



The Pinniped Entanglement Group: Standardizing global data for effective solutions to pinniped entanglement

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ABSTRACT

Entanglement in fishing gear and marine debris is a global threat to pinnipeds. Successful mitigation requires standardized methods and cooperation. The international Pinniped Entanglement Group (PEG), formed in 2009, is dedicated to this effort, through entanglement prevention, response, and education. Here, we report that at least 76% of pinniped species are affected by entanglement (25 of 33 extant species) with fur seals and sea lions more affected than true seals. Commercial and recreational fishing gear caused more harm than other marine debris. Global maps of entangled pinnipeds indicate that unreported species likely represent data deficiency rather than lack of impact. Entanglement data collection methods affect results, and while standardization is difficult to achieve, transparent and detailed methods will aid robust comparisons to target mitigation. We demonstrate the scale of entanglement threat and provide a contemporary review of the literature, PEG member data and mitigation including outreach and working with industry.

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1. Introduction

Entanglement in and ingestion of fishing gear and marine debris is a global problem affecting many marine species, with commercial and recreational fishing gear reported to be one of the greatest threats to marine mammal populations worldwide (Read, 2008; Reeves et al., 2013; Tixier et al., 2021). Marine wildlife entanglement results from interactions with actively used (currently deployed and in-use fishing gear), abandoned, lost or discarded fishing gear (ALDFG) and other marine debris, resulting in hooks and lines encircling, piercing or interacting with the body or having ingested hooks (Kühn and van Franeker, 2020; Tixier et al., 2021; Perroca et al., 2024). The consequences of entanglement are debilitating and include reduced foraging capability, infection, amputation and death (Laist, 1997).

Industrial fishing occurs in more than 55% of the ocean and an estimated 2% of commercial fishing gear is lost, not including gear lost from small artisanal vessels, recreational fishing, illegal, unreported and unregulated (IUU) fishing, fish aggregating devices (FADs) or aquaculture (Kroodsma et al., 2018; Richardson et al., 2022). ALDFG, also known as ghost gear, has a negative impact on ecosystem services with considerable costs to animal welfare, habitat quality and the economy (Do and Armstrong, 2023; Pandey et al., 2025). Stelfox et al. (2016) found that 5400 individuals from 40 different species of marine mammals, reptiles and elasmobranchs had been recorded as entangled in, or associated with, ALDFG, with marine mammals most affected. The number of marine biota impacted by entanglement has substantially increased from 267 species reported in 1997 (Laist, 1997) to 557 species reported in 2015 (Kühn et al., 2015) to 914 species reported in 2019 (Kühn and van Franeker, 2020).

Marine debris, including ALDFG, is generally defined as any human-created persistent solid material that has been deliberately or accidentally released into the marine environment (Shevealy et al., 2012; Richardson et al., 2022). However, much marine debris is sourced from urban environments; for example, in 2010, 4.8 to 12.7 metric tons (MT) of plastic trash were estimated to have entered the oceans (Jambeck et al., 2015). In the absence of interventions, the current rate of plastic waste entering aquatic ecosystems is projected to nearly triple from some 9–14 million tons per year in 2016 to a 23–37 million tons per year by 2040 (UNEP, 2021), exacerbating the threat to marine species. Fishing gear in active use, ALDFG and marine debris have the potential to threaten marine life via both entanglement and/or ingestion (Laist, 1997; Thushari and Senevirathna, 2020; Kühn and van Franeker, 2020; Tixier et al., 2021).

While ingestion of marine debris is of concern (Kühn and van Franeker, 2020), this is not considered an entanglement in this research unless a hook and/or line are ingested. Entanglement is a key threat to pinniped (seal, sea lion, walrus) populations around the world with survivorship expected to be lower for affected individuals (Allen et al., 2012). Specifically, 67% of extant pinniped species were reported to be susceptible to entanglement in 2019, with the expectation that non-reported species are understudied or underreported (Jepsen and de Bruyn, 2019). Pinniped populations are still recovering from over-harvesting in the 19th and 20th centuries and ~ 30% of species are identified as threatened by the International Union for Conservation of Nature's (IUCN) Red List. Pinnipeds are of value both to ecosystem services and human communities, therefore anthropogenic impacts such as entanglement require mitigation (Gilbert et al., 2025; Jackman et al., 2024; Nomokonova et al., 2013). Otariids (eared seals) are more commonly reported than phocids (true seals) (Laist, 1997) with approximately 86% of otariid species and 63% of phocid species known to become entangled in marine debris or ALDFG (Kühn and van Franeker, 2020). To the best of our knowledge, the two sub-species of Odobenidae (walrus) have not been observed entangled although they may be incidentally captured in trawl fishing nets (USGS Alaska Science Center Walrus Research Program, 2023).

Pinnipeds become entangled through passive ALDFG and marine

debris or interactions with active fisheries (Allyn and Scordino, 2020; Reeves et al., 2013; Tixier et al., 2021). Active gear interactions occur when pinnipeds target the same species, depredate gear, are attracted to discards, or encounter baited gear (Hamer and Goldsworthy, 2006; Raum-Suryan et al., 2009; Reeves et al., 2013; Tixier et al., 2021) at times resulting in mortality termed 'bycatch' (Read, 2008; Luck et al., 2020; Goldsworthy et al., 2022). Individuals that escape with injuries or attached gear may be variably classified as entangled or as an active fishery interaction, leading to inconsistent inclusion in reviews of entanglement (e.g. Kühn and van Franeker, 2020). Affected individuals may die even though they were not 'caught' or accounted for in bycatch statistics, which have been termed 'cryptic' entanglements that go unrecorded in either approach (Reeves et al., 2013). Although distinguishing between passive debris, ALDFG, and active gear informs mitigation, limited data resolution often leads to assumptions that most entanglements are passive, underestimating the role of active gear (Høiberg et al., 2022; Jepsen and de Bruyn, 2019). An example of this uncertainty is provided by Australian fur seals (*Arctocephalus pusillus doriferus*) that are commonly observed on land entangled in recreational fishing line including hooks (McIntosh et al., 2015). However, it is unknown whether this occurs passively in ALDFG or via interaction with active recreational gear, or potentially both. In contrast, Steller sea lions (*Eumetopias jubatus*) commonly interact with active commercial, charter, and recreational salmon hook and line fisheries in the states of Oregon, Washington, and Alaska (Allyn and Scordino, 2020; Raum-Suryan et al., 2009; Raum-Suryan and Suryan, 2022), swallowing hooks which cause injury and mortality.

Adding to the confusion in the literature, the term 'active' is also used to define a persistent or currently entangled individual to differentiate them from an individual with a scar resulting from a previous entanglement (Allyn and Scordino, 2020). To ensure clarity, and for the purposes of this paper, we define bycatch as mortality detected during active fishing practices and entangled pinnipeds as observations or counts of live and dead pinnipeds reported as distinct from fishing gear that is actively in use. This includes pinnipeds observed at terrestrial breeding sites (colonies or rookeries) and haul-outs (non-breeding sites) and beach-washed individuals, also called stranded: those found dead or in need of intervention that may include medical attention (Simeone et al., 2024).

Pinniped rescue specialists and researchers around the world have been working to mitigate pinniped entanglement, but these efforts have often been made in isolation from one another. To address the growing problem of pinniped entanglement, the Pinniped Entanglement Group (PEG) [link accessed 04/27/2026] was established in 2009 and has grown to become a global community with more than 200 members from 20 countries, dedicated to the safety and welfare of pinnipeds. PEG was created to provide increased global collaboration and communication among scientists, non-government organizations, non-profits, and others. In addition to collaborating on entanglement response best practices, education, and outreach, PEG provides practical experience by sharing case studies of rescues across a range of pinniped species, methodologies, and terrain types. Researching the causes of and possible solutions to reducing entanglements including gear ingestion comprises the final key element of the group (see Supplementary Material Workshop). PEG includes representatives from diverse groups with variable terminology, we are therefore not prescriptive but do encourage the use of standardized methods and universal terms with clear definitions to improve comprehension and comparison across studies.

Lack of standardized methods and terminology for recording entangled pinnipeds hinders assessment of this threat. At least nine approaches exist, with differing calculations limiting global comparisons (McIntosh et al., 2015). Common metrics include (1) subsamples of harvested or research animals (e.g. Shaughnessy, 1980), (2) counts ashore at a single time (e.g. Hanni et al., 1997), and (3) population-level proportions (e.g. Hofmeyr et al., 2006; Raum-Suryan et al., 2009). Less common approaches rely on opportunistic records such as beach-

washed individuals (e.g. Unger et al., 2017) or public reports (Boren et al., 2006). Comparisons are further confounded by inconsistent use of the terms “rate,” “incidence,” and “prevalence,” with prevalence often misreported as a rate (Raum-Suryan and Suryan, 2022). Adding further complexity, higher effort typically results in higher entanglement counts and confounds comparisons between studies because it is often not included in the methodology or results (McIntosh et al., 2015). Additionally, reporting bias has skewed research towards North America, Oceania (especially Australia) and the sub-Antarctic (Jepsen and de Bruyn, 2019). Surveys are generally limited to breeding sites and haul-outs where seals congregate on land with poor understanding of mortality at sea and may be temporally biased towards fair weather conditions or seasons. There is also limited understanding of the areas where high overlap occurs between marine debris and ALDFG hot spots, active fishing effort and high pinniped abundance, which clouds our understanding of their interplay with pinniped entanglement (e.g. Perez-Venegas et al., 2023). Unfortunately, trends in known pinniped entanglements may be best explained by observer bias or reporting effort rather than clear evidence of actual trends in entanglements (Jepsen and de Bruyn, 2019; McIntosh et al., 2015). Improved standardization, clearer definitions, and broader spatial and temporal coverage are needed to quantify and mitigate this global threat.

The aims of this paper were to collate data from the literature and available unpublished data from PEG members to visualize the global extent of the threat. We compared two metrics of entanglement to demonstrate how method selection can change the observed pattern. The two metrics included: a simple count per year per data record, where a data record is a single pinniped species in a known location; the second metric is a sample prevalence for the data records that have an associated estimate of population at the location (typically a single breeding site or haul-out, sometimes a sub-population of the species). Further aims include:

- Updating the list of pinniped species affected by entanglement.
- Identifying the dominant materials entangling different species of pinnipeds.
- Identifying global regulatory and aspirational resources to reduce entanglement in pinnipeds.
- Visualizing the globally affected phocids and otariids by the two metrics of entanglement and their threatened status.
- Identifying next steps towards mitigating pinniped entanglement including deterrents, education and collaboration.

2. Methods

To demonstrate the importance of standardization and synthesis of global information, raw data from the literature up to October 2023 and unpublished data from participating PEG members were collated (Supplementary Material Map Data). Separate topic searches were performed in Web of Science using keywords entanglement OR entangle OR entangled (4066 references); seal OR sea lion OR phocid OR otariid OR odobenid (141,918 references) and “marine plastic” OR “ALDFG” OR “marine debris” (121,963 references). Publications with entanglement data (28 references) and reviews were retained and their reference lists searched. PEG members provided additional references to address gaps, however data deficiencies may remain.

Pinniped species and the number affected by entanglement were tabulated by defined locations as a row of data with the latitude and longitude for mapping. Data were collected at haul-out and/or breeding sites, or via stranding records and opportunistic observations on coastal areas. Records of entanglement did not include the number of pinnipeds incidentally observed or captured in active fishing nets or gear, nor those reported in published or grey literature as bycatch. The associated dominant materials entangling the reported individuals were identified for each location, along with their conservation status under the IUCN Red List. The goal was to identify the maximum species and locations

affected by entanglement across the globe while standardizing the metrics as much as possible using raw data. Even so, biases in the data are unavoidable, particularly when collating data from studies that investigate different species and populations with varying effort (method, number and experience of observers, temporal and spatial coverage).

As previously defined, reports of entanglements were included if they were observed at a breeding site or haul-out with fishing gear or marine debris entangling a body part or with a hook on a body part or ingested. When the entanglement material was fishing gear, it was generally not possible to determine whether the entanglement had occurred from gear in active use or ALDFG. For reports of entanglement lacking supporting data, proof of entanglement required photographic evidence that confirmed entangling and hooking material. It can be difficult to differentiate a scar from an entanglement therefore it is accepted that entanglement reports may include scars, although thermal drone sensors are being tested to differentiate such cases to aid reporting and response (Yaney-Keller et al., 2026).

Methods used vary around the globe, therefore entanglement data included: an average of multiple surveys per year, a single instantaneous survey, a maximum count of unique entangled individuals, or an extrapolation of several surveys. In most studies unique individuals were counted, but they may have been difficult to discern particularly for entanglements such as embedded recreational fishing line that appear similar to a roll of skin (e.g. Yaney-Keller et al., 2026). Where the data allowed or it was reported in the literature, entanglement prevalence was calculated as a ratio of entangled pinnipeds to non-entangled for a defined population and time-period. This is a common metric for reporting on the threat because it identifies the scale of the problem according to the defined population, with a high entanglement count in a small sample population more likely to affect population vital rates, particularly for endangered species (Baker et al., 2024; Dmitrieva et al., 2013; Jones et al., 2021; Page et al., 2004).

Strict rules on data comparisons have resulted in excised comparisons in previously prepared reviews on the topic, while our intention was to be as inclusive as possible. Effort can be a strong predictor for the number of entangled seals observed over time, and entanglement counts can be affected by time of year as there may be strong seasonality in the likelihood of a pinniped being entangled (Høiberg et al., 2022; McIntosh et al., 2015). These elements were expected to be highly variable across studies and were rarely reported; therefore, such biases were not standardized in this study.

Two simple metrics of entanglement in pinnipeds across the globe were mapped separately to maximize the data available, visualize the global extent of the issue and demonstrate how the metric affects the inclusion or exclusion of data and the pattern in that data. This simple data comparison does not include confidence intervals or exclude data obtained by different methods: the purpose was to be inclusive and represent the global scale of the issue and demonstrate the need for greater standardization and method clarity in future research. The resulting maps are therefore indicative rather than robust comparisons. The calculations were made as follows:

- 1) SIMPLE ANNUAL ESTIMATE: For each taxon and location, an average count of entanglements observed per year was calculated. When unique entangled individuals were identified, the total number per year were summed, then divided by the number of years for the simple annual estimate. For studies over multiple years, with multiple surveys per year, where unique entangled individuals were not identified, survey results within a year were averaged, summed across the years, then divided by the number of years. A total count was used when a single survey was performed for a species, location and year (may include a drone survey).
- 2) PERCENT SAMPLE PREVALENCE: Simple annual estimate/Count of the sample population (or sub population) \times 100, calculated from the simple annual estimate (1) or taken from published estimates. If

sample- or sub- population sizes were not provided in the same source as the entanglement data, other studies were used where available for the corresponding year.

When multiple raw datasets existed for the same site, the most recent or most robust study was used, determined by the amount and quality of the data demonstrated by more frequent surveys (high effort and detailed methods being preferred) and/or a more robust method (standardized survey methods were preferred over opportunistic or incidental observations). The excluded references are provided in the Supplementary Material Map Data. Some studies provided prevalence values without raw data; in the absence of raw data, these were included despite the inability to ensure standardization. In some instances only metadata were provided that spanned multiple years, therefore an average entanglement estimate per year was calculated by dividing the total entanglement count by the number of years. In some locations, beached washed pinnipeds were the only available data and were therefore included and the prevalence estimated by the number of beach-washed pinnipeds entangled and the total number of beach-washed individuals for that taxa used instead of sub- or total- population estimates. A third map was produced to map the phocids and otariids by location and according to their IUCN conservation status. The “simple annual estimate” (1) was used for the conservation status map since this metric contained the most rows of data. The data extracted from the literature and PEG network are provided in Supplementary Material Map Data.

Where possible, the extracted data and entanglement metrics were cross-checked with previous reviews that collated data from the literature to ensure consistency (Høiberg et al., 2022; McIntosh et al., 2015), as well as broader reviews on the topic to ensure a more inclusive list of affected species and data sources (Jepsen and de Bruyn, 2019; Laist, 1997; Poeta et al., 2017; Reeves et al., 2013; Stelfox et al., 2016). Where the literature was non-specific or data was lacking for unreported species, efforts were made to determine the current entanglement status by contacting experts in the field and accessing grey literature. Currently the Marine Mammal Society recognizes 15 extant otariid species and 18 extant phocid species (Society for Marine Mammalogy, 2023). We use the current taxonomy to report on the total number of species affected, but indicate where current taxonomy differs from the literature in Table 1.

To provide examples of useful resources including regulatory frameworks, global aspirational resources and codes of conduct to prevent pinniped entanglement, were collated and tabulated.

3. Results

Our inclusive approach has resulted in the most spatially representative maps of global pinniped entanglement to date. From 46 published and 12 unpublished sources (1970–2024), a total entanglement number of 7012 pinniped entanglement reports were collated for 101 pinniped locations around the globe as summarized by species in Table 1. While duplicate counts of affected individuals may occur, this was minimized in survey methods and by averaging the results of repeated surveys. Importantly, the total number of entanglements in Table 1 represent a tally of the data collated for this study that spanned different years and methodologies and therefore do not represent the number of pinnipeds currently affected by entanglement, or the total number of entangled individuals ever reported. Results included five published studies and four unpublished sources using stranding data to determine prevalence of entanglement.

Maps were used to visualize the scale of the threat in two metrics (simple annual estimate and % sample prevalence, Fig. 1), with the prevalence highlighting more at-risk populations that were corroborated by the IUCN status of those species and populations (Table 1). Metric one, the simple annual count of entangled pinnipeds resulted in 89 locations and metric 2, the percent sample prevalence resulted in 59

locations. According to the IUCN Red List, global classifications for these species include six listed as Endangered, two as Vulnerable, and 15 as Least Concern. While the Steller sea lion is globally categorized as Near Threatened, it is managed by population segment under the U.S. Endangered Species Act: the Western distinct population segment (DPS) is listed as Endangered, whereas the Eastern DPS is classified as recovered (Table 1). Outside of polar regions, all pinniped species were affected (Table 1, Fig. 1). More entangled seal populations were reported for threatened phocid and otariid populations in the northern hemisphere than the southern hemisphere (Fig. 2). These results demonstrate the value of being inclusive with data to visualize the extent of the threat. However, the demonstrated patterns include data that are not standardized for effort or method and therefore should not be used for detailed interpretation. While it is important to identify the mechanism of entanglement via ALDFG-marine debris or interactions with active fishing gear, all sources of entanglement were possible for most species and proof of any is difficult to obtain and generally not available and therefore not reported here.

Ten out of the 18 extant species of phocid as recognized by the Society for Marine Mammalogy in 2025 were identified as entangled (55%). Here, we provide the first reported proof of entanglement for a ringed seal (*Pusa hispida*) (Fig. 3). A photograph on the internet of a bearded seal (*Erignathus barbatus*) thought to be entangled was shared with PEG (Fig. 4); however, the photographer clarified that the material was seaweed.

Reports were confirmed for all 15 extant species of otariid recognized by the Marine Mammal Society in 2025 (100%). This paper provides a robust estimate of entanglement for the Galapagos sea lion (*Zalophus wollebaeki*) via targeted surveys of the species at breeding sites and haul-outs (Fig. 5). Previous proof of entanglement for this species was based on citizen science surveys and photographs (Muñoz-Pérez et al., 2023), while earlier studies had not identified the species as entangled (Alava and Salazar, 2006).

As the first record of an entanglement for an off-range or vagrant pinniped in South America, a Juan Fernandez fur seal (*A. philippii*, case identifier ORCM-6028) was observed on Camaná beach, Arequipa, in southern Peru (Fig. 6), ~1550 kilometer distant from the nearest breeding site at the Desventuradas Islands, Chile. The fur seal was observed with a hook in the mouth, likely from an interaction with active fishing gear.

Although not exhaustive, 34 resources were identified that provide regulatory and global aspirational resources and codes of conduct to prevent pinniped entanglement (Table 2).

4. Discussion

This study provides an inclusive and comprehensive visualization of the global issue of pinniped entanglement. The highest cumulative human impacts in the oceans occur on continental shelves and slopes, where terrestrial and marine pressures overlap (Halpern et al., 2008), coinciding with many pinniped breeding sites and haul-outs where most entanglement studies are conducted (Fig. 1). We identified that 76% of global pinniped species may be entangled and observed at breeding or haul-out sites (25 out of 33 extant species), an increase from the 67% reported previously (Jepsen and de Bruyn, 2019). Similar to previous reviews, more otariids (100% extant species) were documented as entangled in marine debris and fishing gear than phocids (55% of extant species). There are several factors that likely contribute to this difference, the first of which is habitat and distribution. Of the 18 Phocid species, all six that inhabit sub-Antarctic, temperate and tropical waters (Table 1, including leopard seals *Hydrurga leptonyx*) were affected by entanglement according to our definition. The remaining 11 phocid species, other than the Baikal seal (*Pusa sibirica*) that is isolated in an inland lake, live in polar regions. Polar seals are largely or entirely dependent on sea ice for resting and breeding. There may be fewer reports from the polar regions due to the biology of the species, reduced

Table 1

Pinniped taxa including 15 otariids and nine phocids identified with entanglements (1970–2024), the IUCN (International Union for Conservation of Nature's Red List) designation, the dominant material affecting each taxon, and species distribution. Species names align with current accepted taxonomy according to the Society of Marine Mammalogy with updates provided in brackets. The total entanglement number per taxa and data sources are provided and represent individual entangled pinnipeds counts, calculated by adding up the number of entangled pinnipeds per taxa in the Supplementary Material Map Data, excluding three studies where species were combined in the source (*Arctocephalus* spp. – Slip and Burton, 1991, $n = 1$ entanglement; Hofmeyr et al., 2002, $n = 101$ entanglements; *Zalophus californianus* and *Eumetopias jubatus* – Allyn and Scordino, 2020, $n = 178$ entanglements); refer to the Supplementary Material Map Data for the detailed site- and source- specific data used for the map visualizations. Note, while all attempts were made to standardize the data, the number entangled contains some variability in methodology and includes published and unpublished data to October 2023. Unpublished data from Pinniped Entanglement Group members is referenced by “unpub. data”. While this paper has not included data from actively used gear or bycatch associated with fishing activities, * identifies species also recorded as fisheries bycatch by Reeves et al. (2013) and Tixier et al. (2021) to aid future studies endeavoring to incorporate such data. Since different studies may be combined for some species the survey effort may vary over time.

Taxa number	Otariid species and common name	IUCN classification, global trend	Description of main entangling material	Distribution where entangled	Total entanglement number by taxa over time	Year range of data collection	Sources
1	<i>Arctocephalus gazella</i> * Antarctic fur seal (Peters, 1875)	Least concern, decreasing	Plastic packing straps, nets, synthetic line	Sub-Antarctic islands	1176	1988–2013	Hofmeyr et al., 2002, 2006; Hucke-Gaete et al., 1997; Slip and Burton, 1991; Waluda and Staniland, 2013.
2	<i>Arctocephalus tropicalis</i> * Sub Antarctic fur seal (Gray, 1872)	Least concern, stable	Plastic packing straps, trawl net, longline lines and hooks	Sub-Antarctic islands	93	1970–2023	Hofmeyr et al., 2002; Raudino, H. & Waples, K. unpub. data.
3	<i>Arctocephalus forsteri</i> * New Zealand or Long-nosed fur seal (Lesson, 1828)	Least concern, increasing	Green trawl net, plastic packing straps, rope	New Zealand and southern Australia	228	1980–2015	Boren et al., 2006; Page et al., 2004; Raudino, H. & Waples, K. unpub. data.
4	<i>Arctocephalus australis</i> * South American fur seal (Zimmermann, 1783)	Least concern, increasing	Industrial trawl net, artisanal net, ropes, plastic packing straps	Peru, Chile, the Falkland Islands, Argentina, Uruguay and Brazil	123	2007–2020	Ayala et al., 2022; Franco-Trecu et al., 2017; Perez-Venegas et al., 2021; Azevedo-Santos et al., 2021.
5.1	<i>Arctocephalus pusillus doriferus</i> * Australian fur seal (Wood Jones, 1925)	Least concern, increasing	Commercial and recreational fishing material, urban plastics	South-east Australia	607	1989–2020	Claro et al., 2019; McIntosh et al., 2015; McIntosh, R. R. unpub. data; Pemberton et al., 1992; Prendergast, 1996.
5.2	<i>Arctocephalus pusillus pusillus</i> * Cape fur seal (Schreber, 1775)	Least concern, increasing	Fishing materials	Namibia and South Africa	170	2003–2019	Curtis et al., 2021; Hogan and Warlick, 2017;
6	<i>Arctocephalus philippii</i> Juan Fernández fur seal (currently identified as <i>A. philippii philippii</i>) (Peters, 1866)	Least concern, increasing	Trawl net, monofilament line and hook	Isla Robinson Crusoe, Chile and Camaná beach, Arequipa, Peru	2	2004 and 2021	Thiel et al., 2011; Yaipen Llanos, C. unpub. data.
7	<i>Arctocephalus townsendi</i> Guadalupe fur seal (currently identified as <i>A. philippii townsendi</i>) (Merriam, 1897)	Least concern, increasing	Fishing line, net	Baja, Mexico and Southern California	3	2001–2005	Moore et al., 2009.
8	<i>Arctocephalus galapagoensis</i> Galápagos fur seal (Heller, 1904)	Endangered, decreasing	Artisanal net, plastic trash, fishing lines	Galapagos Islands: Isabela & Fernandina	21	2014–2024	Páez-Rosas, D. unpub. data.
9	<i>Callorhinus ursinus</i> * Northern fur seal (Linnaeus, 1758)	Vulnerable, decreasing	Fishing line and hooks, monofilament nets, ropes, plastic packing straps	North Pacific Ocean, Bering Sea, and Sea of Okhotsk	943	1985–2013	Kuzin and Trukhin, 2019; Moore et al., 2009; Stewart and Yochem, 1987; Zavadil et al., 2007.
10	<i>Eumetopias jubatus</i> * Steller sea lion (Western distinct population segment (DPS) and Eastern DPS) (Schreber, 1776)	Near threatened, increasing (Western DPS is listed as Endangered under U.S. Endangered Species)	Plastic packing straps, black rubber bands, monofilament line with hook and lures (flashers), ropes, nets and net fragments, plastic trash, fishing related debris	North Pacific Ocean including northern Japan, Russia, Canada, and U.S. waters south to central California	955	1976–2019	Allyn and Scordino, 2020; Artukhin et al., 2010; Hanni and Pyle, 2000; Jemison, L. unpub. data (State of Alaska); Moore et al., 2009; Raum-Suryana

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Table 1 (continued)

Taxa number	Otariid species and common name	IUCN classification, global trend	Description of main entangling material	Distribution where entangled	Total entanglement number by taxa over time	Year range of data collection	Sources
11	<i>Zalophus californianus</i> * Californian sea lion (Lesson, 1828)	Act; Eastern DPS recovered) Least concern, increasing	Monofilament line and net, hooks, plastic packing straps	North Pacific along west coast of North America	1370	1976–2021	and Suryan, 2022; Raum-Suryan et al., 2009. Aurióles-Gamboa et al., 2003; Barcenás de la Cruz, D. unpub. data; Hanni and Pyle, 2000; Harcourt et al., 1994; Moore et al., 2009; Stewart and Yochem, 1987; Yaipen Llanos, C. unpub. data; Zavala-Gonzalez and Mellink, 1997.
12	<i>Zalophus wollebaeki</i> Galápagos sea lion (Sivertsen, 1953)	Endangered, decreasing	Ropes, artisanal net, fishing hooks, plastic trash and bags, fishing lines, diving bottle bases, rubber band, face mask	Galapagos Islands: San Cristobal, Santa Fe, Florena, Santa Cruz, Santiago and Isabela	76	2006–2024	Páez-Rosas, D. unpub. data
13	<i>Otaria byronia</i> * South American sea lion (Blainville, 1820).	Least concern, stable	Plastic bags, plastic packing straps, Artisanal or sport fishing materials	Western and southeastern coasts of South America	72	1983–2020	Ayala et al., 2022; Franco-Trecu et al., 2017; Ramirez, 1986
14	<i>Neophoca cinerea</i> * Australian sea lion (Peron, 1816)	Endangered, decreasing	Monofilament net and rope, plastic packing straps, rock lobster pots (partially mitigated with Sea Lion Exclusion Devices in south coast crustacean fishery)	Southern and south-western Australia	36	1970–2023	Page et al., 2004; Raudino, H. & Waples, K. unpub. data; Campbell et al., 2008.
15	<i>Phocarctos hookeri</i> * New Zealand sea lion (Gray, 1844)	Endangered, decreasing	Nets	Auckland Island, New Zealand	1	1981	Cawthorn, 1984.
Phocid							
1	<i>Halichoerus grypus</i> * Grey seal (Fabricius, 1791)	Least concern, increasing	Monofilament, trawl nets, fishing related debris, rope	Both shores of the North Atlantic Ocean	546	2000–2020	Bogomolni et al., 2010; Jarvis, D. unpub. data; Leonard, J. S. unpub. data; Martins et al., 2019; Sayer et al., 2015; Geut, G. unpub. data; Salazar-Casals et al., 2022; Rubio-Garcia unpub. data; Unger et al., 2017.
2	<i>Phoca vitulina</i> * Harbour seal (Linnaeus, 1758)	Least concern, unknown	Fishing line, nets and rope, monofilament line and nets and fishing debris	Temperate and Arctic marine coastlines of The Northern Hemisphere, North Carolina	150	1985–2020	Byrd et al., 2014; Hanni and Pyle, 2000; Jarvis, D. unpub. data; Moore et al., 2009; Salazar-Casals et al., 2022; Rubio-Garcia unpub. data; Stewart and Yochem, 1987; Unger et al., 2017.
3	<i>Phoca largha</i> * Spotted seal	Least concern, unknown	Torn nets, ropes, buoys, synthetic mesh bags, plastic bags.	Sea of Japan, Peter the Great Bay	69	1981–2017	Katin et al., 2019
4	<i>Pusa capsica</i> * Caspian seal (Gmelin, 1788)	Endangered, unknown	Large mesh sturgeon net remnants	North Caspian Sea	30	2009	Dmitrieva et al., 2013
5	<i>Pusa hispida</i> * Ringed seal (Schreber, 1775)	Least concern, unknown	Blue plastic packing strap	Sisualiq (Kotzebue Sound), Chukchi Sea, Alaska	1	2008	Frost, K (State of Alaska) unpub. data.
6	<i>Monachus monachus</i> * Mediterranean monk seal (Hermann, 1779)	Vulnerable, increasing	Fishing nets	Mediterranean Sea	7	1991–2007	Karamanlidis et al., 2008
7	<i>Monachus schauinslandi</i> * Hawaiian monk seal (currently identified as genus <i>Neomonachus</i>) (Matschie, 1905)	Endangered, decreasing	Nets, net fragments	Hawaiian Islands, U. S.	173	1982–2004	Donohue and Foley, 2007; Henderson, 2001.

(continued on next page)

Table 1 (continued)

Taxa number	Otariid species and common name	IUCN classification, global trend	Description of main entangling material	Distribution where entangled	Total entanglement number by taxa over time	Year range of data collection	Sources
8	<i>Mirounga angustirostris</i> * Northern elephant seal (Gill, 1866)	Least concern, increasing	Plastic packing straps, rings, monofilament fishing line, gillnet	Pacific coast of the U. S., Canada and Mexico	118	1976–2005	Hanni and Pyle, 2000; Moore et al., 2009; Stewart and Yochem, 1987.
9	<i>Mirounga leonina</i> * Southern elephant seal (Linnaeus, 1758)	Least concern, stable	Squid monofilament line and jigs, plastic packing straps, trawl net, longline lines and hooks	Sub-Antarctic islands	40	1991–2005	Campagna et al., 2007; Hofmeyr et al., 2002.
10	<i>Hydrurga leptonyx</i> * Leopard seal (Blainville, 1820)	Least concern, unknown	Longline, monofilament line and hooks	Observations in Tasmania and Western Australia	2	1970–2023	Raudino, H. & Waples, K. unpub. data; Slater, 1991.

human presence, or the lack of research effort. Of the polar species, the spotted seal (*Phoca largha*) had been reported entangled in the Sea of Japan (Katin et al., 2019) and this study was the first to identify an individual ringed seal that was found entangled in a packing strap, captured, disentangled, and released in 2008 (Fig. 3). Consistent with the global pattern in pinniped entanglements, lower human impacts in general are observed at higher latitudes (Halpern et al., 2008).

Four arctic species, the hooded seal (*Cystophora cristata*), bearded seal, ribbon seal (*Histiophoca fasciata*) and the harp seal (*Phagophilus groenlandicus*) were not identified in this study as being entangled by our definition, but had been previously reported under a broader definition that included interacting with active fishing operations (Artukhin et al., 2010; Hayes et al., 2024; Ólafsdóttir, 2010; Poeta et al., 2017; Tixier et al., 2021). Pacific walrus (*Odobenus rosmarus divergens*) have been reported as bycatch in flatfish trawl nets in the Bering Sea in U.S. waters (USGS Alaska Science Center Walrus Research Program, 2023). Active fishing interactions also included a vagrant female Atlantic walrus (*O. r. rosmarus*), at least 20 years old (Pihlström et al., 2024). The Baikal seal also interacts with and is caught in active fishing nets, particularly those under two years old (Nomokonova et al., 2013). The three-remaining polar phocids that live in the Antarctic, Ross (*Ommatophoca rossii*), crabeater (*Lobodon carcinophagus*) and Weddell (*Leptonychotes weddellii*) have not been reported as entangled or as bycatch (this study, Forcada et al., 2012; Grüss et al., 2023; Reeves et al., 2013).

Fishing pressure in polar regions is significantly less than in warmer waters because the physical presence of sea ice that polar seals rely on makes most commercial fishing operations impractical, if not impossible. Therefore, global pinniped entanglement records do spatially overlap with fishing activity (Kroodsmas et al., 2018), and operational interactions are most likely where pinniped distributions intersect with high fishing effort (Jackson et al., 2024). Notably, 59% of the ocean is experiencing high rates of change from cumulative human stressors (Halpern et al., 2019). As sea ice continues to decline, fisheries are extending further into previously ice-covered seas, increasing the risk to polar pinnipeds of interactions with fishing gear and marine debris (Arctic Council, 2025; Halpern et al., 2008). The perspectives of First Nation Peoples and Alaska Natives should be included for monitoring interactions, which could be particularly informative for remote regions.

In addition to the influence of latitude and the coast, the age, behavior or foraging strategies of pinnipeds may contribute to the risk of entanglement. Juveniles of many pinniped taxa (e.g., New Zealand sea lions *Phocarctos hookeri*; Cawthorn, 1984) are curious and often observed playing with natural and artificial materials (Laist, 1997). Otariids tend to be more social and playful than phocids; both juvenile and adult Steller sea lions have been observed playing with various items including kelp and plastic material (Raum-Suryan and Suryan, 2022). Foraging strategies may, in part, explain the lack of entanglement reports for odobenids and bearded seals as both species specialize on benthic invertebrate prey, which is quite a divergence from other

pinnipeds (Born et al., 2003; Burns, 1981). Additionally, for odobenids, their long tusks may reduce the chances that entangling materials will be able to encircle their neck. However, fisheries interactions have occurred with odobenids and their risk of entanglement may increase should range overlap with emerging fisheries occur, particularly in the Russian sector of the Bering and Chukchi Seas that is data deficient (USGS Alaska Science Center Walrus Research Program, 2023). Tracking pinnipeds can provide some information on where individuals may become entangled and assist with understanding the behavior and survival of individuals released from entanglement. For example, disentangled Steller sea lions ($n = 13$) were tracked for up to two years post release demonstrating the benefits of rescue and release programs (Raum-Suryan et al., 2025).

Data collected for pinniped entanglements are commonly inconsistent; therefore, studies that attempt to model wildlife and pinniped entanglement in conjunction with broader topics such as ocean currents and marine debris density, by necessity, exclude data to attain robust and reliable analyses, reducing the application and impact of the results (e.g. Høiberg et al., 2022; Perez-Venegas et al., 2023). Such modelling analyses provide important contributions that would benefit from improved standardization and detailed reporting by field operatives. Here, we highlight the need for researchers to be transparent and detailed in their methodology, to aim for method standardization and share their raw data to support modelling analyses that are both robust and inclusive. Methods should allow for the calculation of a simple measure of prevalence for a defined population (entanglement count/count of unaffected seals), explain the biases in the data including effort (time taken, field team number and experience), method and equipment (boat, onsite, drone; quick scan or detailed survey); area covered (complete or partial survey of haul-out or breeding site) and a description of the field site including the date and time of day, tidal amplitude and the weather conditions. It is also valuable to report unmeasured biases that may affect the quality of the data to understand its reliability.

Some biases in the data are difficult to manage. For example, observer error may occur when healthy individuals are mistakenly counted as entangled, or when the behavior of the pinniped results in a bias. For example, a roll of skin in an unaffected individual may be mistaken for a difficult to see entanglement such as recreational fishing line, or vice-versa leading to under- or over-reporting. This may also skew the data towards entanglements that are more easily observed such as bulky nets and ropes. Also, entangled pinnipeds may spend more time at sea and go unreported, or more time ashore, perhaps on the edge of the site, biasing prevalence estimates obtained from lateral viewpoints such as when using a boat, a bias avoided using aerial surveys (Martins et al., 2019). The use of high resolution photographic aerial surveys reduces the effect of observer bias because they provide a single instantaneous measure of entangled pinnipeds to non-entangled pinnipeds that can be digitally stored and validated (Claro et al., 2019). Thermal imagery can also improve detection and validation of

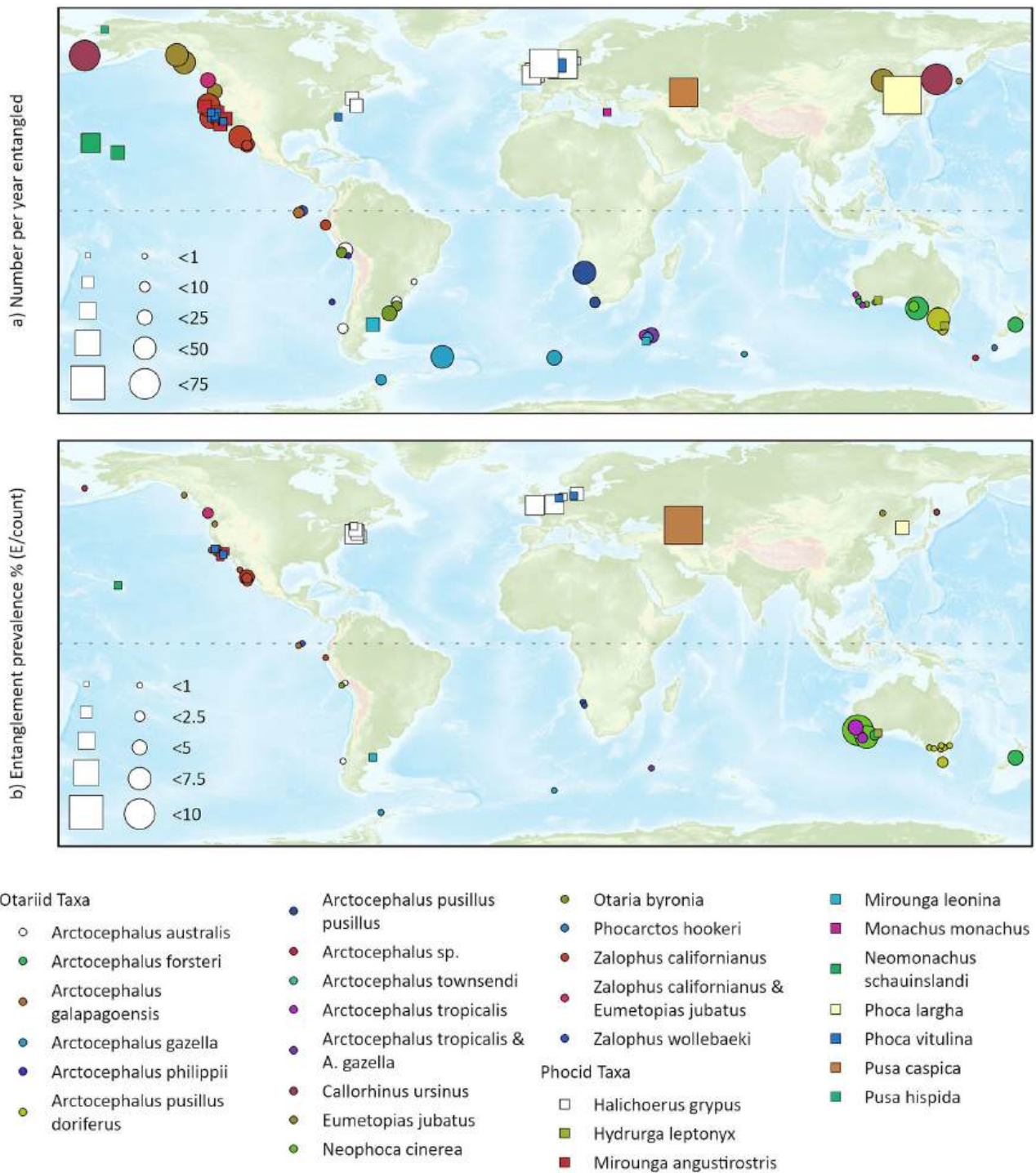


Fig. 1. (a) Global number of pinnipeds entangled using the simple annual estimate and (b) the prevalence % of entanglement as a proportion of the sample population. The shapes categorize phocids (square) and otariids (circle), the size of the shape is the number scale and the color is the species or subspecies (taxa). The graduated scale of the shape size has been simplified with each of the four shapes shown representing four points along the scale, <1, 2–10, 11–25, etc.

entanglement in fur seals (Yaney-Keller et al., 2026). Detection confidence is critical when using digital images (e.g. Azevedo-Santos et al., 2021; Muñoz-Pérez et al., 2023), as demonstrated by the image of the bearded seal with seaweed protruding from its mouth (Fig. 4).

While a simple annual count allows for greater inclusion of data, prevalence is an informative metric for entanglement because it identifies the scale of the threat to the population being monitored (Fig. 1). For example, grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) are the most reported seals to depredate and interact with active

fisheries, with the most affected area being FAO Fishing Area 27 that covers western Europe and the United Kingdom (Tixier et al., 2021). In support of this, grey seals have high annual estimates of entanglement and large prevalence estimates (Fig. 1) compared to other locations and species; however, the prevalence is likely influenced by the small number of individuals in sampled populations that include haul outs. Calculating prevalence on a species scale, while ambitious, is required for all pinnipeds. To further demonstrate the value of the prevalence measure, the Caspian seal (*Pusa caspica*) has a high entanglement count

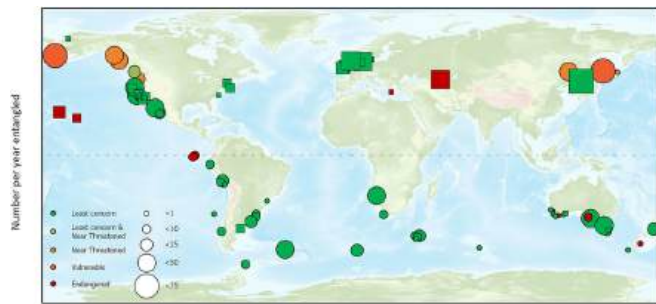


Fig. 2. Global number of pinnipeds entangled using the simple annual estimate, mapped by IUCN threatened species status from green (least concern) to red (endangered). Phocids are represented by squares and otariids by circles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



Fig. 3. Sub-adult male Ringed seal (*Pusa hispida*) entangled in packing strap (24.5 kg weight, 91 cm CL, 84 cm SL, 81 cm Axial girth) at Sisualiq (Kotzebue Sound), Chukchi Sea, Alaska photographed by Kathy Frost (State of Alaska marine mammal biologist) 19 October 2008, this seal was tracked for 291 days after entanglement removal.



Fig. 4. Bearded seal (*Erignathus barbatus*) with seaweed trailing from its whiskers that was mistaken for an entanglement on the internet, Finstown, mainland Orkney, August 2010 © Dave Pullan, pers. comm.

and high prevalence because of the small associated population size, recognized by its Endangered species status (Figs. 1 and 2). Also, while the Australian sea lion (*Neophoca cinerea*) was represented by small annual entanglement estimates, the prevalence was high, particularly in Western Australia due to the small associated populations as recognized by its Endangered status (Figs. 1 and 2). We acknowledge that in the

interest of being inclusive, we have reported data from variable methods and therefore the map visualizations are indicative only. Despite this, the scale of the threat is global and there are seven Endangered species at considerable risk from entanglement. Clearly, the metric used can change the inference or conclusion.

One challenge to overcome is that data from beached-washed (stranding) and operational fishing interactions are highly divergent from data of entangled pinnipeds collected at breeding sites and haul-outs. Defining the count of unaffected individuals that could be used as a population estimate for a measure of prevalence is particularly difficult. For the beached-washed individuals included here, we used the total count of beach-washed individuals of the same taxon as a replacement for a population count of unaffected individuals, which likely inflates the estimate compared to a count of individuals at a haul-out, breeding site or other representative population. Despite the challenges, integrating such data is important for understanding vital rates because the cumulative effect may be a key threat to pinniped populations (Nelms et al., 2023; Reeves et al., 2013).

This speaks to two of the goals of PEG: (1) that studies of entanglement in pinnipeds are standardized as much as possible and include population size estimates to improve global comparisons and modelling of the problem, and (2) that publications include raw data and/or that data are made accessible online as a resource for future modelling projects. Also, there is an urgent need for greater language clarity and clear definitions of terms. Our final major finding identified that while much entanglement research only includes individuals that are observed ashore, many pinnipeds are affected during the active deployment of commercial and recreational fishing gear and with IUU fishing, therefore an unknown number die at sea unreported. There is an urgent need to combine these threats and comprehensively measure the impact of entanglement for the prioritization of mitigation strategies. The threat is currently being underestimated despite our best attempts.

4.1. Context for global community

Entangling materials can cause lacerations, infections, strangulations, reduced mobility and foraging success. Hooks in the mouth with dangling fishing gear or swallowed gear can impact foraging ability and perforate digestive tracts (Barcenas-De la Cruz et al., 2018; Gobush et al., 2016). Most entanglements are considered to be extremely painful resulting in long-term suffering that is expected to result in death without intervention (Allen et al., 2012; Laist, 1997; Simeone et al., 2024).

Overwhelmingly the main materials entangling pinnipeds around the globe are fisheries related materials, both commercial and recreational (Table 1). This negatively affects the social license of commercial and recreational fishing because the public are challenged by seeing pinnipeds entangled in gear and suffering. Six pinniped species reported as entangled in this study are classified as Endangered and one, the Steller sea lion, as Near Threatened under the IUCN Red List. However, under the U.S. Endangered Species Act, the U.S. Western DPS Steller sea lion remains listed as Endangered, whereas the Eastern DPS has officially recovered (Table 1, Fig. 2). This concern can be used to engage both commercial and recreational fishing sectors to work towards mitigating impacts while fishing and reducing discarded or lost gear that becomes marine debris (e.g., Kusmanoff et al., 2022). Mitigation has been attempted for the endangered Galapagos fur seal (*A. galapagoensis*) with local net fisheries using exclusion zones (Jefferson et al., 2015) and for the Australian sea lion through exclusion zones and gear change from gillnet to longline (Goldsworthy et al., 2022). Once a management action has been enacted, further monitoring of entanglement in the affected species or population should be used to detect any corresponding reduction in entanglement or active fishing interactions.

Pinnipeds are a dynamic taxon, and this work demonstrates the significant problem of entanglement across the world. Extralimital records of pinnipeds are being documented more often in recent years as



Fig. 5. Photographs of Galapagos sea lions (*Zalophus wollebaeki*) entangled in fishing hook and line (left), the base of a dive tank (top right) and a plastic strap (bottom right), evidence of the diverse entanglement materials affecting this species. (Photos by Diego Páez-Rosas).



Fig. 6. Juan Fernandez fur seal (*Arctocephalus philippii*) case ORCM-6028, entanglement with the hook of an assumed active fishing gear recorded in Camaná beach, Arequipa, Peru. Example of an off-range or vagrant species revealing the risks for entanglements affecting pinnipeds in the face of climate change (Photo by Carlos Yaipen-Llanos).

many species are being recorded as vagrants in distant locations from their typical known range. Such movements may be a consequence of population growth or as a direct response to climate change, with increasing ocean temperatures causing changes in prey availability and

habitat suitability, such as those observed for southern elephant seals (*Mirounga leonina*, Alava et al., 2022), Australian phocids (Shaughnessy et al., 2012), sub-Antarctic fur seals (*A. tropicalis*, Gales et al., 1992), walrus (Pihlström et al., 2024) and leopard seals (Renwick and Kirkwood, 2004; Hupman et al., 2020). Since more pinniped species are appearing in urbanised and exploited coastal areas, the risk of entanglement increases and examples of entanglement for such vagrants exist for leopard seals (Slater, 1991; Mawson and Coughran, 1999), sub-Antarctic fur seals (this paper) and the Juan Fernandez fur seal (this paper).

Given animal welfare concern and the potential impact on populations, it is not surprising that a global network of responders such as PEG has emerged to collaborate to prevent entanglements through outreach and education (see Supplementary Material Workshop). The group also works with industry to find effective deterrents and mitigate fishery interactions, develop innovative disentanglement tools and techniques, and rescue entangled pinnipeds. The establishment of PEG has united researchers and responders to maximize response effectiveness, standardize approaches and language definitions, establish best practices, and promote mitigation. We highlight the importance of PEG as a world-wide network to exchange knowledge, training, and critical information about unfamiliar species and extralimital records of pinnipeds (entangled and otherwise). The PEG network will strengthen the understanding of shifts in pinniped distribution, in some cases because of climate change, and PEG members are well positioned to respond to this need.

Table 2

List of example regulatory, global aspirational resources and codes of conduct to prevent pinniped entanglement [web addresses accessed 23/05/2025].

Reference	Year	Administration	Link, description or reference
Regulatory framework to reduce ALDFG or marine debris at sea			
London Dumping Convention	1972	United Nations (UN) by the International Maritime Organization	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (imo.org)
The Convention on the Protection of the Marine Environment of the Baltic Sea Area; Helsinki Convention (HELCOM)	1974	Helsinki Convention for the Baltic	The Helsinki Convention – HELCOM
Regional Seas Program of UNEP	1974	UN Environmental Programme (UNEP)	Regional Seas Programme UNEP - UN Environment Programme
Barcelona Convention (UNEPMAP), The Convention for the Protection of the Mediterranean Sea Against Pollution	1976	UN Environmental Programme (UNEP)	Barcelona Convention and Protocols UNEPMAP
The Cartagena Convention, a regional legal agreement for the protection of the Caribbean Sea	1986	Regional Coordinating Unit (UNEP-CAR/RCU), Kingston Jamaica	Cartagena Convention The Caribbean Environment Programme (CEP) (unep.org)
The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), Annex V & Annex 21 - Guidelines for Implementation	1988 & 2017	International Maritime Organization	www.imo.org & Resolution MEPC.295(71), Annex 21
The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.	1989	UN Environmental Programme (UNEP)	https://www.basel.int
Oslo- Paris Convention (OSPAR) for the Protection of the Marine Environment of the North-East Atlantic	1992	OSPAR Commission	Convention OSPAR Commission
Fishing for Litter	2004	KIMO International	https://fishingforlitter.org/
European Union's Marine Strategy Framework Directive	2008	European Union	EU Marine Strategy Framework Directive - European Commission (europa.eu)
The Honolulu Strategy	2011	UN Environmental Programme (UNEP), National Oceanic and Atmospheric Administration	marinedebris.noaa.gov/sites/default/files/publications-files/Honolulu_Strategy.pdf Shevealy et al., 2012.
Agreement on Port State Measures (PSMA), International	2016	Food and Agriculture Organization of the United Nations	Agreement on Port State Measures (PSMA) Food and Agriculture

Table 2 (continued)

Reference	Year	Administration	Link, description or reference
agreement to specifically target illegal, unreported and unregulated (IUU) fishing			Organization of the United Nations (fao.org)
Conservation Measure 26-01 – General environmental protection during fishing	2019	Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)	26-01 (2019) CC AMLR Conservation Measures
Expert Consultation on the Marking of Fishing Gear	2019	Food and Agriculture Organization of the United Nations	Voluntary Guidelines on the Marking of Fishing Gear results FAOLEX Database Food and Agriculture Organization of the United Nations
Regional and Government Policies and Legislation regarding marine plastic pollution	1916–2024	FAOLEX Database, Food and Agriculture Organization of the United Nations	Association of Southeast Asian Nations (ASEAN), Indonesia, Malaysia, USA, Australia, South Pacific Regional Fisheries Management Organisation (SPRFMO), Norway, Canada, Kenya, European Union, China, Vietnam, Tanzania, Sri Lanka, Nigeria, United Kingdom and more.
Legislation to protect pinnipeds from entanglement			
International Union for Conservation of Nature's Red List of Threatened Species	1964	International Union for Conservation of Nature (IUCN)	www.iucnredlist.org/
U.S. Marine Mammal Protection Act (MMPA)	1972	The 92nd United States Congress	www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-protection-act
U.S. Endangered Species Act (ESA)	1973	The 93rd United States Congress	https://www.fisheries.noaa.gov/national/endangered-species-conservation/endangered-species-act
Conservation Measure 63/XV, CCAMLR-XV	1996	Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)	Monitoring marine debris and its impact on marine living resources in Antarctic waters
Listed Key Threatening Processes: Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris (2018).	1999	Australian Government, Environmental Protection and Biodiversity Act	www.environment.gov.au/cgi-bin/sprat/public/publicshowkeythreat.pl?id=14
Species at Risk Act	2002	Canadian government	www.dcccew.gov.au/sites/default/files/documents/tap-marine-debris-2018.pdf https://laws-lois.justice.gc.ca/eng/acts/S-15.3/index.html

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Table 2 (continued)

Reference	Year	Administration	Link, description or reference
Aspirational frameworks Degradable Plastic Ring Rule	1994	US Environmental Protection Agency	Mandating beverage Ring carriers made of photodegradable material that breaks and breaks-down Upon prolonged exposure to sunlight.
Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development	2015	The United Nations Sustainable Development Goals	Goal 14 Department of Economic and Social Affairs un.org
Litter Prevention Strategy 2020–2025	2020	Keep Australia Beautiful Council (Western Australian Government) established under the Litter Act 1979	30% targeted reduction in litter levels in Western Australia between 2020 and 2025 through 4 objectives: increasing community awareness, long-term prevention of marine debris, enforcement of the Litter Act 1979, monitoring marine debris and the effectiveness of programs.
Australian Marine Debris Initiative	2004	Tangaroa Blue Foundation	An Australia-wide not-for-profit organization dedicated to the removal and prevention of marine debris. Remove waste, stop at the source and reduce production.
Reel it in campaign	2013	Western Australian Government	To reduce the impact of discarded fishing line and tackle on animals by providing disposal facilities (104 bins), initially in the Swan Canning Riverpark and now expanded across Western Australia from Broome to Albany.
Industry Code of Conduct Industry Code of Practice to Minimise Interactions with Seals	2007	South East Trawl Fishing Industry Association (SETFIA)	Industry Code of Practice
Industry Code of Practice, Bins on Boats to retain waste onboard vessels	2019	South East Trawl Fishing Industry Association (SETFIA)	Kusmanoff et al., 2022.
Background Paper for the Threat Abatement Plan for the impacts of marine debris on vertebrate marine life	2009	Government of Australia, 2009	Banned packing bands on recreational and commercial fishing vessels, targeting the rock lobster industry UNEP/CMS/ScC16/Inf.9.1.

Table 2 (continued)

Reference	Year	Administration	Link, description or reference
Best Practice Framework for the Management of Fishing Gear	2018	Global Ghost Gear Initiative	https://www.ghosgear.org/resources
Industry change Sea Lion Exclusion Devices (SLEDs).	2008	West coast rock lobster fishery (WCRLF)	Campbell et al., 2008
Gear change and area closures around Endangered Australian sea lion breeding sites and	2022	South Australian Research and Development Institute, Aquatic Sciences lead of collaborative team	Goldsworthy et al., 2022.
Sustainable Fisheries Certification Standard	2022	Marine Stewardship Council	https://www.msc.org/docs/default-source/default-document-library/for-business-program-documents/fisheries-program-documents/msc-fisheries-standard-v3-0.pdf
Non-government organizations Focused on solving the problem of lost and abandoned fishing gear worldwide	2015	Global Ghost Gear Initiative (GGGI)	https://www.ghostgear.org/
Funding marine debris and the issue of pinniped entanglement	1950 to 2014	World Animal Protection	https://www.worldanimalprotection.org/

4.2. Knowledge gaps

Identifying the origin of fishing materials entangling pinnipeds would be improved by legislating the marking of gear (Lovell, 2023), using global positioning devices (GPS) on nets to allow retrieval if lost, and conducting large-scale ocean cleanups (Baker et al., 2024). Take-back schemes that include recycling of end-of-life fishing materials would be beneficial to reduce dumping at sea; however, the nets are often biofouled and contaminated and made from multiple, often unknown, plastic polymers, increasing uncertainty and complicating recycling efforts (Kozioł et al., 2022; Nogueira et al., 2022). Biodegradable nets are being developed but still take time (10+ years) to break down (Wataniyakun et al., 2025). Urban rubbish does contribute to entanglement therefore terrestrial and freshwater waste management practices and community education are needed to reduce waste inputs to the marine environment (Jambeck et al., 2015; Jones et al., 2021). Given the difficulty in determining the mechanism of entanglement via passive or active fishing gear, methods of deterring pinnipeds from interacting with active gear are critical.

4.2.1. Mitigation and deterrents

The most promising methods to reduce depredation (feeding on fisheries catches) are gear modification or behavioral adaptation by fishers. In a review by Tixier et al. (2021) marine mammal depredation was reported in 214 fisheries between 1979 and 2019, affecting fishing fleets from 44 countries including commercial, artisanal, and recreational fisheries, and in all major fishing techniques (nets, traps, and hook and line). Sea Lion Exclusion Devices (SLEDs) or Seal Exclusion Devices (SEDs) in trawl nets, and measures such as spikes in rock-lobster pots, aim to reduce pinniped mortality in active fisheries, but their

effectiveness and post-interaction survival outcomes remain uncertain (Campbell et al., 2008; Hamilton and Baker, 2015; Mackay and Goldsworthy, 2017). Assessing survival is challenging because observers and cameras are biased towards mortality, and escaped individuals are difficult to monitor, with some likely sustaining injuries that affect later survival (Hamer and Goldsworthy, 2006; Hamilton and Baker, 2015). Moreover, SLEDS are often only mandated in specific areas and rarely apply to recreational fisheries, leaving ongoing risk. Deterrents may be a safer and more accessible mitigation option and include non-acoustic (e.g., visual, physical, electrical, chemosensory, tactile) and acoustic methods, the latter divided into impulsive and non-impulsive types (Cowan et al., 2000; Graham et al., 2009; Harris et al., 2014). However, conventional acoustic deterrents have limited long-term success due to habituation and can negatively impact target and non-target species through hearing damage, masking, habitat exclusion, and stress (Goetz and Janik, 2013). Emerging technology using a species-specific acoustic startle response has shown greater promise, increasing avoidance behavior without habituation (Goetz and Janik, 2015) and reducing seal predation by 91–97% at a Scottish fish farm without affecting non-target species or causing hearing damage (Goetz and Janik, 2016a, 2016b). Developing effective, fishery-specific deterrents, in collaboration with fishers and acoustic experts, is critical to reducing pinniped entanglement.

Marine debris mitigation must include reducing source inputs. For example, plastic packing bands continue to be widely reported as a cause for pinniped neck entanglements globally, including 12 pinniped species in Table 1 (Hogan and Warlick, 2017; Curtis et al., 2021; Table 1). Plastic packing bands in the United States and Canada were the most common neck entanglement of Steller sea lions in Southeast Alaska, northern British Columbia, and northern Washington (Raum-Suryan et al., 2009; Allyn and Scordino, 2020) and of California sea lions in Oregon and Washington (Allyn and Scordino, 2020; Raum-Suryan and Suryan, 2022). However, despite years of efforts of PEG members working with researchers to find a biodegradable alternative to plastic packing bands, to our knowledge, there currently is not an economical, waterproof replacement. In Australia, non-mandatory use of biodegradable packing bands and a code of best practice to remove packing bands and leave at port did not result in the reduction of pinniped entanglement (Page et al., 2004). However, Arnould and Croxall (1995) did correlate a reduction of entanglement in packing bands at South Georgia with improved waste disposal behavior under the Convention for the Prevention of Pollution from Ships (MARPOL 1973/78) and a concurrent reduction in fishing activity. Therefore, PEG has been focusing on its message to “Lose the loop” (Raum-Suryan et al., 2009) by cutting any loop before properly discarding it in the garbage, to reduce the number of potential entanglement loops in the environment while we continue to search for an alternative.

4.3. Next steps

Three elements should be addressed to reduce pinniped entanglement: 1) reducing the amount of entangling material entering the ocean; 2) removing what is already in the ocean; and 3) mitigating pinniped interactions with active and passive fishing materials. Various actions can help achieve this, but it will take global collaboration and compromise, particularly since increasing global population will intensify human impacts in the ocean including fishing pressure and ALDFG (Jackson et al., 2024; Vitorino et al., 2022; Halpern et al., 2019; Pandey et al., 2025). The impact of IUU fishing is commonly reported as a gap in our understanding regarding the impact of fishing activities, requiring greater attention (Halpern et al., 2008; World Animal Protection, 2018; Richardson et al., 2022).

Improving ocean literacy is another key to achieving these goals. Public participation through citizen science initiatives should be encouraged (e.g. Nelms et al., 2017; Puskic et al., 2024). The United Nations Ocean Decade launched in 2021 aims to inspire connection and

care for the oceans by promoting ocean literacy, defined as understanding our relationships with the ocean so we can better protect them. Community or citizen science projects improve ocean literacy and people's connection to the ocean that has declined from increased modernization and less immersion in nature (Kelly et al., 2022).

We simply cannot rescue all entangled pinnipeds, and the multifaceted and underreported problem of fisheries bycatch will require stakeholder collaboration to solve. Conflicts are expected to escalate in coming years as human pressures on marine resources increase in response to a growing population and increasing demand. Tixier et al. (2021) suggest that expanding research to the socio-ecological dimension of the conflict, involving stakeholders and resources under a common objective and integrating knowledge and changing perspectives are all needed in a framework suitable for sustainable mitigation.

5. Conclusion

This paper clearly identifies the pervasive nature of entanglement across global pinniped populations, linked to overlap with fishing activities and hotspots of marine debris and ALDFG. Furthermore, treating entanglement as separate from interactions with active fishing gear and bycatch underestimates the scale of the threat and IUU fishing compounds this further (World Animal Protection, 2018; Halpern et al., 2008). Future studies should address this when assessing impacts of marine debris and the fishing industry (recreational, commercial and IUU) on populations. Additionally, more information is needed for many pinniped populations to adequately assess this mortality driver in relation to other threats. Presently more otariids (fur seals and sea lions) are affected by entanglement than phocids (true seals) and no odobenids (walrus) have been reported as entangled; however, all pinnipeds except the three Antarctic phocids (Ross, Weddell and crabeater) have been recorded as interacting with active fishing gear. Measuring the prevalence of entanglement can be difficult but an effort to achieve this by standardizing methodology, providing clear definitions of terms and sharing detailed data records is critical to accurately represent the scale of the threat, monitoring trends and determining the success of mitigation actions. There is limited understanding regarding population level effects because of the difficulty in scaling-up sub-sampled entanglement estimates, but the risks are high for endangered species. As more tracts of ocean become available to industrial fishing with melting sea ice and increased global need for food, as well as the increased likelihood of species moving outside of their existing range, we expect more species and individuals to be affected across more locations including the polar species. Reducing the entanglement of pinnipeds will require multiple approaches and targeted solutions. It is imperative that the researchers, responders, citizens and the fishing community unite to reduce the impact of this threat. PEG has been key to uniting the pinniped entanglement response community and we welcome participation.

CRedit authorship contribution statement

Rebecca Ruth McIntosh: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Kimberly Raum-Suryan:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Data curation, Conceptualization. **Dave Zahniser:** Writing – review & editing, Writing – original draft, Conceptualization. **Daniela Barcenás de la Cruz:** Writing – review & editing, Data curation. **Laura Boren:** Writing – review & editing, Data curation. **Machteld Geut:** Writing – review & editing, Data curation. **Carolin Philipp:** Writing – review & editing, Data curation. **Elizabeth Hogan:** Writing – review & editing, Data curation. **Dan Jarvis:** Writing – review & editing, Data curation. **Shawn Johnson:** Writing – review & editing, Writing – original draft, Conceptualization. **Mark Keenan:** Writing – review & editing, Writing – original draft. **J. Scott Leonard:** Writing – review &

editing, Data curation. **Diego Páez Rosas:** Writing – review & editing, Visualization, Data curation. **Holly Raudino:** Writing – review & editing, Data curation. **Kathryn Rose:** Writing – review & editing, Data curation. **Ana Rubio-García:** Writing – review & editing, Data curation. **Sue Sayer:** Writing – review & editing, Data curation. **Bianca Unger:** Writing – review & editing, Data curation. **Kelly Waples:** Writing – review & editing, Data curation. **Carlos Yaipen-Llanos:** Writing – review & editing, Visualization, Data curation.

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpolbul.2026.119801>.

Data availability

Data in supplementary materials

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