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STARVED: HOW MARINE MAMMAL WELFARE CAN BE IMPACTED BY PREY DEPLETION

(Prepared by OceanCare)

Starved: How marine mammal welfare can be impacted by prey depletion

Graham J. Pierce[1], Silvina Ivaylova Tsanicheva[1], Alberto Hernández González[1], Lonneke IJsseldijk[2], Rebeca Rodríguez-Mendoza[1], Raquel Puig Lozano[3] and Karen A. Stockin[4]

[1] Instituto de Investigaciones Marinas, Consejo Superior de Investigaciones Cientificas (IIM-CSIC), Vigo, Spain
[2] Division of Pathology, Department of Biomolecular Health Sciences, Faculty of Veterinary Medicine, Utrecht University, Utrecht, The Netherlands
[3] Division of Histology and Animal Pathology, University Institute for Animal Health and Food Security (IUSA), Veterinary School, University of Las Palmas de Gran Canaria, Canary Islands, Spain
[4] Cetacean Ecology Research Group, Institute of Advanced Studies, Massey University, Auckland, New Zealand

"Starvation in marine mammals can be caused by prey depletion or indirectly by other health issues. It has profound physiological, physical and welfare consequences and can be fatal."
Graham Pierce

ocean care

This chapter is from the forthcoming OceanCare report
Beneath the Surface: marine mammal welfare in a challenging world.

Introduction

When faced with apparent visual evidence of starvation in a marine mammal, for example news footage of emaciated polar bears (*Ursus maritimus*) (Figure 1), or we come across an emaciated cetacean carcase, it is tempting to both jump to conclusions about the causes of what we are seeing and to anthropomorphise when trying to articulate how the animal has been affected. To put this in context, we need to begin with some definitions. Starvation is defined as a prolonged and severe deficiency in energy intake leading to progressive depletion of body reserves and metabolic adaptation. It is often accompanied by emaciation – a state of being very thin and weak, usually due to illness or extreme hunger. Food deprivation also has adverse physical and physiological effects before it could be classed as starvation. In addition, especially in neonates, a sudden, abrupt, shortage of food can cause death through hypoglycaemia, hypothermia and renal failure, and is not necessarily accompanied by visible emaciation. There is a lack of consensus among veterinary pathologists about how starvation and emaciation should be diagnosed - and about whether they are necessarily the same thing. Finally, malnutrition refers to deficiencies, excesses, or imbalances in the intake of energy and/or nutrients. As such, starvation may be seen as an extreme case of a specific type of malnutrition.

Figure 1: Emaciated polar bear on a small sheet of ice in Svalbard, north of mainland Norway in August 2015. *© Kerstin Langenberger, used with permission.*

Returning to the emaciated polar bear or cetacean mentioned above, we need to know if there is any direct evidence (e.g. necropsy findings) or indirect indications (e.g. the population of a key prey species is known to have crashed or changes in the habitat have restricted access to food) that starvation has caused the animal's emaciated appearance. In relation to the second point, we need a clear understanding of the effects of starvation on welfare, including body condition and health in marine mammals. It is also prudent to consider whether, if starvation is suspected, the issue has wider implications for the conservation status of populations and their habitats – welfare and conservation can be related issues.

From the standpoint of animal welfare frameworks such as the Five Domains Model (Mellor and Beausoleil, 2015; Mellor et al., 2020), adequate nutrition is foundational. Starvation represents deprivation of a basic need, undermining both biological functioning and the capacity for animals to express "normal behaviour," and by extension, to avoid negative emotional states like distress. It is, of course, also potentially fatal.

Prey depletion is an obvious *prima facie* cause of starvation in marine mammals, implying reduced prey abundance (or at least reduced prey availability) or reduced prey quality, for example due to overfishing, less favourable environmental conditions and/or the loss of suitable habitat. Evidence of such changes, e.g., satellite imagery demonstrating the loss

of the Arctic sea ice used by hunting polar bears, stock assessments which confirm unsustainably high fishing mortality of key prey species of seals and cetaceans, or evidence of poor body condition in fish, can suggest that starvation in marine mammals is plausible or at least that physiological effects of poor nutrition, e.g. changes in haematological parameters (Thompson et al., 1997), may be seen. Some causes of reduced prey availability do not necessarily imply a decline in prey abundance; these include shifts in the spatial distribution, life cycle phenology and size distribution of the prey species (or indeed of the marine mammals themselves). Shifts in distribution over different time-scales may, in turn, arise due to a range of natural and/or anthropogenic causal factors, including climate change and disturbance. Thus, noise due to vessel traffic, seismic surveys and naval sonar can cause stress, interfere with prey detection and even result in hearing loss. It may displace marine mammals from preferred foraging areas for varying lengths of time. The impact of other stressors (e.g. pollutant bioaccumulation) on body condition and immune functioning could also reduce an animal's ability to catch prey.

It is important to acknowledge that, even if an animal has evidently not been feeding recently, this does not prove that low prey availability was the root cause, and it can be difficult to disentangle the pathophysiology (i.e. the abnormal functional, biochemical, and cellular changes in the body that result from disease or injury) which would permit us to rule out other reasons for poor body condition. This is often the case for dead stranded animals, not least when the advanced decomposition state of some carcases precludes a full necropsy. In general, the interpretation of the body condition of marine mammals (and of the cause of death in dead individuals) requires an understanding of the context, notably in relation to the animal's underlying health status. Thus, in their guide to best practice in cetacean necropsies, IJsseldijk et al. (2019) distinguish the immediate cause of death, the underlying cause of death and contributory factors (see also Andersen et al., 2007). In the case of apparently starved animals, supporting evidence in relation to prey availability and quality is also valuable.

The Five Domains Model

Considering the latest iteration of the Five Domains Model (Mellor et al., 2020), and its definitions of "nuisances", in the context of wild cetacean welfare (Nicol et al., 2020), it is clear that food deprivation in a marine mammal can have severe and multi-faceted welfare implications. While the welfare assessment tool developed for cetaceans by Nicol et al. (2020) was not specifically tested in relation to prey depletion, and indeed the authors note that assessing welfare is challenging "in scenarios where objective data on cetacean behavioural and physiological responses are sparse", it is evident that domain 1 (nutrition) is directly impacted, and that the effects would also be observable in domains 3 (health, e.g. via loss of body or muscle condition), 4 (behaviour, e.g. via altered time-budgets) and possibly also 2 (environment, since prey depletion could result in sub-optimal habitat use and/or increased predatory pressure). As such, effects in domain 5 (mental state) are also to be expected, most obviously through hunger but potentially also fatigue, confusion and anxiety, resulting in a negative mental state.

In this chapter, therefore, the physical, physiological and welfare implications of starvation in marine mammals, in the context of the Five Domains Model, as well as evidence that starvation (and by implication, prey depletion) is or could be an issue for marine mammals, are considered.

Welfare domain 1: nutrition

Nutrition is critical to understanding a species' biology as it is central to every aspect of life from gestation to death (Raubenheimer et al., 2009). The nutrition domain assesses an animal's access to sufficient, appropriate food and water. When nutrition is inadequate for marine mammals, a range of physical, physiological and reproductive changes can ensue. For example, body condition deterioration as a consequence of fat and blubber stores being depleted, physiological compromise occurs with catabolism (i.e. metabolic pathways which break down molecules into smaller units, for example to release energy from lipids in blubber), dehydration, changes to buoyancy, weakened immunity and increased disease susceptibility; it may also result in the ingestion of non-food material, which could be harmful or even lethal. The use of blubber stores as an energy source also releases previously accumulated lipophilic persistent organic pollutants such as polychlorinated biphenyls (PCBs), resulting in higher concentrations of these compounds in the blood and other tissues, in turn increasing the risk of adverse health effects due to exposure

to these pollutants (e.g., Evans, 2013). Females in poor body condition may skip breeding, abort or fail to lactate sufficiently because of nutritional stress (IJsseldijk et al., 2021). Animals in poor nutritive condition tend to have smaller energy reserves, which can significantly impact their immune capacity, fecundity, and survival chances during food shortages. Consequently, foraging behaviour, migratory patterns, and predator avoidance can also be altered, supporting the use of body condition as a robust predictor of fitness in both reproductive and survival contexts (Bradford et al., 2012; Kershaw et al., 2017; Stewart et al., 2021; Bierlich et al., 2022).

Quantitative studies demonstrate that starvation in marine mammals produces measurable declines in body condition and blubber reserves, which not only have health effects but also direct welfare implications (Castrillon and Bengtson Nash, 2020; Boys et al., 2022). For example, morphometric analyses of humpback whales (*Megaptera novaeangliae*) have shown seasonal decreases in body condition indices of approximately 27 percentage points in juveniles and 12 percentage points in adults between early and late breeding seasons, reflecting significant energetic deficits (Christiansen et al., 2020b). Welfare assessments of free-ranging fin (*Balaenoptera physalus*) and humpback whales in the Gulf of St. Lawrence also revealed that only 46% of fin whales were in a "good" welfare state compared to ~60% of humpback whales, with lower body condition contributing to poorer scores (Boileau et al., 2024).

In many cases, body condition has been used as a measure of nutrition in marine mammals, serving as an indicator of the nutritive status, patho(physio)logical condition, foraging effort, ability to maintain energetic equilibrium, and reproductive requirements throughout their life cycle (Castrillon and Bengtson Nash, 2020; Durden et al., 2023). Poor nutritive condition typically results in smaller energy reserves, which can significantly impact immune capacity, fecundity, and survival chances of an animal during food shortages. Consequently, foraging behaviour, migratory patterns, and predator avoidance can also be altered, supporting body condition as a robust predictor of fitness in both reproductive and survival contexts (Bradford et al., 2012; Kershaw et al., 2019; Stewart et al., 2021; Bierlich et al., 2022). In the field, aerial photogrammetry via unmanned aerial vehicles (UAVs) is a method frequently applied to measure the body volume and thus predict the relative muscle and fat reserves in marine mammals – including cetaceans, pinnipeds and sirenians (e.g., Krause et al., 2017; Noren et al., 2019; Aoki et al., 2021; Bierlich et al., 2021; Arranz et al., 2022; Ramos et al., 2022; Rode et al., 2024). Post-mortem body condition analysis serves as a fundamental morphometric examination, primarily focused on measuring body mass, length, girth, weight, and blubber layer thickness to assess the animal's relative health in the period leading up to its death (e.g., Kershaw et al., 2017; Phipps et al., 2023; Albrecht et al., 2024; Esposito et al., 2025). Due to the strong correlation between volume and body condition, these indices have often been used as proxies for inferring nutritive status (Castrillon and Bengtson Nash, 2020).

Animals require a diverse array of macro- and micronutrients to sustain metabolism, growth, reproduction, and organ function. The optimal balance of these nutrients shifts continuously in response to endogenous and exogenous influences, creating a dynamic nutritional target to which organisms must adapt, across physiological, ontogenetic (i.e. over the course of an animal's development through its whole lifespan), and evolutionary timeframes (Raubenheimer and Simpson, 1999). For growing animals, structural nutrients are as vital as caloric intake, meaning that optimal foraging involves achieving equilibrium across nutritional dimensions rather than maximising energy alone. In common dolphins (*Delphinus delphis*) and Franciscana dolphins (*Pontoporia blainvillei*), this approach has yielded significant data about interspecific feeding associations, intraspecific nutritional preferences, age-related heavy metal bioaccumulation, and ontogenic lactational adaptation (Denuncio et al., 2017, 2025; Machovsky-Capuska et al., 2020; Stockin et al., 2022). Growing evidence supporting the macronutrient priority model in foraging theory underscores the significant influence these nutrients exert over an animal's fitness, how trophodynamics and environmental fluctuations impact their availability and consequently, the population's ability to persist (Raubenheimer et al., 2012; Machovsky-Capuska and Raubenheimer, 2020).

Welfare domains 2-5: the physical environment, health, behaviour and mental state

The state of the physical environment in which an animal lives (domain 2) can be expressed in terms of a number of indicators, such as the availability of prey, competition with conspecifics or fisheries, and habitat conditions affecting foraging efficiency. Thus, when prey abundance is known to be in decline, this domain connects environmental stressors to nutritional compromise.

In relation to health (domain 3), nutritional deficiency or starvation can result in various objectively measurable health disruptions including compromised immune function, poor wound healing, illness, and reproductive suppression, and such impacts can ultimately result in increased mortality risk. See chapter 12 of this report for further details regarding how disease impacts marine mammal welfare (Pietroluongo and Centelleghe, 2026).

In stranded cetaceans, hepatic lipidosis (also known as fatty liver disease) is a recognised disease characterised by the accumulation of excess triglycerides (fat) within liver cells. Hepatic lipidosis is associated with sudden or extreme nutritional deficiency and occurs when the body mobilises fat reserves for energy, as the influx of free fatty acids into the liver is much greater than its capacity to metabolise or export them, excess lipids accumulate in the liver. In stranded porpoises, Hiemstra et al. (2015) reported lipidosis in 28% of the porpoises examined which showed hepatic lesions, with most of these cases (73%) associated with starvation. Furthermore, prolonged nutrient deprivation in mammals has been linked to the progression from simple lipid accumulation in hepatocytes to more severe conditions, including intestinal atrophy, increased liver size, and immunosuppression (Björnvad et al., 2004; Mustonen et al., 2005). The liver becomes overloaded with fat, hindering its ability to function, leading to liver failure and eventually, death (Jaber et al., 2004; Hiemstra et al., 2015). Upon necropsy, this can be indicated by a yellow liver. These findings highlight how lipidosis in cetaceans can be considered not only a marker of nutritional stress but also a potential contributor to impaired liver function and systemic disease, as well as increasing susceptibility to disease.

In relation to domain 4, behaviour, it is expected that prey depletion will primarily affect foraging behaviour (e.g. longer dives, greater distances travelled, otherwise altered foraging patterns). The foraging animal may also become less risk averse when prey are less available. Indeed, there is trade-off between avoiding starvation and avoiding predation such that animals may choose to maintain a lower body weight in order to achieve greater manoeuvrability and hence increase their chances of avoiding predation. Evidence of "mass-dependent predation risk" is well-documented in small birds (e.g., MacLeod et al., 2005) and it has been suggested that the lower blubber thickness in porpoises from the Moray Firth (UK) compared with the adjacent North Sea is related to the higher risk of "predation" (in this case, lethal attacks by resident bottlenose dolphins, *Tursiops truncatus*) in the Moray Firth (MacLeod et al., 2007 c). Social changes may result, e.g., due to aggregation at richer feeding grounds. More generally, such changes will affect the animals' time and energy budgets and potentially disrupt the normal reproductive cycle; as such, they also have impacts on the welfare of the animals.

While effects in domains 1 to 4 may be observable and measurable, impacts in domain 5 (mental state) must generally be inferred. Feelings of hunger, stress, and frustration are evidently likely when energy needs are not met, especially when hunger is persistent, and may be accompanied by the ingestion of non-food material such as plastics, sand or other materials, with further adverse consequences.

Evidence of starvation in wild marine mammal populations

Upon the discovery of emaciated (poor body condition) individuals, dead or alive, it is important to determine whether starvation reflects resource depletion or is a secondary consequence of ill health or injury, and, indeed, whether there is supporting evidence of prey depletion and its causes.

Prey depletion and habitat loss constitute major threats to marine mammal populations, typically driven by a combination of anthropogenic pressures and environmental change that reduces the availability and/or the nutritional quality of prey resources (Guénette et al., 2006; Butterworth, 2017). Commercial fisheries can compete for resources with marine mammals, e.g. when they target species that play important roles in marine food webs, and declines in the abundance of marine mammal populations have been hypothesised to involve factors such as nutritional stress, disease, and competition for commercially targeted prey (e.g., Crowder et al., 2008). It is important to note that such competition and its impacts may occur even when a stock is theoretically being fished sustainably according to single species stock assessments. According to the Food and Agriculture Organization of the United Nations (FAO), the Mediterranean Sea and Black Sea is one of the regions of the world with the highest rate of fishery exploitation and where 52% of fish stocks are being overexploited (FAO, 2025). A recent publication by Bearzi et al. (2026) shows that

bottlenose dolphins in the northern Adriatic Sea are strongly dependent on trawlers for food. In the Veneto region, dolphins were observed following 25.9% of bottom otter trawlers whilst in the Marche region, there were dolphins behind 75.9% of trawlers. Severe prey depletion and habitat disruption by fisheries in the area are the likely causes for the dolphins relying so heavily on the trawlers for foraging and scavenging (Bearzi et al., 2026).

Anthropogenic noise and human activity in marine ecosystems can impact marine mammals' energy balance both by directly disrupting foraging activity and by displacing them from preferred habitats to locations where prey density is lower and the energetic costs of foraging are consequently higher (e.g., Williams et al., 2006; New et al., 2020; Czapanskiy et al., 2021). Such effects can be exacerbated by climate change, which alters ocean temperatures and currents, and can lead to shifts in the spatial and temporal distribution of prey species, thus disrupting predator-prey relationships (Hazen et al., 2013; Mann and Karniski, 2017). The cumulative effects of these stressors have been linked to declines in body condition, reproductive success, and survival rates, hence raising serious concerns about the health and viability of affected populations (Brakes and Dall, 2016; IJsseldijk et al., 2021; Nelms et al., 2021). While many studies on marine mammals address the impacts of stressors on population status and/or individual health, fewer than 1% of studies on marine mammals explicitly address welfare (Clegg et al., 2021).

In polar bears, reduced sea ice is limiting access to prey and leading to body mass loss and declining condition across all age groups (Obbard et al., 2016; Atwood et al., 2021). Melting sea ice can also force other polar species such as walruses (*Odobenus rosmarus*) to travel further and thus expend more energy to access prey, leading to emaciation and abandonment of calves (Metcalf and Robards, 2008; de Vere et al., 2018). Polar bears in Alaska now spend longer on land due to earlier sea-ice breakup and later freeze-up, increasing nutritional stress (Regehr et al., 2023). Most bears on land lose 0.4–1.7 kg/day despite foraging, and feeding on terrestrial foods like berries and birds is not sufficient to offset energy deficits (Pagano et al., 2024).

In California sea lions (*Zalophus californianus*), fluctuations in the abundance of preferred prey are known to be associated with dietary shift, with greater reliance on low quality prey when preferred prey are scarce (McClatchie et al., 2016). Pups are reported to suffer from emaciation and hypoglycaemia due to maternal prey shortages, while older individuals face parasite overload from forced diet shifts (Lawler et al., 2021).

Markussen (1995) reported on the nutritional cost of prey scarcity in juvenile harbour seals (*Phoca vitulina*). Reduced food intake leads to blubber depletion, compromised insulation, and increased mortality risk. Although juvenile harbour seals showed metabolic depression during starvation, lowering energy expenditure by ~20% to conserve fat reserves, approximately 75% of energy used still derived from fat stores, with the consequent catabolism of lean tissue posing a significant threat to survival. Harbour seals in Scotland showed physiological signs of anaemia during periods of low abundance of energy-rich clupeid fish when they switched to feeding on lower-quality prey, indicating that prey quality affects not only body condition but also haematological parameters, with potential long-term implications for population viability (Thompson et al., 1997).

North Atlantic right whales (*Eubalaena glacialis*) were reported to have markedly poorer body condition than southern populations (in Australia, New Zealand and Argentina), with lactating females investing 50% less energy in calves and experiencing longer calving intervals (> 7 years vs. ~ 3.3 years). These differences were associated with lower prey availability in the north, as well as chronic entanglement stress (Christiansen et al., 2020a). Climate-induced shifts in prey distribution have also led to starvation and reproductive failures in both grey (*Eschrichtius robustus*) and southern right whales (*Eubalaena australis*) (de Vere et al., 2018). Gray whales in the Pacific Ocean show variable body condition linked to environmental drivers like the Pacific Decadal Oscillation and upwelling. High sea temperatures lead to reduced prey abundance, which can result in reduced birth rate and higher mortality (Le Boeuf et al., 2000) and reduced health (Akmajian et al., 2021). During years of low prey abundance, dead whales, many of which were emaciated females, were found along their migration route from Mexico to California, suggesting that the whales were not able to find enough food to prevent starvation during the long and energetically costly migration (Le Boeuf et al., 2000). Following mass strandings of gray whales in the Eastern North Pacific between 2018 and 2021, emaciation was confirmed in 26% of the post-mortem investigated individuals as the most likely cause of death, likely resulting from a decline in both prey quality and availability (Raverty et al., 2024). Food deprivation

(leading to emaciation and potentially starvation) along their long migration route is likely to be a painful experience, both for those animals which died and those which survived (see de Vere et al., 2018).

In Scotland, harbour porpoises (*Phocoena phocoena*) exhibited a significant decline in sandeel consumption in spring of 2002–2003, compared to 1993–2001, coinciding with a sixfold increase in starvation-related deaths (MacLeod et al., 2007a, 2007b). Sandeels are high-energy prey and their reduced availability, linked to climate-driven changes, could lead to lower energy intake, compromised blubber insulation, and increased thermoregulatory stress. While the link between prey depletion and starvation is plausible it should be stressed that the sample size was relatively small and that climate change is only one factor affecting sandeel abundance. In the southern North Sea, Leopold (2015) and IJsseldijk et al. (2022) reported that emaciation was a common cause of death in harbour porpoises (see Figure 2). Stranded animals in poor body condition tended to have less food in their stomach but also to have eaten a higher proportion of gobies and gadoids, prey with relatively low energy density. There was a negative correlation between the loss of body mass and the ingestion of fatty fish (Leopold, 2015). Elevated blubber cortisol concentrations have been observed in harbour porpoises during food scarcity, indicating metabolic stress (Kershaw et al., 2017).

Figure 2: Emaciated adult male harbour porpoise, exemplified by the extremely hollow appearance behind the skull and lateral to the dorsal fin; scapula outline observable protruding from the blubber. *© Utrecht University database.*

Impacts of plastic ingestion

Marine mammals may ingest plastics either actively (in some instances apparently mistaking them for prey – as is most likely in squid-eating odontocetes), passively (through the consumption of contaminated prey) or because hunger drives them to ingest non-food materials. As such, plastic ingestion may be a cause and/or a consequence of starvation and indeed it can be difficult or impossible to establish the direction of causation (Puig-Lozano et al., 2018). Ingestion of plastics can reduce nutrient intake, disrupt satiety signals, and skew macronutrient balance, reducing fitness and survival. Nutritional niche modelling suggests that plastic ingestion alters dietary balance and may constrain foraging decisions, with implications for fitness and population health (Machovsky-Capuska et al., 2019). In addition, ingestion of macroplastics can lead to the blockage and potentially the rupture of the digestive tract, resulting in starvation and death (e.g., de Stephanis et al., 2013).

Plastic ingestion, both micro- and macroplastics, leads to exposure to toxic chemicals which are added to or adhere to plastics, e.g. phthalates and PCBs. More polluted habitats may be characterised by higher levels of both plastics and toxic chemicals. Overfishing and climate change (among other factors) can reduce both prey quantity and quality, resulting in cetaceans foraging more in debris-laden or degraded habitats. As such, ingestion of plastics can be associated with malnutrition, organ damage, and endocrine disruption, while entanglement in marine debris causes injury and death, sometimes indirectly as animals are no longer able to forage (e.g., Fossi et al., 2018). See also Chapter 5 in this report (Boileau and Eisfeld-Pierantonio, 2026). In the North Sea, analysis of digestive tract contents

of stranded sperm whales (*Physeter macrocephalus*) revealed ingestion of large quantities of plastic debris, including fishing nets and packaging, with some individuals carrying over 24 kg of waste (Unger et al., 2016). While not the direct cause of death (IJsseldijk et al., 2018), this debris poses chronic risks of gastric obstruction, reduced nutrient intake, and eventual starvation. For further details regarding how plastic ingestion impacts marine mammal welfare, see Chapter 6 in this report (Panti et al., 2026).

Evidence of prey depletion

Competition between marine mammals and fisheries has received considerable attention, including grey seals (*Halichoerus grypus*) feeding on cod *(Gadus morhua*) and Atlantic salmon (*Salmo salar*) (e.g., Rae and Shearer, 1965; Cook et al., 2015) and bottlenose dolphins depredating gill nets in European seas (e.g., Marçalo et al., 2024). Competition between grey seals and fisheries has been a perceived issue in the UK at various times since the late 19th century (e.g., Walker, 1876) and was an important driver behind a range of government-funded research on seal diets in the 1960s and 1980s (e.g., Rae and Shearer, 1965; SMRU, 1984; Pierce et al., 1991). Globally, the strong overlap between marine mammal diets and fishery catches (of fish, cephalopods and krill), coupled with removal of large amounts of fish biomass by both, means that competition between marine mammals and fisheries is likely for a wide range of pinniped, odontocete and mysticete species (e.g., Trites, 1997; Santos et al., 2014; Trathan et al., 2025). As such, prey depletion is essentially inevitable (see Pierce et al., 2022). Even where stocks are fished "sustainably", catch limits may not adequately account for predation by marine mammals (since this tends to be subsumed within a constant that notionally represents total natural mortality in the fished stock). Moreover, prey depletion for marine mammals is not only a matter of prey abundance but also prey quality (e.g., energy density, lipid content and size/age structure), which not only varies between species (e.g., Spitz et al., 2010) but can also vary substantially across regions and years under changing environmental conditions and can substantially alter the consumption rates required to meet energetic needs (e.g., Røjbek et al., 2014; IJsseldijk et al., 2021; Helenius et al., 2024; Wuenschel et al., 2024; Nehasil et al., 2026).

Despite efforts to ensure sustainable utilisation of commercial fished stocks, according to Froese et al. (2016), 64% of 397 European fish and shellfish stocks were subject to ongoing overfishing and 51% of the stocks were outside of safe biological limits, potentially suffering from impaired reproduction. Fewer than 20% of stocks in the Greater North Sea and Bay of Biscay/Iberian Sea/Azores were considered to be capable of Maximum Sustainable Yield (MSY). The situation was somewhat better in the Celtic Seas/Rockall and Baltic Sea (between 20% and 40% of stocks). Among stocks identified as having biomass well below that needed to achieve MSY (and, in many of these cases, also with fishing mortality well above that needed to achieve MSY) were some stocks of cod, haddock (*Melanogrammus aeglefinus*), lesser sandeel (*Ammodytes marinus*), sprat (*Sprattus sprattus*), sardine (*Sardina pilchardus*) and horse mackerel (*Trachurus trachurus*). A substantial proportion of the commercially exploited fish stocks that are eaten by cetaceans are declining (Table 1), making prey depletion increasingly plausible; see Pierce et al. (2022) for further details.

Climate change is resulting in marked shifts in the distribution of fish and squid in European waters (e.g., Oesterwind et al., 2022), so that distribution ranges no longer coincide with historical fishing areas. Thus, the range of Northeast Atlantic mackerel (*Scomber scombrus*) has extended northwards into the waters of Norway, the Faroes and Iceland, all of which now fish this stock, while various European Union (EU) fishing nations continue to fish it. Catches have exceeded quotas for a number of years. The resulting fall in abundance – to the lowest level for 20 years – led to a 77% cut to catch quotas in 2025 (see ICES, 2025a).

In the medium to long-term, climate change represents an existential threat, with prey depletion being just one facet of the almost inevitable consequences. The disruption of thermohaline circulation (e.g., Ditlevsen and Ditlevsen, 2023) and increasing thermal stratification of the oceans (e.g., Cheng et al., 2025) will create ocean heatwaves, restrict nutrient flows and lead to oxygen depletion of surface waters, drastically curtailing productivity. Increased acidity will disrupt the development of many marine animals. Consequences are likely to include habitat degradation, range shifts as animal populations attempt to remain within thermal limits and locate their prey, and the reshuffling of marine communities. Where impacts of climate change are exacerbated (or indeed exceeded) by those of other

stressors such as eutrophication, overfishing and pollution, fishery and ecosystem collapse can rapidly follow, as is happening in the Baltic Sea (Reusch et al., 2018). In relation to overfishing, illegal, unregulated and unreported (IUU) fishing is a persistent and probably increasing issue, with vast factory ships hoovering up fish and squid in international (and national) waters and probably responsible for some unexpected fishery collapses, as in the case of Argentinian shortfin squid (*Illex argentinus*) in 2009 and 2016 (see Pierce et al., 2025). Possibly the most dispiriting aspect of these problems is our own inability to recognise them. This may be in part irrational (seeing the world as we wish rather than how it is) but also, more rationally, due to the issue of shifting baselines (Pauly, 1995): definitions of sustainable fishing adapt to the increasingly impoverished ocean systems, creating an illusion of well-being until collapse reaches the point of no return (as in the Baltic Sea). To address shifting baselines, stock assessments must use long, information-rich time series, ensuring that data accurately reflect the state of marine populations (Schijns and Pauly, 2021). Schijns and Pauly (2021) compared assessments based on short series (ranging from 5 to 49 years in length) and long series (39 to 108 years) for 25 important marine fish and shellfish stocks. Shorter time series were less likely to reveal the full range of stock dynamics (e.g. past maxima or low abundance periods), resulting in difference in the estimated reference points and, perhaps more importantly, a different perception of current stock status.

Table 1. The main prey species recorded in the diet of marine mammal species in the ASCOBANS Agreement area of the North East Atlantic Ocean, adapted from Table 2 in an ASCOBANS report on resource depletion (Pierce et al., 2022). The lists of prey species are not intended to be exhaustive. Detailed descriptions of the diet of each cetacean species, as well as the associated bibliography, are provided in the ASCOBANS report. Diet quality is classified here based on the energy density of the main prey as low (< 4 kJ g^{-1}), moderate (4–6 kJ g^{-1}), and high (> 6 kJ g^{-1}) (after Spitz et al., 2010). Prey stock trends are categorised, based on ICES (2025b), as: ↓declining (overfished), ↕ fluctuating (no clear trend), ↑ increasing (recovering), or NA not available.

Marine mammal species	Foraging	Prey species commonly taken	Average diet calorific content	General prey stocks trend
Harbour porpoise	Mainly benthic	Ammodytidae: sandeels (e.g. *Ammodytes* spp.)	Moderate	↕
		Clupeidae: herring (*Clupea harengus*), sprat (*Sprattus sprattus*)		↕
		Gadidae: cod (*Gadus morhua*), pouts (*Trisopterus* spp.), whiting (*Merlangius merlangus*)		↕
		Gobiidae: gobies		NA
Bottlenose dolphin	Meso- and benthopelagic	Ammodytidae: sandeel	Moderate	↕
		Carangidae: scad (*Trachurus* spp.)		↕
		Clupeidae: herring, sprat		↕
		Gadidae: cod, haddock (*Melanogrammus aeglefinus*), pouts, saithe (*Pollachius virens*), whiting		↕
		Merlucciidae: hake (*Merluccius merluccius*)		↑
		Moronidae: sea bass (*Dicentrarchus labrax*)		↕
		Mugilidae: mullets (*Mullus* spp.)		NA
		Salmonidae: salmon (*Salmo salar*)		↓

Marine mammal species	Foraging	Prey species commonly taken	Average diet calorific content	General prey stocks trend
Common dolphin	Pelagic	Alosidae: sardine (*Sardina pilchardus*)	Moderate	↕
		Ammodytidae: sandeel		↕
		Carangidae: scad		↕
		Clupeidae: sprat		↑
		Engraulidae: anchovy (*Engraulis encrasicolus*)		↑
		Gadidae: blue whiting (*Micromesistius poutassou*), pouts, whiting		↕
		Scombridae: mackerel (*Scomber* spp.)		↓
Risso's dolphin	Mainly benthic	Decapodiformes: cuttlefish (*Sepia* spp.), bobtail squid (Sepiolidae), various small squids (Loliginidae, Ommastrephidae)	Moderate	NA
		Octopodiformes: octopus (e.g. *Eledone cirrhosa*)		NA
Striped dolphin	Meso- and benthopelagic	Belonidae: garfish (*Belone belone*)	Moderate	NA
		Carangidae: scad		↕
		Clupeidae: sprat		↑
		Decapodiformes: squids (e.g. Ommastrephidae, Gonatidae, Loliginidae)		NA
		Engraulidae: anchovy		↑
		Gadidae: blue whiting, haddock, pouts, saithe, silvery pout (*Gadiculus argenteus*), whiting		↕
		Gobiidae: gobies		NA
		Merlucciidae: hake		↑
		Myctophidae: myctophids (e.g. *Notoscopelus kroyeri*)		NA
		Sparidae: bogue (*Boops boops*)		NA
Atlantic white-sided dolphin	Pelagic	Argentinidae: argentine (*Argentina* spp.)	High	NA
		Carangidae: scad		↕
		Clupeidae: herring		↕
		Decapodiformes: squids		NA
		Gadidae: blue whiting, silvery pout		↕
		Myctophidae: myctophids		NA
		Scombridae: mackerel		↓

Marine mammal species	Foraging	Prey species commonly taken	Average diet calorific content	General prey stocks trend
White-beaked dolphin	Pelagic	Ammodytidae: sandeel	Moderate	↕
		Carangidae: scad		↕
		Clupeidae: herring, sprat		↕
		Gadidae: cod, haddock, pouts, whiting		↕
		Gobiidae: gobies		NA
		Merlucciidae: hake		↑
		Octopodiformes: octopus		NA
		Scombridae: mackerel		↓
		Soleidae: sole (*Solea solea*)		↕
Orca	Pelagic	Clupeidae: herring	High	↕
		Gadidae: cod		↓
		Mammalia: other marine mammals		NA
		Pleuronectidae: halibut (*Hippoglossus hippoglossus*)		↕
		Salmonidae: salmon		↓
		Scombridae: mackerel		↓
Long-finned pilot whale	Benthic and pelagic	Anguilliformes: eels	Moderate	↓
		Carangidae: scad		↕
		Decapodiformes: squids (mainly) (e.g. Ommastrephidae, Histioteuthidae)		NA
		Octopodiformes (Eledonidae)		NA
		Gadidae: cod, pollack, pouts, whiting		↕
		Merlucciidae: hake		↑
		Moronidae: sea bass		↕
		Scombridae: mackerel		↓
		Soleidae: sole		↕
Northern bottlenose whale	Benthic and pelagic	Clupeidae: herring	High	↕
		Decapodiformes: mainly squids (particularly *Gonatus* sp.)		NA
		Scorpaenidae: redfish (*Sebastes marinus*)		↕
Sowerby's beaked whale	Mesopelagic	Ammodytidae: sandeel	Moderate	↕
		Decapodiformes: squids		NA
		Gadidae: cod		↓
		Merlucciidae: hake		↑

Marine mammal species	Foraging	Prey species commonly taken	Average diet calorific content	General prey stocks trend
Blainville's beaked whale	Meso- and benthopelagic	Decapodiformes: squids (mainly)	Moderate	NA
		Gadidae		↕
		Myctophidae		NA
Goose-beaked whale	Mainly benthic	Decapodiformes: squids (mainly)	Moderate	NA
		Gadidae: blue whiting		↕
Sperm whale	Mesopelagic	Crustacea: crustaceans	Moderate	NA
		Decapodiformes: squids (mainly)		NA
		Gadidae: saithe		↕
		Lophiidae: monkfish (*Lophius piscatorius*)		↕
		Pleuronectidae: halibut		↕
Minke whale	Meso- and benthopelagic	Ammodytidae: sandeel	Moderate	↕
		Clupeidae: herring, sprat		↕
		Gadidae: cod, haddock, pouts, saithe, whiting		↕
		Gobiidae: gobies		NA
		Scombridae: mackerel		↓
Fin whale	Pelagic	Ammodytidae: sandeel	Moderate	↕
		Clupeidae: herring		↕
		Copepoda: copepods		NA
		Decapodiformes: squids		NA
		Euphausiacea: euphausiids (mainly)		NA
		Gadidae: blue whiting		↕
		Scombridae: mackerel		↓
Sei whale	Pelagic	Copepoda: copepods (mainly)	Moderate	NA
		Decapodiformes: squids		NA
		Euphausiacea: euphausiids		NA
		Teleostei: small schooling fishes		NA
Humpback whale	Pelagic	Ammodytidae: sandeel	High	↕
		Clupeidae: herring, sprat		↕
		Euphausiacea: euphausiids (mainly)		NA

Physical, physiological and behavioural impacts of starvation

The pathology of starvation is well-documented, not least in humans and domestic animals (Gerdin et al., 2015; Amirante et al., 2025). Starvation in marine mammals induces a cascade of physical changes, and physiological and behavioural consequences, including adaptations aimed at coping with the energy deficit caused by food scarcity or consumption of nutritionally inadequate prey (e.g., McCue, 2010, 2012). These changes also impact on the animal's welfare. Chronic undernutrition leads to fat reserve loss, muscle wasting and immunosuppression, hence increased susceptibility to disease. It results in lethargy, and altered or risky foraging behaviour, leading to increased vulnerability to predation or human-related threats. It also results in stress; it can trigger elevated cortisol levels, reproductive suppression, and long-term health deterioration.

The physiological adaptations to fasting include sequential shifts in carbohydrate, lipid, and protein metabolism (Champagne et al., 2012). Initially, energy is derived from glycogen stores. As fasting continues, energy demands are sustained primarily through lipid oxidation. When lipid stores become insufficient, proteins are catabolised to support gluconeogenesis, leading to muscle breakdown. These adaptations result in metabolic depression (characterised by a reduction in resting metabolic rate) and alterations in body composition. Prolonged or severe food deprivation results in measurable changes in body condition, including reduction in blubber thickness, total body mass, and lean body mass. In extreme cases, reductions in organ mass may occur, potentially impairing organ function. Chronic or severe starvation may also impair immune function, heightening susceptibility to pathogens and consequently infectious diseases. In addition, this could induce changes in buoyancy, and subsequent difficulties with catching prey.

Behavioural responses vary and may manifest either as increased foraging effort, commonly referred to as the "hunger response" (Cornish and Mrosovsky, 1965; Collier, 1969), or as reduced activity levels to conserve energy, termed the "fasting response" (Westerterp, 1977), which is often accompanied by lethargy (Rosen and Trites, 2002). Nutritional stress frequently occurs during biologically demanding periods such as breeding, lactation, or migration. In some species, particularly phocid seals, fasting is an intrinsic and adaptive component of their life history strategy. For instance, adult females undergo prolonged fasting during lactation, relying entirely on stored energy reserves to support milk production and pup care (Champagne et al., 2012).

Marine mammals exhibit an endocrine stress response characterised by the secretion of cortisol, a glucocorticoid hormone involved in energy metabolism and the regulation of physiological homeostasis. Agusti et al. (2022) reported that cortisol concentrations (mean ± SD) were approximately six times higher in chronically affected striped dolphins (*Stenella coeruleoalba*) (35.3 ± 23 ng cortisol/g blubber and 6.63 ± 3.22 µg cortisol/dL serum) compared to an acute stress situation (e. g. incidentally captured individuals) (6.2 ± 4.3 ng cortisol/g blubber and 1.15 ± 1.51 µg cortisol/dL serum). Similarly, in a study assessing disturbance of shipping on North Atlantic right whales, noise reduction was associated with decreased baseline levels of stress-related faecal glucocorticoids (Rolland et al., 2012). These findings demonstrate a positive relationship between the duration of nutritional and anthropogenic stress and cortisol levels.

Sustained elevations in cortisol can have detrimental health effects. Chronic hypercortisolemia is associated with immunosuppression, increased muscle catabolism, delayed wound healing, and impaired reproductive function (Sapolsky et al., 2000; Atkinson and Dierauf, 2018). In marine mammals, persistent elevation of cortisol has been linked to degradation of lean muscle mass during prolonged fasting (Champagne et al., 2006), increased vulnerability to disease, and reproductive suppression due to disruption of the hypothalamic-pituitary-gonadal (HPG) axis (Atkinson and Dierauf, 2018). Juveniles and individuals already experiencing energy deficits are particularly susceptible to these physiological consequences.

Conclusion

The effects of starvation are increasingly well-documented in marine mammals, including polar bears, manatees, cetaceans and seals, not least via iconic and disturbing footage of emaciated polar bears searching for food on land, plausibly linked to the climate change-driven loss of sea ice even if a causal link cannot be assumed in individual cases.

Starvation can occur due to prey depletion but may also be an indirect consequence of animals being debilitated by disease or trauma (the latter including impaction within the gastrointestinal tract following ingestion of macroplastics). Since at least the 1990s, prey depletion has been cited as a cause of poor body condition in various marine mammal populations, and is becoming increasingly likely as marine ecosystems are degraded and/or severely modified by a combination of direct and indirect anthropogenic impacts, such as overfishing, pollution and climate change. The latter in particular represents an existential threat to marine ecosystems, not only to marine mammals.

Starvation has cascading effects on individual physiology, body condition, health and survival. Importantly, even short-term reductions in prey availability can have disproportionate consequences if they coincide with periods of peak energetic demand such as reproduction, lactation or migration. Its effects can be seen in each of the five domains of animal welfare. At the population level, widespread starvation has clear conservation implications and, arguably, these implications receive more attention than welfare considerations, at least from scientists and policy-makers. This imbalance underscores the need to better integrate sub-lethal, individual-level indicators, such as chronic nutritional stress, into conservation assessments that have traditionally focused on population trajectories. As mammals ourselves, although our immediate reactions to starvation in other mammals may be anthropomorphic, they are also likely to reflect at least an element of the truth. What actions should we then be recommending, for example in relation to research, monitoring, management and policy?

Recommended actions

Policy

The conservation of marine life is a key topic under the UNEP Sustainable Development Goals (SDGs), not least under SDG 14 (Life Below Water). However, even where it is most relevant, namely under SDG 12 (Responsible Consumption and Production), as UNEP itself acknowledges, "*while the relationship between animal welfare, environmental well-being, and human development is increasingly researched and evidenced, there remains very little recognition of this relationship and the crucial role animal welfare plays in sustainable development for people and planet in United Nations discussions on the Sustainable Development Goals (SDGs)*," (Cox and Bridgers, 2017).

There is arguably a need to ensure that animal welfare is respected in capture fisheries, including the welfare of Endangered, Threatened and Protected species (ETPs or PETs) such as marine mammals. Such considerations refer not only to direct interactions, e.g. bycatch, disturbance and displacement, but also to the indirect interactions - arising from resource competition – which can result in prey depletion. While the Ecosystem Approach to Fisheries Management (EAFM) emphasises the importance of considering ecological impacts of fisheries on non-target species and on the habitat (e.g. damage to the sea floor by bottom trawling), fisheries management in European waters is still largely focused on the status of the target fished stocks. Although the International Council for the Exploration of the Sea (ICES) produces Ecosystem Overviews, they are support tools and "set the broader ecosystem context for other ICES advice products," (ICES, 2026) rather than being an integral part of stock assessment. Similarly, animal welfare is now recognised within the ICES Science Plan (ICES, 2025c): Science Plan code 5.11 is "Assess animal welfare in capture fisheries and aquaculture". However, development of welfare considerations is arguably at an early stage. A key challenge moving forward is therefore, how to operationalise welfare indicators, including nutritional stress, within existing fisheries advice processes that are primarily designed around stock sustainability.

In general, strengthening existing policy underlying conservation and sustainable utilisation of the oceans could contribute to reducing the incidence of starvation. Organisations responsible for fisheries management and advising on fisheries management, and indeed all relevant stakeholders, should give due consideration to the potential adverse indirect impacts of fisheries on the welfare and conservation of marine mammals. More explicit recognition, in policy, of the animal welfare implications of anthropogenic stressors could also make a positive contribution, not least by changing how the general public perceives the issues involved.

Management measures

Starvation in marine mammals is generally unlikely amenable to being managed directly (e.g. by providing supplementary food) not least because the majority are predators and/or spend most or all of their lives at sea. Thus, in cetaceans, starvation is observed mostly in dead, stranded animals. This also means that much of the available evidence is retrospective, highlighting the need for earlier indicators of declining body condition in free-ranging populations.

- The development of biomarkers to assess nutritional status, or endpoints of nutritional conditions, within the 'omics' field is recommended (Xuereb et al., in review).

Nevertheless, some of the underlying causes of starvation are amenable to management, for example by:

- reducing or eliminating negative impacts from other threats such as fishery bycatch mortality, collisions with and disturbance due to vessel traffic and negative effects on health and condition caused by marine pollution including persistent organic pollutants and plastics.

Decision-support tools can help translate prey depletion scenarios into management-relevant indicators and targets. One possible area for development is the use of bioenergetic modelling to translate changes in prey quantity, quality and accessibility into predicted energetic deficits (Pirotta, 2022). Such models can support more specific management measures by identifying when and where prey removal (or shifts towards lower energy prey) is more likely to produce chronic nutritional stress, and by helping set management targets that protect feeding opportunities in critical seasons and areas (Guilpin et al., 2020; Gavrilchuk et al., 2021).

Overall, a welfare-oriented management approach would involve moving away from an "action/no action" paradigm. In that paradigm, management action is typically triggered only once impacts are clear, often at the population level. A welfare-oriented approach instead supports proactive and preventative management. This should be based on clear indicators and targets to reduce human activities that limit prey access, reduce prey quality or disrupt foraging, before impacts become evident as population-level decline (Papastavrou et al., 2017).

The role of science

Historically, research on marine mammals has focused on conservation more than on welfare, on anthropogenic impacts at the population level more than at the individual level, and on mortality more than on sub-lethal impacts. Recognition of the importance of animal welfare is increasing but, arguably, science still needs to take further steps to internalise the fact that understanding animals involves understanding their welfare – and to communicate this reality to society at large.

Future research priorities include developing reliable, non-invasive indicators or biomarkers of body condition and nutritional stress, improving the integration of health, energetic and prey availability data, and strengthening our understanding of the links between ecosystem change and individual welfare outcomes. Relevant topics thus include: treating prey quality as a key factor influencing energetic stress and incorporating it explicitly into monitoring and modelling; developing time-series of prey energy density and age/size structure for key prey species and quantifying spatiotemporal variability in these metrics; testing the sensitivity of predictions about energetic balance to observed changes in prey quality under changing environmental conditions (e.g., Helenius et al., 2024; Wuenschel et al., 2024; Nehasil et al., 2026); and establishing a clear consensus on the definitions of malnutrition, emaciation and starvation, and on methods for their diagnosis in marine mammals (noting that the European Society of Clinical Nutrition and Metabolism (ESPEN) appointed a consensus group with a mission to provide criteria for the diagnosis of malnutrition in humans, leading to a Consensus Statement (Cederholm et al., 2015)).

Transformative change

Arguably, embedding animal welfare considerations into daily human life, regardless of whether specific management and/or policy initiatives help to address issues like starvation in marine mammals, requires transformative changes. We refer the reader to O'Brien et al. (2024), where this kind of argument was developed in some detail (over 400 pages) in the context of reducing biodiversity loss.

While an increasing global population and a continued focus on development arguably create the anthropogenic pressures impacting marine mammal populations, public engagement and pressure is a powerful tool to achieve conservation and welfare goals. Public narratives often focus on dramatic mortality events, yet chronic nutritional stress may represent a more widespread but less visible welfare concern and the challenge is to increase its visibility.

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Author biographies

Graham Pierce *is a research professor at IIM CSIC. His research is mainly in marine biology, ecology and conservation, especially on marine mammals and cephalopods, including studies on feeding ecology, and interactions with fisheries. He is currently working on three EU projects on ETP species bycatch: CIBBRiNA (as scientific coordinator), REDUCE (leading a work package on bycatch impact assessment) and Marine Guardian, as well as co-ordinating a Biodiversa+ Project (EMPHATIC) on cetacean monitoring and hosting a Marie Curie fellow working on octopus fisheries. He has published over 300 scientific papers and several co-edited books. He works with ICES ASCOBANS and the IWC Standing Working Group on Bycatch.*

Silvina Ivaylova Tsanicheva *is a veterinarian whose work has focused on marine mammal health and conservation. She conducted research at the Marine Research Institute (IIM-CSIC) in Vigo, Spain, where she contributed to studies on cetacean health and fisheries interactions. Her interests include marine mammal welfare, biodiversity conservation, and the effects of environmental change on wildlife populations.*

Alberto Hernández González *is a marine biologist specialised in marine mammal ecology and conservation. His PhD focused on cetacean feeding ecology and marine litter impacts. Currently, his research addresses cetacean bycatch and the analysis of long-term stranding data. He has contributed to national and international research projects and working groups. He has also participated in several oceanographic surveys as a Marine Mammal Observer, monitoring the distribution and abundance of marine mammals in European Atlantic waters.*

Lonneke IJsseldijk *is an Assistant Professor at the Faculty of Veterinary Medicine, Utrecht University, where she leads the marine mammal stranding research programme. She holds an MSc in Environmental Biology and earned her PhD studying harbour porpoise health. Her research interests lie at the intersection of marine mammal biology, ecology, and pathology, with a strong focus on translating scientific knowledge into conservation practice, public engagement, and policy.*

Rebeca Rodríguez-Mendoza *is a researcher at the Integrated Marine Ecology Department of the Instituto de Investigaciones Marinas, IIM-CSIC, in Vigo, Spain. She holds a PhD in Biology of Organisms and Ecosystems and specialises in marine ecology, biodiversity monitoring and fisheries bycatch. Her latest research has focused on improving understanding of the bycatch of different marine organisms and developing innovative approaches for*

population assessment and marine biodiversity monitoring. She has contributed to projects including FishGenome, aimed at improving fisheries surveys and fish stock assessments through next-generation sequencing, CetAMBICion, focused on cetacean monitoring and conservation, and EMPHATIC, which applies eDNA, microbiome analysis, photogrammetry and hormone assessment techniques to cetacean research.

***Raquel Puig Lozano** is a Spanish veterinary scientist with a PhD in Animal Health and Food Safety from the University of Las Palmas de Gran Canaria (ULPGC, 2021). Her research focuses on the pathology of stranded cetaceans, particularly traumatic conditions such as fishery interactions, intra- and interspecific aggression, and foreign-body ingestion. She has contributed to multiple publications and research outputs of the IUSA-ULPGC group. She has held postdoctoral positions at ULPGC and IIM-CSIC and currently collaborates closely with CEMMA (Coordinadora para o Estudo dos Mamíferos Mariños) on diagnostics, fieldwork, and marine mammal monitoring. A dedicated science communicator, she leads outreach activities for the IUSA-ULPGC cetacean group as well as CEMMA initiatives. She also serves on the board of the Spanish Cetacean Society.*

***Karen Stockin** is a Professor and the Research Director of the Cetacean Ecology Research Group (CERG), Massey University and additionally an Associate Investigator of the Animal Welfare Science and Bioethics Centre and WILDBASE at the School of Veterinary Science. Karen serves as the Chair of the Society for Marine Mammalogy Ethics Advisory Committee and is a member of the International Whaling Commission (IWC) Strandings Initiative Expert Panel.*

References

Agusti, C., Carbajal, A., Olvera-Maneu, S., et al. (2022) Blubber and serum cortisol concentrations as indicators of the stress response and overall health status in striped dolphins. *Comp Biochem Physiol A Mol Integr Physiol* 272: 111268. doi: 10.1016/j.cbpa.2022.111268

Akmajian, A.M., Scordino, J.J., Gearin, P.J., et al. (2021) Body condition of gray whales (*Eschrichtius robustus*) feeding on the Pacific Coast reflects local and basin-wide environmental drivers and biological parameters. *J Cetacean Res Manage* 22: 87-110. doi: 10.47536/jcrm.v22i1.223

Albrecht, S., Minto, C., Rogan, E., et al. (2024) Emaciated enigma: Decline in body conditions of common dolphins in the Celtic Seas ecoregion. *Ecol Evol* 14: e70325. doi: 10.1002/ece3.70325

Amirante, F., Pititto, F., Pulin, G., et al. (2025) The Pathology of Starvation: A Systematic Review of Forensic Evidence. *Forensic Sci* 5(4): 74. doi: 10.3390/forensicsci5040074

Andersen, M.S., Forney, K.A., Cole, T.V.N., et al. (2007) Differentiating Serious and Non-Serious Injury of Marine Mammals: Report of the Serious Injury Technical Workshop, 10-13 September 2007, Seattle, Washington. United States Department of Commerce, NOAA Technical Memorandum NMFS-OPR-39. 94 pp. Available at: https://repository.library.noaa.gov/view/noaa/4389/noaa_4389_DS1.pdf

Aoki, K., Isojunno, S., Bellot, C., et al. (2021) Aerial photogrammetry and tag-derived tissue density reveal patterns of lipid-store body condition of humpback whales on their feeding grounds. *Proc R Soc B Biol Sci* 288(1943): 20202307. doi: 10.1098/rspb.2020.2307

Arranz, P., Christiansen, F., Glarou, M., et al. (2022) Body Condition and Allometry of Free-Ranging Short-Finned Pilot Whales in the North Atlantic. *Sustainability* 14(22): 14787. doi: 10.3390/su142214787

Atkinson, S. and Dierauf, L.A. (2018) Stress and Marine Mammals. In: Gulland, F.M.D., Dierauf, L.A. and Whitman, K.L. (eds.) CRC Handbook of Marine Mammal Medicine (Third edition). CRC Press, Boca Raton, Florida, USA. pp 153-168. doi: 10.1201/9781315144931

Atwood, T.C., Rode, K.D., Douglas, D.C., et al. (2021) Long-term variation in polar bear body condition and maternal investment relative to a changing environment. *Glob Ecol Conserv* 32: e01925. doi: 10.1016/j.gecco.2021.e01925

Bearzi, G., Bonizzoni, S., Furey, N.B., et al. (2026) Bottlenose dolphin reliance on trawlers in prey-depleted Adriatic Sea regions. *Front Mamm Sci* 5: 1855890. doi: 10.3389/fmamm.2026.1855890

Bierlich, K.C., Hewitt, J., Bird, C.N., et al. (2021) Comparing Uncertainty Associated With 1-, 2-, and 3D Aerial Photogrammetry-Based Body Condition Measurements of Baleen Whales. *Front Mar Sci* 8: 749943. doi: 10.3389/fmars.2021.749943

Bierlich, K.C., Hewitt, J., Schick, R., et al. (2022) Seasonal gain in body condition of foraging humpback whales along the Western Antarctic Peninsula. *Front Mar Sci* 9: 1036860. doi: 10.3389/fmars.2022.1036860

Björnvad, C.R., Elnif, J. and Sangild P.T. (2004) Short-term fasting induces intra-hepatic lipid accumulation and decreases intestinal mass without reduced brush-border enzyme activity in mink (*Mustela vison*) small intestine. *J Comp Physiol B* 174: 625-632. doi: 10.1007/s00360-004-0452-2

Boileau, A., Blais, J., Van Bressem, M.-F., et al. (2024) Physical Measures of Welfare in Fin (*Balaenoptera physalus*) and Humpback Whales (*Megaptera novaeangliae*) Found in an Anthropized Environment: Validation of a First Animal-Based Indicator in Mysticetes. *Animals* 14(23): 3519. doi: 10.3390/ani14233519

Boileau, A. and Eisfeld-Pierantonio, S. (2026) Entangled: How active fishing gear and marine debris impact marine mammal welfare. In: Beneath the Surface: Marine Mammal Welfare in a Challenging World. An OceanCare report.

Boys, R.M., Beausoleil, N.J., Hunter, S., et al. (2022) Assessing animal welfare during a stranding of pygmy killer whales (*Feresa attenuata*). *Mar Mammal Sci* 39: 1076-1105. doi: 10.1111/mms.13029

Bradford, A.L., Weller, D.W., Punt, A.E., et al. (2012) Leaner leviathans: body condition variation in a critically endangered whale population. *J Mammal* 93(1): 251-266. doi: 10.1644/11-MAMM-A-091.1

Brakes, P. and Dall, S.R.X. (2016) Marine Mammal Behavior: A Review of Conservation Implications. *Front Mar Sci* 3: 87. doi: 10.3389/fmars.2016.00087

Butterworth, A. (ed.) (2017) Marine Mammal Welfare: Human Induced Change in the Marine Environment and Its Impacts on Marine Mammal Welfare. Springer International Publishing, Cham, Switzerland.

Castrillon, J. and Bengtson Nash, S. (2020) Evaluating cetacean body condition: a review of traditional approaches and new developments. *Ecol Evol* 10: 6144-6162. doi: 10.1002/ece3.6301

Cederholm, T., Bosaeus, I., Barazzoni, R., et al. (2015) Diagnostic criteria for malnutrition - An ESPEN Consensus Statement. *Clin Nutr* 34(3): 335-340. doi: 10.1016/j.clnu.2015.03.001

Champagne, C.D., Crocker, D.E., Fowler, M.A., et al. (2012) Fasting Physiology of the Pinnipeds: The Challenges of Fasting While Maintaining High Energy Expenditure and Nutrient Delivery for Lactation. In: McCue, M. (ed.) Comparative Physiology of Fasting, Starvation, and Food Limitation. Springer, Berlin, Heidelberg. doi: 10.1007/978-3-642-29056-5_19

Champagne, C.D., Houser, D.S. and Crocker, D.E. (2006) Glucose metabolism during lactation in a fasting animal, the northern elephant seal. *Am J Physiol Regul Integr Comp Physiol* 291(4): R1129-R1137. doi: 10.1152/ajpregu.00570.2005

Cheng, L., Li, G., Long, S.M., et al. (2025) Ocean stratification in a warming climate. *Nat Rev Earth Environ* 6: 637-655. doi: 10.1038/s43017-025-00715-5

Christiansen, F., Dawson, S.M., Durban, J.W., et al. (2020a) Population comparison of right whale body condition reveals poor state of the North Atlantic right whale. *Mar Ecol Prog Ser* 640: 1-16. doi: 10.3354/meps13299

Christiansen, F., Sprogis, K.R., Gross, J., et al. (2020b) Variation in outer blubber lipid concentration does not reflect morphological body condition in humpback whales. *J Exp Biol* 223(8): jeb213769. doi: 10.1242/jeb.213769

Clegg, I.L.K., Boys, R.M. and Stockin, K.A. (2021) Increasing the Awareness of Animal Welfare Science in Marine Mammal Conservation: Addressing Language, Translation and Reception Issues. *Animals* 11: 1596. doi: 10.3390/ani11061596

Collier, G. (1969) Body weight loss as a measure of motivation in hunger and thirst. *Ann N Y Acad Sci* 157: 594-609. doi: 10.1111/j.1749-6632.1969.tb12909.x

Cook, R.M., Holmes, S.J. and Fryer, R.J. (2015) Grey seal predation impairs recovery of an overexploited fish stock. *J Appl Ecol* 52: 969-979. doi: 10.1111/1365-2664.12439

Cornish, E.R. and Mrosovsky, N. (1965) Activity during food deprivation and satiation of six species of rodent. *Anim Behav* 13: 242-248. doi: 10.1016/0003-3472(65)90042-4

Cox, J. and Bridgers, J. (2017) Why is Animal Welfare Important for Sustainable Consumption and Production? Perspectives Issue No. 34. UNEP. Available at: https://www.unep.org/resources/perspective-series/issue-no-34-why-animal-welfare-important-sustainable-consumption-and

Crowder, L.B., Hazen, E.L., Avissar, N., et al. (2008) The impacts of fisheries on marine ecosystems and the transition to ecosystem-based management. *Annu Rev Ecol Evol Syst* 39: 259-278. doi: 10.1146/annurev.ecolsys.39.110707.173406

Czapanskiy, M.F., Savoca, M.S., Gough, W.T., et al. (2021) Modelling short-term energetic costs of sonar disturbance to cetaceans using high-resolution foraging data. *J Appl Ecol* 58: 1643-1657. doi: 10.1111/1365-2664.13903

Denuncio, P., Macagno, M.C., Padula, A.D., et al. (2025) Nutritional Ecology of Lactation in Franciscana Dolphins (*Pontoporia blainvillei*) From Argentina. *Mar Mammal Sci* 41: e70029. doi: 10.1111/mms.70029

Denuncio, P., Paso Viola, M.N., Machovsky-Capuska, G.E., et al. (2017) Population variance in prey, diets and their macronutrient composition in an endangered marine predator, the Franciscana dolphin. *J Sea Res* 129: 70-79. doi: 10.1016/j.seares.2017.05.008

de Stephanis, R., Giménez, J., Carpinelli, E., et al. (2013) As main meal for sperm whales: Plastics debris. *Mar Pollut Bull* 69: 206-214. doi: 10.1016/j.marpolbul.2013.01.033

de Vere, A., Lilley, M. and Frick, E. (2018) Anthropogenic impacts on the welfare of wild marine mammals. *Aquat Mamm* 44: 150-180. doi: 10.1578/AM.44.2.2018.150

Ditlevsen, P. and Ditlevsen, S. (2023) Warning of a forthcoming collapse of the Atlantic meridional overturning circulation. *Nat Commun* 14: 4254. doi: 10.1038/s41467-023-39810-w

Durden, W.N., Jablonski, T., Stolen, M., et al. (2023) Morbidity and mortality patterns of Indian river lagoon common bottlenose dolphins (*Tursiops truncatus truncatus*) 2002-2020. *J Wildl Dis* 59: 616-628. doi: 10.7589/JWD-D-22-00156

Esposito, E., Oliviero, M., Iaccarino, D., et al. (2025) Post mortem findings of cetaceans stranded along the Campania coast from 2016 to 2022. *Animals* 15: 1812. doi: 10.3390/ani15121812

Evans, P.G.H. (ed.) (2013) Proceedings of the ECS/ASCOBANS/ACCOBAMS Joint Workshop on Chemical Pollution and Marine Mammals. Held at the European Cetacean Society's 25th Annual Conference, Cádiz, Spain, 20th March 2011. ECS Special Publication Series No. 55. Available at: https://www.ascobans.org/sites/default/files/publication/Pollution_Proceedings_final.pdf

FAO (Food and Agriculture Organization of the United Nations) (2025) The State of Mediterranean and Black Sea Fisheries 2025. General Fisheries Commission for the Mediterranean, Rome, Italy. doi: 10.4060/cd7701en

Fossi, M.C., Panti, C., Baini, M., et al. (2018) A review of plastic-associated pressures: cetaceans of the Mediterranean Sea and Eastern Australian shearwaters as case studies. *Front Mar Sci* 5: 173. doi: 10.3389/fmars.2018.00173

Froese, R., Garilao, C., Winker, H., et al. (2016) Exploitation and status of European stocks. Oceana report. 142 pp. Available at: http://oceanrep.geomar.de/34476/

Gavrilchuk, K., Lesage, V., Fortune, S.M.E., et al. (2021) Foraging habitat of North Atlantic right whales has declined in the Gulf of St. Lawrence, Canada, and may be insufficient for successful reproduction. *Endanger Species Res* 44: 113-136. doi: 10.3354/esr01097

Gerdin, J.A., McDonough, S.P., Reisman, R., et al. (2015) Circumstances, Descriptive Characteristics, and Pathologic Findings in Dogs Suspected of Starving. *Vet Pathol* 53(5): 1087-1094. doi: 10.1177/0300985815575049

Guénette, S., Heymans, J., Christensen, V., et al. (2006) Ecosystem models show combined effects of fishing, predation, competition, and ocean productivity on Steller sea lions (*Eumetopias jubatus*) in Alaska. *Can J Fish Aquat Sci* 63: 2495-2517. doi: 10.1139/f06-136

Guilpin, M., Lesage, V., McQuinn, I., et al. (2020) Repeated vessel interactions and climate- or fishery-driven changes in prey density limit energy acquisition by foraging blue whales. *Front Mar Sci* 7: 626. doi: 10.3389/fmars.2020.00626

Hazen, E., Jorgensen, S., Rykaczewski, R., et al. (2013) Predicted habitat shifts of Pacific top predators in a changing climate. *Nat Clim Change* 3: 234-238. doi: 10.1038/nclimate1686

Helenius, L.K., Head, E.J.H., Jekielek, P., et al. (2024) Spatial variability in size and lipid content of the marine copepod Calanus finmarchicus across the Northwest Atlantic continental shelves: implications for North Atlantic right whale prey quality. *J Plankton Res* 46(1): 25-40. doi: 10.1093/plankt/fbad047

Hiemstra, S., Harkema, L., Wiersma, L.C.M., et al. (2015) Beyond Parasitism: Hepatic lesions in stranded harbor porpoises (*Phocoena phocoena*) without Trematode (*Campula oblonga*) infections. *Vet Pathol* 52: 1243-1249. doi: 10.1177/0300985814560233

ICES (2025a) Mackerel (*Scomber scombrus*) in subareas 1-8 and 14 and Division 9.a (the Northeast Atlantic and adjacent waters). In Report of the ICES Advisory Committee, 2025. ICES Advice 2025, mac.27.nea. doi: 10.17895/ices.advice.27202689

ICES (2025b) ICES Advice 2025. doi: 10.17895/ices.pub.c.7488219

ICES (2025c) Codes for Mapping Terms of Reference to ICES Science Plan 2025. Available at:

https://www.ices.dk/about-ICES/how-we-work/Documents/SciencePlanCodes_2025.pdf

ICES (2026) Ecosystem Overviews. Available at: https://www.ices.dk/advice/ESD/Pages/Ecosystem_overviews.aspx

IJsseldijk, L.L., Brownlow, A.C. and Mazzariol, S. (eds.) (2019) Best practice on cetacean post mortem investigation and tissue sampling. Joint ACCOBAMS and ASCOBANS document. Available at: https://accobams.org/wp-content/uploads/2021/07/Best-practices-on-cetacean-post-mortem-investigation.pdf

IJsseldijk, L.L., Hessing, S., Mairo, A., et al. (2021) Nutritional status and prey energy density govern reproductive success in a small cetacean. *Sci Rep* 11(1): 19201. doi: 10.1038/s41598-021-98629-x

IJsseldijk, L.L., Leopold, M.F., Begeman, L., et al. (2022) Pathological findings in stranded harbor porpoises (*Phocoena phocoena*) with special focus on anthropogenic causes. *Front Mar Sci* 9: 997388. doi: 10.3389/fmars.2022.997388

IJsseldijk, L.L., Van Neer, A., Deaville, R., et al. (2018) Beached bachelors: An extensive study on the largest recorded sperm whale *Physeter macrocephalus* mortality event in the North Sea. *PLoS One* 13(8): e0201221. doi: 10.1371/journal.pone.0201221

Jaber, J.R., Pérez, J., Arbelo, M., et al. (2004) Hepatic lesions in cetaceans stranded in the Canary Islands. *Vet Pathol* 41(2): 147-153. doi: 10.1354/vp.41-2-147

Kershaw, J.L., Brownlow, A., Ramp, C.A., et al. (2019) Assessing cetacean body condition: Is total lipid content in blubber biopsies a useful monitoring tool? *Aquat Conserv* 29 (S1): 271-282. doi: 10.1002/aqc.3105

Kershaw, J.L., Sherrill, M., Davison, N.J., et al. (2017) Evaluating morphometric and metabolic markers of body condition in a small cetacean, the harbor porpoise (*Phocoena phocoena*). *Ecol Evol* 7(10): 3494-506. doi: 10.1002/ece3.2891

Krause, D.J., Hinke, J.T., Perryman, W.L., et al. (2017) An accurate and adaptable photogrammetric approach for estimating the mass and body condition of pinnipeds using an unmanned aerial system. *PLoS One* 12(11): e0187465. doi: 10.1371/journal.pone.0187465

Lawler, D., Tangredi, B., Matassa, K., et al. (2021) Proximate Aspects of Starvation-Related Morbidity and Mortality Among Young California Sea Lions (*Zalophus californianus*). *J Vet Anat* 14(2): 39-56. doi: 10.21608/jva.2021.197200

Le Boeuf, B.J., Perez-Cortes H.M., Urban-Ramirez, J., et al. (2000) High gray whale mortality and low recruitment in 1999: Potential causes and implications. *J Cetacean Res Manag* 2(2): 85-99. doi: 10.47536/jcrm.v2i2.492

Leopold, M.F. (2015) Eat and be eaten: porpoise diet studies. PhD Thesis. Wageningen University, Wageningen Marine Research: Wageningen. ISBN 978-94-6257-558-5. 239 pp.

Machovsky-Capuska, G.E., Amiot, C., Denuncio, P., et al. (2019) A nutritional perspective on plastic ingestion in wildlife. *Sci Total Environ* 656: 789-796. doi: 10.1016/j.scitotenv.2018.11.418

Machovsky-Capuska, G.E. and Raubenheimer, D. (2020) The Nutritional Ecology of Marine Apex Predators. *Annu Rev Mar Sci* 12: 361-387. doi: 10.1146/annurev-marine-010318-095411

Machovsky-Capuska, G.E., von Haeften, G., Romero, M.A., et al. (2020) Linking cadmium and mercury accumulation to nutritional intake in common dolphins (*Delphinus delphis*) from Patagonia, Argentina. *Environ Pollut* 263: 114480. doi: 10.1016/j.envpol.2020.114480

MacLeod, C.D., Pierce, G.J. and Santos, M.B. (2007a) Starvation and sandeel consumption in harbour porpoises in the Scottish North Sea. *Biol Lett* 3: 535-536. doi: 10.1098/rsbl.2007.0298

MacLeod, C.D., Santos, M.B., Reid, R.J., et al. (2007b) Linking sandeel consumption and the likelihood of starvation in harbour porpoises in the Scottish North Sea: could climate change mean more starving porpoises? *Biol Lett* 3(2): 185-8. doi: 10.1098/rsbl.2006.0588

Macleod, R., Gosler, A.G. and Cresswell, W. (2005) Diurnal mass gain strategies and perceived predation risk in the great tit *Parus major*. *J Anim Ecol* 74: 956-964. doi: 10.1111/j.1365-2656.2005.00993.x

MacLeod, R., MacLeod, C.D., Learmonth, J.A., et al. (2007c) Mass-dependent predation risk and lethal dolphin-porpoise interactions. *Proc R Soc B: Biol Sci* 274: 2717-2723. doi: 10.1098/rspb.2007.0786

Mann, J. and Karniski, C. (2017) Diving beneath the surface: long-term studies of dolphins and whales, *J Mammal* 98(3): 621-630. doi: 10.1093/jmammal/gyx036

Marçalo, A., Samel, V., Carvalho, F., et al. (2024) Evaluating dolphin interactions with bottom-set net fisheries off Southern Iberian Atlantic waters. *Fish Res* 278: 107100. doi: 10.1016/j.fishres.2024.107100

Markussen, N.H. (1995) Changes in metabolic rate and body composition during starvation and semistarvation in harbour seals. *Dev Mar Biol* 4: 383-391. doi: 10.1016/S0163-6995(06)80040-5

McClatchie, S., Field, J., Thompson, A.R., et al. (2016) Food limitation of sea lion pups and the decline of forage off central and southern California. *R Soc Open Sci* 3: 150628. doi: 10.1098/rsos.150628

McCue, M.D. (2010) Starvation physiology: Reviewing the different strategies animals use to survive a common challenge. *Comp Biochem Physiol A Mol Integr Physiol* 156: 1-18. doi: 10.1016/j.cbpa.2010.01.002

McCue, M.D. (ed.) (2012) Comparative Physiology of Fasting, Starvation and Food Limitation. Springer, Berlin, Heidelberg. doi: 10.1007/978-3-642-29056-5

Mellor, D.J. and Beausoleil, N.J. (2015) Extending the 'Five Domains' model for animal welfare assessment to incorporate positive welfare states. *Anim Welf 24*(3): 241-253. doi: 10.7120/09627286.24.3.241

Mellor, D.J., Beausoleil, N.J., Littlewood, K.E., et al. (2020) The 2020 Five Domains Model: Including Human-Animal Interactions in Assessments of Animal Welfare. *Animals* 10(10): 1870. doi: 10.3390/ani10101870

Metcalf, V. and Robards, M. (2008) Sustaining a healthy human-walrus relationship in a dynamic environment: Challenges for co-management. *Ecol Appl* 18(sp2): 148-156. doi: 10.1890/06-0642.1

Mustonen, A.M., Pyykonen, T., Paakkonen, T., et al. (2005) Adaptations to fasting in the American mink (Mustela vison): Carbohydrate and lipid metabolism. *Comp Biochem Physiol A Mol Integr Physiol* 140: 195-202. doi: 10.1016/j.cbpb.2004.12.004

Nehasil, S.E., Zwolinski, J.P., Dorval, E., et al. (2026) Intraspecific variation in prey quality affects the consumption rates of top predators. *J Anim Ecol* 95(1): 65-83. doi: 10.1111/1365-2656.70155

Nelms, S.E., Alfaro-Shigueto, J., Arnould, J.P.Y., et al. (2021) Marine mammal conservation: Over the horizon. *Endanger Species Res* 44: 291-325. doi: 10.3354/esr01115

New, L., Lusseau, D. and Harcourt, R. (2020) Dolphins and Boats: When Is a Disturbance, Disturbing? *Front Mar Sci* 7: 353. doi: 10.3389/fmars.2020.00353

Nicol, C., Bejder, L., Green, L., et al. (2020) Anthropogenic Threats to Wild Cetacean Welfare and a Tool to Inform Policy in This Area. *Front Vet Sci* 7: 57. doi: 10.3389/fvets.2020.00057

Noren, S.R., Schwarz, L., Chase, K., et al. (2019) Validation of the photogrammetric method to assess body condition of an odontocete, the short-finned pilot whale *Globicephala macrorhynchus. Mar Ecol Prog Ser* 620: 185-200. doi: 10.3354/meps12971

O'Brien, K., Garibaldi, L. and Agrawal, A. (2024) Thematic Assessment Report on the Underlying Causes of Biodiversity Loss and the Determinants of Transformative Change and Options for Achieving the 2050 Vision for Biodiversity of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. doi: 10.5281/zenodo.11382215

Obbard, M.E., Cattet, M.R.L., Howe, E.J., et al. (2016) Trends in body condition in polar bears (*Ursus maritimus*) from the Southern Hudson Bay subpopulation in relation to changes in sea ice. *Arct Sci* 2: 15-32. doi: 10.1139/as-2015-0027

Oesterwind, D., Barrett, C.J., Sell, A.F., et al. (2022) Climate change-related changes in cephalopod biodiversity on the North East Atlantic Shelf. *Biodivers Conserv* 31: 1491-1518. doi: 10.1007/s10531-022-02403-y

Pagano, A.M., Rode, K.D., Lunn, N.J., et al. (2024) Polar bear energetic and behavioral strategies on land with implications for surviving the ice-free period. *Nat Commun* 15: 947. doi: 10.1038/s41467-023-44682-1

Panti, C., Baini, M. and Fossi, M.C. (2026) Choked: How the intake of plastics can impact marine mammal welfare. In: Beneath the Surface: Marine Mammal Welfare in a Challenging World. An OceanCare report.

Papastavrou, V., Leaper, R. and Lavigne, D. (2017) Why management decisions involving marine mammals should include animal welfare. *Mar Policy* 79: 19-24. doi: 10.1016/j.marpol.2017.02.001

Pauly, D. (1995) Anecdotes and the shifting baseline syndrome of fisheries. *Trends Ecol Evol* 10(10): 430. doi: 10.1016/S0169-5347(00)89171-5

Phipps, J.E., Silva-Krott, I., Marchetti, J., et al. (2023) Variation in blubber thickness and histology metrics across the body topography of a false killer whale (*Pseudorca crassidens*). *Front Physiol* 14: 1001734. doi: 10.3389/fphys.2023.1001734

Pierce, G.J., Brownlow, A., Evans, P.G.H., et al. (2022) Report of the ASCOBANS Resource Depletion Working Group. ASCOBANS/AC27/Doc.2.2. Available at: https://www.ascobans.org/sites/default/files/document/ascobans_ac27_doc2.2_report-resource-depletion-wg.pdf

Pierce, G.J., Roumbedakis, K., Pita, C., et al. (2025) Problems and solutions in European cephalopod fisheries. In: Russell, B.D. and Todd, P.A. (eds.) Oceanography and Marine Biology: An Annual Review (First edition). CRC Press, Boca Raton, Florida, USA. pp 114-162. doi: 10.1201/9781003589600

Pierce, G.J., Thompson, P.M., Miller, A., et al. (1991) Seasonal variation in the diet of common seals in the Moray Firth. *J Zool* 223: 641-652. doi: 10.1111/j.1469-7998.1991.tb04393.x

Pietroluongo, G. and Centelleghe, C. (2026) Diseased: how disease silently undermines marine mammal welfare. In: Beneath the Surface: Marine Mammal Welfare in a Challenging World. An OceanCare report.

Pirotta, E. (2022) A review of bioenergetic modelling for marine mammal populations. *Conserv Physiol* 10(1): coac036. doi: 10.1093/conphys/coac036

Puig-Lozano, R., Bernaldo de Quirós, Y., Díaz-Delgado, J., et al. (2018) Retrospective study of foreign body-associated pathology in stranded cetaceans, Canary Islands (2000-2015). *Environ Pollut* 243(A): 519-527. doi: 10.1016/j.envpol.2018.09.012

Rae, B.B. and Shearer, W.M. (1965) Seal damage to salmon fisheries. *Marine Research* 1965 (2), Department of Agriculture and Fisheries for Scotland, Her Majesty's Stationery Office, Edinburgh. pp 1-39.

Ramos, E.A., Landeo-Yauri, S., Castelblanco-Martínez, N., et al. (2022) Drone-based photogrammetry assessments of body size and body condition of Antillean manatees. *Mamm Biol* 102: 765-779. doi: 10.1007/s42991-022-00228-4

Raubenheimer, D. and Simpson, S.J. (1999) Integrating nutrition: a geometrical approach. *Entomol Exp Appl* 91(1): 67-82. doi: 10.1046/j.1570-7458.1999.00467.x

Raubenheimer, D., Simpson, S.J. and Mayntz, D. (2009) Nutrition, ecology and nutritional ecology: Toward an integrated framework. *Funct Ecol* 23(1): 4-16. doi: 10.1111/j.1365-2435.2008.01522.x

Raubenheimer, D., Simpson, S.J. and Tait, A.H. (2012) Match and mismatch: conservation physiology, nutritional ecology and the timescales of biological adaptation. *Philos Trans R Soc B Biol Sci* 367: 1628-1646. doi: 10.1098/rstb.2012.0007

Raverty, S., Duignan, P., Greig, D., et al. (2024) Gray whale (*Eschrichtius robustus*) post-mortem findings from December 2018 through 2021 during the Unusual Mortality Event in the Eastern North Pacific. *PLoS ONE* 19(3): e0295861. doi: 10.1371/journal.pone.0295861

Regehr, E.V., Laidre, K.L., Atwood, T.C., et al. (2023) Sea-ice conditions predict polar bear land use around military installations in Alaska. *Hum-Wildl Interact* 17(1): 21-36. Available at: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1821&context=hwi

Reusch, T.B.H., Dierking, J., Andersson, H.C., et al. (2018) The Baltic Sea as a time machine for the future coastal ocean. *Sci Adv* 4(5): eaaar8195. doi: 10.1126/sciadv.aar8195

Rode, K.D., Fischbach, A., Synnott, M., et al. (2024) Photogrammetry-based body condition for monitoring an Arctic marine mammal experiencing habitat loss. *Mar Ecol Prog Ser* 751: 211-227. doi: 10.3354/meps14738

Røjbek, M.C., Tomkiewicz, J., Jacobsen, C., et al. (2014) Forage fish quality: seasonal lipid dynamics of herring (*Clupea harengus L.*) and sprat (*Sprattus sprattus L.*) in the Baltic Sea. *ICES J Mar Sci* 71(1): 56-71. doi: 10.1093/icesjms/fst106

Rolland, R.M., Parks, S.E., Hunt, K.E., et al. (2012) Evidence that ship noise increases stress in right whales. *Proc R Soc B: Biol Sci* 279(1737): 2363-2368. doi: 10.1098/rspb.2011.2429

Rosen, D.A.S. and Trites, A.W. (2002) Changes in metabolism in response to fasting and food restriction in the Steller sea lion (*Eumetopias jubatus*). *Comp Biochem Physiol B Biochem Mol Biol* 132: 389-399. doi: 10.1016/S1096-4959(02)00048-9

Santos, M.B., Saavedra, C. and Pierce, G.J. (2014) Quantifying the predation on sardine and hake by cetaceans in the Atlantic waters of the Iberian Peninsula. *Deep-Sea Res II* 106: 232-244. doi: 10.1016/j.dsr2.2013.09.040

Sapolsky, R.M., Romero, L.M. and Munck, A.U. (2000) How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory, and preparative actions. *Endocr Rev* 21: 55-89. doi: 10.1210/er.21.1.55

Schijns, R. and Pauly, D. (2021) Management implications of shifting baselines in fish stock assessments. *Fish Manag Ecol* 29(2): 183-195. doi: 10.1111/fme.12511

SMRU (1984) Interactions between grey seals and UK fisheries. Sea Mammal Research Unit, Natural Environment Research Council, Cambridge.

Spitz, J., Mourocq, E., Leauté, J.-P., et al. (2010) Prey selection by the common dolphin: Fulfilling high energy requirements with high quality food. *J Exp Mar Biol Ecol* 390: 73-77. doi: 10.1016/j.jembe.2010.05.010

Stewart, J., Durban, J., Fearnbach, H., et al. (2021) Survival of the fattest: linking body condition to prey availability and survivorship of killer whales. *Ecosphere* 12(8): e03660. doi: 10.1002/ecs2.3660

Stockin, K.A., Amiot, C., Meynier, L., et al. (2022) Understanding common dolphin and Australasian gannet feeding associations from nutritional and ethological perspectives. *ICES J Mar Sci* 79: 2032-2042. doi: 10.1093/icesjms/fsac133

Thompson, P.M., Tollit, D.J., Corpe, H.M., et al. (1997) Changes in Haematological Parameters in Relation to Prey Switching in a Wild Population of Harbour Seals. *Funct Ecol 11*(6): 743-750. Available at: http://www.jstor.org/stable/2390305

Trathan, P., Friedlaender, A., Johnson, C., et al. (2025) The fishery for Antarctic krill: Conflicts between industrial production, protection of biodiversity, and legal governance. *Mar Policy* 180: 106787. doi: 10.1016/j.marpol.2025.106787

Trites, A., Christensen, V. and Pauly, D. (1997) Competition Between Fisheries and Marine Mammals for Prey and Primary Production in the Pacific Ocean. *J Northwest Atl Fish Sci* 22: 173-187. doi: 10.2960/J.v22.a14

Unger, B., Rebolledo, E.L.B., Deaville, R., et al. (2016) Large amounts of marine debris found in sperm whales stranded along the North Sea coast in early 2016. *Mar Pollut Bull* 112(1-2): 134-141. doi: 10.1016/j.marpolbul.2016.08.027

Walker, R. (1876) On the grey seal, *Halichoerus grypus*, on the east coast of Scotland. *The Scottish Naturalist* 3: 154-160.

Westerterp, K. (1977) How rats economize. *Physiol Zool* 50: 331-362. doi: 10.1086/physzool.50.4.30155736

Williams, R., Lusseau, D. and Hammond, P.S. (2006) Estimating relative energetic costs of human disturbance to killer whales (*Orcinus orca*). *Biol Conserv* 133: 301-311. doi: 10.1016/j.biocon.2006.06.010

Wuenschel, M.J., Bean, K.A., Rajaniemi, T., et al. (2024) Variation in energy density of northwest Atlantic forage species: Ontogenetic, seasonal, annual, and spatial patterns. *Mar Coast Fish* 16(2): e10287. doi: 10.1002/mcf2.10287

Xuereb, N., Machovsky-Capuska, G.E., Peters, K.J., et al. (in review) Evaluating nutritional stress in marine mammals: Review and recommendations.

To receive further information about this report, or OceanCare's work, please contact:

Nicolas Entrup
Director International Relations
nentrup@oceancare.org

Laetitia Nunny
Report Editor and Senior Science Officer
lnunny@oceancare.org

Fabienne McLellan
Chief Executive Officer
fmclellan@oceancare.org

OceanCare
Gerbestrasse 6
P.O. Box 31
CH-8820 Wädenswil
Switzerland

Tel: +41 (0) 44 780 66 88
Fax: +41 (0) 44 780 68 08

www.oceancare.org