an animal-borne ‘sonar tag’ for quantifying prey availability: test deployments on northern elephant seals. Anim Biotelem 3:22

Lee A, Porter L, Turner J, Wood J (2018) The coastal acoustic buoy: a new mitigation tool for marine mammal monitoring. Western Pacific Acoustics Conference, New Delhi.

Lennox RJ, Harcourt R, Bennett JR, Davies A and others (2020) A novel framework to protect animal data in a world of e-surveillance. BioScience 70:468–476

Leroy G, Carroll EL, Bruﬀord MW, DeWoody JA, Strand A, Waits L, Wang J (2018) Next-generation metrics for monitoring genetic erosion within populations of conservation concern. Evol Appl 11:1066–1083

Levy AM, Brenner O, Scheinin A, Morick D, Ratner E, Goffern O, Kerem D (2009) Laryngeal snaring by ingested fishing net in a common bottlenose dolphin (Tursiops truncatus) off the Israeli shoreline. J Wildl Dis 45:834–838

Lewison RL, Soykan CU, Cox T, Peckham H and others (2011) Ingredients for addressing the challenges of fisheries bycatch. Bull Mar Sci 87:235–250

Lewison RL, Crowder LB, Wallace BP, Moore JE and others (2014) Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proc Natl Acad Sci USA 111:5271–5276

Liebsch N, Wilson RP, Borneham H, Adelung D, Plötz J (2007) Mouthing off about fish capture: jaw movement in pinnipeds reveals the real secrets of ingestion. Deep Sea Res II 54:256–269

Lotze HK, Coll M, Magera AM, Ward-Paige C, Airoldi L (2011) Recovery of marine animal populations and ecosystems. Trends Ecol Evol 26:595–605

Lusher AL, Hernandez-Milian G, O’Brien J, Berrow S, O’Connor I, Ofﬁcer R (2015) Microplastic and macroplastic ingestion by a deep diving, oceanic cetacean: the True’s beaked whale Mesoplodon mirus. Environ Pollut 199:185–191

Lyle JM, Willcox ST, Hartmann K (2016) Underwater observations of seal–ﬁshery interactions and the effectiveness of an exclusion device in reducing bycatch in a midwater trawl ﬁshery. Can J Fish Aquat Sci 73:436–444

Machado R, Ott PH, Moreno IB, Danilewicz D and others (2016) Operational interactions between South American sea lions and gillnet fishing in southern Brazil. Aquat Conserv 26:108–120

Magagna D, Uihlein A (2015) Ocean energy development in Europe: current status and future perspectives. Int J Mar Energy 11:84–104

Magera AM, Mills Flemming JE, Kaschner K, Christensen LB, Lotze HK (2013) Recovery trends in marine mammal populations. PLOS ONE 8:e77908

Mangel JC, Alfaro-Shigueto J, Van Waerebeek K, Cáceres C, Bearhop S, Witt MJ, Godley BJ (2010) Small cetacean captures in Peruvian artisanal ﬁsheries: high despite protective legislation. Biol Conserv 143:136–143

Manuel C, Ritter F (2010) Increasing numbers of ship strikes in the Canary Islands: proposals for immediate action to reduce risk of vessel–whale collisions. J Cetacean Res Manag 11:131–138

Marques TA, Thomas L, Ward J, DiMarzio N, Tyack PL (2009) Estimating cetacean population density using ﬁxed passive acoustic sensors: an example with Blainville’s beaked whales. J Acoust Soc Am 125:1982–1994

Marsh H, Sobtzick S (2017) Dugong Dugong dugon. IUCN Red List Threat Species:e.T6909A43792211. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T6909A43792211.en

Marsh H, O’Shea TJ, Reynolds JE III (2011) Ecology and conservation of the Sirenia: dugongs and manatees. Cambridge University Press, Cambridge.

Martin TG, Nally S, Burbidge AA, Arnall S and others (2012) Acting fast helps avoid extinction. Conserv Lett 5:274–280

Martins MCI, Sette L, Josephson E, Bogomolni A and others (2019) Unoccupied aerial system assessment of entanglement in Northwest Atlantic gray seals (Halichoerus grypus). Mar Mammal Sci 35:1613–1624

Mate BR, Irvine LM, Palacios DM (2017) The development of an intermediate-duration tag to characterize the diving behavior of large whales. Ecol Evol 7:585–595

Mathavarajah S, Stoddart AK, Gagnon GA, Dellaire G (2021) Pandemic danger to the deep: the risk of marine mammals contracting SARS-CoV-2 from wastewater. Sci Total Environ 760:143346

Maxwell SM, Hazen EL, Bograd SJ, Halpern BS and others (2013) Cumulative human impacts on marine predators. Nat Commun 4:2688

Maxwell SM, Ban NC, Morgan LE (2014) Pragmatic approaches for effective management of pelagic marine protected areas. Endang Species Res 26:59–74

Maxwell SM, Hazen EL, Lewison RL, Dunn DC and others (2015) Dynamic ocean management: deﬁning and conceptualizing real-time management of the ocean. Mar Policy 58:42–50

Maxwell SM, Gjerde KM, Connors MG, Crowder LB (2020) Mobile protected areas for biodiversity on the high seas. Science 367:252–254

McCarthy MA, Possingham HP (2007) Active adaptive management for conservation. Conserv Biol 21:956–963

McClanachan L, Cooper AB (2008) Extinction rate, historical population structure and ecological role of the Caribbean monk seal. Proc R Soc B 275:1351–1358

McElderry H, Pria MJ, Dyas M, McVeigh R (2010) A pilot study using EM in the Hawaiian longline ﬁshery. Report prepared for the Western Paciﬁc Fishery Management Council. Archipelago Marine Research Ltd., Victoria

McElderry H, Beck M, Pria MJ, Anderson S (2011) Electronic monitoring in the New Zealand inshore trawl ﬁsh-
ery: a pilot study. DOC Mar Conserv Serv Ser 9. Department of Conservation, Wellington

McFadden JE, Hiller TL, Tyre AJ (2011) Evaluating the efficacy of adaptive management approaches: Is there a formula for success? J Environ Manag 92:1354–1359

McIntosh R, Holmberg R, Dann P (2018) Looking without landing—using remote piloted aircraft to monitor fur seal populations without disturbance. Front Mar Sci 5:202

McIntyre T (2014) Trends in tagging of marine mammals: a review of marine mammal biologging studies. Afr J Mar Sci 36:409–422

McKnight JC, Bennett KA, Galloway TS, Godley BJ, Jarvis DS, Lindeque PK (2018) Investigating microplastic trophic transfer in marine top predators. Environ Pollut 236:999–1007

McNelms SE, Barnett J, Brownlow A, Davison NJ and others (2019a) Microplastics in marine mammals stranded around the British coast: ubiquitous but transitory? Sci Rep 9:1075

McNelms SE, Parry HE, Bennett KA, Galloway TS, Godley BJ, Santillo D, Lindeque PK (2019b) What goes in, must come out: combining scat-based molecular diet analysis and quantification of ingested microplastics in a marine top predator. Methods Ecol Evol 10:1712–1722

Meyer S, Robertson BC, Chilvers BL, Krkošek M (2017) Effects of rearing methods on survival of released free-ranging juvenile southern sea otters. Biol Conserv 138:313–320

Mcknight JC, Stafford KM, Moore SE, Dziak RP, Matsumoto H (2007) An overview of fixed passive acoustic methods for cetaceans. Oceanography 20:45

Merkens KP, Simonis AE, Oleson EM (2019) Geographic and temporal patterns in the acoustic detection of sperm whales Physeter macrocephalus in the central and western North Pacific Ocean. Endang Species Res 39:115–133

Meyer S, Robertson BC, Chilvers BL, Krkošek M (2017) Marine mammal population decline linked to obscured bycatch. Proc Natl Acad Sci USA 114:11781–11786

Michelot T, Blackwell PG, Mathiopoulos J (2019) Linking resource selection and step selection models for habitat preferences in animals. Ecology 100:e02452

Mikkelsen L, Riget FF, Kyhn LA, Sveegaard S and others (2016) Comparing distribution of harbour porpoises Phocoena phocoena derived from satellite telemetry and passive acoustic monitoring. PLOS ONE 11:e0158788

Minton G, Smith BD, Braulik GT, Kreb D, Sutaria D, Reeves R (2017) Irrawaddy dolphin Orcaella brevirostris (errata version published in 2018). The IUCN Red List of Threatened Species 2017: e.T15419A123790805. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T15419A103678960.en

Mintzer VJ, Diniz K, Frazer TK (2018) The use of aquatic mammals for bait in global fisheries. Front Mar Sci 5:191

Monteagudo JP, Legorburu G, Justel-Rubio A, Restrepo V (2015) Preliminary study about the suitability of an electronic monitoring system to record scientific and other information from the tropical tuna purse seine fishery. Collect Vol Sci Pap ICCAT 71:440–459

Moore SE (2008) Marine mammals as ecosystem sentinels. J Mammal 89:534–540

Moore SE, Huntington HP (2008) Arctic marine mammals and climate change: impacts and resilience. Ecol Appl 18:S157–S165

Moore SE, Reeves RR (2018) Tracking arctic marine mammal resilience in an era of rapid ecosystem alteration. PLOS Biol 16:e2006708

Moreland EE, Cameron MF, Angliss RP, Boveng PL (2015) Evaluation of a ship-based unoccupied aircraft system (UAS) for surveys of spotted and ribbon seals in the Bering Sea pack ice. J Unmanned Veh Syst 3:114–122

Moreno CA, Castro R, Mújica L, Reyes P (2008) Significant conservation benefits obtained from the use of a new fishing gear in the Chilean Patagonian toothfishery. CCAMLR Sci 15:79–91

Moxley JH, Bogomolni A, Hammill MO, Moore KMT and others (2017) Google haul out: Earth observation imagery and digital aerial surveys in coastal wildlife management and abundance estimation. Bioscience 67:760–768

Mozumder MMH, Shamsuzzaman MM, Rashid-Un-Nabi M, Karim E (2018) Social-ecological dynamics of the small scale fisheries in Sundarban Mangrove Forest, Bangladesh. Aquacult Fish 3:38–49

Mustika PLK, Welters R, Ryan GE, D’Lima C, Sorongon-Yap P, Jutapruet S, Peter C (2017) A rapid assessment of wildlife tourism risk posed to cetaceans in Asia. J Sustain Tour 25:1138–1158

Nelms SE, Williams JE, Lichatowich JA (1991) Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16:4–21

Nelms SE, Galloway TS, Godley BJ, Jarvis DS, Lindeque PK (2018) Comparing distribution of harbour porpoises Phocoena phocoena in the central and western North Pacific Ocean. Endang Species Res 37:39–45

Nelms SE, Barnett J, Brownlow A, Davison NJ and others (2019a) Microplastics in marine mammals stranded around the British coast: ubiquitous but transitory? Sci Rep 9:1075

Nelms SE, Parry HE, Bennett KA, Galloway TS, Godley BJ, Santillo D, Lindeque PK (2019b) What goes in, must come out: combining scat-based molecular diet analysis and quantification of ingested microplastics in a marine top predator. Methods Ecol Evol 10:1712–1722

Nguyen VM, Brooks JL, Young N, Lennox RJ and others (2017) To share or not to share in the emerging era of big data: perspectives from fish telemetry researchers on data sharing. Can J Fish Aquat Sci 74:1260–1274

Nicholson TE, Mayer KA, Staedler MM, Johnson AB (2007) Using microsatellites to assess the geographic origin of released and recaptured California sea lions—using remote piloted aircraft to monitor fur seal populations without disturbance. Front Mar Sci 5:202

Nicol C, Bejder L, Green L, Johnson C and others (2020) Anthropogenic threats to wild cetacean welfare and a tool to inform policy in this area. Front Vet Sci 7:57

NMFS (2010) Longline electronic reporting and monitoring. Third Meeting of the WCPFC E-reporting and E-monitoring Working Group. ERandEMWG03-US. Pacific Islands Fisheries Science Center, National Marine Fisheries Service, Honolulu, HI

Northridge S, Sanderson D, Mackay A, Hammond P (2003) Analysis and mitigation of cetacean bycatch in UK fisheries. Final Rep to DEFRA, Proj MF0726, Sea Mammal Research Unit, School of Biology, University of St Andrews

Notarbortolo di Sciara GN, Hoyt E, Reeves R, Ardron J, Marsh H, Vongraven D, Barr B (2016) Place-based approaches to marine mammal conservation. Aquat Conserv 26:85–100

Novak BJ, Maloney T, Phelan R (2018) Advancing a new toolkit for conservation: from science to policy. CRISPR J 1:11–15

Nowlin MB, Roady SE, Newton E, Johnston DW (2019) Applying unoccupied aircraft systems to study human behavior in marine science and conservation programs. Front Mar Sci 6:567

Ogden R, Linacre A (2015) Wildlife forensic science: a review of genetic geographic origin assignment. Forensic Sci Int Genet 18:152–159

Olson JK, Wood J, Osborne RW, Barrett-Lennard L, Larson S (2018) Sightings of southern resident killer whales in the Salish Sea 1976–2014: the importance of a long-term opportunistic dataset. Endang Species Res 37:105–118
Roe WD, Howe L, Baker EJ, Burrows L, Hunter SA (2013) An atypical genotype of Toxoplasma gondii as a cause of mortality in Hector's dolphins (Cephalorhynchus hectori). Vet Parasitol 192:67–74
Rojas-Bracho L, Gulland FMD, Smith CR, Taylor B and others (2019) A field effort to capture critically endangered vaquitas Phocoena sinus for protection from entanglement in illegal gillnets. Endang Species Res 38:11–27
Roman J, Estes JA, Morissette L, Smith C and others (2014) Whales as marine ecosystem engineers. Front Ecol Environ 12:377–385
Ropert-Coudert Y, Beaulieu M, Hanuise N, Kato A (2009) Diving into the world of biologging. Endang Species Res 10:21–27
Ross HA, Lento GM, Dalebout ML, Goode M and others (2016) Avoidance of wind farms by harbour seals is limited to pile driving activities. J Appl Ecol 53:1642–1652
Russell DJF, Haste GD, Thompson D, Janik VM and others (2016) Multispecies functional response of the minke whale Balaenoptera acutorostrata based on small-scale foraging studies. Mar Ecol Prog Ser 341:277–291
Society for Marine Mammalogy (2019) List of marine mammal species and subspecies. https://www.marinemammalscience.org/species-information/list-marine-mammal-species-subspecies/ (accessed 6 June 2019)
Smout S, Lindstrøm U (2007) Multispecies functional response of the pygmy sperm whale Kogia breviceps due to oil spills. J Cetacean Res 29:65–70
Smith CE, Sykora-Bodie ST, Bloodworth B, Pack SM, Spradlin TR, LeBoeuf NR (2016) Avoidance of wind farms by harbour seals is limited to pile driving activities. J Appl Ecol 53:1642–1652
Smout S, Lindstrøm U (2007) Multispecies functional response of the minke whale Balaenoptera acutorostrata based on small-scale foraging studies. Mar Ecol Prog Ser 341:277–291
Sorice MG, Donlan CJ (2015) A human-centered framework for innovation in conservation incentive programs. Ambio 44:788–792
Sousa-Lima RS, Norris TF, Oswald JN, Fernandes DP (2013) Automated detection and enumeration of marine mammals: data gaps and recommendations for researchers in the United States. J Unmanned Veh Syst 4:31–44
Southall BL, Bowles AE, Ellison WT, Finnaner JJ and others (2008) Marine mammal noise-exposure criteria: initial scientific recommendations. Bioacoustics 17:273–275
Stafford KM, Baumgartner MP (2014) Marine mammal conservation and the role of research. Curr Conserv 8:18–25
Stamper MA, Whitaker BR, Schofield TD (2006) Case study: drones for research on sea turtles and other marine vertebrates—a review. Biol Conserv 130:108214
Stockin KA (2019) Marine mammal welfare: human induced change in the marine environment and its implications on marine mammal welfare. Springer International Publishing, New York, NY
Sule M, Bopardikar, I, Jog K, Jamalabad A, Panicker D, Trengenza N, Sutaria D (2017) A review of finless porpoise records from India with a special focus on the population in Sindhudurg, Maharashtra. Primary paper SC/67A/SM/09. International Whaling Commission
Sutaria D (2009) Understanding species conservation in complex socio-ecological systems: case of Irrawaddy dol-
phins in Chilika Lagoon, India. PhD dissertation, James Cook University, Townsville
Sutaria D, Panicker D, Jog K, Sule M, Muralidharan R, Bopardikar I (2015) Humpback dolphins (Genus Sousa) in India: an overview of status and conservation issues. Adv Mar Biol 72:229–256
Sweeney KL, Shertzer KW, Fritz LW, Read AJ (2015) A novel approach to compare pinniped populations across a broad geographic range. Can J Fish Aquat Sci 72: 175–185
Teh LSL, Teh LCL, Hines E, Junchompoo C, Lewison RL (2015) Contextualising the coupled socio-ecological conditions of marine megafauna bycatch. Ocean Coast Manag 116:449–465
Thaler AD, Parsons ECM, de Vos A, Rose NA, Smith C, Fretz D (2019) Bot meets whale: best practices for mitigating negative interactions between marine mammals and microROVs. Front Mar Sci 6:506
Thiel M, Penna-Diaz MA, Luna-Jorguera G, Salas S, Sellanes J, Stotz W (2014) Citizen scientists and marine research: volunteer participants, their contributions, and projection for the future. Oceanogr Mar Biol Annu Rev 52:257–314
Thomas P, Gulland F (2017) Report of the International Workshop on the Conservation of Irrawaddy Dolphins in the Mekong River. http://www.iucn-csg.org/wp-content/uploads/2010/03/Report-of-the-2017-International-Workshop-on-the-Conservation-of-Irrawaddy-Dolphins-in-the-Mekong-River.pdf
Torres LG, Nieukirk SL, Lemos L, Chandler TE (2018) Drone up! Quantifying whale behavior from a new perspective improves observational capacity. Front Mar Sci 5:319
Toughard J, Carstensen J, Teilmann J, Skov H, Rasmussen P (2009) Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (Phocoena phocoena (L.)). J Acoust Soc Am 126:11–14
Trippel EA, Holy NL, Palka DL, Shepherd TD, Melvin GD, Terhune JM (2003) Nylon barium sulphate gillnet reduces porpoise and seabird mortality. Mar Mamm Sci 19:240–243
Trites AW, Christensen V, Pauly D (1997) Competition between fisheries and marine mammals for prey and primary production in the Pacific Ocean. J Northwest Atl Fish Sci 22:173–187
Tulloch V, Grech A, Jonsen I, Pirotta V, Harcourt R (2020a) Cost-effective mitigation strategies to reduce bycatch threats to cetaceans identified using return-on-investment analysis. Conserv Biol 34:168−179
Tulloch V, Pirotta V, Grech A, Crocetti S and others (2020b) Long-term trends and a risk analysis of cetacean entanglements and bycatch in fisheries gear in Australian waters. Biodivers Conserv 29:251–282
Turvey ST, Pitman RL, Taylor BL, Barlow J and others (2007) First human-caused extinction of a cetacean species? Biol Lett 3:537–540
Tyack PL, Zimmer WMX, Moretti D, Southall BL and others (2011) Beaked whales respond to simulated and actual navy sonar. PLOS ONE 6:e17009
Tyne JA, Johnston DW, Rankin R, Loneragan NR, Jebed L (2015) The importance of spinner dolphin (Stenella longirostris) resting habitat: implications for management. J Appl Ecol 52:621–630
United Nations (2019) The United Nations Decade of Ocean Science for Sustainable Development (2021–2030). United Nations, Paris
van der Hoop JM, Moore MJ, Barco TG, Cole TVN and others (2013) Assessment of management to mitigate anthropogenic effects on large whales. Conserv Biol 27: 121–133
van der Hoop JM, Nowacek DP, Moore MJ, Triantafyllou MS (2017) Swimming kinematics and efficiency of entangled North Atlantic right whales. Endang Species Res 32:1−17
Van Parijs SM, Clark CW, Sousa-Lima RS, Parks SE, Rankin S, Risch D, Van Opzeeland IC (2009) Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Mar Ecol Prog Ser 395:21–36
Van Waerebeek K, Barnett L, Camara A, Cham A and others (2004) Distribution, status, and biology of the Atlantic humpback dolphin, Sousa teusii (Kükenthal, 1892). Aqual Mamm 30:56–83
Van Waerebeek K, Baker AN, Félix F, Gedamke J and others (2007) Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere, an initial assessment. Lat Am J Aqual Mamm 6:43–69
Vaquita SAFE (2019) Vaquita marina Conservation Action Plan 2016–2018. https://assets.speakcdn.com/assets/2332/final_vaquita_cap_42117.pdf
Verfuss UK, Sparling CE, Arnot C, Judd A, Coyle M (2016) Review of offshore wind farm impact monitoring and mitigation with regard to marine mammals. In: Popper AN, Hawkins A (eds) The effects of noise on aquatic life II. Advances in Experimental Medicine and Biology Vol 875. Springer, New York, NY, p 1175–1182
Verfuss UK, Aniceto AS, Harris DV, Gillespie D and others (2019) A review of unmanned vehicles for the detection and monitoring of marine fauna. Mar Pollut Bull 140: 17−29
Vianna JA, Ayerdi P, Medina-Vogel G, Mangel JC, Zeballos H, Apaza M, Faugeron S (2010) Phylogeography of the marine otter (Lutra lutra): historical and contemporary factors determining its distribution. J Hered 101:676−689
Vu L, Ponnampalam L (2018) Stranded online: utilizing social media to monitor marine mammal strandings in Vietnam. Poster presented at the 5th International Marine Conservation Congress, Kuching, Malaysia, 24−29 June 2018
Wade PR (1998) Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Mar Mamm Sci 14:1−37
Walsh WA, Kleiber P, McCracken M (2002) Comparison of logbook reports of incidental blue shark catch rates by Hawaii-based longline vessels to fishery observer data by application of a generalized additive model. Fish Res 58:79−94
Wang D (2015) Progress achieved on natural ex situ conservation of the Yangtze finless porpoise. IUCN SSC-Cetacean Specialist Group. https://iucn-csg.org/progess-achieved-on-natural-ex-situ-conservation-of-the-yangtze-finless-porpoise/
Wang JY, Reeves R (2017) Narrow-ridged finless porpoise Neophocaena asiagorientalis. The IUCN Red List of Threatened Species 2017: e.T41754A50381766. https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T41754A50381766.en
Weir CR, Collins T (2015) A review of the geographical distribution and habitat of the Atlantic humpback dolphin (Sousa teusii). Adv Mar Biology 72:79–117
Weir CR, Van Waerebeek K, Jefferson TA, Collins T (2011) West Africa’s Atlantic humpback dolphin (Sousa teusii):
