Chapter 13
The Welfare Impact on Pinnipeds of Marine Debris and Fisheries

Andy Butterworth and Sue Sayer

Abstract Uncounted, and usually unobserved, numbers of the animals that live in the oceans find themselves snared, trapped or entangled in lost fishing gear, monofilament line, nets, rope, plastic packaging and packing bands from crates, or become hooked on discarded fishing gear, or ingest human marine debris. Seals, sea lions and walrus (the pinnipeds) seem particularly susceptible to entanglement in marine debris—their exploratory natures may make this more likely, or perhaps they come upon plastic waste and rope on the shoreline to a greater extent than the other fully aquatic mammals. Pinnipeds meeting with plastic, either in the sea or on the shoreline, may carry debris wrapped around themselves for long periods. They often die as a result, sometimes from major chronic wounds. Although a wide range of the global species of seals can be affected by marine debris, some species are much more significantly affected than others. The key seal species affected by entanglement are monk seals, fur seals and California sea lions. Seals which become entangled or who ingest marine debris may be subjected to distress, pain, trauma, infection, skin and muscle lesions and compromised ability to move, feed and carry out normal behaviour. For these reasons marine debris has the capacity to present a significant and global issue with respect to animal welfare, as well as to more immediately apparent concerns regarding habitats and the quality of the marine environment.

13.1 Introduction

Uncountable and unobserved in many cases, large number of pinnipeds are becoming tangled, or trapped, in discarded or lost fishing gear, net, rope, packaging and monofilament fishing line, or are hooked on fishing equipment (Convention on Biological Diversity 2012). Pinnipeds may be captured as by-catch and die (e.g. in

A. Butterworth (✉)
Department of Clinical Veterinary Science, University of Bristol, Langford, Bristol, UK
e-mail: andy.butterworth@bris.ac.uk

S. Sayer
Cornwall Seal Group Research Trust, Cornwall, UK

A. Butterworth (ed.), *Marine Mammal Welfare*, Animal Welfare 17,
DOI 10.1007/978-3-319-46994-2_13

live operational fishing gear—mostly gill and trawl nets) or become live entangled (mostly in storm damaged or discarded ghost fishing gear) with consequent welfare implications. The pinnipeds appear particularly susceptible to entanglement in this kind of marine waste; perhaps they encounter net, rope and waste on shorelines and in coastal waters more than the oceanic marine mammals. As highly intelligent mammals, pinnipeds appear curious about their environment and so likely to investigate materials floating in the water column, particularly juvenile animals when playing. Seals, walrus and sea lions meeting with waste or ghost fishing gear (*ghost gear is abandoned, lost or otherwise discarded fishing gear—ALDFG—which continues to 'fish' in an indiscriminate way*), in the shallow water of the coast or on the shore, may carry this material wrapped around them for a long period and sometimes die from the penetrating wounds caused by the rope and line. A broad range of species can be affected by entanglement, but some are much more commonly seen wrapped with rope, net or marine debris than others, especially monk seals, fur seals, grey seals and California sea lions. Seals wrapped or trapped in loops of marine debris may experience pain, fear, skin lesions and infection and sometimes deeply incised wounds from rope or line, which can amputate limbs, and cut down to bone (Fig. 13.1). The lines or fragments of net can interfere with their ability to move and perform natural behaviours—to keep up with conspecifics, to hunt, to forage, to mate and to move through the water at speed. Entanglement may also lead to complications such as oedema in pregnant females with the potential for reducing

Fig. 13.1 Live juvenile grey seal with deep open wound from trailing trawl net freed by the British Divers Marine Life Rescue. *Image credit*: Sue Sayer, Cornwall Seal Group Research Trust

survival and fecundity. Entangled debris presents a global animal welfare concern, and the recent launch of the Global Ghost Gear Initiative by World Animal Protection (WAP 2016) is the first major organisational initiative with a direct focus on marine debris in relation to animal welfare. Debris can damage local habitats by smothering rock and seabed substrates, resulting in the need to animals to alter their feeding behaviour. Many pinniped species have telescopic necks that improve their ability to accelerate forward to snatch prey, and with many entanglements occurring around the neck and head area, this ability can be severely reduced. The natural panic reaction for some pinnipeds is to spin their bodies and this can further entangle them in fishing gear. Different types of entangling materials have different impacts. Monofilament net or line tends to incise deeply through skin and into flesh, caused by the animal's movement alone and then by subsequent growth. Multifilament net may be more prone to harbour bacteria and so likely result in infection—one grey seal was known to have died within 128 days of his last pre-entanglement sighting as a result of trawl net (Sayer et al. 2015), whilst others have been known to live over 14 years with presumed monofilament wounds. Post-mortems have shown that flesh and skin can completely regrow over the entangling material (Sayer et al. 2015).

Marine debris may also be a source of chemical pollutants in the sea; plastics may release plasticisers and additives, which can cause toxicity in top predators when these toxins accumulate in their marine food.

Marine debris is found in all corners of the oceanic world, but the reporting of the effects on pinnipeds is not uniform and is linked to the number of 'observers' who report entangled animals (Fig. 13.2). Perhaps because of the patchiness of

Fig. 13.2 Adult female grey entangled seal dead and decomposing, undetected whilst alive. *Image credit*: *Liz Clark, Cornwall Seal Group Research Trust*

reporting rates, there is almost no reported and published information on pinniped entanglement in some parts of the world. Moore et al. (2013) reported that post-mortems of dead and live stranded pinnipeds correlate with the distribution of human impacts including fishing gear entanglement, boat strikes and malicious gunshot wounding. Harcourt et al. (1994) suggest that published rates of entanglement are likely to be underestimates, because they report only animals seen when they come onto shore and do not report or detect those animals which die out at sea (Fig. 13.3). Both of these authors note that inaccessibility, delayed discovery and human safety concerns for access to places where these animals are found may limit the accurate reporting of the cause of death and so result in under-reporting of animals dying as a result of marine debris and entanglement. Assumptions are often made about similarly entangled animals being the same individual, and only detailed photo identification research can reveal the true extent of this issue.

There are big variations in the geographical spread of research into marine debris and its potential effects on animals. The 2012 Convention on Biological Diversity report (CBD 2012) identifies this imbalance and indicates the numbers of reports reviewed which concern entanglement in debris in a wide range of species (not only pinnipeds) from different oceans: They report ‘Americas (North and South) (117), Australasia (56), Europe (52), Africa (12), Antarctic (7), Asia (6) and Arctic (5)’.

Fig. 13.3 Litter raft of mixed materials including lost fishing gear and a dead grey seal. *Image credit*: *Mike Stephens, Cornwall Seal Group Research Trust*

Estimates for animal entanglement and ingestion rates rely on reports of animals seen alive, or which have only recently died (otherwise the carcases become too decomposed for full analysis); therefore, the scale of this issue is likely to be seriously underestimated. If animals die unseen, as will be the case for many, possibly even the majority, of animals, then they will not be reported. Dead stranded animals with ghost fishing gear around their necks have been observed to decompose in such a way as leading to headless carcasses which further clouds accurate reporting. As Cole et al. (2006) say—'Our greatest concern remains the number of animals we never saw'.

Overall comments on the reporting variability for entanglements are made by Butterworth et al. (WSPA 2012). And even if regional reporting bias is taken into account, it is apparent that some areas produce higher risks of ingestion and entanglement than others, and so it is possible that highly targeted action in these areas of high risk might act to ameliorate localised marine debris impacts and that it may be worthwhile to focus resource and work to create improvements in these areas. The reported 'hotspots' for entanglement of pinnipeds are the western coast of the USA, sea lions and fur seals; the eastern coast of Australia, fur seals; the south African coast, fur seals; and the Celtic and North Seas, where the gulf stream is known to bring large amounts of debris, grey seals.

13.2 A Short History of Marine Debris

When the explorer Thor Heyerdahl crossed the Atlantic Ocean in 1970, he was so concerned about the marine debris that he observed on the oceans that he submitted a report to the United Nations 1972 Stockholm conference on the Human Environment (United Nations 1972). Marine litter is defined by the United Nations Environment Programme as 'any persistent, manufactured or processed solid material discarded, disposed or abandoned in the marine and coastal environment', and the United Nations Environment Programme of 2005 (United Nations 2005) estimated that 6.4 million tonnes of 'litter' end up in oceans every year. Estimates for the total amount of marine debris now present in the oceans vary, but, on average, around 300,000 items of litter and debris are estimated to be present per km^2 of ocean surface (NRC 2008). Marine waste and debris comprise plastics, metal, glass, rubber, paper and objects comprised of multiple man-made substances such as packaging boxes, bottles, fishing nets and floating accumulations of mixed waste material bound together into litter rafts (Fig. 13.3).

Plastic dominates marine litter because it is usually either neutrally buoyant or slightly denser than sea water, and because of its longevity. The top debris items collected between 1989 and 2007 were (ICC 2008)

> 'Cigarettes/cigarette filters: 24.6%, Bags (paper and plastic): 9.4%, Caps/lids: 9.1%, Food wrappers/containers: 8.9%, Cups/plates/forks/knives/spoons: 7.2%, Plastic cans: 4.6%, Straws/stirrers: 4.4%, Rope: 2.1%'.

Wilcox et al. (2016) listed the potential impacts of various forms of marine debris on marine mammals from the highest rank (risk) to the lowest rank: ‘Buoys/traps/pots; Monofilament line; Fishing nets; plastic bags; Butts (cigarette butts); Plastic utensils; Balloons; Plastic caps; Food packaging; Plastic food lids; Straws/stirrers; Takeout containers; Hard plastic; Cans; Cups and plates; Glass bottles; Beverage bottles; Paper bags’.

‘Plastics’ are made from synthetic organic polymers—common forms of plastic include polyesters, polyethylene aramids and acrylics, polyethylene terephthalate (PET), polypropylene, nylon and high-density polyethylene (HDPE). Most rope, monofilament line and fishing net and a large proportion of packaging material are manufactured from plastic, sometimes woven, braided or plaited, to increase its strength as a fibre. Rope, monofilament line and net are specifically designed for use in the sea, are very strong, are resistant to degrading by saltwater and sunlight, and are resistant to abrasion. Plastics are usually neutrally dense or buoyant in the sea and float at the surface or sink only slowly in the water and can be carried by ocean currents. Nylon monofilament fishing line was first sold in 1939 (New World Encyclopedia 2016), and since that time monofilament plastic line has become much stronger, almost invisible in water (monofilament lines have low optical density) and extremely strong. Fishing lines are strong when related to their thickness, and this thin strength can result in extreme tissue damage when animals become entangled. Some plastics may last for up to 600 years in the sea, and because of their durability and longevity, abandoned, lost or otherwise discarded fishing gear (ALDFG) or derelict fishing gear (DFG), nets, lines, lost traps, floats with line, rope or net attached and monofilament fishing line (sometimes with hooks) are a particular concern for animal welfare.

‘Packing bands’ are extremely strong (by design) and are used to close containers and packages. They are usually made from polypropylene, nylon or polyester, often reinforced with other plastic fibres, and they are not only strong and resistant to degradation but are commonly formed into loops (around the original container), and these looped structures more commonly trap animals, particularly pinnipeds, than straight lines or ropes. Loops of packing band are seen in a wide range of loop size, and each type of loop may represent a particular hazard to a species or age group of seal or sea lion.

The US National Marine Debris Monitoring Program (Sheavly 2007) indicated that 17.7% of marine litter found on beaches came from ocean activity, with a large proportion of debris linked with fishing, including nets, fish baskets, fishing line, rope, buoys, floats, pots and traps. In the UK, fishing-derived marine debris includes nets, buoys, line and floats, and is the second largest source of marine debris after litter from beach visitors (Marine Conservation Society [MCS] 2007). Sayer and Williams (WAP, 2015) identified differences in the fishing gear found lost at sea (buoys and floats, 41%; trawl net, 17%; monofilament net, 14%; rope, 12%; others, 9%; pot related, 6%, and monofilament line, 1%) to that recorded on land (beaches) in the same area (monofilament line, 29%; rope, 26%, pot related, 11%; trawl net, 11%, others, 10%; buoys and floats, 8%; monofilament net, 5%)—this representing a kind of ‘selection’ for some types of fishing-related gear to be more likely to occur as lost in the sea. Marine debris comes from a wide range of other man-made sources; from intentional and unintentional waste tipping from shipping, including fishing vessels; from accidental or deliberate dumping of domestic, commercial or industrial waste into the sea from the land; from waste blown from shore or from boats; and from land-based debris or waste moving down rivers and into the sea after storms or floods.

The manufacturing origin (however, not the disposal location) of many objects can be determined from the barcode that the object carries (the initial three letters of the code indicate the manufacturing country). Santos et al. (2005) reported the source of debris found on beaches in Brazil and found that the country of origin of identifiable objects was ‘USA 12.2%, Italy 7.6%, South Africa 6.4%, Argentina 6.0%, Germany 5.6%, United Kingdom 4.6%, Taiwan 4.4%, Singapore 3.6%, Spain 3.6%, Malaysia 3.1%, with ‘others’ 35.2% and ‘unidentified’ 7.6%’.

Barcode tracing for plastic debris shows that marine debris can be found 10 years later and 10,000 km from its origin (Barnes et al. 2009).

Marine litter in the ocean slowly breaks down into small particles, and these plastic pieces are now found in the water and marine sediments across the world. The Great Pacific Oceanic Gyre has debris estimated to have a mass of 100 million tonnes, and this is particularly concentrated into an area the size of France and Spain together (Sheavly 2007). Before the 1980s, relatively small quantities of marine litter reached the Southern Ocean. Today, there is now movement and accumulation of marine litter across the whole southern hemisphere, and significant amounts of marine debris have moved towards Antarctica (Barnes 2005). Plastic tends to break down rather slowly in the marine environment. Wang et al. (2016) report that the effects of UV-B radiation and exposure to oxygen, and autocatalytic degradation of plastic in the low temperatures of the sea is very slow when compared to degradation in the terrestrial environment. Zalasiewicz et al. (2016) state that degraded plastic is so widespread in ocean sediments that degraded plastic may become a key future geological indicator of the Anthropocene (current time, time of mankind).

One perceived route to reduction of marine debris, and hence having the potential to reduce wildlife entanglement, is through educational programmes. Pearson et al. (2014) report a survey used to assess the familiarity of the Australian public in coastal communities with an initiative called ‘Seal the Loop’—an educational programme aimed at protecting seals from marine litter. A majority of the participants in the study were familiar with the education programme, but 32% of the participants were not able to explain what the risks of marine debris to wildlife actually were. The respondents also underestimated the actual impact on wildlife numbers, however, this study did conclude that ‘learning something new about the impact of marine debris did change waste disposal behaviours’. A lost fishing gear recording scheme in Cornwall, UK, saw the removal of 50 tonnes of lost fishing gear recorded in a 12-month period, with an assessed reduction in serious risk posed to grey seals from 47 to 26% (Sayer and Williams 2015).

13.3 Plastic Waste Impacts on Animal Welfare Through the Entanglement of Pinnipeds

For many people, a description of an animal as having ‘good welfare’ might include the animal being ‘well’ (i.e. not unwell) and also that the animal had the potential for ‘well-being’—or, at least, not subject to high levels of distress or high frequencies of interference. With regard to a state of ‘good welfare’, disease or physiological or anatomical damage, injury and trauma would provide potential welfare challenges. Sandoe and Simonsen (1992) used the term ‘cost of coping’ implying that emotional distress, pain or increased levels of physiological or disease-related challenge would have a ‘cost’ to the animal and that if this cost was great, or in some cases excessive, then the animal would be less likely to ‘cope’. Prolonged failure to cope would probably result in suffering.

For wild animals, entanglement in a loop of rope, a discarded net or a packing band could represent a severe compromise to their ability to cope and so induce suffering. The entanglement could result in altered; feeding behaviours, use of food sources, social interactions and breeding patterns, hunting or foraging patterns and territorial or animal–human interactions.

For an individual animal, the capacity to cope (or not) would depend on the severity of the entanglement and whether the entanglement caused restriction of movement or, in some cases; trauma, skin lesions, wounds and an altered ability to swim, mate or feed. The size, locality, physiology, feeding habits, behaviours and types of marine debris found in the sea around different pinniped species will affect whether entanglement happens, how and when it takes place, at what age (linked to body size and inquisitive behaviour) and with what debris items. Entanglement could be ‘acute’, causing sudden and severe welfare problems such as asphyxiation, or trapping underwater, or ‘chronic’, in which the welfare impacts may increase over time through incisive wounds, susceptibility to infection and long-term restriction of behaviours.

A large number of seal and sea lion species are recorded to have been entangled, with 58% of all species of seals and sea lions reported by Boland and Donohue (2003). The incidence rate of entanglement for seal and sea lion species is reported to be from 0.001 to 5% annually of the local seal population, with notably high levels of entanglement of up to 7.9% in California sea lions from Mexico (Harcourt et al. 1994). Williams et al. (2011) report high entanglement rates for northern elephant seals (*Mirounga angustirostris*), Steller sea lion (*Eumetopias jubatus*) and harbour seal (*Phoca vitulina*) around the coast of British Columbia. A study of Bering Sea northern fur seals estimated that 40,000 seals were killed by marine debris entanglement each year (Derraik 2002). Rates of entanglement in grey seals in South West England are of a similar magnitude, averaging 3.1% between 2000 and 2013 (Sayer et al. 2015).

When seals become entangled, this can involve a ring of packing strap, or a fragment of fishing net, or a loop of monofilament line—which commonly forms a collar around the neck, or less commonly a loop around the central abdomen. The loop becomes tighter as the seal grows and may become deeply trapped in the skin. This is because the animal cannot remove it due to its tension or the directional hair of the coat (which is flattened against the body in the direction of least water resistance). If the seal is adult, the loop can cut into the tissues of the flipper or the neck and may become firmly embedded in the skin, subcutaneous fat or muscle and sometimes, finally, into bone. If the loop becomes deeply enmeshed or embedded, then it is unlikely that the seal can ever remove it. Most entanglements are in young animals, maybe because they are more curious, inquisitive and exploratory than adults, or perhaps because they are naïve feeders, less familiar with the hazards represented by fishing net fragments, or packing band loops. Young seals with severe constrictions may have feeding restricted to the point of starvation. Loop ligatures can cause amputation of the flippers, or create wounds open to infection, which limit the likelihood of survival. The constriction around the neck can embed in the tissues and finally cause strangulation as the animal grows into the noose. Because plastic-based rope, net and packaging bands are so durable, after death, the debris can returned to the sea, with the potential to entangle other animals (WSPA 2012).

Trailing entangling materials have a tendency to cause asymmetrical wounds as they catch under the animal's body during locomotion on land, causing deeply incised wounds at the back of the neck when the animal moves on land. Longer trailing materials can have a significant impact on survivorship, with longer trailing material lengths associated with poorer survival rates (Sayer et al. 2015). Entangled seals will experience increased drag during swimming (Boland and Donohue 2003). Derraik (2002) describe how northern fur seals (*Callorhinus ursinus*) entangled in even small net fragments of as little as 200 g in weight experience a fourfold increase in the energetic requirement to compensate for drag caused by altered water flow. This drag effect restricts movement and may ultimately lead to the exhaustion or drowning of the animal. Where stellar sea lions (*Eumetopias jubatus*) in Alaska and British Columbia ingest lost fishing line with hooks attached, the hooks and lures lodge in the animal or can damage the mouth and the digestive tract and reduce the animal's capacity to forage and feed effectively.

13.4 Severity Scoring for Pinniped Interactions with Marine Debris

In human medicine, scoring scales are used to describe wounds and to enable clinicians to gauge and communicate how the wounds are healing. The Red Cross has a classification of war wounds, used to describe wounds based on their visual appearance (not based on what caused them) (Coupland 1992). Work has been initiated on the assessment of entanglements in marine mammals. At the 2007 NOAA/NMFS (NOAA 2007) Serious Injury Technical Workshop, held in Seattle, a hierarchical descriptive scale for entanglement injuries to marine mammals was proposed:

> *"Serious—gear-related injury; ingestion of gear; trailing gear (e.g. flasher or lure), when it has the potential to anchor or drag, or when it is wrapped around the animal; gear attached to the body with the potential to wrap around flippers, body, or head; foreign bodies penetrating into a body cavity;*
>
> *Multiple wraps around the body; missing flippers—front and back flipper (serious), for both otariids or phocids; deep external injuries."*

> *"Non-serious—gear-related injuries; hooked in the lip; hooked in flipper, etc. with minimal trailing gear that does not have the potential to wrap around body parts, accumulate drag, or anchor; freely swimming animals encircled by purse seine nets."*

> *"Grey area—gear-related injuries (less clear how serious the welfare impact is): hooked in head (serious injury could be assumed, but it depends on several factors, including where on the head the hooking took place, the depth of the hooking, the type of hook, etc.); animals stressed by being encircled or trapped (e.g., purse seine); animals released without gear following entanglement (this designation depends on the extent of the injury or how long the animal was submerged, how long the gear was on the animal, and the degree of restraint)."*

Other impacts of interactions with humans were also discussed: 'Pinniped brought onto a vessel' (this was considered in this report to be 'non-serious') and the severity for the animal of being brought up onto a boat which depended on how the animal was brought up, e.g. in net, or a roller (a fishing boat net handling device), or through the power block (the powered device used to haul a net onto the deck).

Some scenario examples of 'serious scores' are provided to illustrate the possible welfare impacts, which could cause severe welfare insults, and based on descriptions of observed seal entanglements from Spraker and Lander (2010):

> *"Rope fragment wrapped around shoulder, strands had cut through the muscles of the right shoulder and halfway through the mid-portion of the humerus.*
>
> *Material wrapped around upper neck, line had cut through the lower half of trachea.*
>
> *Line wrapped around mid-neck, had cut through all dorsal muscles of the neck exposing the dorsal spinal processes of the cervical vertebrae."*

Successful trials were conducted to assess the risks posed to marine life by lost fishing gear by Sayer and Williams (WAP, 2015). Firstly, risk was assessed in terms of likelihood of marine life interaction with the lost fishing gear—described as 'possible' (P) if seals/birds used the area routinely, 'likely' (L) if seals/birds were within 5 m of the item and 'witnessed' (W) if they were observed touching the item; otherwise the risk was assessed as 'unlikely' (U). Secondly, risk was assessed according to the likelihood of marine life entanglement in the lost fishing gear—described as 'possible' (P) if the item was looped/meshed or a balled mass, 'likely' (L) if they were within 5 m of a looped/meshed or balled item and 'witnessed' (W) if marine life was seen entangled; otherwise the risk was assessed as 'unlikely' (U). The two risk ratings were combined into the following categories: UU, UP, PU, PP, LU, LP, LL, LW, WL and WW. Categories PP + (PP, LP, LL, LW, WL or WW) were considered to pose a serious threat to marine life (especially seals and birds).

13.5 Fur Seals

Hofmeyr et al. (2002) recorded 101 fur seals (*Arctocephalus* spp.) and five southern elephant seals (*Mirounga leonina*) entangled over a period of 10 years on Marion Island in the Southern Ocean. These authors describe how 67% of the materials causing the entanglement came from the fishing industry. Polypropylene packaging straps (associated with the fishery) were the most common material causing entanglement, followed by fish trawl netting. These authors also noted longline hooks embedded in animals and that fishing line entanglements only started to be seen after longline fishing started in 1996 in this area. Hofmeyr et al. (2002) estimated that 0.24% of this population of fur seals were entangled each year. Hofmeyr et al. (2006), in a further study of Antarctic fur seals (*Arctocephalus gazella*) between 1996 and 2002 on Bouvetøya, an Antarctic island, reported entanglement rates from 0.024 to 0.059% and concluded that these rates were relatively low when compared to other pinniped populations because, they suggested, of the isolation of the site. This 2006 study found that more than two-thirds of materials causing entanglement were from fisheries sources.

Spraker and Lander (2010) estimated the causes of mortality in northern fur seals (*Callorhinus ursinus*) in the Alaskan St. Paul Islands. These authors describe combinations of the pathological effects of entanglement, with trauma and asphyxiation being caused by net fragments or packing band loops. In one case a heavily entangled living animal was dragging a decomposing seal in the same piece of entangling net.

Lawson and co-workers carried out a study on a series of beaches from the islands around the coast of Southern Australia, where there is an estimated Australian fur seal (*Arctocephalus pusillus doriferus*) population of about 30,000 animals (Lawson et al. 2015). Between 1997 and 2012, 138 entanglements were reported and the entangling debris was collected. In the debris, 50% ($n = 69$) of the objects were plastic twine or rope, which included trawl nets; 20% ($n = 27$) were packing straps, plastic bags and balloon strings; 17% ($n = 24$) were monofilament fishing line (which included gill nets); and 8% ($n = 11$) were rubber litter items. This study also recorded the characteristics of the entangling material; its 'type, colour, mesh size, overall mass, number of threads, whether the item was braided, twisted, knotted, if it was monofilament, and the number of strands for all entanglement items'. White plastic packaging straps were the most common (67%, $n = 6$) of the packing strap entanglements; 61% ($n = 43$) of rope entanglements were with green-coloured material, whilst grey- and white-coloured rope accounted for lower percentages of entangling material at 10% ($n = 7$) and 9% ($n = 6$), respectively. For the monofilament line entanglements, most of the monofilament was clear or green in colour (52% and 26%, respectively). Information on the location, date, age of the seal (pup, juvenile, adult) and the type and severity of the injury (whether the wound was cutting deep into tissue or was a surface wound) was also compiled. Analysis of this carefully collected data indicated that the majority 94% ($n = 46$) of entanglements involved pups or juvenile seals, with more pups (53%) than juveniles (41%) being entangled.

McIntosh and others, working at Seal Rocks, South-Eastern Australia, reported 359 entangled Australian fur seals and showed that the most common entanglement materials were from commercial fisheries and that entanglements were most frequent in pups and juveniles (McIntosh et al. 2015). Entanglement was most commonly observed from July to October, when the animals approached weaning. Using generalized additive mixed models (GAMMs), these authors estimated that 1.0% (CI = 0.6–1.7%) of the local population was entangled each year.

The loop diameters of entangling materials, which entangled Antarctic fur seals from a study at Bird Island, South Georgia, are described by Waluda and Staniland (2013). They reported material found entangling 90 animals, with loops from 11 to 69 cm in diameter (with a median diameter of 18 cm). These authors found that loop diameter was closely related to age class. Pups were more commonly entangled in small loops (median = 15.5 cm), and juveniles and adult females were entangled in loop diameters of about 17 cm (adult females = 17 cm, juveniles = 18 cm). Adult males were more likely to be snared in large loops (median = 34 cm). These authors report that juveniles were five times more likely to be snared than adult females. They propose that younger animals meet entangling material through inquisitive play. Adult males were least likely to become entangled, which may be because of the shape of their broad muscular necks and also their relatively small numbers within the total population and also potentially due to differences in their feeding and exploratory behaviours. This report notes also that if entanglement is fatal to a juvenile, then individuals prone to entanglement will possibly have been selected out of the population. This study also identifies that more ‘very severe’ entanglements occurred in the (Southern) winter, and these authors speculate that this may be due to changes in the ability to observe and report entangled animals, rather than a true alteration in entanglement rate. During winter, the animals are hauled out onto the shoreline and are thus more readily observed. This report also suggested that there has been a decline in the number of seals snared in packaging bands at Bird Island across the period of the study. In ‘1988/1999—58% of entanglements were with packing bands, between 1989 and 1994 this fell to 46%, and between 1994 and 2013 the proportion was 39%’. These authors suggest that the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) ban on packaging bands, which began in 1995, may have started to have a reducing, but not complete eliminating, effect on the rate of packing band entanglements. Other studies suggest that the rate of entanglement of Antarctic fur seals (*Arctocephalus gazella*) halved over the 5-year period (1990–1994) after the introduction of MARPOL Annex V (in 1973, the International Maritime Organization IMO adopted the International Convention for the Prevention of Pollution from Ships, now known as MARPOL, which has been amended by the Protocols of 1978 and 1997 and kept updated with relevant amendments) (IMO 2016); however, polypropylene packing straps, synthetic fibre rope and fishing net fragments were still found to be common debris items which entangled seals in all the years of this study (Arnould and Croxall 1995).

Page et al. (2004) indicate that, in New Zealand, fur seals are most commonly entangled in loops of packing tape and pieces of trawl net originating from the rock lobster and trawl fisheries. These authors (Page et al. 2004) published entanglement rates for Australian sea lions and New Zealand fur seals in derelict fishing gear and in other marine debris. In 2002, the authors calculated that the Australian sea lion entanglement rate was 1.3% of the population annually, and the New Zealand Fur seal entanglement rate was 0.9%. Australian sea lions were commonly found to be entangled in monofilament line or net (rather than any other entangling materials), and these fishing materials appeared to be most likely derived from the local shark fishery.

On St. Paul Island, in the Alaskan Pribilof Islands, northern fur seal (*Callorhinus ursinus*) entanglement rates were studied by Fowler (1987), and various objects were found to entangle these animals around their necks, shoulders and flippers, with an estimated incidence rate of about 0.4% annually. The majority of these entanglements were with trawl nett fragments and plastic packing bands. This author noted that entanglement was more common in young animals, which were 'sometimes observed entangled together in groups attached to the same large items of debris'.

Shaughnessy (1980) reports entanglement in Cape fur seals (*Arctocephalus pusillus*), in the period 1972–1979. The majority of the entangling objects were around the seals' necks, with the incidence rate recorded at the Cape Cross colony of 0.56–0.66% per year. Animals were entangled with 'string, rope, fishing net, plastic straps, monofilament line and rubber O-rings', with a rate of entanglement estimated to be 0.4% annually of the population. These authors estimated 15,000 seal entanglements to take place each year and that 5700 of these animals would die as a result of their entanglement. Zavadil et al. (2007) reports northern fur seals (*Callorhinus ursinus*) on St. George Island to have an estimated entanglement rate of 0.06–0.08% annually for pups and with the maximum entanglement rate occurring in October with up to 0.11% of the population entangled just before weaning.

New Zealand fur seals (*Arctocephalus forsteri*) in the Kaikoura region of New Zealand breed close to a busy tourist and fishing area and become entangled in lost net and plastic waste (Boren et al. 2006). Entanglement rates are described in Boren et al.'s study as being in the range of 0.6–2.8% annually, with green trawl net pieces (42%) and plastic strapping bands (31%) being the most common entangling items. These authors also report that, perhaps due to the high density of 'observers' in this area, nearly half of the entangled seals were caught and released from their entanglement (43%) and that post-release monitoring has shown that the likelihood of an individual surviving is high, even after a significant entanglement wound.

Hanni and Pyle (2000) describe 914 California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), Pacific harbour seals (*Phoca vitulina*), northern elephant seals (*Mirounga angustirostris*) and northern fur seals (*Callorhinus ursinus*) reported as entangled at South-east Farallon Island, in North California, between 1976 and 1998. The most common entangling materials were *monofilament line and net*, *heavy fishnet*, *other net*, *salmon fishing lure and line*, *fish hooks and line*, *packing straps*, *other miscellaneous marine debris and 'constriction'* (where no actual material could be seen, but material was presumed to be present, hidden in the fur or in a wound, with a circular indentation or wound present around the head, neck or torso).

13.6 Elephant Seals

Campagna et al. (2007) discuss the impact of entanglement on Southern elephant seals (*Mirounga leonina*) in relation to the characteristics of the wounds around the neck caused by monofilament fishing lines. In this study, entangled elephant seals were caught, and, where possible, the material was removed. The monofilament line found was typically 1.3–1.5 mm thick and was tied into a loop with a knot, presumably by the original fisherman. In some animals the entangling line still had lures or hooks attached, and the configuration of hooks and lures was typical of that found in gear used for local squid fishing. However, they do suggest this to be an underestimate, as observations were made at a time of year when juveniles were not present. These authors discuss how the monofilament line entanglement becomes a deep chronic wound associated with infection and note the severe consequences for the animals affected, and they judge, from the depth of the wounds, that entangled seals may have lived for months or even years with the monofilament line cutting into the neck tissues.

13.7 Sea Lions

In Australia, it is estimated that 1500 Australian sea lions (*Neophoca cinerea*) die annually from entanglement, mostly from snaring in monofilament gillnet from the shark fishery located where the sea lions forage (Page et al. 2003).

In California, Dau et al. (2009) report 1090 seal entanglements, of which 11.3% were related to fishing gear and with a particularly high incidence of fishing gear entanglement injury observed in the San Diego region. Zavala-González and Mellink (1997) report entanglement in California sea lion (*Zalophus californianus*) from a population which extends from British Columbia to Mazatlan in Mexico, including populations from the Gulf of California. The population of sea lions in the Mexican part of range area is estimated at 74,467 along the Pacific coast and 28,220 and in the Gulf of California, and these authors report annual entanglement rates in this region of 2.24% (which could equate to approximately 2300 animals annually).

A survey reported by the National Oceanic and Atmospheric Administration (NOAA 2012) indicates that packing bands cause more than 50% of neck entanglement in Steller sea lions (*Eumetopias jubatus*) in Alaska. A survey of 386 Steller sea lions (*Eumetopias jubatus*) in South-east Alaska and northern British Columbia reported an estimated incidence annual rate of entanglement of 0.26% (Raum-Suryan et al. 2009). These authors reported that the common materials causing entanglement were packing bands (54%), large rubber bands (rubber packing bands)

Fig. 13.4 California sea lion (known as Shammyrock) is seen here with an entanglement on March 16, 2014. *Image credit*: *The Marine Mammal Center*

(30%), pieces of net (7%), rope (7%) and monofilament fishing line (2%) (Fig. 13.4). This study also looked at the incidence of fishing gear ingestion or entanglement for these Steller sea lions and reports that ‘salmon fishery flashers and lures (80%), long-line gear (12%), hooks and line (4%), spinners or spoons (2%), and bait hooks (2%)’ comprised the major items found. Raum-Suryan et al. also describe a local education campaign—‘Lose the Loop!’—which promoted cutting of entangling loops of fishing material and elimination of packing bands from local waste to help prevent entanglements.

13.8 Monk Seals

Donohue and Foley (2007) assess the influence of storm weather on monk seal entanglement in the North Pacific Ocean. They describe how, for the 23 years leading up to 2007, monk seal entanglement increased during episodes of severe weather associated with El Niño. They propose that ocean current processes linked with El Niño may contribute to changes in entanglement potentially because of introduction of new marine debris along with the changes in the ocean currents. The Hawaiian monk seal (*Neomonachus schauinslandi*) is an endangered species breeding only on six small islands and atolls in North-west Hawaii. Between 1996 and 2000, an initiative in this area aimed to reduce the amount of derelict fishing gear in the reefs close to the breeding sites for these seals (Boland and Donohue 2003) and a total of 195 tonnes of derelict fishing gear was removed from the area. Karamanlidis (2000) found that entanglement in abandoned nets was having a measurable effect on the population of monk seals (*Monachus monachus*) in the Mediterranean, and this author reported that the use of gillnets posed a significant threat to this endangered population of monk seals around the Desertas Islands off Madeira.

13.9 Grey Seals and Common Seals

Entanglements of grey seals (*Halichoerus grypus*) on the Dutch coast in the period between 1985 and 2010 are described by Hekman and Osinga (2010). They report that entanglement was relatively (relative to population size) more commonly observed in grey seals than common seals (*Phoca vitulina*) (about twice as often in the grey seal), and that in both species more of the entangled seals were males and that entanglement was more likely to occur in juveniles. ALDFG (lost fishing gear) was the most common entangling material, and the numbers of grey and common seals seen entangled and reported were believed to be only a small portion of the number of animals affected because of the animals assumed to be lost and undetected at sea.

Allen et al. (2012) report the physiological and anatomical effects of debris entanglement on grey seals (*Halichoerus grypus*) in Cornwall, UK, between 2000 and 2008. They describe how an under-reported aspect of entanglement is the effect of increased drag from trailing material and the increased foraging time required to feed because of the raised metabolic demands created by the entangling material. Allen et al. discussed the animal welfare impact of the entanglement injuries and report the types of injuries sustained by the animals to be '"constriction" (43%); "wound" (7%); "constriction and wound" (14%); "evident" (visible entanglement but wound type unclear, 36%)'. Allen et al. (2012) estimated that entangled seals form 8.7% of the seals recorded in the Cornish photo identification database (up to the end of 2011) and that of 58 seals showing evidence of entanglement in the database, 37 (64%) had visible lesions showing a constriction or an open wound, or both (Figs. 13.5, 13.6, 13.7, 13.8, 13.9, 13.10, and 13.11). These authors estimate entanglement rates in these seals to have declined from 5% (annually) of sightings in 2004 to 3% in 2011 and that entanglement had a significant impact on survivorship. A report (Sayer et al. 2015) extending and summarising this dataset obtained between 2000 and 2013 (262 animals) reported a mean annual rate of 3.1% of animals observed to be entangled. In contrast to other studies, most entangled animals were adult (62%), with an approximately even split between males and females. When visible, the entangling material was identified ($n = 92$), and all but one was fishery related with the majority being monofilament (72%) (Fig. 13.7) or trawl net

Fig. 13.5 Adult female grey seal severely injured with constricted open wound, Isles of Scilly. *Image credit*: *Rebecca Allen, Cornwall Seal Group Research Trust*

Fig. 13.6 Juvenile grey seal in a packing band with which she was observed playing. *Image credit*: *Dave McBride, Cornwall Seal Group Research Trust*

Fig. 13.7 (Post-mortem) monofilament lesion in an entangled grey seal. *Image credit*: *Sue Sayer, Cornwall Seal Group Research Trust and James Barnett, University of Exeter/Cornwall Wildlife Trust Marine Strandings Network*

Fig. 13.8 Juvenile grey seal entangled in plastic packing material— later successfully rescued. *Image credit*: *Simon Bone, Cornwall Seal Group Research Trust*

Fig. 13.9 Juvenile grey seal being rescued from trawl net by the British Divers Marine Life Rescue and the Cornish Seal Sanctuary. *Image credit*: *Sue Sayer, Cornwall Seal Group Research Trust*

Fig. 13.10 Adult male grey seal named ‘Railway Arch’ has lived with a partly healed entanglement wound for 13 years. *Image credit*: *Sue Sayer, Cornwall Seal Group Research Trust*

Fig. 13.11 Galapagos fur seal (*Arctocephalus galapagoensis*) with neck entanglement. *Image credit*: *Juan Pablo Muñoz*

(11%) (Figs. 13.1 and 13.9). Entanglements were observed around the neck (89%), body (2%), head (1%), mouth (2%), flipper (1%) and across multiple parts of the body (5%). The length of the trailing material and the presence of deeply constricted wounds were both significantly linked to reduced survivorship. Almost twice as many non-entangled seals survived over 10 years compared to those with deep constrictions. Rescues have routinely been performed successfully ($n = 30$) in this area in conjunction with the British Divers Marine Life Rescue and the Cornish Seal Sanctuary (Figs. 13.1 and 13.9). Post rescue photo identification of rescued, rehabilitated and released disentangled animals shows at the time of writing they can survive for long periods (up to 7 years is recorded by Sayer et al. 2015).

13.10 Conclusions

Pinnipeds are visible barometers of the spectrum of marine animals which can become snared, entangled, trapped or caught in marine debris. Seals are more visible than many marine animals because of their partial terrestrial habit. Marine plastic in the form of net, rope, monofilament line and packing bands can cause entanglement in a wide range of pinniped species, sometimes with severe consequences. There is the potential for severe acute welfare impacts on the individual animals through starvation and highly restrictive entanglement and some animals live for months or years (up to 16 years in one study of grey seals) with chronic deep incised wounds from net, packing band or monofilament line/net looped entanglement. Entanglement lesions can become chronic wounds, with deep infection that have debilitating consequences for the individual animal and leading to premature death in others.

Plastic is a 'new' challenge to these animals, man-made and entering the ocean in large quantities during the last century, and with an apparent dramatic rise in quantity, spread and effect particularly in the last 20 years. Plastic is probably very long lived in the sea (we don't yet know how long in practice), and there are plastic objects floating in the sea which have travelled thousands of kilometres. The effects of marine debris are not just aesthetic; marine debris has the potential to cause significant, widespread and 'hidden and unreported' animal suffering, through wounding, constriction, amputation, drag, infection, compromised feeding and ingestion. The pinniped species most likely to be affected by entanglement are fur seals, monk seals, California sea lions, grey seals, common seals and monk seals. Entanglement rates described in the literature range up to 7.9% of local populations annually (see

Table 13.1 Summary tabulation of reported entanglement rates for the pinniped species found in different ocean regions—the rate of entanglement (estimated % of population annually), the net, plastic and fishing line (% of reported entanglement cases for each category respectively) and the published source of the data

Ocean region	Species/subspecies	Rate of entanglement (%)	Net	Plastic	Fishing line	Published source
North-east Pacific	Steller sea lion	0.26	7	54	2	Raum-Suryan et al. (2009)
	Northern fur seal	0.4	65	19		Fowler (1987)
	Northern fur seal	0.08–0.35	39	37	9	Allen and Angliss (2014)
Eastern Central Pacific	Californian sea lion	0.08–0.22	19	25	14	Stewart and Yochem (1987)
	Californian sea lion	3.9–7.9	50		33	Harcourt et al. (1994)
	Northern elephant	0.15	19	36	33	Stewart and Yochem (1987)
	Harbour seal	0.09		33		Stewart and Yochem (1987)
	Northern fur seal	0.24	50			Stewart and Yochem (1987)
	Steller sea lion		4		4	Hanni and Pyle (2000)
Central Pacific	Hawaiian monk seal	0.7	32	8	28	Henderson (2001)
South-west Pacific	Kaikoura fur seal South	0.6–2.8	42	31		Boren et al. (2006)

(continued)

Table 13.1 (continued)

Ocean region	Species/subspecies	Rate of entanglement (%)	Net	Plastic	Fishing line	Published source
North-west Atlantic	Grey seal	3.1–5				Allen et al. (2012)
South-east Atlantic	Antarctic fur seal	0.024–0.059	48	18		Hofmeyr et al. (2002)
	Antarctic fur seal	0.4		46–52		Arnould and Croxall (1995)
	Cape fur seal	0.1–0.6		50		Shaughnessy (1980)
South-west Atlantic	Southern elephant seal	0.001–0.002		36	64	Campagna et al. (2007)
	Australian fur seal	1.9	40	30		Pemberton et al. (1992)
	New Zealand fur seal	0.9	29	30	3	Page et al. (2004)
	Australian sea lion	1.3	66	11	6	Page et al. (2004)
Western Indian Ocean	Antarctic and subantarctic fur seal	0.24	17	41	10	Hofmeyr et al. (2002)

Table 13.1)—with packing bands; fragments of lost net, rope, monofilament line and net; fishery flashers and lures; longline fishing gear, hooks and line; and bait hooks as the common and recurrent entangling materials in a number of seal and sea lion species.

The spread of plastic material in the ocean leaves seals entangled and, through entanglement and injury, sometimes results in their death through acute or chronic lesions, and this is a welfare concern. Entanglement results from human activity which was not anticipated or directly intentional, but which nonetheless is having a significant effect on animal welfare.

References

Allen BM, Angliss RP (2014) National Fur Seal (*Callorhinus ursinus*): Eastern Pacific Stock; Annual Human-Caused Mortality and Serious Injury National Oceanic and Atmospheric Administration. http://www.nmfs.noaa.gov/pr/sars/pdf/stocks/alaska/2014/ak2014_ northern-furseal- cp.pdf. Accessed 20 Oct 2016

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

Arnould JPY, Croxall JP (1995) Trends in entanglement of Antarctic fur seals (*Arctocephalus gazella*) in man-made debris at South Georgia. Mar Pollut Bull 30(11):707–712

Barnes DKA (2005) Remote islands reveal rapid rise of southern hemisphere, sea debris. Sci World J 5:915–921

Barnes DKA, Galgani F, Thompson RC, Barlaz M (2009) Accumulation and fragmentation of plastic debris in global environments. Philos Trans R Soc B 364(1526):1985–1998

Boland RC, Donohue MJ (2003) Marine debris accumulation in the nearshore marine habitat of the endangered Hawaiian monk seal, *Monachus schauinslandi* 1999–2001. Mar Pollut Bull 46:1385–1394

Boren LJ, Morrissey M, Muller CG, Gemmell NJ (2006) Entanglement of New Zealand fur seals in man-made debris at Kaikoura, New Zealand. Mar Pollut Bull 52:442–446

Campagna C, Falabella V, Lewis M (2007) Entanglement of southern elephant seals in squid fishing gear. Mar Mamm Sci 23(2):414–418

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. Northeast Fisheries Science Center Reference Document 06-04

Convention on Biological Diversity (CBD) (2012) Impacts of marine debris on biodiversity: current status and potential solutions. Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF (2012), Montreal. Technical series no. 67. ISBN 92-9225-444-8

Coupland RM (1992) The Red Cross classification of war wounds: the E.X.C.F.V.M. scoring system. World J Surg 16(5):910–917

Dau BK, Gilardi KV, Gulland FM, Higgins A, Holcomb JB, Leger JS, Ziccardi MH (2009) Fishing gear-related injury in California marine wildlife. J Wildl Dis 45(2):355–362

Derraik JGB (2002) The pollution of the marine environment by plastic debris: a review. Mar Pollut Bull 44(9):842–852

Donohue MJ, Foley DG (2007) Remote sensing reveals links among the endangered Hawaiian monk seal, marine debris, and El Niño. Mar Mamm Sci 23(2):468–473

Fowler CW (1987) Marine debris and northern fur seals: a case study. Mar Pollut Bull 18(6b):326–335

Hanni KD, Pyle P (2000) Entanglement of pinnipeds in synthetic materials at south-east Farallon Island, California, 1976–1998. Mar Pollut Bull 40(12):1076–1081

Harcourt R, Aurioles D, Sanchez J (1994) Entanglement of California sea lions at Los Islotes, Baja California Sur, Mexico. Mar Mamm Sci 10:122–125

Hekman R, Osinga N (2010) Stichting Zeehondencreche Lenie t' Hart 2010. http://www.zeehondencreche.nl/wb/pages/wetensch.-onderzoek/wetenschappelijke-publicaties.php. Accessed 2/4/16

Henderson JR (2001) A pre- and post-MARPOL Annex V summary of Hawaiian monk seal entanglements and marine debris accumulation in the northwestern Hawaiian Islands, 1982–1998. Mar Pollut Bull 42:584–589

Hofmeyr GJG, De Maine M, Bester MN, Kirkman SP, Pistorius PA, Makhado AB (2002) Entanglement of pinnipeds at Marion Island, Southern Ocean: 1991–2001. Aust Mammal 24:141–146

Hofmeyr GJ, Bester M, Kirkman SP, Lydersen C, Kovacs KM (2006) Entanglement of Antarctic fur seals at Bouvetøya, Southern Ocean. Mar Pollut Bull 52:1077–1080

International Coastal Cleanup (ICC) (2008) Annual report—Ocean Conservancy 2008. http://www.oceanconservancy.org/our-work/marine-debris/2016-data-release/2016-data-release-1.pdf. Accessed 27 June 2016

International Maritime Organization (IMO) (2016) International convention for the prevention of pollution from ships. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Pages/Default.aspx. Accessed 18 Oct 2016

Karamanlidis AA (2000) Monitoring human and Mediterranean monk seal activity in the National Marine Park of Alonnissos and Northern Sporades, Greece. Monachus Guardian 3(1). http://www.monachus-guardian.org/mguard05/05covsto.htm. Accessed 3 Apr 17

Lawson TJ, Wilcox C, Johns K, Dann P, Hardesty BD (2015) Characteristics of marine debris that entangle Australian fur seals (*Arctocephalus pusillus doriferus*) in southern Australia. Mar Pollut Bull 98(2015):354–357

Marine Conservation Society (MCS) (2007) Beachwatch 2006. The 14th annual beach litter survey report. Marine Conservation Society, Ross on Wye. https://www.mcsuk.org/press/view/181 Accessed 6 Apr 16

MARPOL International Convention for the Prevention of Pollution from Ships (MARPOL) International Maritime Organization (1973). http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx. Accessed 27 June 2016

McIntosh RR, Kirkwood R, Sutherland DR, Dann P (2015) Drivers and annual estimates of marine wildlife entanglement rates: a long-term case study with Australian fur seals. Mar Pollut Bull 101(2015):716–725

Moore MJ, van der Hoop J, Barco SG (2013) Criteria and case definitions for serious injury and death of pinnipeds and cetaceans caused by anthropogenic trauma. Dis Aquat Org 103(3):229–232

New World Encyclopedia (2016) History of fishing line. http://www.newworldencyclopedia.org/entry/Fishing_line. Accessed 18 Oct 2016

NOAA (2012) Marine mammal entanglement: pinniped. https://alaskafisheries.noaa.gov/pr/pinniped-entanglement. Accessed 12 July 2016

NOAA/NMFS (2007) Serious injury technical workshop, Seattle, 2007. Severity indexes page 7. http://www.nmfs.noa,a.gov/pr/pdfs/interactions/serious_injury_techmemo2008.pdf. Accessed 2 Apr 2016

NRC National Research Council (2008) Tackling marine debris in the 21st century. Committee on the effectiveness of international and national measures to prevent and reduce marine debris and its impacts. http://docs.lib.noaa.gov/noaa_documents/NOAA_related_docs/marine_debris_2008.pdf. Accessed 2 Apr 2016

Page B, Welling A, Chambellant M, Goldsworthy SD, Dorr T, van Veen R (2003) Population status and breeding season chronology of Heard Island fur seals. Polar Biol 26:219–224

Page B, McKenzie J, McIntosh R, Baylis A, Morrissey A, Calvert N, Haas T, Berris M, Dowie D, Shaughnessy PD, Goldsworthy SD (2004) Entanglement of Australian sea lions and New Zealand fur seals in lost fishing gear and other marine debris before and after Government and industry attempts to reduce the problem. Mar Pollut Bull 49:33–42

Pearson E, Mellish S, Sanders B, Litchfield C (2014) Marine wildlife entanglement: assessing knowledge, attitudes, and relevant behaviour in the Australian community. Mar Pollut Bull 89:136–148

Pemberton D, Brothers NP, Kirkwood R (1992) Entanglement of Australian fur seals in man-made debris in Tasmanian waters. Wildl Res 19:151–159

Raum-Suryan KL, Jemison LA, Pitcher KW (2009) Entanglement of Steller sea lions (*Eumetopias jubatus*) in marine debris: identifying causes and finding solutions. Mar Pollut Bull 58:1487–1495

Sandoe P, Simonsen HB (1992) Assessing animal welfare: where does science end and philosophy begin? Anim Welf 1:257–267

Santos IR, Friedrich AC, Barretto FP (2005) Overseas garbage pollution on beaches of northeast Brazil. Mar Pollut Bull 50(7):782–786

Sayer S, Williams K (2015) Ghost gear in Cornwall, UK 2014 to 2015. World Animal Protection Commissioned Report

Sayer S, Hockley K, Allen R (2015) Entanglement and its effects on grey seals (*Halichoerus grypus*) 2000 to 2013. World Animal Protection Commissioned Report, Cornwall and North Devon, UK

Shaughnessy PD (1980) Entanglement of cape fur seals with man-made objects. Mar Pollut Bull 11:332–336

Sheavly SB (2007) National Marine Debris Monitoring Program: Final Program Report, Data Analysis and Summary. Prepared for U.S. Environmental Protection Agency by Ocean Conservancy, Grant Number X83053401-02. 76 pp

Spraker TR, Lander ME (2010) Causes of mortality in northern fur seals (*Callorhinus ursinus*), St. Paul Island, Probilof Islands, Alaska, 1986–2006. J Wildl Dis 46(2):450–473

Stewart BS, Yochem PK (1987) Entanglement of pinnipeds in synthetic debris and fishing net and line fragments at San Nicolas and San Miguel Islands, California, 1978–1986. Mar Pollut Bull 18:336–339

United Nations (1972) Declaration of the United Nations conference on the human environment, Stockholm, 5–16 June 1972. http://www.unep.org/documents.multilingual/default.asp?documentid=97&articleid=1503. Accessed 18 Oct 2016

United Nations (2005) Environment programme, UNEP annual report 2005. http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=67&ArticleID=5125&l=en. Accessed 18 Oct 2016

Waluda CM, Staniland IJ (2013) Entanglement of Antarctic fur seals at Bird Island, South Georgia. Mar Pollut Bull 74:244–252

Wang J, Zhi Tan Z, Peng J, Qiu Q, Li M (2016) The behaviors of microplastics in the marine environment. Mar Environ Res 113:7–17

Wilcox C, Mallos NJ, Leonard GH, Rodriguez A, Hardesty BD (2016) Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife. Mar Policy 65(2016):107–114

Williams R, Ashe E, O'Hara PD (2011) Marine mammals and debris in coastal waters of British Columbia, Canada. Mar Pollut Bull 62(6):1303–1316

World Animal Protection WAP (2016) Global ghost gear initiative. http://www.ghostgear.org. Accessed 18 Oct 2016

World Society for the Protection of Animals (WSPA) (2012) Marine debris: a global picture of the impact on animal welfare and of animal-focused solutions. In: Butterworth A, Clegg I, Bass C (eds). WSPA International, London. http://oceansandplastics.info/wp-content/uploads/2015/07/REP_WSPA_2012.pdf. Accessed 27 June 2016

Zalasiewicz J et al (2016) The geological cycle of plastics and their use as a stratigraphic indicator of the Anthropocene. Anthropocene 13:4–17. doi:10.1016/j.ancene.2016.01.002

Zavadil PA, Robson BW, Lestenkof AD, Holser R, Malavansky A (2007) Northern Fur Seal Entanglement Studies on the Pribilof Islands in 2006. For National Oceanic and Atmospheric Administration Prescott Stranding Grant Program and Alaska Regional Stranding Network Coordinator. http://doc.nprb.org/web/research/research%20pubs/outside_publications/733_entanglement.pdf. Accessed 2 Apr 2016

Zavala-González A, Mellink E (1997) Entanglement of California sea lions, *Zalophus californianus* californianus, in fishing gear in the central-northern part of the Gulf of California, Mexico. Fish Bull 95:180–184