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Anthropogenic Impacts on the Welfare of Wild Marine Mammals

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Abstract

Marine mammal welfare has most frequently been a topic of discussion in reference to captive animals. However, humans have altered the marine environment in such dramatic and varied ways that the welfare of wild marine mammals is also important to consider as most current publications regarding anthropogenic impacts focus on population-level effects. While the preservation of the species is extremely important, so too are efforts to mitigate the pain and suffering of marine mammals affected by noise pollution, chemical pollution, marine debris, and ever-increasing numbers of vessels. The aim of this review is to define welfare for wild marine mammals and to discuss a number of key anthropogenic effects that are currently impacting their welfare.

Key Words: marine mammals, welfare, anthropogenic impacts, pollution, entanglement, fishery interactions

Introduction

Intrinsic value refers to an animal's individual worth, which is independent of how others, including humans, use the animal (Duncan, 1981; Lavigne et al., 2006). This ethical concept means that the treatment of animals must involve consideration of individual well-being, and not simply population viability and ecosystem role (Lavigne et al., 2006). To some, this may seem a stretch in terms of the likelihood of being considered outside of animal welfare fields, but this concept is already included in many national policy documents and international agreements. In terms of marine mammals, both seals (European Food Safety Authority [EFSA], 2007) and whales (International Whaling Commission [IWC], 2011) have been explicitly considered sentient by such bodies, and, as a result, their value beyond humane killing methods must be considered (Lavigne & Lynn, 2011). Although by no means the only definition of sentience, the International Whaling Commission (2011) has considered whales sentient on the basis that they have some level of awareness, have some ability to evaluate the actions of others, and have the ability to recall their own actions with associated consequences.

For wild marine mammals, discussions of the welfare of individual animals are rare, despite substantial concern for those in captivity (Brando et al., 2017). Instead, evaluations of impacts on wild animals tend to focus on implications for population viability and subsequent conservation concerns. While these are extremely important outcomes, the argument that wild animals have intrinsic value means that we should also consider their individual welfare. It can be argued further that humans have a responsibility to address those welfare concerns caused by anthropogenic impacts, just as for conservation.

To discuss the effects of human activities on the welfare of wild marine mammals, welfare must first be defined operationally. A widely accepted definition of welfare used for domestic and captive animals defines good welfare as a state in which an animal is free from physical injury or disease and has what it wants (Dawkins, 2003). Although this definition considers "wants" as approximately equivalent to preferences, many definitions have included the related concept of "needs." Basic needs are biological requirements for certain resources and/or environmental or bodily conditions (Broom, 1986). If an animal has an unmet need, whether behavioral or physiological in nature, coping strategies may emerge to fulfill that need (Broom, 1991). For example, hunger is a basic need that can be remedied by an animal finding and consuming food. Under certain conditions, these coping strategies may not be sufficient to return the animal to a state in which coping is not required. In these situations, the animal can be considered stressed as there is a threat to the maintenance of its internal systems (Guyton & Hall, 1996). When an animal is in a situation where its needs are not being met (e.g., hungry, diseased, or otherwise stressed), its welfare would be considered reduced. Additionally, pain and suffering are central components in definitions of welfare (Brakes, 2004). Pain is linked only with physical stimuli, in which experience of an aversive sensation is associated with perceived tissue damage (Broom, 2001). Suffering results from the interactions of physical stimuli, including pain and psychological well-being (Brakes, 2004), and it can include a number of negative emotions (Dawkins, 1980). It may be considered a combination of subjective feelings and lack of control (Broom, 1991).

Welfare, therefore, can be considered as a combination of both the coping status of an animal, including their health, physiological stress, pain, and suffering status, and the experience of negative psychological states. Health is clearly an important component of welfare (Dawkins, 1980; Broom & Fraser, 2007) as are presence or absence of physical injuries. Coping, and therefore "needs," are included in this definition rather than the concept of "wants" because the latter may be less relevant for wild compared to captive animals. Experimental studies have examined wants/preferences for various resources (e.g., Dawkins, 1977; Delfour & Beyer, 2011), which may be difficult to achieve and likely impractical for most wild marine mammals. Both broad components of this definition can be assessed using a variety of indicators, and multiple authors have emphasized the importance of using more than one measure to create the most accurate portrait of an animal's welfare (Dawkins, 2000; Broom, 2011).

In applying this definition, several other factors should be taken into account to assess the severity of an anthropogenic activity on welfare. First, the welfare of an individual animal cannot be categorized dichotomously as good or bad; rather, welfare exists on a spectrum of very good to very bad. Secondly, welfare can be assessed on different time scales, from short- to long-term (Broom, 1991), similar to the concept of acute vs chronic stress (Fair & Becker, 2000). For instance, welfare outcomes are not directly comparable for one animal experiencing substantially decreased welfare for a very short period of time and another animal experiencing slightly decreased welfare on a repeated basis. The time scale of an impact is also extremely important because different indicators are suitable for long- vs short-term assessments. For example, heart rate and blood plasma cortisol concentrations are common short-term stress and welfare measurements, whereas immunosuppression and behavioral habituation/sensitization are more useful as long-term indicators (Broom, 2011). Welfare impacts, therefore, may be conceptualized by two axes: one representing current welfare on the spectrum of very good to very bad, and one indicating the time scale of the welfare impact. These may alternatively be referred to as the intensity and duration of an impact, respectively (Broom, 2001; IWC, 2011). Finally, it is also important to acknowledge the number of animals affected (Kirkwood, 2011). While welfare involves considerations of individual animals, the total number of animals affected by an activity is significant for understanding which impacts to prioritize for management and improvement of welfare.

This review is a comprehensive, but not exhaustive, evaluation of a number of anthropogenic activities that have been documented to negatively affect the welfare of marine mammals. While many of these human activities are frequently reported in terms of their potential to significantly affect the population or species in question, there are also indications that the welfare of individual marine mammals can be reduced.

Anthropogenic Noise

Marine mammals rely heavily on acoustic communication for multiple aspects of their life history (i.e., navigation, location of objects or conspecifics, foraging, reproduction, and social exchanges; Wright et al., 2007). The importance of sound for marine mammal communication suggests that increased exposure to anthropogenic noise will have detrimental effects on these functions. One of the primary effects of anthropogenic noise is its interference with animal communication, termed *acoustic masking* (Clark et al., 2009). By reducing the range and clarity of acoustic signals sent and received when communicating (Wright et al., 2007), acoustic masking may contribute to the reduction of marine mammal welfare via decreased foraging efficiency and greater energy requirements for communication. Despite growing concern, there is an escalating number of sound sources being introduced to the ocean with the potential to affect marine mammal species. These include, but are not limited to, shipping/vessel traffic, seismic air gun activity, pile driving, and navy sonar (Clark et al., 2009; Moretti et al., 2014; Merchant et al., 2015; Williams et al., 2015).

The effects of anthropogenic noise differ across species due to variation in auditory processing and sensitivities. For example, pinnipeds typically have a high-frequency cut-off in their underwater hearing range between 30 to 60 kHz, whereas odontocetes (i.e., toothed whales) exhibit a high-frequency cut-off between 80 to 150 kHz (National Research Council [NRC], 2005), suggesting the latter taxon may be more vulnerable to a greater variety of sound types. Vessel traffic contributes a wide range of interfering noise to the marine environment, which can lead to cetaceans modifying their acoustic signals in response. Bottlenose dolphins (*Tursiops truncatus*) significantly increased their rate of vocalizations when a boat was approaching (Buckstaff, 2004), and killer whales (*Orcinus orca*) increased their call signal amplitude as background noise from motorized vessel traffic increased (Holt et al., 2009).

Non-acoustic behavioral changes in response to vessel noise (i.e., surface behaviors, increased traveling, and disruptions to dives) can occur at a metabolic cost (Holt et al., 2009). When North Atlantic right whales (*Eubalaena glacialis*) were exposed to three playback conditions (vessel noise, whale vocalizations, and a synthetic signal designed to alert that boats were approaching), almost all whales exposed to the alert signal ceased any dives in progress and made a sudden, rapid ascent to the surface followed by prolonged traveling at the surface (Nowacek et al., 2004). These types of behavioral changes in conjunction with acoustic modifications can result in high energy expenditure by cetaceans (e.g., Holt et al., 2015). Vessels may also have an observable impact even at great distances; for example, dolphin schools continuously adjusted their travel trajectories such that they increased the distance between themselves and approaching vessels—in some cases, when the vessel was still over 9.6 km away (Au & Perryman, 1982). For North Atlantic right whales, ship noise playback conditions did not elicit a behavioral response, but this may be due to acclimation to continuous vessel noise in the environment (Nowacek et al., 2004). Still, any observed or suggested behavioral habituation in response to vessel noise/traffic should not be assumed to indicate tolerance by the affected animals (Beale, 2007). Ambient noise in marine environments may still be perceived as a stressor without causing observable behavioral indicators of stress (Wright et al., 2007). Overall, behavioral responses to anthropogenic noise can reduce the welfare of marine mammals by decreasing feeding, increasing traveling, and generally inducing energetic costs, which have consequences for an animal's physiological stress status.

As well as behavioral responses to noise, marine mammals may also experience physical damage to their auditory systems, which clearly reduces welfare. When exposed to high-intensity sounds for prolonged periods of time, cochlear hairs in mammalian ears can fatigue and distort their physical shape, decreasing the affected animal's hearing sensitivity (Willott et al., 2001). Hearing loss due to the damaged hair cells is considered temporary, providing the sound exposure is below a certain threshold in terms of duration and frequency. This effect is termed a temporary threshold shift (TTS) in hearing sensitivity (Finneran et al., 2001, 2005; Nachtigall et al., 2004). If the sound exposure exceeds this threshold, the cochlear cells can die and cause permanent damage and hearing loss, or permanent threshold shift (PTS) in sensitivity (Finneran et al., 2000; NRC, 2005). Bottlenose dolphins exposed to short tones resembling sonar pings exhibited TTS at between 192 to 201 dB re 1 μPa^2 (Schlundt et al., 2000). TTS has also been reported in harbor seals (*Phoca vitulina*) when they are exposed to airborne construction noise (Kastak & Schusterman, 1996), and in California sea lions (*Zalophus californianus*), harbor seals, and elephant seals (*Mirounga angustirostris*) due to underwater vessel noise (Kastak et al., 1999). In areas with pile-driving activity, PTS onset is suggested to occur close to the sound source, approximately 5 m for cetaceans and 20 m for pinnipeds (Southall et al., 2007). Even temporary hearing loss constitutes a clear reduction in welfare, and the sudden and unexpected loss of a major sense may be associated with negative psychological states and stress.

Determining the behavioral and physical responses of marine mammals to anthropogenic noise depends on species-specific anatomy and ecology. Sound types with varying properties and intensities can have different effects on the responses exhibited (e.g., Finneran et al., 2000, 2001, 2005). In addition to shipping/vessel noise, two other major categories of anthropogenic noise are discussed below for their unique features and subsequent effects: (1) sonar and (2) seismic activity.

Sonar

The low-frequency sounds produced by military sonar have been the subject of much research because U.S. federal agencies are required to evaluate the probability of noise-related impacts on marine mammals at both the individual and population levels under the Marine Mammal Protection Act (Harris et al., 2017). Animals may perceive sonar sounds as a threat, and they may exhibit species-specific anti-predator behaviors in response (Nowacek et al., 2004; Curé et al., 2016; Harris et al., 2017). Variation in the behavioral responses exhibited between and within individuals and populations highlights the importance of considering the exposure context. The majority of experimental research regarding the effect of sonar utilizes artificially simulated sonar signals transmitted from scaled sound sources on research vessels, as control of or access to a machine that produces a full navy-based sonar signal is extremely limited (Tyack et al., 2003). In opportunistic exposure studies, however, observations are made around real-world naval activities, which reduces the amount of control the experimenter/observer has (i.e., experimental protocols such as randomization into control and treatment groups are not possible; Harris et al., 2017) and limits the ability to rule out confounding factors.

Recent studies suggest that whales exhibit strong avoidance reactions to sonar, with marked reductions in the number of resident animals present during sonar activity. Two Blainville's beaked whales (*Mesoplodon densirostris*) experimentally exposed to a signal resembling mid-frequency active (MFA) sonar terminated their foraging dives, moved slowly toward the surface, and then moved away from the sound source (Tyack et al., 2011). Similarly, one study documented a reduction of almost 75% in beaked whale abundance during sonar operations, with a concurrent increase in abundance once sonar activity ceased (Moretti et al., 2010). Reduced vocalizations detected during sonar activity (McCarthy et al., 2011) further suggest an avoidance response to sonar signals. Together, these data indicate that whales exposed to sonar may experience reduced welfare as a result of disrupted foraging, increased traveling, and potential associated stress.

There is also concern that sonar can cause physical harm as it has been associated with a number of cetacean mass strandings (Rommel et al., 2005; D'Amico et al., 2009; Filadelfo et al., 2009). Increased sonar-related strandings have been documented in beaked whales, occurring a few hours to days after naval maneuvers using mid-frequency sonar (Fernández et al., 2005; Hildebrand, 2009). These whales were affected by fat and gas bubble emboli, presenting symptoms highly similar to decompression sickness ("the bends") in human divers (Jepson et al., 2003; Fernández et al., 2005). Beaked whales are known to perform deep dives that, when disturbed (i.e., startle response to sonar), may negatively affect normal physiological nitrogen buffering, triggering the formation of nitrogen bubbles that can potentially lead to fatal pulmonary emboli (Cox et al., 2006; Tyack et al., 2006). The close proximity of naval sonar activities implicates naval exercises as a main contributor to these symptoms (Fernández et al., 2005; Hildebrand, 2005); however, there may be other possible explanations. Another hypothesis is that the navy maneuvers may induce the formation of nitrogen bubbles through rectified diffusion: the growth of microscopic bubbles in the presence of high-intensity sounds that can be fatal when formed in the blood (Crum & Mao, 1996; Wright et al., 2007). Regardless of the mechanism, this severe physical damage certainly decreases the welfare of affected marine mammals due to both death itself and to the internal injuries, stress, and likely suffering experienced prior to death. Welfare will be particularly poor if there is an extended interval between initial emboli formation and death.

Seismic Activity

Auditory effects from high-intensity sounds such as seismic activity, drilling, or pile drivers are now known to induce behavioral responses indicative of stress and, thus, reduced welfare in a variety of marine mammal species. During seismic surveys, airgun assays produce high-intensity emissions at low frequencies (i.e., 0.2 to 22 kHz) that overlap with the call signal frequencies of several species of baleen whales (Greene & Richardson, 1988; Richardson & Würsig, 1997; Weir, 2008). The impacts of these intense sound sources on acoustic and non-acoustic marine mammal behavior can include displacement, increased travel time at the surface, possible PTS or TTS, and increasing call signal amplitude and frequency (Richardson et al., 1986, 1999; Richardson & Würsig, 1997; McCauley et al., 1998, 2000; Moore & Clarke, 2002; Wright et al., 2007; Yazvenko et al., 2007; Weir, 2008). The likelihood of these outcomes is influenced by the distance of the animal from the sound source, water depth, duration of exposure, and other possibly confounding variables. Each response is representative of fatigue, pain, and/or stress in the affected animal, which would all contribute to a reduction in welfare.

The high-energy, low-frequency signals produced by airgun arrays overlap to a lesser extent with odontocete signals as the latter are produced at higher frequencies (e.g., 0.5 to 150.0 kHz; Popper, 1980). However, airgun noise can still span these frequencies (e.g., 0.2 to 22.0 kHz range) and be detected by odontocetes at relatively long distances (< 10 km) (Madsen et al., 2006b). Odontocete species exhibit great variation in their responses to seismic activity. Atlantic spotted dolphins (*Stenella frontalis*) maintained a greater distance from the sound source during full-array seismic activity compared to when the guns were off (Weir, 2008). Interestingly, these dolphins would approach and bow ride alongside the vessel when the airguns were inactive, indicating that avoidance responses were short term (Weir, 2008). However, if these changes occur on a repeated basis, they may constitute a significant source of stress and longer-term negative impact on welfare.

The numerous anthropogenic sources of sound in the ocean today suggest that there is a high probability that many marine mammals could experience TTS at some point in their lives—for some, possibly even multiple times. This shift in hearing threshold can mean an affected individual will be limited in their ability to gather acoustic information, which could lead to intermittent loss of feeding, mating, or socializing opportunities. Perhaps more concerning are the welfare impacts on marine mammals that experience permanent hearing damage. These individuals may slowly starve, become separated from their social groups, and not be able to efficiently navigate their environment.

Though some anthropogenic noise sources can be pinpointed as causing specific events of welfare concern to marine mammals, of significant concern is the potential for many different sources of noise to interact over long periods of time. Dramatic increases in commercial shipping off California have increased low-frequency ambient noise by 2.5 to 3 dB per decade (McDonald et al., 2006), and every 6 min during daylight hours a vessel passes within 100 m of the resident bottlenose dolphins in Sarasota Bay (Buckstaff, 2004). Long-term, chronic effects are more difficult to establish as causing reduced welfare, but considering that animals are unable to forage effectively due to shipping noise, are displaced by seismic airgun activity, and may experience hearing or tissue damage from sonar, it is highly likely that many marine mammals experience reduced welfare as a consequence of anthropogenic noise.

Pollution

Humans contribute a number of pollutants to the world's oceans, many of which have potential impacts on marine mammals. As with the other issues discussed in this review, however, the welfare of individual animals is not often considered when the effects of pollution are reviewed. In light of this paucity, possible welfare implications of both chemical and plastic pollution on marine mammals are discussed below.

Chemical

In the last decade or so, there has been an increase in research that examines the effects of chemical pollutants on marine mammals. High concentrations of persistent organic pollutants (POPs) found in the tissues of multiple marine mammal species have been associated with impairments in organ and immune function, reproduction, and increased strandings (Reijnders et al., 2009). All of these outcomes reduce physical health and may be associated with pain and suffering, thus also reducing welfare. POPs are particularly problematic due to their resistance to physical, chemical, and biochemical degradation and their environmental bioaccumulation over time (Jenssen, 2006). These chemical contaminants are ingested by marine mammal species and accumulate in increasing concentrations in various organs and tissues (Beckmen et al., 2003; Martineau, 2007; Wright et al., 2007). Compounds of particular concern include many types of industrial organochlorines (OCs) such as polychlorinated biphenyls (PCBs), polychlorinated dibenzofurans (PCDFs), polybrominated diphenyl ethers (PBDEs), and perfluorooctane sulfonate (PFOS) (Giesy & Kannan, 2001; Ikonomou et al., 2002; Herzke et al., 2003; Wolkers et al., 2004).

A major barrier to fully understanding the impact of chemical pollutants on marine mammals is the relative impossibility of experimenting in laboratory conditions with these animals, as well as the frequent occurrence of confounding factors in the wild (Reijnders et al., 2009). Additionally, information is lacking on other biological variables affecting sample tissue quality, disease prevalence across species and its pathology, and information on interactions with other anthropogenic impacts. Nevertheless, biomarkers in tissue samples from free-ranging and stranded animals can be extremely useful; in many cases, stranded animals can provide brain, liver, blood, skin, subcutaneous blubber, muscle, and fur samples for analysis. Fecal samples from dolphins and pinnipeds can be analyzed for concentrations of porphyrins and OCs, whereas blood samples provide additional data on levels of cortisol and concentrations of heavy metals (Fossi & Marsili, 1997).

To best address concerns regarding the effects of chemical pollutants on marine mammal welfare, it is imperative to better understand the relationship between increased concentrations of POPs and disease susceptibility (Jepson et al., 2005; Desforges et al., 2016). The chemicals in this class of compounds are stable, bioaccumulative, highly toxic, and persist for long periods of time in the environment (Macdonald et al., 2002). Endocrine-disrupting chemicals (EDCs), a type of POP, disrupt normal endocrine system functions by mimicking and/or blocking the effects of endocrine hormones in marine mammals due to structural similarities (Colborn et al., 1993; Crisp et al., 1998; Meerts et al., 2001; Jenssen, 2006; Wright et al., 2007). Endocrine disruption can impair thyroid function and cause neurological and cognitive deficits (Schantz & Widholm, 2001; Zoeller et al., 2002; Desforges et al., 2016). All of the above effects have the potential to reduce welfare through disease and impaired organ function overtaxing coping systems, which may contribute to chronic stress and psychological suffering.

In recent history, the number and type of chemical compounds present in the tissues of marine mammals has increased significantly. Several species of marine mammals tested globally in the 1960s contained traces of five different OC compounds, while surveys several decades later in the 1990s found over 300 pollutants present (Tanabe, 2002). Blubber samples taken from stranded California sea lions, harbor seals, and elephant seals between 1994 and 2006 revealed highly elevated PBDE concentrations (Meng et al., 2009), and skin biopsies of free-ranging bottlenose dolphins around the Spanish Canary Islands demonstrated that POP levels showed a marked increase between 2003 and 2011 (Garcia-Alvarez et al., 2014). All organohalogenated compounds were at fatally toxic concentrations (Letcher et al., 2010).

Marine mammals residing in Arctic regions have shown high susceptibility to many POPs and OCs—for example, beluga whales (*Delphinapterus leucas*) in the St. Lawrence estuary have developed bacterial infections likely related to exposure to immunosuppressive contaminants such as PCBs (Martineau et al., 1988; Jenssen, 2006; Wright et al., 2007). There are significant relationships between PCBs and thyroid hormones (Skaare et al., 2001; Braathen et al., 2004) and OCs and cortisol in polar bears (*Ursus maritimus*) (Oskam et al., 2004). Correlated plasma PCB and progesterone levels in female polar bears may disrupt the normal reproductive cycle and hinder successful mating (Haave et al., 2003), while male bears experience reduced testosterone levels with increased concentrations of OCs and PCBs (Oskam et al., 2003). Cortisol concentrations altered by OC levels may inhibit physiological processes necessary for homeostasis and make the polar bears less capable of dealing with environmental stressors (Oskam et al., 2004; Bourgeon et al., 2017). Factories began phasing out novel POPs such as perfluorooctane sulfonate (PFOS) in 2000 due to concerns regarding effects on the metabolism of high trophic-level predators like the polar bear and ringed seal (*Phoca hispida*) (Berthiaume & Wallace, 2002; Bossia et al., 2005). Nevertheless, these compounds have been detected in polar bear tissues (Bossia et al., 2005) and are known to be associated with decreased immune and endocrine responses in seals (Hall et al., 2003; Neale et al., 2005; Frouin et al., 2010). These effects all relate directly to the health and physiological stress elements of welfare, as well as likely being associated with reduced psychological well-being. In addition, the accumulative nature of many chemical pollutants increases the probability that affected marine mammals experience long-term reductions in welfare. Addressing chemical pollutant concerns is imperative for improving reproductive success of threatened and endangered species and for ensuring that wild marine mammals experience good welfare.

Plastic Debris

Individuals of almost 300 species are affected by marine debris globally, predominantly via ingestion and/or entanglement (Laist, 1997). At least 49 marine mammal species have been affected, 17 by ingestion only, with a further nine experiencing both ingestion and entanglement (Laist, 1997). In terms of the number of species affected and the frequency of occurrence, entanglement in marine debris appears to be a more severe threat to marine mammals than ingestion and is discussed elsewhere in this review. Nevertheless, these data indicate that a large number of marine mammal species are affected by ingestion. One of the predominant reasons for ingestion is that marine mammals confuse debris with intended prey and consume it as a result. Alternatively, debris may be ingested directly but not intentionally, such as if the animal does not detect the debris while attempting to ingest prey items, or during play (Butterworth, 2016). Indirect and accidental ingestion may occur when the prey of marine mammals have ingested debris prior to consumption. In any case, ingestion has the potential to cause starvation, internal injuries, and toxic chemical leakage. All of these effects decrease welfare by reducing the physical health of an affected animal, likely contributing to pain and psychological suffering over potentially long time scales.

Of all the cetaceans who have ingested debris, approximately half of documented cases involve plastic pollution (Baulch & Perry, 2014). Unlike other types of pollution, plastic has the potential to injure animals regardless of its environmental concentration (Laist, 1997), with even small quantities of ingested plastics having substantial negative effects (e.g., stomach rupture; Jacobsen et al., 2010). Furthermore, it is likely that, in many cases, marine mammals experiencing negative encounters with plastic debris may not die immediately. Some authors have referred to the potential for reduced quality of life as a result of plastic ingestion (de Stephanis et al., 2013), but the potential welfare consequences of ingested plastic debris are not often addressed directly. Possible welfare impacts of both microplastic and macroplastic pollution are discussed below.

Microplastic Pollution—The two major types of plastic pollution are classified by size: microplastics are between 0.3 and 5 m, while macroplastics are greater than 5 mm in size (National Oceanic and Atmospheric Administration [NOAA] Marine Debris Program, 2017). While more difficult to immediately observe, microplastics may pose a threat to marine mammal welfare by contributing to the bioaccumulation of POPs (Teuten et al., 2007), which may leach into marine mammal tissues once ingested. The potential welfare implications of these compounds have been discussed above, with evidence discussed below regarding the likelihood that marine mammals are exposed to toxic compounds specifically via ingestion of microplastics.

It is extremely difficult to determine the source of pollutants in marine mammal tissue; chemicals, such as PCBs, may be introduced via a range of sources, including microplastics. Evidence for the role of microplastics comes from concurrent detection of microplastics and plastic additives in ocean water (Fossi et al., 2012), and subsequent detection of these additives in the blubber of stranded fin whales (*Balaenoptera physalus*). Higher levels of plastic additives in fin whale biopsies also coincide with higher microplastic concentrations in water samples (Fossi et al., 2012). Baleen whales, in particular, may ingest large quantities of microplastics directly from the water column and indirectly via contaminated prey (Besseling et al., 2015). Additionally, the potential for chronic exposure to microplastics is high in long-lived species like marine mammals. Current evidence suggests that large cetaceans are most at risk from toxic microplastic leakage and associated welfare concerns, but only preliminary conclusions can be drawn from presently available data.

While most marine mammal plastic pollution literature focuses on cetaceans, some data are available for pinnipeds. In this taxon, microplastic exposure most likely comes from consumption of contaminated prey, as the size of plastic particles recovered from seal scats are much smaller than would be expected if consumed directly (Goldsworthy et al., 1997; McMahon et al., 1999; Eriksson & Burton, 2003). Scat samples, however, may not provide accurate estimations of pinniped plastic ingestion as assessments examining stomach contents have found small pieces of plastic even when seal scats from the same location showed no evidence of their ingestion (Bravo-Rebolledo et al., 2013).

Macroplastic Pollution—The potential for negative impacts from macroplastics stems from the physical effects of ingestion as well as toxicity. Macroplastic ingestion can substantially reduce marine mammal welfare via internal injuries, disease, malnutrition and starvation, chemical leaching, and reproductive failure (Derraik, 2002; Butterworth et al., 2012; Lavers et al., 2014), all of which can prevent the fulfillment of basic needs and vastly overtax coping systems. Welfare is reduced by the pain and suffering almost certainly associated with these outcomes, which may take place over long time scales before healing or eventual death.

Ingested macroplastics may cause physical damage to internal tissues or lead to starvation via two possible routes: (1) physical blockage in the digestive system and/or (2) false satiation sensation (Laist, 1997). Some necropsies reveal plastic debris in the digestive system blocking prey items from descending, while others find plastics but no prey, suggesting that the animal had not attempted to feed since debris ingestion. Various cases have been described supporting both of these mechanisms. For example, large quantities of plastics have been recovered from the stomachs of minke whale (*Balaenoptera acutorostrata*; De Pierrepont et al., 2005), Blainville's beaked whale (Secchi & Zarzur, 1999), Cuvier's beaked whale (*Ziphius cavirostris*; Poncelet et al., 2000), and striped dolphin (*Stenella coeruleoalba*; Pribanic et al., 1999) carcasses. In all cases, animals had very thin blubber layers and were extremely emaciated with no fresh prey in their stomachs, suggesting that ingested plastic could have been responsible for false satiation signals that ultimately led to their death. Starvation is a slow way for an animal to die, and it is clearly associated with the frustration of basic needs, namely hunger, which internal coping systems are unable to remedy. Starving marine mammals are also highly likely to experience negative psychological states and extensive physiological stress, all of which contributes to greatly reduced welfare.

Both blockage and internal injuries from macroplastic ingestion have been documented in stranded sperm whales (*Physeter macrocephalus*), with almost 100 kg of debris recovered from the stomachs of two individuals (Jacobsen et al., 2010). In other examples, it seems that ingested plastic has little observable effect on the ingester and, therefore, little associated reduction in welfare. In a number of cases, plastic debris was found in the stomachs of stranded cetaceans along with recent prey with no evidence of obstruction of or injury to the digestive tract (Fernández et al., 2009; Mazzariol et al., 2011). The potential welfare outcomes of macroplastic ingestion are likely to be highly variable and difficult to predict without further data.

In terms of estimated numbers affected, available data differ greatly across species and are biased toward samples from stranded individuals. Although macroplastic ingestion is detected in almost two-thirds of cetacean species (Kühn et al., 2015), certain species seem to be more vulnerable than others. Occurrence of plastic debris in the stomachs of stranded individuals range from 2.3% (of 128) of stranded short beaked common dolphins (*Delphinus delphis*; Simmonds, 2012) to between 16 and 28% of bycaught La Plata River dolphins (*Pontoporia blainvillei*; Denuncio et al., 2011; Di Beneditto & Ramos, 2014). Variation exists within species, such as harbor porpoises (*Phocoena phocoena*), for which marine debris was ingested by only 2.2% (of 459) of individuals examined in the United Kingdom between 2005 and 2010 (Simmonds, 2012), but in 11.9% (of 42) of bycaught or stranded animals in the Black Sea (Tonay et al., 2007). Eventual outcomes are also highly varied—for example, 6.3% (of 63) of Florida manatees (*Trichechus manatus*) that ingested debris eventually died as a result (Beck & Barros, 1991), while ingested plastic did not appear to have caused complete digestive blockage in any of 30 affected La Plata River dolphins (Denuncio et al., 2011). Certain taxa seem to be overrepresented in the macroplastic ingestion literature, such as beaked whales; the use of suction feeding by this family of whales is thought to possibly make them more susceptible to fatal ingestion (Simmonds, 2012). Although pinnipeds have been assessed less frequently than cetacean species, a recent review determined that 38% (of 32) of seal species occasionally ingest plastics (Ryan et al., 2016), increasing their risk of reduced welfare via internal injuries and/or starvation.

Given that much of the data discussed comes from examinations of stranded individuals, little information is available regarding the ingestion–mortality interval—an important consideration in relation to welfare implications. Although data are incomplete, and the extent to which an animal is affected by macroplastic ingestion seems to be highly variable, it is clear that damage to internal organs and starvation, whether eventually leading to death or not, impair the coping status of affected animals and are associated with pain and suffering. As such, macroplastic ingestion is a significant threat to marine mammal welfare.

Entanglement

Becoming trapped by fishing nets and suffocating under water, choking to death from a plastic packing band around the neck, or dying from emaciation due to dragging fishing gear are all prolonged deaths for many marine mammals. Research on entanglement has focused historically on how issues such as bycatch in fishing nets affect marine mammals at the population level. For some species, such as the North Atlantic right whale, entanglement in fixed fishing gear has killed enough individuals to be of conservation concern, with focused attention now given to this threat to the population's existence (Moore, 2013). The experiences of individual right whales that are entangled for an average of 6 mo before they succumb to starvation, exhaustion, infection, or a combination of these effects is also extremely concerning (Dolman & Moore, 2017). This section will discuss welfare concerns associated with entanglement in active fishing gear and marine debris.

Entanglement in Active Fishing Gear

Bycatch, the harvest of non-target species, is one of the primary conflicts that exists between the fishing industry and marine mammals (Read, 2008). Even though public concern for dolphins led to dolphin-safe tuna initiatives, marine mammals are still frequent victims of bycatch. In the most recent comprehensive assessment, global estimates of bycatch in the 1990s were over 600,000 marine mammals per year, most of which were caught and asphyxiated in gill-net fisheries (Read et al., 2006). Take reduction plans have helped lower the number of marine mammals killed, but accurate reporting of bycatch incidents has been difficult to obtain, and it is thus challenging to discern if such programs have helped lower this number (Read et al., 2006). While threats to population or species survival are of great importance, it is also thought provoking to consider the individual experience of all the whales, dolphins, and pinnipeds that are caught in nets, unable to free themselves or breathe. When caught at depth, marine mammals may experience decompression sickness and other severe injuries that can contribute to prolonged stress and pain prior to death by asphyxiation (Dolman & Moore, 2017). Entanglement, therefore, poses a great threat to marine mammal welfare, both due to the extremely poor welfare experienced by individual animals and the scale of the problem.

One solution to trawl fishing gear bycatch is to incorporate excluder devices, which help animals escape instead of remaining in the net. These devices are not always effective, however: sea lion bycatch in the New Zealand squid trawl fishery was not reduced as a result (Chilvers, 2008). Some New Zealand sea lions (*Phocarctos hookeri*) that did make it through the excluder device were found to have both head and internal injuries (Chilvers, 2008), compromising their individual welfare even though they were not immediately killed by the trawl net. Severe injuries such as broken jaws could lead to a number of painful and deadly issues, including shock, blood loss, infection, compromised immune system, or organ failure (Dolman & Moore, 2017). Nevertheless, continued improvements to excluder devices, such as increasing the size of the device, could help lower mortality rates, as could regulating where and when fishing takes place (Lyle et al., 2015).

Even when animals are not killed or severely injured, stress from temporary entanglement can reduce an individual's well-being and may lead to prolonged issues. In instances when dolphins are freed from purse-seine tuna nets, mothers and calves may become separated, which can result in calf starvation or death due to predation. Pregnant females may have spontaneous abortions due to increased stress levels from entanglement (Dolman & Moore, 2017). In cases of prolonged entanglement in fixed fishing gear, marine mammals are highly likely to experience chronic stress; this has been documented in North Atlantic right whales via elevated levels of stress hormone in their fecal matter (Hunt et al., 2006). This is significant because these animals in particular are already facing many other stressors (e.g., noise pollution). In some populations, almost all individuals are affected by entanglement: 83% of North Atlantic right whales have been entangled at least once in their lives, with some individuals entangled as many as six times (Moore & van der Hoop, 2012; Dolman & Moore, 2017). This is a large proportion of an endangered population whose welfare is compromised due to anthropogenic activity.

The entanglement of North Atlantic right whales has been referred to as a costly life-history stage because entanglements can last several months, yielding long-term effects (van der Hoop et al., 2017). The fishing gear often creates a large amount of drag, which alters swim patterns and reduces welfare by increasing the energy requirements of swimming (van der Hoop et al., 2014, 2016). In over half of entanglement cases, the rope was wrapped around the head, reducing foraging opportunities even further (Moore & van der Hoop, 2012). Coping strategies are unlikely to be effective in meeting basic needs, such as hunger, in these animals. It is hypothesized that estimates of entanglement underrepresent the severity of the problem as many whales may die and sink before the entangled whale or entanglement scarring are witnessed by a person (Glass et al., 2010).

Another welfare concern of long-term entanglement is the pain associated with tissue damage caused by fishing gear. The fixed fishing gear responsible for large whales' entanglement can cause lacerations and scars that penetrate deep into the blubber layer (Moore, 2013). Studies indicate that bottlenose dolphin skin is very sensitive to touch, similar to humans' touch sensitivity (Ridgway & Carder, 1990). Given this known tactile sensitivity in at least one cetacean species, it is likely that pain is experienced by animals that have wounds penetrating the skin surface. Some of the ropes entangling North Atlantic right whales have cut tissue to the bone and caused unnatural bone growth (Moore, 2013). In one case, a rope entangled around a whale for 5 mo dissected a portion of blubber off the animal's back (Moore, 2014). Not only are entangled whales limited in movement, speed, and foraging, but they often experience extreme physical injuries, with substantial associated pain, stress, and negative psychological states, all of which greatly reduce welfare.

Moore and van der Hoop (2012) have been vocal regarding how marine mammal welfare is affected by entanglement as this is often overlooked in favor of associated species' conservation concerns. Overall, there is little pressure from the public to change laws and practices on the basis of welfare because awareness of the large number of animals entangled in fishing gear is generally minimal. When marine mammals drown in fishing gear, this process is generally slower than deaths of land mammals that are killed commercially and recreationally (Moore & van der Hoop, 2012). Even in the case of modern commercial whaling, whales are typically killed with efficiency using explosive harpoons (Moore, 2014). While whaling can be just as much a threat to conservation as entanglement, broadly speaking, commercial whaling methods do not inflict the prolonged pain and suffering, nor is there a reduction in welfare such as in the case of entanglement or asphyxiation (Moore, 2014).

Changes in the fishing industry will require consumer action, publicity campaigns, new fishing technologies, and policy changes (Moore & van der Hoop, 2012). For example, if harbor porpoises can only detect bottom-set gillnets from a few meters away, this may be too late to avoid entanglement. Future research should focus on developing technologies to improve the detectability of fishing gear (Kastelein et al., 2000).

Entanglement in Marine Debris

Marine debris, including discarded fishing gear, monofilament line, rope, and plastic packaging, is often responsible for marine mammal entanglement. Documentation of entanglement by man-made materials, excluding active fishing gear, is difficult, and so incidence estimates likely underrepresent this issue (Laist, 1997). Rates of entanglement and type of material involved vary by geographic location (Butterworth, 2016): in some areas, fishing gear is the main culprit; while in other areas, plastic twine, rope, packing bands, and monofilament line are more likely to cause entanglements. Entanglement in marine debris affects many marine mammal species and can cause exhaustion, starvation, asphyxiation, and severe wounds and infections (Laist, 1997; Baulch & Perry, 2014). All of these outcomes vastly reduce animal welfare due to the overtaxing of coping mechanisms and probable psychological suffering. Pinnipeds are particularly likely to become entangled in debris because they live close to shorelines where marine pollution frequently collects, and young animals are likely to become entangled more often due to greater exploratory tendencies and smaller size (Butterworth, 2016).

Entangled pinnipeds may drown because they do not have the energy to swim back to shore or they may be unable to escape predators (Laist, 1997). In these cases, elevated stress and pain levels contribute to poor welfare (Butterworth, 2016). Furthermore, these instances of entanglement are often not recorded because no one observes the entanglement. Even if animals are able to move while entangled, they experience greater energetic costs for locomotion and may not be able to forage efficiently (Laist, 1997). Entangling marine debris may cause chronic wounds and lead to infections or suffocation over time (e.g., elephant seals are known to survive years with monofilament line cutting into their necks; Butterworth, 2016). Current estimates suggest that approximately 40,000 seals die annually due to entanglement in plastic (Butterworth, 2016), indicating that this problem is severe in terms of both the welfare of individual animals and its overall scale.

Many of the problematic plastic loops come from bait boxes used by fishermen (Hofmeyr et al., 2002). Possible solutions to reduce pinniped suffering with neck entanglements include educating and motivating fishermen to collect and recycle gear and to switch to more natural and biodegradable material (Franco-Trecu et al., 2017). Similar to the lack of awareness regarding large whale entanglements, members of the public are often unaware of the extent to which entanglement in marine debris causes welfare issues for marine mammals. Solutions to entanglements require greater public awareness, reduced marine debris pollution, and the development of new technology to disentangle the animals that are found alive.

Overall, entanglement due to anthropogenic activity negatively impacts the welfare of many marine mammals. Entanglement in the nets of active fisheries often causes short-term reductions in welfare before the animal dies, while entanglement in debris or fixed-line fisheries can lead to long-term entanglement and a prolonged period of poor welfare before the animal is rescued or dies. In general, all entangled marine mammals experience some level of poor welfare as they lack control over their movement, are unable to fulfill basic needs (e.g., breathing, foraging, and reproducing), and may experience injury and disease.

Fishery Interactions

Although fisheries and marine mammals typically interact directly via bycatch, other, nonlethal interactions can also contribute to animal welfare concerns. There are several documented incidents in which both pinnipeds and cetaceans directly and indirectly affect fisheries via damage to gear, entanglement, and depredation (Pemberton et al., 1991; Kemper & Gibbs, 2001; Würsig & Gailey, 2002; Kemper et al., 2003). *Depredation* refers to intentional removal of captured fish from longlines by marine mammals (Read, 2005, 2008; Gilman et al., 2007; Powell & Wells, 2011). Longlines placed near the surface and along the seafloor have lines that branch off with baited hooks attached. Longlines are commonly used for most fish stock, such as swordfish and tuna, with a global effort of approximately 1.4 billion hooks on longlines reported in 2000 (Lewison et al., 2004).

While lethal marine mammal–fishery interactions, such as bycatch, have been discussed in a previous section of this review, animals who survive interactions with fisheries can also experience reduced welfare. This can occur via several possible mechanisms, including injuries from gear, retaliation by fishermen, and the use of deterrents. If animals break free from the longline hooks from which they attempted to consume captured fish, hooks often remain lodged in their tissues (Werner et al., 2015). The now extinct baiji (*Lipotes vexillifer*) was at high risk of being snagged by "rolling hooks" on the Yangtze River bottom (Turvey et al., 2007). These injuries pose short-term risks to welfare as they inherently involve tissue damage and perhaps associated pain and suffering. Depending on the length of time that these injuries take to heal, if at all, these may become long-term welfare concerns. Depredation may also result in changes to the diet, foraging behavior, or geographic distribution of various species of marine mammals (Gilman et al., 2007). These changes could reduce welfare if they result in increased incidence of basic needs going unfulfilled such as if use of different geographic areas result in worsened physical condition from non-ideal prey and/or increased predation risk.

Perceived or actual losses to fishermen as a result of depredation can lead to further potential sources of decreased welfare. Fishermen may take actions in response to marine mammals engaged in depredation, including shooting and using small explosive devices (Read, 2005). There may be a risk of such actions becoming more frequent as depredation by odontocetes has been occurring frequently over the past few decades (Read, 2008). For example, killer whale and sperm whale depredation in a Patagonian toothfish Crozet fishery in the southern Indian Ocean reduced annual catch by approximately 40%, a loss of $5 million yearly (Roche et al., 2007), which seems likely to put the animals at risk from retaliatory measures taken by fishermen. Efforts aimed at managing the impact of marine mammals on fisheries can include nonlethal and lethal deterrents, both of which pose associated welfare risks to marine mammals.

Nonlethal Deterrents

Nonlethal deterrents available for use in response to marine mammal–fisheries interactions include spatial management, acoustic, and physical methods (Hamer et al., 2012; Werner et al., 2015). Spatial management practices consist of closing parts of fishing grounds for set periods (i.e., static closures; Dunn et al., 2014) or closing set areas in response to reaching a catch quota (i.e., move-on rule; Dunn et al., 2014). Triggered closures involve the entire fishery closing for a set period in response to reaching catch quota. While difficult to enforce, if fisheries adhere to their specific regulations, these deterrents have the potential to be effective (Werner et al., 2015). Spatial models such as predictive forecasting (identifying areas of high fishery–marine mammal conflict through habitat modeling; Passadore et al., 2012, 2015) and near real-time monitoring (instantaneous detection of marine mammals near fishery via tagging or acoustic monitoring; Thode et al., 2005) are promising possibilities for minimizing marine mammal–fishery interactions. If successful, these models would theoretically reduce the number of animals that are exposed to nonlethal interactions with fisheries while also reducing the incidence of any effects on welfare. Still, these spatial models are currently limited to short-term forecasts for longitudinal datasets (Werner et al., 2015).

In cases where nonlethal deterrents are used by fisheries, there are method-specific ways in which animal welfare may be affected. Acoustic deterrents include jamming in which noise is utilized to interfere with an animal's ability to echolocate (Mooney et al., 2009). In theory, acoustic harassment causes short-term physical discomfort to the animals via playbacks of predator signals or alarms intended to promote negative behavioral responses (Götz & Janik, 2015). If these signals do cause the intended discomfort, then the animal's welfare would be reduced based on the pain and potential negative psychological states experienced. The physical discomfort caused is intended to deter the animals from the area, and this method is employed frequently by fisheries (Tixier et al., 2014). Alternatively, acoustic decoys attempt to divert the approach of marine mammals from fishing operations using sound emissions that mimic predators (Thode et al., 2012, 2015). These may still create stress and reduce welfare to the animal, but to a lesser extent than deterrents that can cause physical harm. However, the potential for physical damage (i.e., exceeding TTS) could result in hearing damage or deafness (PTS), which would affect welfare beyond the temporary physical discomfort intended (Götz & Janik, 2013).

Lethal Deterrents

Lethal deterrents deployed by fisheries most often involve culling—the intentional reduction in size of a target population (Jewell & Holt, 1981). Culling is not always lethal, but nonlethal approaches, such as relocation, have been of limited use due to their general ineffectiveness and high cost (Lavigne, 2003). There is little evidence, however, that lethal marine mammal culls have the intended effect of reducing conflict with fisheries. Namibian fur seals (*Arctocephalus pusillus*) have been culled since 1993 with the justification of relieving pressure on fishery stocks. Current quotas are set at 91,000 seals per year (Ministry of Fisheries and Marine Resources, 2008), but there has been no assessment of the effectiveness of the cull (Bowen & Lidgard, 2011). Icelandic gray seal (*Halichoerus grypus*) culls intend to reduce competition with cod populations, but no change in cod biomass has been documented (International Council for the Exploration of the Sea [ICES], 2009) alongside the 6% decrease in seal population size per year (Hauksson & Bogason, 1997; Hauksson, 2007). Nevertheless, perceived marine mammal–fishery interactions have contributed to documented culls in at least 15 countries, involving at least three cetacean species (United Nations Environment Programme [UNEP], 1999) and eight pinniped species (Bowen & Lidgard, 2013). Unlike the hunting of marine mammals, culls do not often consider the consequences for animal welfare. There is no mention of evaluating the proposed culling methods with regards to their humaneness in the United Nations' protocol for evaluating culling proposals; only guidelines for evaluating the cull's effect at the population level are provided (UNEP, 1999). Obviously, inherent in killing an animal is a reduction in its welfare. However, when death is the intent, potential welfare issues concern the effectiveness of the killing method and the extent to which an animal experiences physical injury and associated pain and suffering prior to death.

One of the main methods used to lethally cull marine mammals is shooting with a firearm. To facilitate the effectiveness of shooting, regulations are typically in place regarding the conditions under which an animal can be shot, the features of the firearm used, and the qualifications of the shooter. Gray and harbor seals can be legally shot in the UK to protect a fishery as long as the firearm meets governmental criteria and the shooter has a police-endorsed firearm certificate (Scottish Office of Agriculture, 1997). Still, conclusions that can be drawn about the welfare of shot animals are limited by incomplete data. In 2005 and 2006, only 9% of UK shot seal carcasses were retrieved, a relatively small proportion when one considers that, on average, 317 seals were shot per year between 2011 and 2015 (Marine Scotland, 2016). Of the 37 necropsied individuals, 10.8% showed injuries suggesting that they had not died immediately (Nunny et al., 2016), but necropsied individuals may also not be representative of all shot animals (Scotland's Rural College [SRUC] Wildlife Unit, 2012). Shooters may report and/or recover the carcasses of only those seals that have been shot well, and injured seals may swim away (Nunny et al., 2016). Thirty-five percent of 37 necropsied gray seals across three seasons were pregnant (Nunny et al., 2016), and most harbor seals were killed during the pupping season (Butler et al., 2008), which raises the possibility that shot seals may be lactating females foraging alone at sea away from their dependent pups (Marine Scotland, 2014). As mother–pup separation before the pup has weaned is associated with very low pup survival rates (Anderson et al., 1979; Osinga et al., 2012), shooting a seal has potential negative welfare consequences for two animals. An abandoned, dependent seal pup that starves will experience greatly reduced welfare, both in terms of its inability to cope with hunger and the possible associated negative psychological states, until death, regardless of the effectiveness with which the targeted seal is killed. The UK additionally lacks an independent system to verify the numbers of seals shot (Nunny et al., 2016).

In some culls, marine mammals are trapped and then euthanized in a controlled setting. This can be advantageous from a management perspective as traps can be set up near the target fishing gear to target relevant individuals, while diminishing the chance that animals will be nonfatally injured (Westerberg, 2010). From a welfare perspective, it is important to assess how long animals are trapped before being euthanized as trapped individuals could experience substantial stress and negative psychological well-being, as well as potentially injuring themselves if they attempt to escape. In one study, new trap models, which were developed to catch gray seals raiding Swedish salmon traps, were required to take animal welfare into account to be approved by the Swedish Environmental Protection Agency (Konigson et al., 2013). The authors, however, did not provide details regarding how the trapped seals were killed or results from the examinations for signs of stress. California sea lions have been trapped and euthanized in the Columbia River using cages that trap animals when they haul out (Oregon Department of Fish and Wildlife, 2013). Only individually identified sea lions that fulfil the criteria for permanent removal are not released, which consisted of 102 individuals between 2008 and 2015, most of which were removed via chemical euthanasia, and a few by placement into zoological facilities (U.S. Army Corps of Engineers, 2016). When in use, traps are monitored to determine when a sea lion has been captured, and traps are locked when not in use (Oregon Department of Fish and Wildlife, 2013). Thus, welfare issues are most likely to arise in the interval between trapping and sedation/euthanasia due to stress experienced and/or the occurrence of self-injury while trying to escape, aside from the obvious reduction in welfare associated with any lethal action. Evidence is currently sparse regarding the trapping-euthanasia window, thus limiting the extent to which accurate conclusions can be drawn regarding the welfare of affected marine mammals.

Collisions

Vessel Strikes

Fatal collisions between marine mammals and vessels have been recorded since the late 1800s, but the number of collisions did not increase substantially until top speeds and overall number of vessels dramatically increased after 1950 (Knowlton et al., 2001). In general, most mortalities and severe injuries are associated with collisions with vessels 80 m or more in length (Knowlton et al., 2001) or vessels traveling at 14 kts or greater (Carrillo & Ritter, 2010); although under certain circumstances, slower and smaller ships can also be lethal (Ritter, 2012). The ability to determine the risk posed by vessel strikes to marine mammals is limited by the likelihood that most ship strikes go unreported; one survey suggested that this is the case for at least three out of four collisions in southeastern Alaska (Neilson et al., 2012). Most assessments of vessel strikes refer to potential impacts on affected marine mammal populations. It has been argued, however, that humans have a responsibility to mitigate and prevent collisions to prevent whales from experiencing extended suffering in the time between being struck and dying (Neilson et al., 2012). The extent to which struck animals experience reduced welfare depends on the type, severity, and duration of their injuries.

Classifying Vessel Strike Injuries—Injuries likely resulting from physical interactions with vessels must be described and classified to subsequently assess their potential impact on populations and individual animals. They can be categorized as blunt or sharp force trauma, or as minor or major injuries. Blunt force trauma injuries typically lack external signs and are thought to be caused by collision with a vessel's hull (Campbell-Malone et al., 2008). This type of trauma manifests in injuries such as fractures, massive bruising, and hemorrhages, with mortalities predominantly attributed to blood loss and/or severe head trauma (Moore, 2013). Sharp trauma most likely results from collisions with ship propellers and typically manifests in regularly spaced external gashes that can completely or partially sever appendages (Knowlton et al., 2001; Moore, 2013). The frequency with which these two types of injury occur may differ between species: 29 of 31 stranded fin whales had been killed by sharp trauma, while blunt trauma was solely responsible for seven of ten right whale deaths (Knowlton et al., 2001).

Minor injuries may include infection, scarring, blood loss, and avoidance of wound contact (Campbell-Malone et al., 2008), while major injuries can comprise deep tissue damage, significant blood loss, broken bones, and complete appendage severance, all of which are generally considered lethal (Knowlton & Kraus, 2001). Injuries that initially appear minor can become severe; infections may enter shallow cuts and cause more extensive tissue damage (Costidis et al., 2013). In some cases, the classifications used to describe observed injuries may also mask their possible welfare implications. Cole et al. (2006) did not consider injuries severe unless they were likely to lead to mortality, even if injuries prevented the whale from performing behaviors necessary for feeding and swimming.

Lethal Strikes and Severe Injuries—Death as a consequence of lethal marine mammal–vessel collisions clearly results in reduced welfare for the struck animals. The number of marine mammals affected by severe, and ultimately fatal, ship strike injuries varies greatly between populations. For North Atlantic right whales, at least 20% (of 25) of carcasses recovered between 1970 and 1989 had serious injuries consistent with ship collisions (Kraus, 1990), while 72% (of 29) of confirmed baleen whale strikes along the eastern U.S. coast were fatal (Cole et al., 2006), and percentages range from around 10 to 15% for cetaceans in several other locations (Jefferson, 2000; Douglas et al., 2008; Carrillo & Ritter, 2010). Manatees may experience severe strikes with relatively high frequency, with 24.3% (of 2,940) of Florida manatee deaths attributed to vessel strikes between 1993 and 2003 (Lightsey et al., 2006). As evidenced by these reports, vessel strikes are inherently biased by reliance on stranding data, which includes a predisposition toward more accessible and populated areas (Douglas et al., 2008).

Stranding data also provide little information regarding strike–mortality intervals. This period is important for determining the extent to which welfare is reduced while animals are still alive. A marine mammal killed instantly upon collision experiences a shorter duration of reduced welfare while alive than an individual who survives for days or even years before dying from collision-related injuries. Only a few case studies provide information regarding strike–mortality intervals. Campbell-Malone et al. (2008) documented two North Atlantic right whales that died, likely from infections after healed wounds from previous vessel collisions re-opened because their girth expanded during pregnancy. In another example, a killer whale calf struck by a vessel propeller was seen alive for 15 d post collision despite severe injuries but is now presumed dead (Ford et al., 1994). A bottlenose dolphin calf survived for at least a month with three open wounds on the peduncle and fluke, one of which cut as deep as the spine (Dwyer et al., 2014). Death may have ultimately been caused by a combination of factors such as emaciation, infection, and internal injuries. Marine mammals that experience ultimately fatal ship strike injuries may suffer substantial threats to their ability to cope prior to death, including physical injuries, pain, stress, and associated negative psychological states, all of which constitute reduced welfare.

The negative welfare implications of an extended injury–mortality interval are clear for the hit individual, but the potential negative impacts on mothers when a dependent calf is killed, and vice versa, must also be considered. In Florida, Mazzoil et al. (2008) reported on a lethal vessel collision with a bottlenose dolphin whose dependent calf subsequently died less than 3 wks later due to a combination of pneumonia, chronic stress, and starvation resulting from the loss of its mother. Thus, major welfare considerations associated with lethal vessel–marine mammal collisions include the severity of injuries experienced, the strike–mortality interval, and non-struck individuals that may be affected by the struck animal's death.

Nonlethal Injuries—Nonlethal injuries may result from both blunt and sharp force trauma. These injuries will have minimal effect at the population level but will have impact on the welfare of individual animals via the physical injuries themselves, reduction in physical health, physiological stress and pain, and any associated psychological suffering. Nonlethal injuries are difficult to document because struck animals are often not sighted or individually identified, and long-term monitoring requires injuries to be observable. What data do exist are not comprehensive and typically come from longitudinally studied populations or reported collisions. For example, only 2% (of 150) of photographed gray whales (*Eschrichtius robustus*) had visible scars clearly sourced as from vessel collisions (Bradford et al., 2009), while the same was true for 7% (of 12 individuals) of extant North Atlantic right whales (Kraus, 1990; Campbell-Malone et al., 2008). Smaller cetaceans are also affected: 2.8% (of 213) of the Indo-Pacific humpback dolphins (*Sousa chinensis*) in the Pearl River Estuary, Hong Kong (Jefferson, 2000), and 6% (of 714) of the known bottlenose dolphins in Indian River Lagoon, Florida (Bechdel et al., 2009), have observable marks from vessel impact injuries. Along the eastern U.S. coast between 2000 and 2004, 27% (of 29) of vessel strikes involving several baleen whale species were confirmed to be nonfatal (Cole et al., 2006); and in Alaskan waters alone, more than 75% (of 108) of reported vessel–whale collisions between 1978 and 2011 were nonfatal (Neilson et al., 2012). Although data are not comprehensive, the extent to which marine mammals experience minor ship strike injuries and associated reductions in welfare seems to vary greatly across populations and locations.

Given the paucity of available data, the extent of long-term welfare implications of nonlethal vessel strikes is difficult to assess. Photographic data offer a non-invasive tool for reliable re-identification of individual animals, but the focus is usually only on dorsal fins and flukes. Scarring or injuries may not be observed if located on less visible, less photographed body parts such as the peduncle, a known location for strike injuries (Knowlton & Kraus, 2001). Recording injuries and their progression (healing or not) relies on repeated regular sightings of affected individuals. The outcome and injury status for a ship-struck whale is often unknown (Neilson et al., 2012; Ritter, 2012), allowing the distinct possibility that a substantial proportion of injured whales go unobserved, and subsequent welfare implications are underestimated.

Renewable Marine Energy Structures

To date, little data exist regarding possible welfare risks associated with marine renewable energy sources such as tidal and wind turbines. Extant research has focused on noise produced by these structures rather than risk of physical collisions or behavioral responses associated with the structures (e.g., Madsen et al., 2006a). Still, there is some concern regarding the potential for collisions of marine mammals with tidal turbine blades, in much the same way that wind turbines cause mortalities for many bird species (e.g., Smallwood et al., 2009). In marine mammals, these concerns are generally raised in relation to the population-level impacts and associated conservation concerns (Simmonds & Brown, 2010). Welfare concerns related to these structures are similar to those for vessel collisions in terms of whether strikes cause mortality, the length of the strike–mortality interval, and the effects of nonlethal injuries on animal health. These outcomes will depend on several factors such as specific turbine design, blade speed and location, and features of the affected marine mammal species.

In the absence of available data, several studies have modeled the likelihood of various outcomes if a marine mammal were to come into contact with tidal turbines. In one model, an estimate was made for the most severe possible strike from an OpenHydro turbine blade on a killer whale (Carlson et al., 2012). Though preliminary with several assumptions, this model predicted that blade impact would not be expected to cause permanent injury to an adult killer whale because soft tissue would absorb the strike force without penetrating the skin. This finding contrasts with comparisons to ship propeller strikes on marine mammals for which data suggest that blubber is not sufficient to provide injury protection from a large impact (Wilson et al., 2006). Some evidence suggests that the likelihood of marine mammals encountering renewable energy structures is high (Wilson et al., 2006), while other models predict high levels of avoidance, resulting in low predicted numbers of potential collisions (Davies & Thompson, 2011). However, such models typically assume that marine mammals will not be attracted to or repelled by the structures.

Marine renewable energy structures might have noncollision impacts on marine mammals. These include behavioral changes in response to increased vessel traffic around the site and structure presence (Dolman et al., 2007). It is difficult to tease apart the effects of a structure's physical presence from the noise it generates to determine the extent of non-noise impacts. Research on the extent to which the physical presence of marine renewable energy structures affects marine mammals is in its infancy, thus limiting the conclusions that can currently be made about possible welfare implications.

Vessel Traffic and Tourism Harassment

Vessels affect marine mammals not only via collision, but also via passive traffic and active vessel harassment (Pirotta et al., 2015). Short-term behavioral responses exhibited by marine mammals exposed to commercial, recreational, and tourism vessel traffic include reduced resting, foraging, and socializing, as well as changes in breathing patterns (Bejder et al., 1999; Lusseau, 2003; Stockin et al., 2008). In some cases, vessel traffic escalates into active harassment of marine mammals. This often occurs in conjunction with the lucrative ecotourism industry, driven by the public's interest in seeing charismatic species such as marine mammals in the wild. While ecotourism activities provide a platform for education about marine mammals and conservation efforts, they are not without consequence for the animals subjected to the public's fascination. Laws and regulations exist in some places to curtail the extent to which the public can interact with wild marine mammals, but these laws are often broken or not well-enforced; and even when followed, ecotourism can still have an impact on marine mammals and their welfare (Bejder & Samuels, 2003).

Measures of the impacts vessel traffic and tourism have on marine mammals differ between taxa. For cetaceans, their dive duration distribution has been used to infer the extent of stress experienced, with increased dive and decreased surface interval durations indicative of increased stress (Seuront & Cribb, 2011). Pinniped behavioral responses are readily documented because of their terrestrial haulouts, typically used for resting and pupping. "Flushing" pinnipeds move from the haulout to the water, which reduces time spent hauled out and, therefore, decreases resting. Rapid flushing of multiple animals may separate mothers and pups or cause pup injury or death via trampling (Cates & Acevedo-Gutierrez, 2017). Repeatedly disturbing nursing pups may have substantial negative impacts on weight gain/maintenance and, ultimately, survival (Harding et al., 2005). Physiological effects associated with these behavioral responses can lead to acute and/or chronic stress (Bejder & Samuels, 2003).

General vessel traffic differs from tourism activities due to the former's more passive interaction with marine mammals in that vessels may pass by animals without intending to seek them out. Nevertheless, in response to such traffic, bottlenose dolphins have been observed to stop foraging and begin traveling, as well as to cluster closer together (Miller et al., 2008). Killer whales have also been observed to reduce foraging behavior when vessels are within 400 m, which is estimated to reduce their energy intake by 18% (Williams et al., 2006; Lusseau et al., 2009). Cetacean dive durations tend to increase in the presence of vessels, indicating a stress response (Ng & Leung, 2003; Miller et al., 2008). Dusky dolphins (*Lagenorhynchus obscurus*) in New Zealand showed changes in certain behaviors depending on the season and time of day (Lundquist et al., 2012), and also decreased their time feeding and socializing when boats were present (Dans et al., 2008). As is seen in cetaceans, pinnipeds generally exhibit greater disturbance with increased vessel proximity. For example, three-quarters of harbor seals flushed when cruise ships passed within 200 m of Alaskan haulout sites (Jansen et al., 2010). Current evidence suggests that flushing is more prevalent for pinnipeds in areas with less vessel traffic, likely due to a lack of habituation to vessels (Cates & Acevedo-Gutierrez, 2017). There may also be indirect negative consequences of habituation to repeated exposure such as decreased vigilance responses to natural predators (Olson & Acevedo-Gutierrez, 2017).

More severe disturbance can be caused when tourism vessels actively approach and/or interact with marine mammals, even for the most apparently passive tourism activities. Seals exhibit greater flushing in response to approaching boats than to those passing by (Jansen et al., 2010), and they are more likely to flush when disturbed by quiet, slow-moving vessels such as kayaks and other nonmotorized boats (Cates & Acevedo-Gutierrez, 2017); approaching boats provide minimal opportunity for pinnipeds to have advance warning of their presence (Johnson & Acevedo-Gutierrez, 2006). These responses suggest that quiet, slow-moving tourism vessels may actually pose the greatest source of disturbance to pinnipeds. This is particularly significant given that, in some areas, regulations prohibit vessels from approaching pinnipeds within a certain buffer zone, but kayakers frequently disregard these rules (Johnson & Acevedo-Gutierrez, 2007). Similar disregard of regulations is documented elsewhere. Tour boats in Port Phillip Bay, Australia, frequently violate restrictions placed on the amount of time boats are allowed in proximity to dolphins and the amount of time swimmers are allowed in the water (Scarpaci et al., 2003), increasing the likelihood of disturbance. Some groups of cetaceans, such as the southern resident killer whales, are so popular that they may be surrounded by tens of boats at a time (Williams et al., 2009).

Vessel disturbance may cause physiological stress responses. Even with low-level vessel disturbance, individuals may experience chronic stress if disturbed repeatedly over time (Seuront & Cribb, 2011). Additionally, the energetic cost incurred by increased traveling and decreased foraging and resting may lead to chronic stress (Bechdel et al., 2009). When physiological impacts have been measured directly, the potential for chronic stressors are often not assessed, at least in part because of the difficulty in documenting their effects long-term. No association was found between vessel occurrence and killer whale fecal stress hormones once the delay in hormone excretion was accounted for, but possible cumulative effects over time were not assessed (Ayres et al., 2012). Pinnipeds physiologically require a certain amount of time hauled out to meet their resting needs (Brasseur et al., 1996). As a result, they may experience chronic stress if vessel traffic repeatedly causes them to flush (Cates & Acevedo-Gutierrez, 2017), particularly in cold locations where pups who spend too much time in the water experience thermal stress (Jansen et al., 2010).

Both vessel traffic and tourism boats are therefore generally associated with marine mammals spending less time resting and feeding. These are both behaviors that meet basic needs, so this disturbance requires animals to engage in coping strategies. Resultant increases in energy output, in combination with decreased feeding efficiency, may lead to suboptimal levels of nutrition and/or disease. There is some evidence of long-term behavioral changes, including habituation and sensitization to vessels, and changes in habitat use (Spradlin et al., 1998; Bejder & Samuels, 2003; Bejder et al., 2006) that may lead to poor physical health and chronic stress. As a result, these anthropogenic activities can be considered likely to reduce the welfare of marine mammals, particularly those individuals exposed regularly and repeatedly to disturbance. Current data likely underestimate the effects of vessel presence as assessments are generally made after disturbance has already begun, and individuals with lower disturbance tolerances may have already left the studied sites.

Non-vessel interactions with marine mammals also have potential effects on welfare. These activities include supervised and unsupervised interactions both in and out of the water. For example, disturbance of manatees by swimmers has been documented in overwintering areas, with these animals exhibiting less resting and nursing when more people were in the water, and exhibiting avoidance by moving into sanctuary areas (King & Heinen, 2004). Dolphins may also spend less time nursing calves and more time traveling when increased numbers of swimmers are present (Stensland & Berggren, 2007). As resting and nursing both fulfill basic needs, this disturbance can decrease animal welfare. Chronic disturbance may also contribute to physiological stress and the experience of associated negative psychological states.

Additional harassment of marine mammals occurs when individual members of the public attempt interactions on their own. These instances include high-profile news stories such as tourists in Spain passing around a baby dolphin to take selfies, leading to the dolphin's death (Wordern, 2017), and a similar event in Argentina (Holley, 2016). In Peru, a beached dolphin died after a couple posed with it for pictures, pretended to ride it, and even urinated on it (Ward, 2015). It is highly likely that these animals experienced extreme physiological and psychological stress until they died and, thus, suffered greatly reduced welfare. In areas where pinnipeds frequently haul out, there is an increasing trend to take pictures with sleeping and resting animals, especially young pups. Harassment of pinnipeds can lead to mothers abandoning their pups, displacement from convenient haulout areas, stampedes during avoidance behavior, and ingesting unnatural food (Newson & Rodger, 2007). These outcomes are likely to reduce welfare via physical injuries, pain, and suffering experienced, or if animals cannot fulfill basic needs such as feeding and resting. Consequently, government agencies have issued press releases and campaigns to explain that this behavior is illegal, that young animals may be abandoned by their mothers, and that these interactions can be very stressful and energetically costly for the animals (Addessi, 2016).

Although its long-term effects are uncertain, repeated interactions and provisioning of wild marine mammals can be detrimental to their welfare. Resident dolphins near Panama City Beach, Florida, are fed food that could make them sick (Samuels & Bejder, 2004). Feeding wild dolphins also allows them to associate boats and people with food, thus increasing the risk of boat strikes or other injuries (Samuels & Bejder, 2004), which have their own associated welfare concerns. In settings of controlled provisioning by government-sanctioned organizations, there is mixed evidence on the effects of provisioning wild dolphins with fish. While there do not seem to be short-term consequences for the dolphins at Tangalooma, Australia, there is a lower survival rate of offspring from provisioned mothers and behavioral changes associated with provisioning for the dolphins in Monkey Mia, Australia (Neil & Brieze, 1998). Though some harassment incidents are short-term events leading to very poor welfare or death, an overall increase in vessel traffic and/or harassment is likely to reduce the welfare of a large number of individuals in the long-term.

Hunting

Whaling and sealing are types of hunting specific to marine mammals and refer to the pursuit and killing of these animals for utilization of their parts or products made from these parts. While killing an animal ultimately equates with poor welfare, in cases where the intent is to cause death, the most relevant welfare issues concern the "humaneness" of the killing process. Unlike the other issues discussed in this review, the welfare of hunted whales and seals has been a focus of these activities. As a result, there is a relatively large amount of data regarding the effectiveness of hunting and killing methods in relation to their effect on animal welfare. Indeed, there is a general consensus that hunting methods are highly effective, with minimal time between their initial deployment and animals becoming insensible (Moore, 2014). Of concern is the substantial variation in the welfare consequences of hunting between individual marine mammals. The two most common types of marine mammal hunts are whaling and sealing.

Whaling

In 1986, the IWC declared a moratorium on commercial whaling, although several nations are opposed to this ban and continue whaling operations. All modern whaling falls into one of three categories: (1) commercial, (2) aboriginal, and (3) scientific. In commercial whaling, parts or products from caught whales are sold commercially, whereas aboriginal whaling is carried out by indigenous populations for subsistence purposes (IWC, 2018a). Under the original 1946 International Convention for the Regulation of Whaling, the IWC (2018b) allows whaling for scientific research, and take of whales under this provision is referred to as scientific whaling. Across all these hunting types, methods involve an initial chase phase, deployment of a primary killing method, and, in some cases, delivery of a secondary killing method (Whale and Dolphin Conservation Society [WDCS] & Humane Society of the United States [HSUS], 2003).

The IWC (1992) defined *humane killing* as methods causing death "without pain, stress or distress perceptible to the animal." However, the IWC Scientific Committee's review process for scientific whaling proposals do not require ethical or welfare evaluations (IWC, 2018c). While the efficacy of killing methods in whaling are some of the most efficient and best documented of all the topics covered by this review, several organizations have repeatedly argued that current whaling methods do not meet the standards of humane killing (WDCS & HSUS, 2003).

The effectiveness of the killing methods themselves is typically well-documented. A less-recognized potential welfare concern involved in whaling is the chase phase. Whaling vessels must get close enough to the hunted animal to deploy a primary killing method, a time frame that tends to take longer in aboriginal hunts (Øen, 1999). Chased cetaceans are highly likely to experience physical exertion, negative emotional states, and stress given that they have not undergone strong selection for the physiological capacity for extended periods of high-speed swimming (Maas, 2003) and that stress is experienced when an animal's control systems are overtaxed (Broom & Johnston, 1993). In cases where cetaceans are chased but a killing method is not successfully deployed, it is possible that the animal may experience further reductions in welfare if they develop exertional myopathy (EM). In non-marine mammal taxa, this syndrome is associated with extreme exertion and stress and has negative physiological consequences (Williams & Thorne, 1996) such as necrosis of muscle tissue and resultant fatal scarring (Jubb et al., 1993). What data are available for marine mammals suggest that extreme stress reactions occur in many cetacean species during chasing and capture contexts (Thomson & Geraci, 1986; St. Aubin & Geraci, 1988).

The effectiveness of the killing methods used in whaling are described elsewhere in the literature (Øen, 1994; Kestin, 1995; Knudsen & Øen, 2003) but are briefly discussed here as they clearly pertain to the welfare of hunted animals. Time between initial deployment of a killing method to the whale and death is known as "time to death" (TTD) and identifies the window of time during which the whale may experience suffering (Butterworth, 2004). In general, present criteria for defining TTD are likely to provide overestimates (IWC, 1984; Øen, 1994; Knudsen & Øen, 2003), which corresponds with an overestimate of the extent to which welfare is reduced. Currently, the most common primary killing method in commercial and scientific whaling is the exploding penthrite harpoon. When a penthrite harpoon is shot into a whale, the barbs extend to anchor it in the whale's body, causing a wound at least 20 cm wide (Kestin, 1995), followed by penthrite grenade detonation (Knudson & Øen, 2003). A whale that is harpooned but not rendered immediately dead or unconscious, therefore, has experienced extensive tissue damage, is highly likely to experience significant suffering (van Liere, 2004), and has greatly reduced welfare. A broad concern is that these methods were originally developed for and tested on the small minke whale but are now used for much larger species (Brakes, 2004). Despite these apparent limitations, the average TTD for minke whales is between 2 to 3 min (IWC, 2003), which is a relatively narrow window of time in which animals experience reduced welfare. There is still substantial variation in these times, however, with some whales remaining alive for more than 30 min after the initial strike (Papastavrou, 2006). More welfare concerns remain for aboriginal whaling activities in which a lower proportion of targeted whales are successfully killed and TTDs are longer (e.g., between 5 and 35 min; IWC, 2009). Collective hunts have particularly long TTDs, with some hunts taking 300 min to kill a targeted minke whale (Anonymous, 2003). Overall, aboriginal whaling provides the most concern regarding the amount of time in which struck whales are likely to experience stress, physical injury, and suffering prior to death.

Perhaps one of the most significant welfare concerns associated with whaling is that of whales which are struck but are subsequently "lost" in that they are not captured and killed (Brakes & Fisher, 2004). Outcomes for these whales could be highly varied, but even nonlethal injuries may still be extremely debilitating for the animal due to significant blood loss, organ damage, muscle or limb atrophy, and eventual starvation (Brakes & Fisher, 2004). Of major concern is the lack of strike limits for all hunts, with the exception of the Alaskan bowhead whale (*Balaena mysticetus*) and West Greenland minke whale hunts (Brakes & Fisher, 2004; IWC, 2011). Given the large wounds known to be caused by the penthrite harpoon (Kestin, 1995; van Liere, 2004), struck and lost whales are highly likely to experience extensive physical injury, pain, and, therefore, reduced welfare, potentially for however long it takes for the wound to heal, if at all.

Finally, the IWC does not currently regulate the hunting of small cetaceans and, as a result, the welfare of animals in these hunts is of greater concern. In the Faroe Islands, several hundred pilot whales (*Globicephala melas*) are killed each year (Lonsdale, 2004). After being herded, often for several kilometers, whales are secured by one of two methods: (1) a steel whaling hook, which is being phased out due to welfare problems (Faroe Islands Department of Fisheries, 1991), and (2) a rounded hook. This latter tool is inserted into the blowhole (Olsen, 1999), which risks tissue damage, internal bleeding, and obstruction of breathing (Lonsdale, 2004). Animals are then rendered insensible by using a knife to cut the spinal column (Olsen, 1999). In the Japanese hunt of the Dall's porpoise (*Phocoenoides dalli*), harpooned individuals are attached to buoys while the hunt continues. As a result, there are few checks in place to ensure that harpooning has caused permanent loss of consciousness. Furthermore, porpoises with calves are frequently targeted, but calves are not taken, and so will ultimately die (Perry, 1999). The lack of regulation of these hunts is, therefore, of substantial welfare concern.

Sealing

Although sealing occurs elsewhere in the world, the Canadian seal hunt has received perhaps the greatest amount of public attention in terms of marine mammal welfare and is also one of the most well-researched. As with whaling, the killing of marine mammals inherently reduces their welfare, but for hunting purposes, the effectiveness of methods for rendering animals insensible is the primary welfare concern. The two main methods used in the Canadian seal hunt are the hakapik and rifle (Anonymous, 2000). The hakapik is a wooden club with a metal cap used to strike seals on the top of the head when ice conditions are such that the sealer can approach on foot, while a rifle is used when ice conditions are not safe for sealers to make their approach. The hakapik may actually be better from a welfare perspective because seals can be immediately checked for signs of consciousness, and, in general, this method appears to cause unconsciousness almost immediately (Daoust & Caraguel, 2012). Indeed, some argue that shooting seals from boats is never an acceptable method as seals, by definition, cannot be immediately checked for signs of consciousness and, if necessary, be struck again (Fielder et al., 2001; Butterworth et al., 2007).

Sealing methods share similarities with those used in whaling in that they are broadly studied and considered to involve some of the fewest welfare concerns of all the issues discussed in this review. The well-researched nature of this activity demonstrates that there is still a substantial amount of variability in the welfare outcomes experienced by hunted seals. Although some assessments indicate that the skull of almost every clubbed seal is completely crushed, rendering those animals immediately unconscious (Daoust & Caraguel, 2012), other hunts exhibit lower levels of certainty in welfare outcomes (Fielder et al., 2001). In one example, 5% of 280 seals killed required more than one rifle shot before being brought onboard sailing vessels, increasing the time the animal spent experiencing pain and suffering prior to death (Daoust & Caraguel, 2012). Sealers also do not always check seals for consciousness (Butterworth et al., 2007), raising the possibility that they remain able to experience physical injury, pain, and suffering for longer periods of time than current estimates indicate.

Overall, even when the killing of marine mammals is intentional, several whaling and sealing methods are used that still produce variable outcomes and have the potential for a death that is not instantaneous and likely painful in many instances. Improving methods and regulations for killing and enforcing these regulations can all lead to better welfare outcomes for affected marine mammals.

Climate Change

The impacts of climate change on marine mammals have not received as much attention from researchers or the public compared to other anthropogenic impacts. Perhaps this is because climate change is responsible for a plethora of changes that vary by geographic location and can impact species in dramatically different ways. The connection between human actions causing the issue and the outcome of suffering marine mammals is much less direct. Increases in sea surface temperatures (SSTs) and melting of the ice caps can lead to welfare issues, including starvation, strandings, increased incidence of disease, poor health, and further exposure to anthropogenic threats (Le Boeuf et al., 2000; Evans et al., 2005; Burek et al., 2008; Ragen et al., 2008).

Starvation occurs due to changes in prey distribution and abundance. A decrease in the prey of gray whales due to higher SSTs likely led to high mortality and fewer successful births of these whales in 1999 (Le Boeuf et al., 2000). Dead whales, many of which were emaciated females, were found along their migration route from Mexico to California. It was hypothesized that the whales were not able to find enough food to prevent starvation during the long, energetically costly migration (Le Boeuf et al., 2000). Starvation along a long migration route is likely to be a painful experience—not only for the whales who died, but also for the ones that survived but were emaciated to the extent that it hindered reproductive success. Additionally, climate change has implications for the population dynamics of Southern right whales (*Eubalaena australis*; Leaper et al., 2006). Changes in climate that lead to shifts in prey availability can result in nutritional deficiencies linked with late-term pregnancy or lactation failures, eventually leading to calf starvation (Leaper et al., 2006). Furthermore, cetacean stranding events in Australia have been linked to large-scale climate events (Evans et al., 2005). Increases in strandings could be due to shifts in prey or an increase in frequency and strength of storms, which can cause exhaustion or confusion (Evans et al., 2005). In either scenario, the welfare of the individuals involved was likely greatly reduced.

Prey abundance and accessibility are also a primary topic of concern for polar-dwelling marine mammals. As their habitats are undergoing dramatic changes with the melting of the ice caps, climate change will affect polar marine mammals far beyond the iconic starving polar bear. Some species, such as the walrus (*Odobenus rosmarus*), rely on ice for haulout sites that are relatively close to prey. Without ice as a place to rest, walruses may have to swim great distances to access food, exceeding their energy stores and becoming emaciated to the point of starvation (Metcalf & Robards, 2008). Research has already revealed the poor body condition of many walruses and the tendency for females to abandon their calves, resulting in many calves starving or drowning from exhaustion (Metcalf & Robards, 2008). Significant effects are expected as the Arctic ice cap melts and permits increased human activity, including more industry, fishing, shipping, and oil and gas drilling, in areas that were previously difficult to access (Ragen et al., 2008). In turn, these activities will bring increased noise and chemical pollution, entanglement, and potential for vessel strikes (Burek et al., 2008; Moore & Huntington, 2008). Increased competition from invasive species and incidence of disease is expected to occur as organisms that were previously limited in range by the ice and cold temperatures shift closer to the poles (Burek et al., 2008; Moore & Huntington, 2008).

The health of marine mammals around the world will also be affected by changing global temperatures. For example, manatees are expected to shift their range further northward with warming global ocean temperatures. These marine mammals use warm-water refugia during winter months and short-term weather changes, but the changing climate has led to a loss of these refugia, as well as changes to sea grass beds and increases in toxic algal blooms (Edwards, 2013). As a result, there have been increasing numbers of manatees experiencing cold stress, which can cause emaciation, dehydration, skin lesions, gastrointestinal disorders, and death (Edwards, 2013). If hundreds of manatees died from cold stress in 2010 alone (Edwards, 2013), it is likely that many others also suffered decreased physical health and increased stress, decreasing their overall welfare. While the climate changing is not an unnatural process, humans have accelerated the rate of change beyond that to which many species can adapt. The impacts of climate change are widespread and difficult to curtail; however, the current literature reveals how little is known about the effects of climate change on marine mammal welfare and how much more research needs to be done.

Marine Mammal Research

Some research on wild marine mammals may have negative impacts on their welfare, even though, ironically, the overall goal of research is to help the studied animals. Most research concerning anthropogenic impacts on marine mammals is focused on species-level conservation issues with less attention to individual welfare. Consequently, much research is needed on welfare impacts of marine mammal research to ensure that the potential for harm is minimized.

In particular, tagging and tissue sampling methods pose potential welfare concerns, including physical injury, stress, and disruption to animal behavior. An evaluation of biopsy sampling found that bottlenose dolphins had a larger behavioral reaction when the biopsy tissue sample was larger and that biopsy wounds took approximately 23 d to heal (Krützen et al., 2002). Although wounds are not generally substantial, any physical injury and potential associated pain constitutes reduced welfare. One common dolphin died after it was hit with a biopsy dart, which is likely due to extreme stress or vertebral trauma as this individual had only 7 mm of blubber near the dorsal fin (Bearzi, 2000). Even when wounds appear to heal properly, tissue sampling or tag deployment may be a stressful event, especially when combined with other everyday stressors. Baumgartner et al. (2015) found that dermal tag attachment in bowhead whales was minimally disruptive, but prolonged dives and increased respiration rates were observed for 1 to 1.5 h after the tagging event, which suggests at least mild stress is associated with tagging. A review of marking and tagging methods found no clear consensus regarding the extent of large whales' behavioral reactions to tagging (Walker et al., 2012).

Use of telemetry tags on large whales may cause histological reactions, secondary health impacts, and may be painful if the tag penetrates into the muscle (Moore et al., 2013). Tissue swellings and depressions were observed when tagged baleen whales were resighted several years after initial tagging (Calambokidis, 2015). Further, many types of dorsal fin tags deployed during routine health assessments can cause tissue destruction, with freeze branding the least destructive in the long-term (Irvine et al., 1982). Still, even contemporary procedures for routine health assessments include freeze-branding, drilling through the dorsal fin to attach a single-pin satellite-linked transmitter tag, and removing a tooth, all without mention of even temporary welfare impacts to the individual (Balmer et al., 2011). Many sea otters (*Enhydra lutris*) experienced flipper injuries from transmitter tags, implants sometimes caused internal bleeding or prevented wound healing in sea otters and pinnipeds, and branding caused changes in behavior for several days that suggested a sea lion was in pain (Walker et al., 2012). Despite these findings, pain management was only mentioned in a few recent studies.

The welfare of many marine mammal subjects is impacted by the use of tags, biopsy methods, and branding. These methods can cause tissue damage, pain, stress, and are likely associated with negative psychological states. In some instances, these reductions in welfare only last minutes; while in others, research-related injuries may persist for years or even be fatal. Though research on marine mammals can provide valuable information regarding population dynamics, habitat use, and health, it is important to consider the welfare of the studied individuals. Improving the welfare of these animals may require pain management when applicable, using the least destructive or least painful technique possible, and developing new technologies that improve the research process and minimize risks to the animals involved.

Conclusions

The oceans, once seemingly too vast to be affected by humans, are now polluted by noise, chemicals, and marine debris. There is an ever-increasing number of fast moving cargo ships, fishing vessels, and whale-watching boats full of people waiting for a glimpse of wild animals. As concern for marine mammal welfare expands, substantial research and outreach efforts have focused on how anthropogenic activities impact wild populations. Still, the effects of human activity on the welfare of wild marine mammals remain a growing concern. When the welfare of individual animals is considered, it is clear that anthropogenic impacts have led to starvation, increases in disease, physical injuries, asphyxiation, and, at times, painful deaths.

The good news is that humans are working on solutions to decrease many of the negative welfare issues we created for marine mammals. New technology is being developed for fishing, shipping, and research. Every piece of trash removed from the ocean and every observed law means there are fewer marine mammals becoming entangled or being harassed by tourists. As we recognize ourselves as a primary contributor to poor animal welfare, in the wild and in captivity, we must also grasp that we have both the capacity and the responsibility to offer solutions that improve the welfare of marine mammals.

Literature Cited

Addessi, A. (2016). "Selfie" culture puts marine wildlife at risk. *NOAA Fisheries–West Coast Region*. Retrieved from www.westcoast.fisheries.noaa.gov/stories/2016/26_09262016_selfies_w_seals.html

Anderson, S. S., Baker, J. R., Prime, J. H., & Baird, A. (1979). Mortality in grey seal pups: Incidence and causes. *Journal of Zoology*, *189*, 407-417. https://doi.org/10.1111/j.1469-7998.1979.tb03972.x

Anonymous. (2000). *Data needed to assess welfare aspects of whaling* (IWC.52.RMS2). Submitted by the UK.

Anonymous. (2003). *Revised action plan on whale killing methods* (Appendix 4 of the *Report of the Workshop on Whale Killing Methods and Associated Welfare Issues*, Berlin, 2003 IWC/55/Rep3).

Au, D., & Perryman, W. (1982). Movement and speed of dolphin schools responding to an approaching ship. *Fishery Bulletin*, *80*(2), 371-379.

Ayres, K. L., Booth, R. K., Hempelmann, J. A., Koski, K. L., Emmons, C. K., Baird, R. W., . . . Wasser, S. K. (2012). Distinguishing the impacts of inadequate prey and vessel traffic on an endangered killer whale (*Orcinus orca*) population. *PLOS ONE*, *7*, e36842. https://doi.org/10.1371/journal.pone.0036842

Balmer, B., Wells, R., Schwacke, L., Rowles, T., Hunter, C., Zolman, E., . . . Pabst, D. (2011). Evaluation of a single-pin, satellite-linked transmitter deployed on bottlenose dolphins (*Tursiops truncatus*) along the coast of Georgia, USA. *Aquatic Mammals*, *37*(2), 187-192. https://doi.org/10.1578/AM.37.2.2011.187

Baumgartner, M. F., Hammar, T., & Robbins, J. (2015). Development and assessment of a new dermal attachment for short-term tagging studies of baleen whales. *Methods in Ecology and Evolution*, *6*, 289-297. https://doi.org/10.1111/2041-210X.12325

Baulch, S., & Perry, C. (2014). Evaluating the impacts of marine debris on cetaceans. *Marine Pollution Bulletin*, *80*, 210-221. https://doi.org/10.1016/j.marpolbul.2013.12.050

Beale, C. M. (2007). The behavioral ecology of disturbance responses. *International Journal of Comparative Psychology*, *20*(2), 111-120.

Bearzi, G. (2000). First report of a common dolphin (*Delphinus delphis*) death following penetration of a biopsy dart. *Journal of Cetacean Research and Management*, *2*, 217-222.

Bechdel, S. E., Mazzoil, M. S., Murdoch, M. E., Howells, E. M., Reif, J. S., McCulloch, S. D., . . . Bossart, G. D. (2009). Prevalence and impacts of motorized vessels on bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida. *Aquatic Mammals*, *35*(3), 367-377. https://doi.org/10.1578/AM.35.3.2009.367

Beck, C. A., & Barros, N. B. (1991). The impact of debris on the Florida manatee. *Marine Pollution Bulletin*, *22*(10), 508-510. https://doi.org/10.1016/0025-326X(91)90406-I

Beckmen, K. B., Blake, J. E., Ylitalo, G. M., Stott, J. L., & O'Hara, T. M. (2003). Organochlorine contaminant exposure and associations with hematological and humoral immune functional assays with damage as a factor in free-ranging northern fur seal pups (*Callorhinus ursinus*). *Marine Pollution Bulletin*, *46*(5), 594-606. https://doi.org/10.1016/S0025-326X(03)00039-0

Bejder, L., & Samuels, A. (2003). Evaluating impacts of nature-based tourism on cetaceans. In N. Gales, M. Hindell, & R. Kirkwood (Eds.), *Marine mammals: Fisheries, tourism and management issues* (pp. 229-256). Clayton, Australia: CSIRO Publishing.

Bejder, L., Dawson, S. M., & Harraway, J. A. (1999). Responses by Hector's dolphins to boats and swimmers in Porpoise Bay, New Zealand. *Marine Mammal Science*, *15*, 738-750. https://doi.org/10.1111/j.1748-7692.1999.tb00840.x

Bejder, L., Samuels, A., Whitehead, H., & Gales, N. (2006). Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. *Animal Behaviour*, *72*(5), 1149-1158. https://doi.org/10.1016/j.anbehav.2006.04.003

Berthiaume, J., & Wallace, K. (2002). Perfluorooctanoate, perflourooctanesulfonate, and *N*-ethyl perfluorooctanesulfonamido ethanol: Peroxisome proliferation and mitochondrial biogenesis. *Toxicology Letters*, *129*, 23-32. https://doi.org/10.1016/S0378-4274(01)00466-0

Besseling, E., Foekema, E. M., Van Franeker, J. A., Leopold, M. F., Kuhn, S., Bravo Rebolledo, E. L., . . . Koelmans, A. A. (2015). Microplastic in a macro filter feeder: Humpback whale *Megaptera novaeangliae*. *Marine Pollution Bulletin*, *95*, 248-252. https://doi.org/10.1016/j.marpolbul.2015.04.007

Bossia, R., Riget, F., Dietz, R., Sonne, C., Fauser, P., Dam, M., & Vorkamp, K. (2005). Preliminary screening of perfluorooctane sulfonate (PFOS) and other fluorochemicals in fish, birds, and marine mammals from Greenland and the Faroe Islands. *Environmental Pollution*, *136*(2), 323-329. https://doi.org/10.1016/j.envpol.2004.12.020

Bourgeon, S., Riemer, A. K., Tartu, S., Aars, J., Polder, A., Jenssen, B. M., & Routti, H. (2017). Potentiation of ecological factors on the disruption of thyroid hormones by organo-halogenated contaminants in female polar bears (*Ursus maritimus*) from the Barents Sea. *Environmental Research*, *158*, 94-104. https://doi.org/10.1016/j.envres.2017.05.034

Bowen, W. D., & Lidgard, D. (2011). *Vertebrate predator control: Effects on prey populations in terrestrial and aquatic ecosystems* (Research Document 2011/028). Ottawa, ON: Canadian Science Advisory Secretariat, Maritimes Region. ISSN 1919-5044

Bowen, W. D., & Lidgard, D. (2013). Marine mammal culling programs: Review of effects on predator and prey populations. *Mammal Review*, *43*(3), 207-220. https://doi.org/10.1111/j.1365-2907.2012.00217.x

Braathen, M., Derocher, A. E., Wiig, Ø., Sormo, E. G., Lie, E., Skaare, J. U., & Jenssen, B. M. (2004). Relationships between PCBs and thyroid hormones and retinol in female and male polar bears. *Environmental Health Perspectives*, *112*(8), 826-833. https://doi.org/10.1289/ehp.6809

Bradford, A., Weller, D., Ivaschenko, Y., Burdin, A., & Brownell, R., Jr. (2009). Anthropogenic scarring of western gray whales (*Eschrichtius robustus*). *Marine Mammal Science*, *25*(1), 161-175. https://doi.org/10.1111/j.1748-7692.2008.00253.x

Brakes, P. (2004). A background to whaling. In P. Brakes, A. Butterworth, M. Simmonds, & P. Lymbery (Eds.), *Troubled waters: A review of the welfare implications of modern whaling activities* (pp. 6-12). London: World Society for the Protection of Animals.

Brakes, P., & Fisher, S. (2004). Commercial and aboriginal subsistence whaling. In P. Brakes, A. Butterworth, M. Simmonds, & P. Lymbery (Eds.), *Troubled waters: A review of the welfare implications of modern whaling activities* (pp. 38-53). London: World Society for the Protection of Animals.

Brando, S., Broom, D., Acasuso-Rivero, C., & Clark, F. (2017). Optimal marine mammal welfare under human care: Current efforts and future directions. *Behavioural Processes*. https://doi.org/10.1016/j.beproc.2017.09.011

Brasseur, S., Creuwels, J., Werf, B. V. D., & Reijnders, P. (1996). Deprivation indicates necessity for haul-out in harbor seals. *Marine Mammal Science*, *12*, 619-624. https://doi.org/10.1111/j.1748-7692.1996.tb00077.x

Bravo-Rebolledo, E. L., van Franeker, J. A., Jansen, O. E., & Brasseur, S. M. (2013). Plastic ingestion by harbour seals (*Phoca vitulina*) in The Netherlands. *Marine Pollution Bulletin*, *67*(1), 200-202. https://doi.org/10.1016/j.marpolbul.2012.11.035

Broom, D. M. (1986). Indicators of poor welfare. *British Veterinary Journal*, *142*, 524-526. https://doi.org/10.1016/0007-1935(86)90109-0

Broom, D. M. (1991). Animal welfare: Concepts and measurement. *Journal of Animal Science*, *69*, 4167-4175. https://doi.org/10.2527/1991.69104167x

Broom, D. M. (2001). Coping, stress and welfare. In D. M. Broom (Ed.), *Coping with challenge: Welfare in animals including humans* (pp. 1-9). Berlin: Dahlem University Press.

Broom, D. M. (2011). The science of animal welfare and its relevance to whales. In International Whaling Commission (Ed.), *Report of the Whale Welfare and Ethics Workshop, Eden Project* (IWC/63/WKM&AWI4). Cambridge, UK: International Whaling Commission.

Broom, D. M., & Fraser, A. F. (2007). *Domestic animal behaviour and welfare* (4th ed.). Wallingford, UK: CABI. https://doi.org/10.1079/9781845932879.0000

Broom, D. M., & Johnston, K. G. (1993). *Stress and animal welfare*. Dordrecht, The Netherlands: Kluwer Academic Publishers. https://doi.org/10.1007/978-94-024-0980-2

Buckstaff, K. C. (2004). Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. *Marine Mammal Science*, *20*(4), 709-725. https://doi.org/10.1111/j.1748-7692.2004.tb01189.x

Burek, K., Gulland, F. M. D., & O'Hara, T. M. (2008). Effects of climate change on Arctic marine mammal health. *Ecological Applications*, *18*(2), S126-S134. https://doi.org/10.1890/06-0553.1

Butler, J. R. A., Middlemas, S. J., McKelvey, S. A., McMyn, I., Leyshon, B., Walker, I., & Baxter, J. M. (2008). The Moray Firth Seal Management Plan: An adaptive framework for balancing the conservation of seals, salmon, fisheries, and wildlife tourism in the UK. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *18*(6), 1025-1038. https://doi.org/10.1002/aqc.923

Butterworth, A. (2004). Review of criteria for determining death and insensibility in cetacea. In P. Brakes, A. Butterworth, M. Simmonds, & P. Lymbery (Eds.), *Troubled waters: A review of the welfare implications of modern whaling activities* (pp. 84-90). London: World Society for the Protection of Animals.

Butterworth, A. (2016). A review of the welfare impact on pinnipeds of plastic marine debris. *Frontiers in Marine Science*, *3*, 149. https://doi.org/10.3389/fmars.2016.00149

Butterworth, A., Clegg, L., & Bass, C. (2012). *Untangled – Marine debris: A global picture of the impact on animal welfare and of animal-focused solutions*. London: World Society for the Protection of Animals.

Butterworth, A., Gellego, P., Gregory, N., Harris, S., & Soulsbury, C. (2007). *Welfare aspects of the Canadian seal hunt: Preliminary report and final report*. Document submitted to European Food Safety Authority.

Calambokidis, J. (2015). *Examination of health effects and long-term impacts of deployments of multiple tag types on blue, humpback, and gray whales in the eastern North Pacific*. Olympia, WA: Cascadia Research Collective. Retrieved from https://www.onr.navy.mil/reports/FY13/nocalamb.pdf

Campbell-Malone, R., Barco, S. G., Daoust, P. Y., Knowlton, A. R., McLellan, W. A., Rotstein, D. S., & Moore, M. J. (2008). Gross and histologic evidence of sharp and blunt trauma in North Atlantic right whales (*Eubalaena glacialis*) killed by vessels. *Journal of Zoo and Wildlife Medicine*, *39*, 37-55. https://doi.org/10.1638/2006-0057.1

Carlson, T. J., Elster, J. L., Jones, M. E., Watson, B. E., Copping, A. E., Watkins, M., . . . Metzinger, K. (2012). *Assessment of strike of adult killer whales by an OpenHydro tidal turbine blade* (Contract DE-AC05-76RL01830). Washington, DC: U.S. Department of Energy. https://doi.org/10.2172/1087285

Carrillo, M., & Ritter, F. (2010). Increasing numbers of ship strikes in the Canary Islands: Proposals for immediate action to reduce risk of vessel–whale collision. *Journal of Cetacean Resource Management*, *11*(2), 131-138.

Cates, K., & Acevedo-Gutierrez, A. (2017). Harbor seal (*Phoca vitulina*) tolerance to vessels under different levels of boat traffic. *Aquatic Mammals*, *43*(2), 193-200. https://doi.org/10.1578/AM.43.2.2017.193

Chilvers, B. L. (2008). New Zealand sea lions *Phocarctos hookeri* and squid trawl fisheries: Bycatch problems and management options. *Endangered Species Research*, *5*, 193-204. https://doi.org/10.3354/esr00086

Clark, C., Ellison, W., Southall, B., Hatch, L., Van Parijs, S., Frankel, A., & Ponirakis, D. (2009). Acoustic masking in marine ecosystems: Intuitions, analysis, and implication. *Marine Ecology Progress Series*, *395*, 201-222. https://doi.org/10.3354/meps08402

Colborn, T., vom Saal, F. S., & Soto, A. M. (1993). Developmental effects of endocrine-disrupting chemicals in wildlife and humans. *Environmental Health Perspectives*, *101*(5), 378-384. https://doi.org/10.1289/ehp.93101378

Cole, T., Hartley, D., & Garron, M. (2006). *Mortality and serious injury determinations for baleen whale stocks along the eastern seaboard of the United States, 2000-2004*. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Costidis, A. M., Berman, M., Cole, T., Knowlton, A., McLellan, W. A., Neilson, J., . . . Raverty, S. (2013). Sharp trauma induced by vessel collision with pinnipeds and cetaceans. *Diseases of Aquatic Organisms*, *103*, 251-256.

Cox, T. M., Ragen, T. J., Read, A. J., Vos, E., Baird, R. W., Balcomb, K., . . . Crum, L. (2006). Understanding the impacts of anthropogenic sound on beaked whales. *Journal of Cetacean Research and Management*, *7*(3), 177-187.

Crisp, T. M., Clegg, E. D., Cooper, R. L., Wood, W. P., Anderson, D. G., Baetcke, K. P., . . . Touart, L. W. (1998). Environmental endocrine disruption: An effects assessment and analysis. *Environmental Health Perspectives*, *106*(1), 11-56. https://doi.org/10.2307/3433911

Crum, L. A., & Mao, Y. (1996). Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. *The Journal of the Acoustical Society of America*, *99*(5), 2898-2907. https://doi.org/10.1121/1.414859

Curé, C., Isojunno, S., Visser, F., Wensveen, P. J., Sivle, L. D., Kvadsheim, P. H., . . . Miller, P. J. (2016). Biological significance of sperm whale responses to sonar: Comparison with anti-predator responses. *Endangered Species Research*, *31*, 89-102. https://doi.org/10.3354/esr00748

D'Amico, A., Gisiner, R. C., Ketten, D. R., Hammock, J. A., Johnson, C., Tyack, P. L., & Mead, J. (2009). Beaked whale strandings and naval exercises. *Aquatic Mammals*, *35*(4), 452-472. https://doi.org/10.1578/AM.35.4.2009.452

Dans, S., Crespo, E., Pedraza, S., Degrati, M., & Garaffo, G. (2008). Dusky dolphin and tourist interaction: Effect on diurnal feeding behavior. *Marine Ecology Progress Series*, *369*, 287-296. https://doi.org/10.3354/meps07629

Daoust, P. Y., & Caraguel, C. (2012). The Canadian harp seal hunt: Observations on the effectiveness of procedures to avoid poor animal welfare outcomes. *Animal Welfare*, *21*, 445-455. https://doi.org/10.7120/09627286.21.4.445

Davies, I. M., & Thompson, F. (2011). *Assessment of collision risk for seals and tidal stream turbines* (ICES CM S11). Retrieved from www.ices.dk/sites/pub/CM%20Doccuments/CM-2011/S/S1111.pdf

Dawkins, M. (1977). Do hens suffer in battery cages? Environmental preferences and welfare. *Animal Behaviour*, *25*(4), 1034-1046. https://doi.org/10.1016/0003-3472(77)90054-9

Dawkins, M. (1980). *Animal suffering*. London: Chapman and Hall. https://doi.org/10.1007/978-94-009-5905-7

Dawkins, M. S. (2000). Animal minds and animal emotions. *American Zoology*, *40*, 883-888. https://doi.org/10.1093/icb/40.6.883

Dawkins, M. S. (2003). Behaviour as a tool in the assessment of animal welfare. *Zoology*, *106*(4), 383-387. https://doi.org/10.1078/0944-2006-00122

De Pierrepont, J., Dubois, B., Desormonts, S., Santos, M., & Robin, J. (2005). Stomach contents of English Channel cetaceans stranded on the coast of Normandy. *Journal of the Marine Biological Association of the United Kingdom*, *85*, 1539-1546. https://doi.org/10.1017/S0025315405012762

de Stephanis, R., Gimenez, J., Carpinelli, E., Gutierrez-Exposito, C., & Canadas, A. (2013). As main meal for sperm whales: Plastics debris. *Marine Pollution Bulletin*, *69*, 206-214. https://doi.org/10.1016/j.marpolbul.2013.01.033

Delfour, F., & Beyer, H. (2011). Assessing the effectiveness of environmental enrichment in bottlenose dolphins (*Tursiops truncatus*). *Zoo Biology*, *31*, 137-150.

Denuncio, P., Bastida, R., Dassis, M., Giardino, G., Gerpe, M., & Rodriguez, D. (2011). Plastic ingestion in Franciscana dolphins, *Pontoporia blainvillei* (Gervais and d'Orbigny, 1944), from Argentina. *Marine Pollution Bulletin*, *62*, 1836-1841. https://doi.org/10.1016/j.marpolbul.2011.05.003

Derraik, J. G. B. (2002). The pollution of the marine environment by plastic debris: A review. *Marine Pollution Bulletin*, *44*, 842-852. https://doi.org/10.1016/S0025-326X(02)00220-5

Desforges, J. P. W., Sonne, C., Levin, M., Siebert, U., De Guise, S., & Dietz, R. (2016). Immunotoxic effects of environmental pollutants in marine mammals. *Environment International*, *86*, 126-139. https://doi.org/10.1016/j.envint.2015.10.007

Di Beneditto, A. P. M., & Ramos, R. M. A. (2014). Marine debris ingestion by coastal dolphins: What drives differences between sympatric species? *Marine Pollution Bulletin*, *83*(1), 298-301. https://doi.org/10.1016/j.marpolbul.2014.03.057

Dolman, S., & Moore, M. (2017). Welfare implications of cetacean bycatch and entanglements. In A. Butterworth (Ed.), *Marine mammal welfare: Human induced change in the marine environment and its impacts on marine mammal welfare* (*Animal Welfare Series*, Vol. 17, pp. 41-65). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-46994-2

Dolman, S. J., Green, M., & Simmonds, M. P. (2007). *Marine renewable energy and cetaceans* (SC/59/E10). Submitted to the Scientific Committee of the International Whaling Commission.

Douglas, A. B., Calambokidis, J., Raverty, S., Jeffries, S. J., Lambourn, D. M., & Norman, S. A. (2008). Incidence of ship strikes of large whales in Washington State. *Journal of the Marine Biological Association of the United*

Kingdom, *88*(6), 1121-1132. https://doi.org/10.1017/S0025315408000295

Duncan, I. J. H. (1981). Animal rights – Animal welfare: A scientist's assessment. *Poultry Science*, *60*, 489-499. https://doi.org/10.3382/ps.0600489

Dunn, D. C., Boustany, A. M., Roberts, J. J., Brazer, E., Sanderson, M., Gardner, B., & Halpin, P. N. (2014). Empirical move-on rules to inform fishing strategies: A New England case study. *Fish and Fisheries*, *15*(3), 359-375. https://doi.org/10.1111/faf.12019

Dwyer, S. L., Kozmian-Ledward, L., & Stockin, K. A. (2014). Short-term survival of severe propeller strike injuries and observations on wound progression in a bottlenose dolphin. *New Zealand Journal of Marine and Freshwater Research*, *48*(2), 1-9. https://doi.org/10.1080/00288330.2013.866578

Edwards, H. H. (2013). Potential impacts of climate change on warmwater megafauna: The Florida manatee example (*Trichechus manatus latirostris*). *Climatic Change*, *121*, 727-738. https://doi.org/10.1007/s10584-013-0921-2

Eriksson, C., & Burton, H. (2003). Origins and biological accumulation of small plastic particles in fur seals from Macquarie Island. *Royal Swedish Academy of Sciences*, *32*(6), 380-384. https://doi.org/10.1579/0044-7447-32.6.380

European Food Safety Authority (EFSA). (2007). Animal welfare aspects of the killing and skinning of seals, scientific opinion of the panel on animal health and welfare. *The EFSA Journal*, *610*, 1-122. Retrieved from http://onlinelibrary.wiley.com/doi/10.2903/j.efsa.2007.610/epdf

Evans, K., Thresher, R., Warneke, R. M., Bradshaw, C. J. A., Pook, M., Thiele, D., & Hindell, M. A. (2005). Periodic variability in cetacean strandings: Links to large-scale climate events. *Biology Letters*, *1*, 147-150.

Fair, P. A., & Becker, P. R. (2000). Review of stress in marine mammals. *Journal of Aquatic Ecosystem Stress and Recovery*, *7*, 335-354. https://doi.org/10.1023/A:1009968113079

Faroe Islands Department of Fisheries. (1991). *Whales and whaling in the Faroe Islands*. Torshavn: Faroe Islands Department of Fisheries.

Fernández, A., Edwards, J. F., Rodriguez, F., De Los Monteros, A. E., Herraez, P., Castro, P., . . . Arbelo, M. (2005). "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (family Ziphiidae) exposed to anthropogenic sonar signals. *Veterinary Pathology*, *42*(4), 446-457. https://doi.org/10.1354/vp.42-4-446

Fernández, R., Santos Vazquez, M. B., Carrillo, M., Tejedor, M., & Pierce, G. J. (2009). Stomach contents of cetaceans stranded in the Canary Islands 1996-2006. *Journal of the Marine Biological Association of the United Kingdom*, *89*(5), 873-883. https://doi.org/10.1017/S0025315409000290

Fielder, J., Burden, R. L., Gripper, J., Longair, J. A., Robinson, I., & Ruehlmann, D. (2001). *Veterinary report: Canadian commercial seal hunt, Prince Edward Island, March 2001*. New Brunswick: International Fund for Animal Welfare. Retrieved from www.ifaw.org/canada/node/6346

Filadelfo, R., Mintz, J., Michlovich, E., D'Amico, A., Tyack, P. L., & Ketten, D. R. (2009). Correlating military sonar use with beaked whale mass strandings: What do the historical data show? *Aquatic Mammals*, *35*(4), 435-444. https://doi.org/10.1578/AM.35.4.2009.435

Finneran, J. J., Carder, D. A., & Ridgway, S. H. (2001). Temporary threshold shift (TTS) in bottlenose dolphins (*Tursiops truncatus*) exposed to tonal signals. *The Journal of the Acoustical Society of America*, *110*(5), 2749. https://doi.org/10.1121/1.4777567

Finneran, J. J., Carder, D. A., Schlundt, C. E., & Ridgway, S. H. (2005). Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. *The Journal of the Acoustical Society of America*, *118*(4), 2696-2705. https://doi.org/10.1121/1.2032087

Finneran, J. J., Schlundt, C. E., Carder, D. A., Clark, J. A., Young, J. A., Gaspin, J. B., & Ridgway, S. H. (2000). Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. *The Journal of the Acoustical Society of America*, *108*(1), 417-431. https://doi.org/10.1121/1.429475

Ford, J. K. B., Ellis, G. M., & Balcomb, K. C. (1994). *Killer whales: The natural history and genealogy of* Orcinus orca *in British Columbia and Washington State*. Vancouver: University of British Columbia Press.

Fossi, M. C., & Marsili, L. (1997). The use of non-destructive biomarkers in the study of marine mammals. *Biomarkers*, *2*, 205-216. https://doi.org/10.1080/135475097231571

Fossi, M. C., Panti, C., Guerranti, C., Coppola, D., Giannetti, M., Marsili, L., & Minutoli, R. (2012). Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (*Balaenoptera physalus*). *Marine Pollution Bulletin*, *64*, 2374-2379. https://doi.org/10.1016/j.marpolbul.2012.08.013

Franco-Trecu, V., Drago, M., Katz, H., Machín, E., & Marín, Y. (2017). With the noose around the neck: Marine debris entangling otariid species. *Environmental Pollution*, *220*, 985-989. https://doi.org/10.1016/j.envpol.2016.11.057

Frouin, H., Lebeuf, M., Hammill, M., Masson, S., & Fournier, M. (2010). Effects of individual polybrominated diphenyl ether (PBDE) congeners on harbour seal immune cells in vitro. *Marine Pollution Bulletin*, *60*, 291-298. https://doi.org/10.1016/j.marpolbul.2009.09.006

Garcia-Alvarez, N., Martin, V., Fernández, A., Almunia, J., Xuriach, A., Arbelo, M., . . . Luzardo, O. P. (2014). Levels and profiles of POPs (organochlorine pesticides, PCBs, and PAHs) in free ranging common bottlenose dolphins of the Canary Islands, Spain. *Science of the Total Environment*, *493*, 22-31. https://doi.org/10.1016/j.scitotenv.2014.05.125

Giesy, J. P., & Kannan, K. (2001). Global distribution of perfluorooctane sulfonate in wildlife. *Environmental Science & Technology*, *35*(7), 1339-1342. https://doi.org/10.1021/es001834k

Gilman, E., Brothers, N., McPherson, G., & Dalzell, P. (2007). A review of cetacean interactions with longline gear. *Journal of Cetacean Research and Management*, *8*(2), 215-223.

Glass, A., Cole, T., & Garron, M. (2010). *Mortality and serious injury determinations for baleen whale stocks along the United States and Canadian Eastern Seaboards, 2004-2008* (NOAA Technical Memorandum NMFS-NE, 214, 02543-1026). Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Goldsworthy, S. D., Hindell, M. A., & Crowley, H. M. (1997). Diet and diving behaviour of sympatric fur seals *Arctocephalus gazella* and *A. tropicalis* at Macquarie Island. *Marine Mammal Research in the Southern Hemisphere*, *1*, 151-163.

Götz, T., & Janik, V. M. (2013). Acoustic deterrent devices to prevent pinniped depredation: Efficiency, conservation concerns, and possible solutions. *Marine Ecology Progress Series*, *492*, 285-302. https://doi.org/10.3354/meps10482

Götz, T., & Janik, V. M. (2015). Target-specific acoustic predator deterrence in the marine environment. *Animal Conservation*, *18*(1), 102-111. https://doi.org/10.1111/acv.12141

Greene, C. R., Jr., & Richardson, W. J. (1988). Characteristics of marine seismic survey sounds in the Beaufort Sea. *The Journal of the Acoustical Society of America*, *83*(6), 2246-2254. https://doi.org/10.1121/1.396354

Guyton, A. C., & Hall, J. E. (1996). *Textbook of medical physiology* (9th ed.). Philadelphia, PA: W. B. Saunders.

Haave, M., Ropstad, E., Derocher, A. E., Lie, E., Dahl, E., Wiig, Ø., . . . Munro, B. (2003). Polychlorinated biphenyls and reproductive hormones in female polar bears at Svalbard. *Environmental Health Perspectives*, *111*, 431-436. https://doi.org/10.1289/ehp.5553

Hall, A. J., Kalantzi, O. I., & Thomas, G. O. (2003). Polybrominated diphenyl ethers (PBDEs) in grey seals during their first year of life—Are they thyroid hormone endocrine disrupters? *Environmental Pollution*, *126*, 29-37. https://doi.org/10.1016/S0269-7491(03)00149-0

Hamer, D. J., Childerhouse, S. J., & Gales, N. J. (2012). Odontocete bycatch and depredation in longline fisheries: A review of available literature and of potential solutions. *Marine Mammal Science*, *28*(4), E345-E374. https://doi.org/10.1111/j.1748-7692.2011.00544.x

Harding, K. C., Fujiwara, M., Axberg, Y., & Harkonen, T. (2005). Mass-dependent energetics and survival in harbour seal pups. *Functional Ecology*, *19*, 129-135. https://doi.org/10.1111/j.0269-8463.2005.00945.x

Harris, C. M., Thomas, L., Falcone, E. A., Hildebrand, J., Houser, D., Kvadsheim, P. H., . . . Slabbekoorn, H. (2017). Marine mammals and sonar: Dose-response studies, the risk-disturbance hypothesis and the role of exposure context. *Journal of Applied Ecology*, *55*(1), 396-404. https://doi.org/10.1111/1365-2664.12955

Hauksson, E. (2007). Abundance of grey seals in Icelandic waters, based on trends of pup-counts from aerial surveys. *NAMMCO Science Publications*, *6*, 85-97. https://doi.org/10.7557/3.2725

Hauksson, E., & Bogason, V. (1997). Comparative feeding of grey (*Halichoerus grypus*) and common seals (*Phoca vitulina*) in coastal waters of Iceland, with a note on the diet of hooded (*Cystophora cristata*) and harp seals (*Phoca groenlandica*). *Journal of the Northwest Atlantic Fishery Science*, *22*, 125-135. https://doi.org/10.2960/J.v22.a11

Herzke, D., Gabrielsen, G. W., Evenset, A., & Burkow, I. C. (2003). Polychlorinated camphenes (toxaphenes), polybrominated diphenylethers and other halogenated organic pollutants in glaucous gull (*Larus hyperboreus*) from Svalbard and Bjørnøya (Bear Island). *Environmental Pollution*, *121*(2), 293-300. https://doi.org/10.1016/S0269-7491(02)00217-8

Hildebrand, J. A. (2009). Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series*, *395*, 5-20. https://doi.org/10.3354/meps08353

Hofmeyr, G., De Maine, M., Bester, M., Kirkman, S., Pistorius, P., & Makhado, A. (2002). Entanglement of pinnipeds at Marion Island, Southern Ocean: 1991-2001. *Australian Mammalogy*, *24*, 141-146. https://doi.org/10.1071/AM02141

Holley, P. (2016). Endangered baby dolphin dies after swimmers pass around for selfies. *Washington Post*. Retrieved from https://www.washingtonpost.com/news/speaking-of-science/wp/2016/02/18/endangered-baby-dolphin-dies-after-swimmers-pass-it-around-for-selfies/?utm_term=.ed3297c05d1a

Holt, M. M., Noren, D. P., Dunkin, R. C., & Williams, T. M. (2015). Vocal performance affects metabolic rate in dolphins: Implications for animals communicating in noisy environments. *Journal of Experimental Biology*, *218*(11), 1647-1654. https://doi.org/10.1242/jeb.122424

Holt, M. M., Noren, D. P., Veirs, V., Emmons, C. K., & Veirs, S. (2009). Speaking up: Killer whales (*Orcinus orca*) increase their call amplitude in response to vessel noise. *The Journal of the Acoustical Society of America*, *125*(1), EL27-EL32. https://doi.org/10.1121/1.3040028

Hunt, K., Rolland, R., Kraus, S., & Wasser, S. (2006). Analysis of fecal glucocorticoids in the North Atlantic right whale (*Eubalaena glacialis*). *General and Comparative Endocrinology*, *148*, 260-272. https://doi.org/10.1016/j.ygcen.2006.03.012

International Council for the Exploration of the Sea (ICES). (2009). *Report of the Ad Hoc Group on Icelandic Cod: HCR evaluation (AGICOD)* (ICES CM 2009\ACOM:56). Copenhagen, Denmark: ICES.

Ikonomou, M. G., Rayne, S., & Addison, R. F. (2002). Exponential increases of the brominated flame retardants, polybrominated diphenyl ethers, in the Canadian Arctic from 1981 to 2000. *Environmental Science & Technology*, *36*(9), 1886-1892. https://doi.org/10.1021/es011401xx

International Whaling Commission (IWC). (1984). *Thirty-Fourth Report of the International Whaling Commission*. Cambridge, UK: IWC.

IWC. (1992). *Report of the Workshop on Whale Killing Methods* (IWC/44/18SUP). Cambridge, UK: IWC.

IWC. (2003). *Report of the Whale Watching Sub-Committee*. Cambridge, UK: IWC.

IWC. (2009). *Sixty-First Report of the International Whaling Commission*. Funchal, Madeira Island, Portugal: IWC. Retrieved from www.catca-ews.org/wordpress/wp-content/uploads/2016/02/iwc61report2009.pdf

IWC. (2011). *Report of the Whale Welfare and Ethics Workshop* (IWC/63/WKM&AWI4). Eden Project, UK: IWC.

IWC. (2018a). *Conservation and management: Whaling*. Cambridge, UK: IWC. Retrieved from https://iwc.int/whaling

IWC. (2018b). *Conservation and management: Special permit whaling*. Cambridge, UK: IWC. Retrieved from https://iwc.int/permits

IWC. (2018c). *Scientific Committee handbook*. Cambridge, UK: IWC. Retrieved from https://iwc.int/scientific-committee-handbook#seven

Irvine, A. B., Wells, R. S., & Scott, M. D. (1982). An evaluation of techniques for tagging small odontocete cetaceans. *Fishery Bulletin*, *80*, 135-143.

Jacobsen, J. K., Massey, L., & Gulland, F. M. D. (2010). Fatal ingestion of floating net debris by two sperm whales (*Physeter macrocephalus*). *Marine Pollution Bulletin*, *60*, 765-767. https://doi.org/10.1016/j.marpolbul.2010.03.008

Jansen, J. K., Boveng, P., Dahle, S. P., & Bengtson, J. L. (2010). Reaction of harbor seals to cruise ships. *Journal of Wildlife Management*, *74*(6), 1186-1194. https://doi.org/10.1016/j.marpolbul.2010.03.008

Jefferson, T. A. (2000). Population biology of the Indo-Pacific humpbacked dolphin in Hong Kong waters. *Wildlife Monographs*, *144*, 1-65.

Jenssen, B. M. (2006). Endocrine-disrupting chemicals and climate change: A worst-case combination for Arctic marine mammals and seabirds? *Environmental Health Perspectives*, *114*(1), 76-80. https://doi.org/10.1289/ehp.8057

Jepson, P. D., Bennett, P. M., Deaville, R., Allchin, C. R., Baker, J. R., & Law, R. J. (2005). Relationships between polychlorinated biphenyls and health status in harbor porpoises (*Phocoena phocoena*) stranded in the United Kingdom. *Environmental Toxicology and Chemistry*, *24*(1), 238-248. https://doi.org/10.1897/03-663.1

Jepson, P. D., Arbelo, M., Deaville, R., Patterson, I. A. P., Castro, P., Baker, J. R., . . . Rodriguez, F. (2003). Gas-bubble lesions in stranded cetaceans. *Nature*, *425*(6958), 575-576. https://doi.org/10.1038/425575a

Jewell, P. A., & Holt, S. (1981). *Problems in management of locally abundant wild mammals*. New York: Academic Press.

Johnson, A., & Acevedo-Gutierrez, A. (2007). Regulation compliance by vessels and disturbance of harbour seals (*Phoca vitulina*). *Canadian Journal of Zoology*, *85*, 290-294. https://doi.org/10.1139/Z06-213

Jubb, K. V. F., Kennedy, P. C., & Palmer, N. (1993). *Pathology of domestic animals*. New York: Academic Press.

Kastak, D., & Schusterman, R. J. (1996). Temporary threshold shift in a harbor seal (*Phoca vitulina*). *The Journal of the Acoustical Society of America*, *100*(3), 1905-1908. https://doi.org/10.1121/1.41601

Kastak, D., Schusterman, R. J., Southall, B. L., & Reichmuth, C. J. (1999). Underwater temporary threshold shift induced by octave-band noise in three species of pinniped. *The Journal of the Acoustical Society of America*, *106*(2), 1142-1148. https://doi.org/10.1016/S0141-1136(99)00081-12

Kastelein, R. A., Au, W. L. L., & De Haan, D. (2000). Detection distances of bottom-set gillnets by harbour porpoises (*Phocoena phocoena*) and bottlenose dolphins (*Tursiops truncatus*). *Marine Environmental Research*, *49*, 359-375. https://doi.org/10.1016/S0141-1136(99)00081-1

Kemper, C. M., & Gibbs, S. E. (2001). Dolphin interactions with tuna feedlots at Port Lincoln, South Australia and recommendations for minimising entanglements. *Journal of Cetacean Research and Management*, *3*(3), 283-292.

Kemper, C. M., Pemberton, D., Cawthorn, M., Heinrich, S., Mann, J., Würsig, B., . . . Gales, R. (2003). Aquaculture and marine mammals: Co-existence or conflict. In N. Gales, M. Hindell, & R. Kirkwood (Eds.), *Marine mammals: Fisheries, tourism and management issues* (pp. 208-225). Collingwood, Australia: CSIRO Publishing.

Kestin, S. C. (1995). Welfare aspects of the commercial slaughter of whales. *Animal Welfare*, *4*, 11-27.

King, J., & Heinen, J. (2004). An assessment of the behaviors of overwintering manatees as influenced by interactions with tourists at two sites in central Florida. *Biological Conservation*, *117*, 227-234. https://doi.org/10.1016/j.biocon.2003.07.001

Knowlton, A. R., & Kraus, S. D. (2001). Mortality and serious injury of northern right whales (*Eubalaena glacialis*) in the western North Atlantic Ocean. *Journal of Cetacean Resource Management*, *2*, 193-208.

Knowlton, A. R., Mead, J. G., Collet, A. S., & Podesta, M. (2001). Collisions between ships and whales. *Marine Mammal Science*, *17*(1), 35-75. https://doi.org/10.1111/j.1748-7692.2001.tb00980.x

Knudsen, S. K., & Øen, E. O. (2003). Blast induced neurotrauma in whales. *Neuroscience Research*, *46*, 377-386. https://doi.org/10.1016/S0168-0102(03)00101-9

Konigson, S., Fjalling, A., Berglind, M., & Lunneryd, S. (2013). Male gray seals specialize in raiding salmon traps. *Fisheries Research*, *148*, 117-123. https://doi.org/10.1016/j.fishres.2013.07.014

Kraus, S. D. (1990). Rates and potential causes of mortality in North Atlantic right whales (*Eubalaena glacialis*). *Marine Mammal Science*, *6*, 278-291. https://doi.org/10.1111/j.1748-7692.1990.tb00358.x

Krützen, M., Barré, L. M., Möller, L. M., Heithaus, M. R., Simms, C., & Sherwin, W. B. (2002). A biopsy system for small cetaceans: Darting success and wound healing in *Tursiops* spp. *Marine Mammal Science*, *18*, 863-878. https://doi.org/10.1111/j.1748-7692.2002.tb01078.x

Kühn, S., Bravo Rebolledo, E. L., & van Franeker, J. A. (2015). Deleterious effects of litter on marine life. In M. Bergmann, L. Gutow, & M. Klages (Eds.), *Marine anthropogenic litter* (pp. 75-116). Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-16510-3_4

Laist, D. (1997). Impacts of marine debris: Entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In J. M. Coe & D. B. Rogers (Eds.), *Marine debris* (pp. 99-139). New York: Springer. https://doi.org/10.1007/978-1-4613-8486-1_10

Lavers, J. L., Bond, A. L., & Hutton, I. (2014). Plastic ingestion by flesh-footed shearwaters (*Puffinus carneipes*): Implications for fledgling body condition and the accumulation of plastic-derived chemicals. *Environmental Pollution*, *187,* 124-129. https://doi.org/10.1016/j.envpol.2013.12.020

Lavigne, D. M. (2003). Marine mammals and fisheries: The role of science in the culling debate. In N. Gales, M. Hindell, & R. Kirkwood (Eds.), *Marine mammals: Fisheries tourism and management issues* (pp. 31-47). Melbourne, Australia: CSIRO Publications.

Lavigne, D. M., & Lynn, W. S. (2011). Canada's commercial seal hunt: It's more than a matter of humane killing. *Journal of Animal Ethics*, *1*, 1-5. https://doi.org/10.5406/janimalethics.1.1.0001

Lavigne, D. M., Kidman Cox, R., Menon, V., & Wamithi, M. (2006). Reinventing wildlife conservation for the 21st century. In D. M. Lavigne (Ed.), *Gaining ground: In pursuit of ecological sustainability* (pp. 379-406). Guelph, ON: International Fund for Animal Welfare and University of Limerick.

Leaper, R., Cooke, J., Trathan, P., Reid, K., Rowntree, V., & Payne, R. (2006). Global climate drives southern right whale (*Eubalaena australis*) population dynamics. *Biology Letters*, *2*, 289-292. https://doi.org/10.1098/rsbl.2005.0431

Le Boeuf, B. J., Perez-Cortes M., H., Urban R., J., Mate, B., & Ollervides U., F. (2000). High gray whale mortality and low recruitment in 1999: Potential causes and implications. *Journal of Cetacean Research and Management*, *2*(2), 85-99.

Letcher, R. J., Bustnes, J. O., Dietz, R., Jenssen, B. M., Jorgensen, E. H., Sonne, C., . . . Gabrielson, G. W. (2010). Exposure and effects assessment of persistent organohalogen contaminants in Arctic wildlife and fish. *Science of the Total Environment*, *408*, 2995-3043. https://doi.org/10.1016/j.scitotenv.2009.10.038

Lewison, R. L., Crowder, L. B., Read, A. J., & Freeman, S. A. (2004). Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology & Evolution*, *19*, 598-604. https://doi.org/10.1016/j.tree.2004.09.004

Lightsey, J. D., Romel, S. A., Costidis, A. M., & Pitchford, T. D. (2006). Methods used during gross necropsy to determine watercraft-related mortality in the Florida manatee (*Trichechus manatus latirostris*). *Journal of Zoo and Wildlife Medicine*, *37*(3), 262-275. https://doi.org/10.1638/04-095.1

Lonsdale, J. (2004). The small cetacean dimension. In P. Brakes, A. Butterworth, M. Simmonds, & P. Lymbery (Eds.), *Troubled waters: A review of the welfare implications of modern whaling activities* (pp. 6-12). London: World Society for the Protection of Animals.

Lundquist, D., Gemmell, N. J., & Würsig, B. (2012). Behavioural responses of dusky dolphin groups (*Lagenorhynchus obscurus*) to tour vessels off Kaikoura, New Zealand. *PLOS ONE*, *7*, e41969. https://doi.org/10.1371/journal.pone.0041969

Lusseau, D. (2003). Effects of tour boats on the behavior of bottlenose dolphins: Using Markov chains to model anthropogenic impacts. *Conservation Biology*, *17*, 1785-1793. https://doi.org/10.1111/j.1523-1739.2003.00054.x

Lusseau, D., Bain, D. E., Williams, R., & Smith, J. C. (2009). Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*. *Endangered Species Research*, *6*, 211-221. https://doi.org/10.3354/esr00154

Lyle, J., Willcox, S., & Hartmann, K. (2015). Underwater observations of seal–fishery interactions and the effectiveness of an exclusion device in reducing bycatch in a midwater trawl fishery. *Canadian Journal of Fisheries and Aquatic Sciences*, *73*, 436-444. https://doi.org/10.1139/cjfas-2015-0273

Maas, B. (2003). *The potential stress effects of whaling operations and the welfare implications for hunted cetaceans* (IWC/55/WK19). Submitted to the IWC Workshop on Whale Killing Methods and Associated Welfare Issues, Berlin, Germany.

Macdonald, R. W., Mackay, D., & Hickie, B. E. (2002). Contaminant amplification in the environment. *Environmental Science & Technology*, *36*, 457-462. https://doi.org/10.1021/es022470u

Madsen, P. T., Wahlberg, M., Tougaard, J., Lucke, K., & Tyack, P. (2006a). Wind turbine underwater noise and marine mammals: Implications of current knowledge and data needs. *Marine Ecology Progress Series*, *309*, 279-295. https://doi.org/10.3354/meps309279

Madsen, P. T., Johnson, M., Miller, P. J. O., Soto, N. A., Lynch, J., & Tyack, P. L. (2006b). Quantitative measures of air-gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. *The Journal of the Acoustical Society of America*, *120*(4), 2366-2379. https://doi.org/10.1121/1.2229287

Marine Scotland. (2014). *Guidance on the offence of harassment at seal haul-out sites*. Retrieved from www.gov.scot/Resource/0045/00452869.pdf

Marine Scotland. (2016). *Seal licensing*. Retrieved from www.gov.scot/Topics/marine/Licensing/SealLicensing

Martineau, D. (2007). Potential synergism between stress and contaminants in free-ranging cetaceans. *International Journal of Comparative Psychology*, *20*(2), 194-216.

Martineau, D., Lagacé, A., Béland, P., Higgins, R., Armstrong, D., & Shugart, L. R. (1988). Pathology of stranded beluga whales (*Delphinapterus leucas*) from the St. Lawrence Estuary, Québec, Canada. *Journal of Comparative Pathology*, *98*(3), 287-311. https://doi.org/10.1016/0021-9975(88)90038-2

Mazzariol, S., Di Guardo, G., Petrella, A., Marsili, L., Fossi, C. M., Leonzio, C., . . . Fernández, A. (2011). Sometimes sperm whales (*Physeter macrocephalus*) cannot find their way back to the high seas: A multidisciplinary study on a mass stranding. *PLOS ONE*, *6*(5), e19417. https://doi.org/10.1371/journal.pone.0019417

Mazzoil, M. J. S., Reif, M., Youngbluth, M. E., Murdoch, S. E., Bechdel, E., Howells, S. D., . . . Bossart, G. D. (2008). Home ranges of bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida: Environmental correlates and implications for management strategies. *EcoHealth*, *5*(3), 278-288. https://doi.org/10.1007/s10393-008-0194-9

McCarthy, E., Moretti, D., Thomas, L., DiMarzio, N., Morrissey, R., Jarvis, S., . . . Dilley, A. (2011). Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (*Mesoplodon densirostris*) during multiship exercises with mid-frequency sonar. *Marine Mammal Science*, 27(3), 206-226. https://doi.org/10.1111/j.1748-7692.2010.00457.x

McCauley, R. D., Jenner, M. N., Jenner, C., McCabe, K. A., & Murdoch, J. (1998). The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey: Preliminary results of observations about a working seismic vessel and experimental exposures. *Australian Petroleum Production Exploration Association Journal*, *1998*, 692-706. https://doi.org/10.1071/AJ97045

McCauley, R. D., Fewtrell, J., Duncan, A. J., Jenner, C., Jenner, M-N., Penrose, J. D., . . . McCabe, K. (2000). Marine seismic surveys: A study of environmental implications. *Australian Petroleum Production Exploration Association Journal*, *2000*, 692-708. https://doi.org/10.1071/AJ99048

McDonald, M., Hildebrand, J., & Wiggins, S. (2006). Increases in deep ocean ambient noise in the northeast Pacific west of San Nicolas Island, California. *The Journal of the Acoustical Society of America*, *120*, 711-718. https://doi.org/10.1121/1.2216565

McMahon, C. R., Holley, D., & Robinson, S. (1999). The diet of itinerant male Hooker's sea lions, *Phocarctos hookeri*, at sub-Antarctic Macquarie Island. *Wildlife Research*, *26*(6), 839-846. https://doi.org/10.1071/WR98079

Meerts, I. A., Letcher, R. J., Hoving, S., Marsh, G., Bergman, A., Lemmen, J. G., . . . Brouwer, A. (2001). In vitro estrogenicity of polybrominated diphenyl ethers, hydroxylated PDBEs, and polybrominated bisphenol A compounds. *Environmental Health Perspectives*, *109*(4), 399-407. https://doi.org/10.1289/ehp.01109399

Meng, X. Z., Blasius, M. E., Gossett, R. W., & Maruya, K. A. (2009). Polybrominated diphenyl ethers in pinnipeds stranded along the southern California coast. *Environmental Pollution*, *157*(10), 2731-2736. https://doi.org/10.1016/j.envpol.2009.04.029

Merchant, N. D., Fristrup, K. M., Johnson, M. P., Tyack, P. L., Witt, M. J., Blondel, P., & Parks, S. E. (2015). Measuring acoustic habitats. *Methods in Ecology and Evolution*, *6*, 257-265. https://doi.org/10.1111/2041-210X.12330

Metcalf, V., & Robards, M. (2008). Sustaining a healthy human–walrus relationship in a dynamic environment: Challenges for co-management. *Ecological Applications*, *18*, 148-156. https://doi.org/10.1890/06-0642.1

Miller, L., Solangi, M., & Kuczaj II, S. A. (2008). Immediate response of Atlantic bottlenose dolphins to high-speed personal watercraft in the Mississippi Sound. *Journal of the Marine Biological Association of the United Kingdom*, *88*, 1139-1143. https://doi.org/10.1017/S0025315408000908

Ministry of Fisheries and Marine Resources. (2008). *Annual report 2007*. Windhoek, Namibia: Ministry of Fisheries and Marine Resources. Retrieved from www.mfmr.gov.na

Mooney, T. A., Pacini, A. F., & Nachtigall, P. E. (2009). False killer whale (*Pseudorca crassidens*) echolocation and acoustic disruption: Implications for longline bycatch and depredation. *Canadian Journal of Zoology*, *87*(8), 726-733. https://doi.org/10.1139/Z09-061

Moore, M. (2013). Welfare of whales by-caught in fishing gear or struck by vessels. *Animal Welfare*, *22*, 117-121. https://doi.org/10.7120/09627286.22.1.117

Moore, M. (2014). How we all kill whales. *ICES Journal of Marine Science*, *71*, 760-763. https://doi.org/10.1093/icesjms/fsu008

Moore, M., & van der Hoop, J. (2012). The painful side of trap and fixed net fisheries: Chronic entanglement of large whales. *Journal of Marine Biology*, *2012*, Article ID 230653. https://doi.org/10.1155/2012/230653

Moore, M., Andrews, R., Austin, T., Bailey, J., Costidis, A., . . . McLellan, W. (2013). Rope trauma, sedation, disentanglement, and monitoring-tag associated lesions in a terminally entangled North Atlantic right whale (*Eubalaena glacialis*). *Marine Mammal Science*, *29*, 98-113. https://doi.org/10.1111/j.1748-7692.2012.00591.x

Moore, S., & Clarke, J. T. (2002). Potential impact of offshore human activities on gray whales (*Eschrichtius robustus*). *Journal of Cetacean Research and Management*, *4*(1), 19-25.

Moore, S., & Huntington, H. (2008). Arctic marine mammals and climate change: Impacts and resilience. *Ecological Applications*, *18*, 157-165. https://doi.org/10.1890/06-0571.1

Moretti, D., Marques, T. A., Thomas, L., DiMarzio, N., Dilley, A., Morrissey, R., . . . Jarvis, S. (2010). A dive counting density estimation method for Blainville's beaked whale (*Mesoplodon densirostris*) using a bottom-mounted hydrophone field as applied to a mid-frequency active (MFA) sonar operation. *Applied Acoustics*, *71*(11), 1036-1042. https://doi.org/10.1016/j.apacoust.2010.04.011

Moretti, D., Thomas, L., Marques, T., Harwood, J., Dilley, A., Neales, B., . . . Morrissey, R. (2014). A risk function for behavioral disruption of Blainville's beaked whales (*Mesoplodon densirostris*) from mid-frequency active sonar. *PLOS ONE*, *9*(1), e85064. https://doi.org/10.1371/journal.pone.0085064

Nachtigall, P. E., Supin, A. Ya., Pawloski, J., & Au, W. W. L. (2004). Temporary threshold shifts after noise exposure in the bottlenose dolphin (*Tursiops truncatus*) measured using evoked auditory potentials. *Marine Mammal Science*, *20*, 673-687. https://doi.org/10.1111/j.1748-7692.2004.tb01187.x

National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program. (2017). *Plastics*. Retrieved from https://marinedebris.noaa.gov/info/plastic.html

National Research Council (NRC). (2005). *Marine mammal populations and ocean. Noise: Determining when noise causes biologically significant effects*. Washington, DC: National Academy Press.

Neale, J. C. C., Gulland, F. M. D., Schmelzer, K. R., Harvey, J. T., Berg, E. A., Allen, S. G., . . . Tjeerdema, R. S. (2005). Contaminant loads and hematological correlates in the harbor seal (*Phoca vitulina*) of San Francisco Bay, California. *Journal of Toxicology and Environmental Health*, *68*, 617-633. https://doi.org/10.1080/15287390590921748

Neil, D., & Brieze, I. (1998). Wild dolphin provisioning at Tangalooma, Moreton Island: An evaluation. *Moreton Bay and Catchment*, *487-500*, 135-148. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.532.5224&rep=rep1&type=pdf

Neilson, J. L., Gabriele, C. M., Jensen, A. S., Jackson, K., & Straley, J. M. (2012). Summary of reported whale-vessel collisions in Alaskan waters. *Journal of Marine Biology*, Article ID106282. https://doi.org/10.1155/2012/106282

Newson, D., & Rodger, K. (2007). The impacts of tourism on pinnipeds and implications for tourism management. In J. Higham & M. Lück (Eds.), *Marine wildlife and tourism management: Insights from the natural and social sciences* (pp. 182-205). Wallingford, UK: CABI. https://doi.org/10.1079/9781845933456.0182

Ng, S. L., & Leung, S. (2003). Behavioral response of Indo-Pacific humpback dolphin (*Sousa chinensis*) to vessel traffic. *Marine Environmental Research*, *56*, 555-567. https://doi.org/10.1016/S0141-1136(03)00041-2

Nowacek, D. P., Johnson, M. P., & Tyack, P. L. (2004). North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. *Proceedings of the Royal Society of London B: Biological Sciences*, *271*(1536), 227-231. https://doi.org/10.1098/rspb.2003.2570

Nunny, L., Langford, F., & Simmonds, M. P. (2016). Does the seal licensing system in Scotland have a negative impact on seal welfare? *Frontiers in Marine Science*, *3*(142). https://doi.org/10.3389/fmars.2016.00142

Øen, E. O. (1994). *Report from the 1992 scientific catch* (IWC/45/HK1). Cambridge, UK: International Whaling Commission.

Øen, E. O. (1999). *Improvements in hunting and killing methods for minke whales in Norway* (IWC/51/WK11). Submitted by the Government of Norway to the 1999 IWC Workshop on Whale Killing Methods.

Olsen, J. (1999). *Killing methods and equipment in the Faroese Pilot Whale Hunt* (NAMMCO/99/WS/2).

Olson, J. K., & Acevedo-Gutiérrez, A. (2017). Influence of human exposure on the anti-predator response of harbor seals (*Phoca vitulina*). *Aquatic Mammals*, *43*(6), 673-681. https://doi.org/10.1578/AM.43.6.2017.673

Oregon Department of Fish and Wildlife. (2013). *Sea lion management Q&As*. Retrieved from www.dfw.state.or.us/fish/sealion/faqs.asp

Osinga, N., Nussbaum, S. B., Brakefield, P. M., & Udo de Haes, H. A. (2012). Response of common seals (*Phoca vitulina*) to human disturbances in the Dollard estuary of the Wadden Sea. *Mammalian Biology*, *77*, 281-287. https://doi.org/10.1016/j.mambio.2012.02.005

Oskam, I. C., Ropstad, E., Dahl, E., Lie, E., Derocher, A. E., Wiig, Ø., . . . Skaare, U. (2003). Organochlorines affect the major androgenic hormone, testosterone, in male polar bears (*Ursus maritimus*) at Svalbard. *Journal of Toxicology and Environmental Health*, *66A*, 2119-2139. https://doi.org/10.1080/15287390390211342

Oskam, I. C., Ropstad, E., Lie, E., Derocher, A. E., Wiig, Ø., Dahl, E., . . . Skaare, U. (2004). Organochlorines affect the steroid hormone cortisol in free-ranging polar bears (*Ursus maritimus*) at Svalbard, Norway. *Journal of Toxicology and Environmental Health*, *67A*, 959-977. https://doi.org/10.1080/15287390490443731

Papastavrou, V. (2006). *In the name of science? A review of scientific whaling*. Bristol, UK: International Fund for Animal Welfare. 16 pp.

Passadore, C., Domingo, A., & Secchi, E. R. (2015). Depredation by killer whale (*Orcinus orca*) and false killer whale (*Pseudorca crassidens*) on the catch of the Uruguayan pelagic longline fishery in southwestern Atlantic Ocean. *ICES Journal of Marine Science*, *72*(5), 1653-1666. https://doi.org/10.1093/icesjms/fsu251

Passadore, G., Monego, M., Altissimo, L., Sottani, A., Putti, M., & Rinaldo, A. (2012). Alternative conceptual models and the robustness of groundwater management scenarios in the multi-aquifer system of the Central Veneto Basin, Italy. *Hydrogeology Journal*, *20*(3), 419-433. https://doi.org/10.1007/s10040-011-

Pemberton, D., Brothers, N., & Copson, G. (1991). Predators on marine fish farms in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania*, *125*, 33-35.

Perry, C. (1999). *Status of the Dall's porpoise (*Phocoenoides dalli*) in Japan* (IWC51/SC51/SM46). Cambridge, UK: International Whaling Commission.

Pirotta, E., Merchant, N. D., Thompson, P. M., Barton, T. R., & Lusseau, D. (2015). Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity. *Biological Conservation*, *181*, 82-89. https://doi.org/10.1016/j.biocon.2014.11.003

Poncelet, E., van Canneyt, O., & Boubert, J. J. (2000). Considerable amount of plastic debris in the stomach of a Cuvier's beaked whale (*Ziphius cavirostris*) washed ashore on the French Atlantic coast. *European Research on Cetaceans*, *14*, 44-47.

Popper, A. N. (1980). Sound emission and detection by delphinids. In L. M. Herman (Ed.), *Cetacean behaviour: Mechanisms and processes* (pp. 1-51). New York: John Wiley & Sons.

Powell, J. R., & Wells, R. S. (2011). Recreational fishing depredation and associated behaviors involving common bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Marine Mammal Science*, *27*(1), 111-129. https://doi.org/10.1111/j.1748-7692.2010.00401.x

Pribanic, S., Holcer, D., & Miokovic, D. (1999). First report of plastic ingestion by striped dolphin (*Stenella coeruleoalba*) in the Croatian part of the Adriatic Sea. *European Research on Cetaceans*, *13*, 443-446.

Ragen, T., Huntington, H., & Hovelsrud, G. (2008). Conservation of Arctic marine mammals faced with climate change. *Ecological Applications*, *18*(2), 166-174. https://doi.org/10.1890/06-0734.1

Read, A. J. (2005). Bycatch and depredation. In J. E. Reynolds, W. F. Perrin, R. R. Reeves, S. Montgomery, & T. J. Ragen (Eds.), *Marine mammal research: Conservation beyond crisis* (pp. 5-17). Baltimore, MD: Johns Hopkins University Press.

Read, A. J. (2008). The looming crisis: Interactions between marine mammals and fisheries. *Journal of Mammalogy*, *89*, 541-548. https://doi.org/10.1644/07-MAMM-S-315R1.1

Read, A. J., Drinker, P., & Northridge, S. (2006). Bycatch of marine mammals in U.S. and global fisheries. *Conservation Biology*, *20*, 163-169. https://doi.org/10.1111/j.1523-1739.2006.00338.x

Reijnders, P. J. H., Aguilar, A., & Borrel, A. (2009). Pollution and marine mammals. In W. F. Perrin, B. Würsig, & J. G. M. Thewissen (Eds.), *Encyclopedia of marine mammals* (2nd ed., pp. 948-956). San Diego: Academic Press.

Richardson, W. J., & Würsig, B. (1997). Influences of man-made noise and other human actions on cetacean behaviour. *Marine and Freshwater Behaviour and Physiology*, *29*(1-4), 183-209. https://doi.org/10.1080/10236249709379006

Richardson, W. J., Miller, G. W., & Greene, C. R., Jr. (1999). Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. *The Journal of the Acoustical Society of America*, *106*(4), 2281. https://doi.org/10.1121/1.4278011

Richardson, W. J., Würsig, B., & Greene, C. R., Jr. (1986). Reactions of bowhead whales, *Balaena mysticetus,* to seismic exploration in the Canadian Beaufort Sea. *The Journal of the Acoustical Society of America*, *79*(4), 1117-1128. https://doi.org/10.1121/1.393384

Ridgway, S., & Carder, D. (1990). Tactile sensitivity, somatosensory responses, skin vibrations, and the skin surface ridges of the bottle-nose dolphin, *Tursiops truncatus*. In J. A. Thomas & R. A. Kastelein (Eds.), *Sensory abilities of cetaceans* (pp. 163-179). Boston: Springer. https://doi.org/10.1007/978-1-4899-0858-2_9

Ritter, F. (2012). Collisions of sailing vessels with cetaceans worldwide: First insights into a seemingly growing problem. *Journal of Cetacean Resource Management*, *12*(1), 119-127.

Roche, C., Guinet, C., Gasco, N., & Duhamel, G. (2007). Marine mammals and demersal longline fishery interactions in Crozet and Kerguelen Exclusive Economic Zones: An assessment of depredation levels. *CCAMLR Science*, *14*, 67-82.

Rommel, S. A., Costidis, A. M., Fernández, A., Jepson, P. D., Pabst, D. A., McLellan, W. A., . . . Barros, N. B. (2005). Elements of beaked whale anatomy and diving physiology and some hypothetical causes of sonar-related stranding. *Journal of Cetacean Research and Management*, *7*(3), 189-209.

Ryan, P. G., de Bruyn, P. J. N., & Bester, M. N. (2016). Regional differences in plastic ingestion among Southern Ocean fur seals and albatrosses. *Marine Pollution Bulletin*, *104*, 207-210. https://doi.org/10.1016/j.marpolbul.2016.01.032

Samuels, A., & Bejder, L. (2004). Chronic interaction between humans and free-ranging bottlenose dolphins near Panama City Beach, Florida. *Journal of Cetacean Research and Management*, *6*, 69-77.

Scarpaci, C., Dayanthi, N., & Corkeron, P. J. (2003). Compliance with regulations by "swim-with-dolphins" operations in Port Phillip Bay, Victoria, Australia. *Environmental Management*, *31*, 342-347. https://doi.org/10.1007/s00267-002-2799-z

Schantz, S. L., & Widholm, J. J. (2001). Cognitive effects of endocrine-disrupting chemicals in animals. *Environmental Health Perspectives*, *109*(12), 1197-1206. https://doi.org/10.1289/ehp.011091197

Schlundt, C. E., Finneran, J. J., Carder, D. A., & Ridgway, S. H. (2000). Temporary shift in masked hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. *The Journal of the Acoustical Society of America*, *107*(6), 3496-3508. https://doi.org/10.1121/1.429420

Scotland's Rural College (SRUC) Wildlife Unit. (2012). *Scottish marine animal stranding scheme* (Seal Management Cases 1 January to 31 December 2012 for Marine Scotland, Scottish Government).

Scottish Office of Agriculture. (1997). *Report of the Scottish Salmon Strategy Task Force*. Edinburgh: Scottish Office of Agriculture, Environment and Fisheries Department.

Secchi, E. R., & Zarzur, S. (1999). Plastic debris ingested by a Blainville's beaked whale, *Mesoplodon densirostris*, washed ashore in Brazil. *Aquatic Mammals*, *25*(1), 21-24.

Seuront, L., & Cribb, N. (2011). Fractal analysis reveals pernicious stress levels related to boat presence and type in the Indo-Pacific bottlenose dolphin, *Tursiops aduncus*. *Physica A: Statistical Mechanics and Its Applications*, *390*, 2333-2339. https://doi.org/10.1016/j.physa.2011.02.015

Simmonds, M. P. (2012). Cetaceans and marine debris: The great unknown. *Journal of Marine Biology*, *2012*. 684279. https://doi.org/10.1155/2012/684279

Simmonds, M. P., & Brown, C. B. (2010). Is there a conflict between cetacean conservation and marine renewable-energy developments? *Wildlife Research*, *37*, 688-694. https://doi.org/10.1071/WR10020

Skaare, J. U., Bernhoft, A., Wiig, Ø., Norum, K. R., Haug, E., Eide, D. M., & Derocher, A. E. (2001). Relationships between plasma levels of organochlorines, retinol, and thyroid hormones from polar bears (*Ursus maritimus*) at Svalbard. *Journal of Toxicology and Environmental Health*, *62*, 227-241. https://doi.org/10.1080/00984100145939

Smallwood, K. S., Rugge, L., & Morrison, M. L. (2009). Influence of behavior on bird mortality in wind energy developments. *Journal of Wildlife Management*, *73*(7), 1082-1098. https://doi.org/10.2193/2008-555

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene, C. R., Jr., . . . Tyack, P. L. (2007). Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals*, *33*(4), 1-121. https://doi.org/10.1578/AM.34.2.33.4.2007.1

Spradlin, T. R., Terbush, A. D., & Smullen, W. S. (1998). NMFS update on human/dolphin interactions in the wild. *Soundings*, *Magazine of the International Marine Animal Trainers Association*, *23*(1), 25-27.

St. Aubin, D. J., & Geraci, J. (1988). Capture and handling stress suppresses circulating levels of thyroxine (T4) and triiodothyronine (T3) in beluga whales *Delphinapterus leucas*. *Biology*, *6*, 170-175. https://doi.org/10.1086/physzool.61.2.30156148

Stensland, E., & Berggren, P. (2007). Behavioural changes in female Indo-Pacific bottlenose dolphins in response to boat-based tourism. *Marine Ecology Progress Series*, *332*, 225-234. https://doi.org/10.3354/meps332225

Stockin, K. A., Pierce, G. J., Binedell, V., Wiseman, N., & Orams, M. B. (2008). Factors affecting the occurrence and demographics of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Aquatic Mammals*, *34*(2), 200-211. https://doi.org/10.1578/AM.34.2.2008.200

Tanabe, S. (2002). Contamination and toxic effects of persistent endocrine disrupters in marine mammals and birds. *Marine Pollution Bulletin*, *45*(1), 69-77. https://doi.org/10.1016/S0025-326X(02)00175-3

Teuten, E. L., Rowland, S. J., Galloway, T. S., & Thompson, R. C. (2007). Potential for plastics to transport hydrophobic contaminants. *Environmental Science & Technology*, *41*(22), 7759-7764. https://doi.org/10.1021/es071737s

Thode, A., Straley, J., Mathias, D., Wild, L., Falvey, D., O'Connell, T., & Folkert, K. (2012). Reducing sperm whale depredation via decoy deployments and active deterrent testing. *North Pacific Research Board Final Report*, *918*, 235.

Thode, A., Straley, J., Tiemann, C., Teloni, V., Folkert, K., O'Connell, T., & Behnken, L. (2005). Sperm whale and longline fisheries interactions in the Gulf of Alaska—Passive acoustic component. *North Pacific Research Board Final Report F*, *412*, 57.

Thode, A., Mathias, D., Straley, J., O'Connell, V., Behnken, L., Falvey, D., . . . Liddle, J. (2015). Cues, creaks, and decoys: Using passive acoustic monitoring as a tool for studying sperm whale depredation. *ICES Journal of Marine Science*, *72*(5), 1621-1636. https://doi.org/10.1093/icesjms/fsv024

Thomson, C. A., & Geraci, J. R. (1986). Cortisol, aldosterone, and leukocytes in the stress response of bottlenose dolphins, *Tursiops truncatus*. *Canadian Journal of Fish and Aquatic Science*, *43*, 1010-1016. https://doi.org/10.1139/f86-125

Tixier, P., Vacquie Garcia, J., Gasco, N., Duhamel, G., & Guinet, C. (2014). Mitigating killer whale depredation on demersal longline fisheries by changing fishing practices. *ICES Journal of Marine Science*, *72*(5), 1610-1620. https://doi.org/10.1093/icesjms/fsu137

Tonay, A. M., Dede, A., Ozturk, A. A., & Ozturk, B. (2007). *Stomach contents of harbour porpoises (*Phocoena phocoena*) from the Turkish Western Black Sea in spring and early summer*. CIESM Congress Proceedings, Istanbul.

Turvey, S. T., Pitman, R. L., Taylor, B. L., Barlow, J., Akamatsu, T., Barrett, L. A., . . . Wei, Z. (2007). First human-caused extinction of a cetacean species? *Biology Letters*, *3*(5), 537-540. https://doi.org/10.1098/rsbl.2007.0292

Tyack, P. L., Gordon, J., & Thompson, D. (2003). Controlled exposure experiments to determine the effects of noise on marine mammals. *Marine Technology Society Journal*, *37*(4), 41-53. https://doi.org/10.4031/002533203787537087

Tyack, P. L., Johnson, M., Soto, N. A., Sturlese, A., & Madsen, P. T. (2006). Extreme diving of beaked whales. *Journal of Experimental Biology*, *209*(21), 4238-4253. https://doi.org/10.1242/jeb.02505

Tyack, P. L., Zimmer, W. M., Moretti, D., Southall, B. L., Claridge, D. E., Durban, J. W., . . . McCarthy, E. (2011). Beaked whales respond to simulated and actual navy sonar. *PLOS ONE*, *6*(3), e17009. https://doi.org/10.1371/journal.pone.0017009

United Nations Environment Programme (UNEP). (1999). *Protocol for the scientific evaluation of proposals to cull marine mammals*: *Report of the Scientific Advisory Committee of the Marine Mammals Action Plan*. A study supported by Greenpeace, World Wild Fund for Nature, International Fund for Animal Welfare, and UNEP.

U.S. Army Corps of Engineers. (2016). *2015 field report: Evaluation of pinnipeds' predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2015*. Cascade Locks, OR: U.S. Army Corps of Engineers, Bonneville Lock and Dam.

van der Hoop, J., Corkeron, P., & Moore, M. (2017). Entanglement is a costly life-history stage in large whales. *Ecology and Evolution*, *7*, 92-106. https://doi.org/10.1002/ece3.2615

van der Hoop, J., Corkeron, P., Kenney, J., Landry, S., Morin, D., Smith, J., & Moore, M. (2016). Drag from fishing gear entangling North Atlantic right whales. *Marine Mammal Science*, *32*, 619-642. https://doi.org/10.1111/mms.12292

van der Hoop, J., Moore, M., Fahlman, A., Bocconcelli, A., George, C., Jackson, K., . . . Smith, J. (2014). Behavioral impacts of disentanglement of a right whale under sedation and the energetic cost of entanglement. *Marine Mammal Science*, *30*, 282-307. https://doi.org/10.1111/mms.12042

van Liere, D. (2004). Weather, sea condition and ship motions affecting accuracy in whaling. In P. Brakes, A. Butterworth, M. Simmonds, & P. Lymbery (Eds.), *Troubled waters: A review of the welfare implications of modern whaling activities* (pp. 63-68). London: World Society for the Protection of Animals.

Walker, K., Trites, A., Haulena, M., & Weary, D. (2012). A review of the effects of different marking and tagging techniques on marine mammals. *Wildlife Research*, *39*, 15-30. https://doi.org/10.1071/WR10177

Ward, A. (2015). Picture of couple posing with beached dolphin "that later died" causes outrage. *Independent*. Retrieved from www.independent.co.uk/news/world/americas/photos-of-man-and-woman-posing-with-beached-dolphin-case-internet-outrage-10270561.html

Weir, C. R. (2008). Overt responses of humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and Atlantic spotted dolphins (*Stenella frontalis*) to seismic exploration off Angola. *Aquatic Mammals*, *34*(1), 71-83. https://doi.org/10.1578/AM.34.1.2008.71

Werner, T. B., Northridge, S., Press, K. M., & Young, N. (2015). Mitigating bycatch and depredation of marine mammals in longline fisheries. *ICES Journal of Marine Science*, *72*(5), 1576-1586. https://doi.org/10.1093/icesjms/fsv092

Westerberg, H. (2010). *Potential solutions to seal–fisheries conflicts* (Study Note to the Directorate General for Internal Policies, Policy Department B: Structural and Cohesion Policies, Fisheries, European Parliament, Brussels). 31 pp.

Whale and Dolphin Conservation Society (WDCS) & Humane Society of the United States (HSUS). (2003). *Hunted: Dead or still alive? A report on the cruelty of whaling*. Retrieved from http://uk.whales.org/sites/default/files/work/whaling_hunted_still_alive.pdf

Williams, E., & Thorne, E. T. (1996). Exertional myopathy (capture myopathy). In A. Fairbrother, L. N. Locke, & G. L. Hoff (Eds.), *Non-infectious diseases of wildlife* (2nd ed., pp. 181-193). Ames: Iowa State Press.

Williams, R., Lusseau, D., & Hammond, P. (2006). Estimating relative energetic costs of human disturbance to killer whales (*Orcinus orca*). *Biological Conservation*, *133*, 301-311. https://doi.org/10.1016/j.biocon.2006.06.010

Williams, R., Bain, D., Smith J., & Lusseau, D. (2009). Effects of vessels on behaviour patterns of individual southern resident killer whales *Orcinus orca*. *Endangered Species Research*, *6*, 199-209. https://doi.org/10.3354/esr00150

Williams, R., Wright, A. J., Ashe, E., Blight, L. K., Bruintjes, R., Canessa, R., . . . Hammond, P. S. (2015). Impacts of anthropogenic noise on marine life: Publication patterns, new discoveries, and future directions in research and management. *Ocean & Coastal Management*, *115*, 17-24. https://doi.org/10.1016/j.ocecoaman.2015.05.021

Willott, J. F., Chisolm, T. H., & Lister, J. J. (2001). Modulation of presbycusis: Current status and future directions. *Audiology and Neurotology*, *6*(5), 231-249. https://doi.org/10.1159/000046129

Wilson, B., Batty, R. S., Daunt, F., & Carter, C. (2006). *Collision risks between marine renewable energy devices and mammals, fish and diving birds* (Report to the Scottish Executive). Oban: Scottish Association for Marine Science.

Wolkers, H., Van Bavel, B., Derocher, A. E., Wiig, Ø., Kovacs, K. M., Lydersen, C., & Lindström, G. (2004). Congener-specific accumulation and food chain transfer of polybrominated diphenyl ethers in two Arctic food chains. *Environmental Science & Technology*, *38*(6), 1667-1674. https://doi.org/10.1021/es030448a

Wordern, T. (2017). Killed for a selfie: Baby dolphin dies after being passed around by tourists as they posed for a photo with it on a Spanish beach. *Daily Mail*. Retrieved from www.dailymail.co.uk/news/article-4795028/Baby-dolphin-dies-tourists-selfies-Spain.html

Wright, A. J., Soto, N. A., Baldwin, A. L., Bateson, M., Beale, C. M., Clark, C., . . . Hatch, L. T. (2007). Do marine mammals experience stress related to anthropogenic noise? *International Journal of Comparative Psychology*, *20*, 274-315.

Würsig, B., & Gailey, G. A. (2002). Marine mammals and aquaculture: Conflicts and potential resolutions. In R. R. Stickney & J. P. McVey (Eds.), *Responsible marine aquaculture* (pp. 45-59). New York: CAP International Press.

Yazvenko, S. B., McDonald, T. L., Blokhin, S. A., Johnson, S. R., Melton, H. R., Newcomer, M. W., . . . Wainwright, P. W. (2007). Feeding of western gray whales during a seismic survey near Sakhalin Island, Russia. *Environmental Monitoring and Assessment*, *134*, 93-106. https://doi.org/10.1007/s10661-007-9810-3

Zoeller, T. R., Dowling, A. L., Herzig, C. T., Iannacone, E. A., Gauger, K. J., & Bansal, R. (2002). Thyroid hormone, brain development, and the environment. *Environmental Health Perspectives*, *110*, 355-361. https://doi.org/10.1289/ehp.02110s3355