Increased Incidence of Entanglements and Ingested Marine Debris in Dutch Seals from 2010 to 2020

Salazar-Casals, Anna; de Reus, Koen; Greskewitz, Nils; Havermans, Jarco; Geut, Machteld; Villanueva, Stella; Rubio-Garcia, Ana

Published in:
Oceans

DOI:
https://doi.org/10.3390/oceans3030026

Publication date:
2022

oceans

Article

Increased Incidence of Entanglements and Ingested Marine Debris in Dutch Seals from 2010 to 2020

Anna Salazar-Casals [1,*], Koen de Reus [2,3], Nils Greskewitz [1], Jarco Havermans [4], Machteld Geut [5], Stella Villanueva [1] and Ana Rubio-Garcia [1]

[1] Sealcentre Pieterburen, 9968AG Pieterburen, The Netherlands
[2] Comparative Bioacoustics Group, Max Planck Institute for Psycholinguistics, 6525XD Nijmegen, The Netherlands
[3] Artificial Intelligence Lab, Vrije Universiteit Brussel, 1050 Ixelles, Belgium
[4] Ecomare, 1796AZ De Koog, The Netherlands
[5] Stichting A Seal Centrum voor Zeezoogdierenzorg, 3251LD Stellendam, The Netherlands
* Correspondence: anna.salazarcasals@zeehondencentrum.nl

Abstract: In recent decades, the amount of marine debris has increased in our oceans. As wildlife interactions with debris increase, so does the number of entangled animals, impairing normal behavior and potentially affecting the survival of these individuals. The current study summarizes data on two phocid species, harbor (*Phoca vitulina*) and gray seals (*Halichoerus grypus*), affected by marine debris in Dutch waters from 2010 to 2020. The findings indicate that the annual entanglement rate (13.2 entanglements/year) has quadrupled compared with previous studies. Young seals, particularly gray seals, are the most affected individuals, with most animals found or sighted with fishing nets wrapped around their necks. Interestingly, harbor seals showed a higher incidence of ingested debris. Species differences with regard to behavior, foraging strategies, and habitat preferences may explain these findings. The lack of consistency across reports suggests that it is important to standardize data collection from now on. Despite increased public awareness about the adverse environmental effects of marine debris, more initiatives and policies are needed to ensure the protection of the marine environment in the Netherlands.

Keywords: harbor seal; gray seal; entanglement; ingestion; marine debris; fishing nets

check for updates

Citation: Salazar-Casals, A.; de Reus, K.; Greskewitz, N.; Havermans, J.; Geut, M.; Villanueva, S.; Rubio-Garcia, A. Increased Incidence of Entanglements and Ingested Marine Debris in Dutch Seals from 2010 to 2020. *Oceans* **2022**, *3*, 389–400. https://doi.org/10.3390/oceans3030026

Academic Editors: Shawn Johnson and Claire Simeone

Received: 30 April 2022
Accepted: 3 August 2022
Published: 5 August 2022

1. Introduction

During the last few decades, the environmental effects of marine debris have become more and more apparent [1–4]. Marine debris is defined as "any persistent, manufactured, or processed solid material that is directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment" [5]. This classification of debris includes diverse materials such as plastics, metals, fabrics, and petroleum. Currently, debris made of plastic poses the biggest environmental threat due to the material's slow degradation and widespread access [4,6]. However, thanks to the results of multiple scientific reports, several policy changes are being developed and implemented worldwide. One example is the 2008 Marine Strategy Framework Directive (MSFD) by the European Union (EU) which, according to descriptor10 Marine Litter, "requires EU Member States to ensure that properties and quantities of marine litter do not cause harm to the coastal and marine environment" [7]. Although society has become increasingly aware of the problems caused by litter, large quantities still end up in the marine environment.

Marine debris can cause a variety of environmental effects. According to Kuo and Huang [8], the impact of marine debris can be divided into three categories: injury or death of marine wildlife, harm to marine ecosystems, and effects on human lives and properties. Conservationists are particularly concerned with the direct impacts on wildlife [9]. Over a period of 18 years (1997 to 2015), researchers observed a 49% increase in the number of aquatic species that were either entangled in or had ingested marine debris [3,10]. The list of species affected by marine debris includes seabirds [11], sea turtles [12,13], cetaceans [14], and pinnipeds [15–18], among others [19]. An animal that becomes entangled in marine debris (e.g., fishing nets) will first suffer from physical discomfort and, as the situation becomes more chronic, will find it difficult to express normal behavioral patterns, such as not being able to forage properly. This, in time, may lead to pain, injuries, starvation, and potentially death [20]. Such a case was observed by Sealcentre Pieterburen (SCP) in 2019: a severely entangled gray seal (*Halichoerus grypus*) was found unable to forage properly due to its injuries and had to be admitted into rehabilitation (see the Supplementary Materials for more detailed information). Moreover, the ingestion of marine debris can cause internal injuries [2,20]. According to Parga [12], the most dangerous ingested foreign bodies are fishing lines. Swallowed fishing lines can affect the normal peristaltic movements of the intestines or cause an obstruction, and swallowed hooks can cause esophageal or stomach perforations [20]. In short, interactions with marine debris may negatively affect an animal's behavior and potentially be life-threatening [20].

According to Barnes and colleagues [21], the waters of the Northern Hemisphere contain more debris than those of the Southern Hemisphere. European coastal areas, such as those found in the Netherlands, are particularly affected [21,22]. The last Wadden Sea Quality Status Report [4] indeed showed that litter quantities in the Wadden Sea are increasing. This document highlighted the potential threats litter poses to marine mammals, but that information on animal interactions with marine debris is lacking. The report states that "a proper estimation of the effects of marine litter on mammals should not only consider ingestion of litter and direct mortality but also other types of interaction [s] such as entanglement and direct injury. Information on these types of interaction [s] is currently not available for the North Sea mammals from the Wadden Sea region" [4]. The two species of phocids found around the Dutch coast are harbor seals (*Phoca vitulina*) and gray seals (*Halichoerus grypus*), where they are the apex predators [23]. Animals at the top of the food chain are considered ecological indicators of a healthy environment, making seals particularly important species for measuring the wellbeing of coastal ecosystems, such as the Wadden Sea [24].

Although both species have healthy populations which are currently reaching carrying capacity [23], to the best of the authors' knowledge, the information available regarding the effect of marine debris on Dutch seal populations is limited and outdated [4]. The aim of this project was to present an in-depth report on how marine debris has affected phocids in the Netherlands over an 11-year period (2010 to 2020). The current study is a follow-up of two previous Dutch reports: a 2010 SCP internal communication [25] about fishing net entanglements in phocids from 1985 to 2010; and a manuscript by Osinga and colleagues [15] who reported the patterns of dead strandings in phocids from 1979 to 2002. This comprehensive study includes data from all the active rehabilitation centers in the Netherlands (A Seal, Ecomare, and SCP) and includes sighting and stranding reports of both live and dead animals, providing a more complete overview on the number of seals affected by marine debris in Dutch waters.

2. Materials and Methods

This report includes information regarding sightings and strandings of seals (dead or alive) affected by marine debris in Dutch waters over a period of 11 years, from 2010 to 2020. The 145 encounters were reported by members of established strandings networks or the public to one of the three main seal rehabilitation centers in the Netherlands: Ecomare (17), A Seal (8), and SCP (120). Taken together, the three rehabilitation centers cover the whole Dutch coast, with each center being in charge of a given coastal area. Every center recorded the information based on their own protocols, but every report contained basic information such as the date and location of the encounter, the name of the center it was reported to, information on the animal (action taken, species, age, and sex), and the information on the entanglement (type of entanglement, body location, and origin of the debris).

The animals were found either dead or alive. Dead animals were either disposed of (i.e., advanced decomposition state) or brought to one of the rehabilitation centers for post-mortem examination. For the animals found alive, one of three possible actions were taken: (1) *no action*, if the animal could not be caught nor any other action could be taken at that moment; (2) *released on site*, if the animal could be caught, freed from the entangled debris, presented none to very mild wounds, and could be released immediately afterwards; or (3) *brought into rehabilitation*, if the animal could be caught and presented moderate to severe wounds that required further medical treatment. In situations where the survival of the individual was compromised due to medical reasons, euthanasia was performed by a licensed veterinarian, first sedating the animal and then injecting pentobarbital sodium (100 mg/kg) intravenously [26]. No animals were euthanized for the purpose of this study.

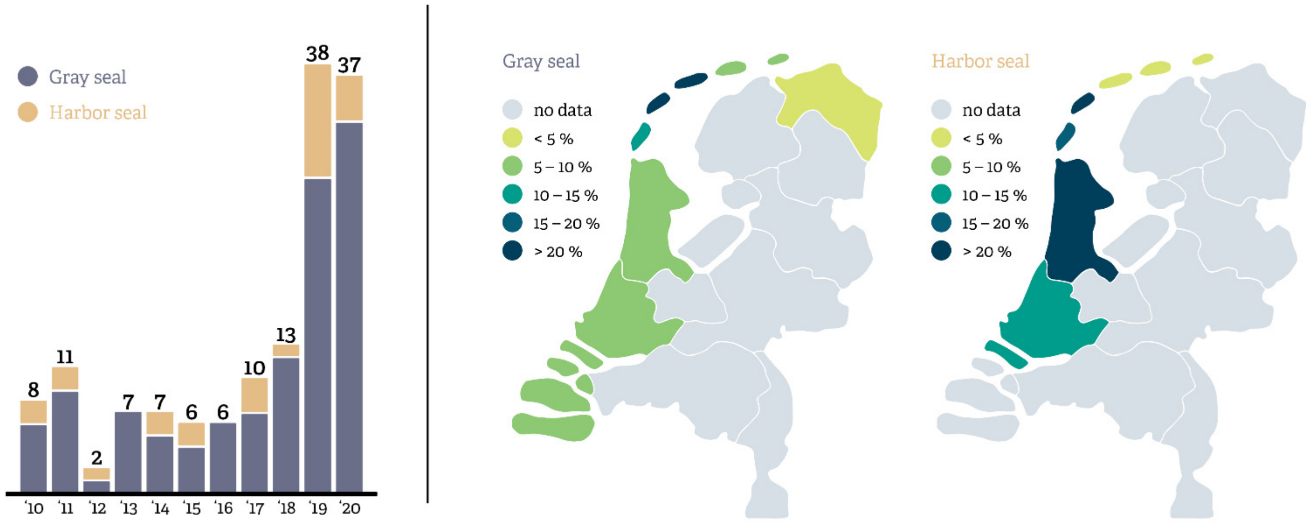
Reports were grouped by species, age, and sex [27]. The encounters were from the two phocid species found in the Netherlands, gray seals and harbor seals. The individuals reported comprised all age classes (pups, juveniles, and adults) and both sexes. Age determination was performed based on body size, condition of dentition, presence or absence of lanugo, and shape of the head [28]. Animals were classified as pups when the estimated age was less than four weeks old (i.e., 26 days old). We chose this threshold because the average lactation period is 26 days for both species [29,30]. Juveniles are independent, non-sexually mature animals which include weaners (<1 year old), yearlings (1–2 years old), and subadults (<3 years old). Pups were not included in the juvenile category because, during the lactation period, they are still dependent on their mothers for food. Males and females of both native species reach sexual maturity at the age of 3; hence, animals were classified as adults if they were estimated to be more than 3 years of age [30]. Age and sex were reported as unknown if the individuals were far away from the observer or if they were lying on their abdomen, or swimming. The same was true for dead animals who were in an advanced state of decomposition.

The entanglement was described in more detail, including the type (external or ingested), location (e.g., where on the body), the origin of debris (from boating/fishing industry or of other origin), and lesions caused. The entanglement type was reported as external when the material was found around (part of) the body, and as ingested when the material was found in the digestive tract. Debris that originated from the boating/fishing industry included, among others, fishing lines, nets, hooks, and ropes. Marine debris of other origin could include textiles, domestic or industrial plastics, etc. Unfortunately, due to the lack of consistency while reporting the type of material the debris was made of (i.e., metal, plastic, fabric, etc.), and the lesions caused by marine debris, no further data analysis was performed regarding the type of material or the severity of the animal's wounds.

Data was analyzed in R version 4.1.0 (RStudio version 1.4.1717). Only summary statistics, including absolute counts and percentages, were performed. We also looked at yearly and geographical trends. Yearly trends were analyzed by reporting the number of strandings per year from 2010 to 2020. We also looked at yearly entanglement trends, separating those per stranding location, age, sex, and origin of the entangled debris. Lastly, we computed, for both species, the yearly entanglement rates, expressed as a percentage, by dividing the number of reported entanglements by the number of animals counted during the molting period [23]. Geographical trends were analyzed by compiling the WGS 84 satellite coordinates of all reported strandings and creating a map to show their distribution in the Netherlands. The proportion of strandings in each mainland province (Zeeland, South Holland, North Holland, Friesland, and Groningen) and each of the Wadden islands (Texel, Vlieland, Terschelling, Ameland, and Schiermonnikoog) was indicated using color coding.

3. Results

Entangled seals were observed every year during the studied time period (2010–2020). A total number of 145 entanglements with marine debris were reported, of which the majority were gray seals (81.4%). The average yearly number of reported entanglements was 13.2 reports per year (10.7 for gray seals; 2.5 for harbor seals). Overall, the numbers of yearly strandings were rather stable at the start of the study, with around seven reports per year. However, from 2017 onwards, there was a gradual increase in reported strandings, with a clear spike after 2018 (Figure 1a).



(**a**) (**b**)

Figure 1. Overview of the yearly and geographical trends in phocids affected by marine debris around the Dutch coast. Gray seals are represented in purple and harbor seals in light orange. (**a**) The graph shows the annual number of individuals, grouped by species, affected by marine debris during the 11-year period. (**b**) The maps correspond to the percentage of entanglements found in each mainland province or Wadden island. Gray seals are represented on the left and harbor seals on the right.

Entanglement rates varied yearly in both species. On average, yearly entanglement rates for gray and harbor seals were 0.3% and 0.04%, respectively, suggesting that gray seals are entangled more frequently. For gray seals, entanglements were seen every year, with the lowest entanglement rate being 0.03% in 2012; and the highest being 0.6% in 2019. For harbor seals, the lowest entanglement rates were in 2013 and 2016 when no entanglements were reported. The highest entanglement rate was 0.14% in 2019.

In the Netherlands, entanglements occurred more frequently on the Wadden islands (70.3%) as opposed to the mainland (29.7%). Gray seals were stranded 2.8 times more frequently on the Wadden islands than on the mainland, but harbor seal strandings seemed to occur at almost the same frequency in both locations (Figure 1b). Due to the variability in the number of reports per year, we could not reliably compare yearly stranding rates based on location. However, the general trend per year did not seem to vary much: entangled gray seals were found more frequently on the Wadden islands, and it was equally likely to find entangled harbor seals on the islands than on the mainland (see Figures S1 and S2 in the Supplementary Materials).

From the 145 reports, 15 animals were found dead and 130 were found alive. For 30 of the individuals found alive, no action could be taken at the moment of the encounter (e.g., they could not be caught). There were 41 animals released on-site from their entanglements (this applied to external entanglements only), and 59 were caught and transported to one of the rehabilitation centers. Three animals died while being transported to rehabilitation, and eight died or were euthanized during the rehabilitation process. The cause of death of these eight individuals was not always related to the severity of the lesions caused by the entanglement; in some cases, a concomitant disease (e.g., parasitic pneumonia) was the most likely cause of death. The remaining 48 animals were released back into the wild after a period in rehabilitation. Overall, the survival rate for animals accepted into rehabilitation was 85.7% (Figure 2).

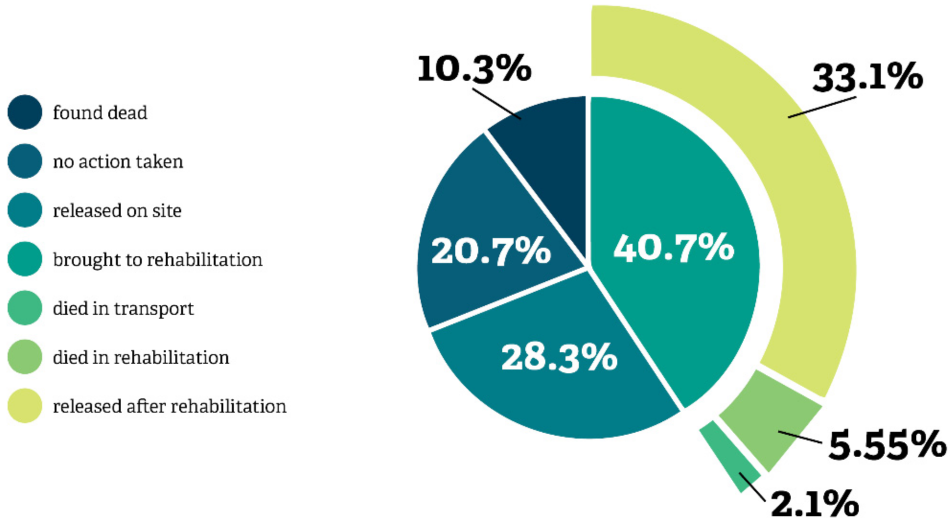


Figure 2. Outcome for all entangled animals.

We checked for age and sex differences in the number of reported entanglements. We found that juveniles comprised more than 67% of the sample, suggesting that animals of a younger age are more affected by marine debris (Figure 3). There were no noticeable sex differences in the two seal species. Age and sex trends were similar across the years (see Figures S1 and S2 in Supplementary Materials).

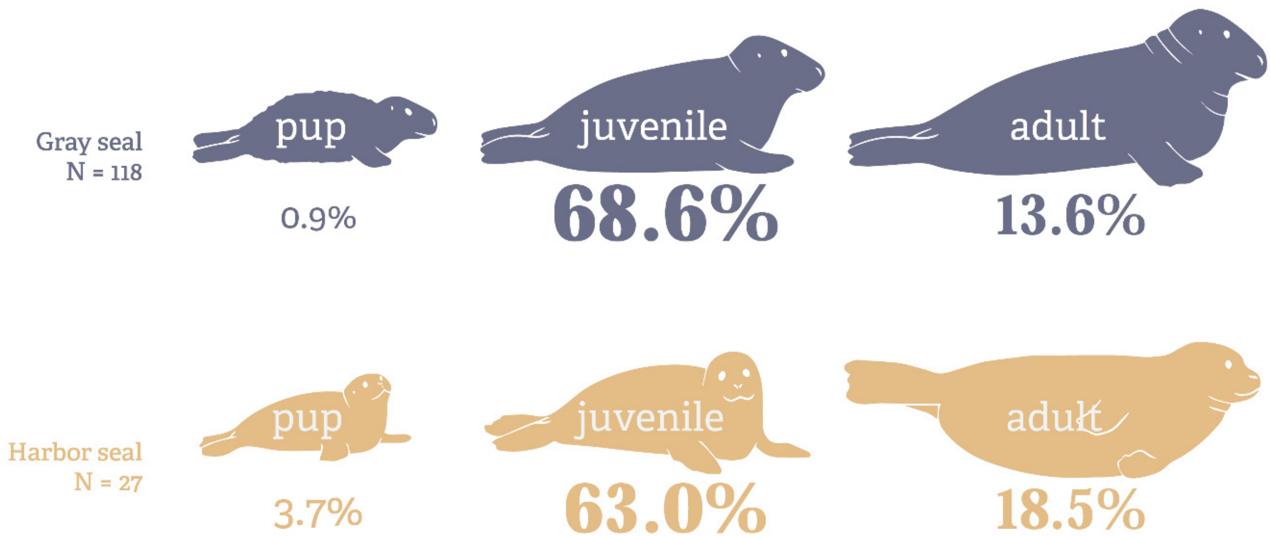


Figure 3. Percentage of individuals, grouped by age class, affected by marine debris.

External entanglements (93.8%) were more common than debris ingestion (4.8%). In two cases, the animals presented both an external entanglement and ingestion of debris (1.4%). The results showed that gray seals were mostly affected by external entanglements (98.3%), whereas harbor seals showed a higher incidence of ingested debris (22.2%) when compared with gray seals. External entanglements located around the neck of the animal were more common (69%) than those located in other body parts (e.g., flippers or head) (Figure 4). In some cases, the animals were affected by the entanglement at two different body sites.

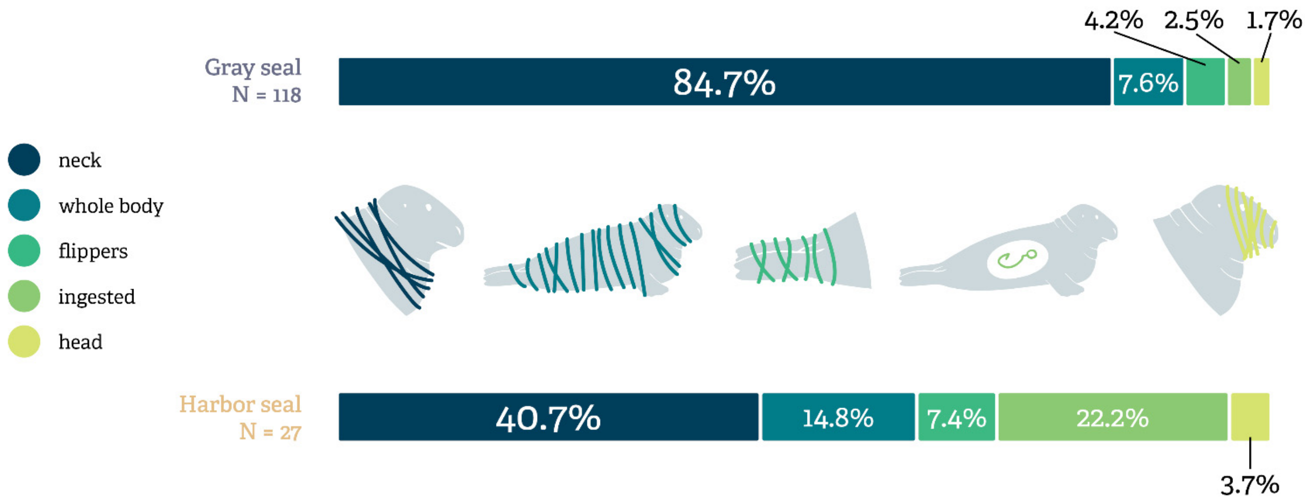


Figure 4. Body locations of the entanglements and their incidence separated by species. Gray seal numbers are shown at the top of the figure, and harbor seal numbers at the bottom.

The majority of entanglements were caused by marine debris which originated from the boating/fishing industry (83.4%), such as fishing nets, ropes, fishing lines, fishing hooks, etc. From the marine debris in this category, fishing nets (88.4%) were the most abundant. In 12% of the reported entanglements, the debris had a different origin (i.e., frisbee, clothing, potato net, rubber band, tarpaulin, etc.). Debris from fishing/boating was reported every year, whereas debris from other origins was not (see Figures S1 and S2 in the Supplementary Materials). Entanglements could be caused by a single piece of debris (89.7%) or by several pieces (5.5%) (e.g., fishing net and wrapping plastic). In seven cases, no information was reported about the origin of the debris (4.8%) (Figure 5).

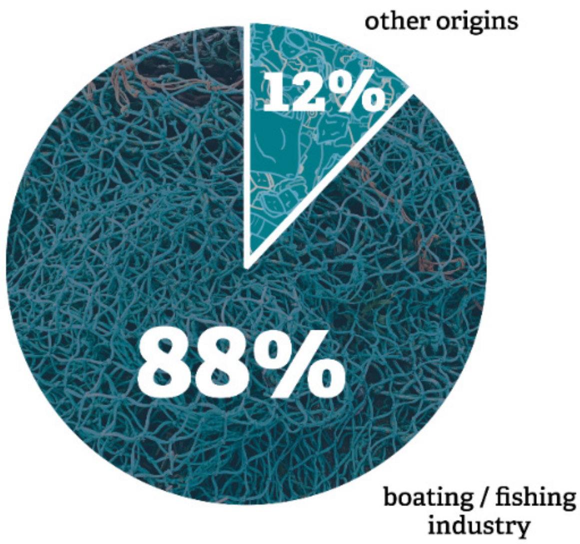


Figure 5. Percentages of the different origins of the entangling debris.

4. Discussion

The results of our study show that (i) the number of entangled seals increased over the last years, (ii) gray seals are more affected by marine debris than harbor seals, (iii) the most affected animals were juveniles, (iv) gray seals suffer more from external entanglements (i.e., around the neck) and harbor seals ingest debris more frequently, and (v) most marine debris causing entanglements, such as fishing nets, comes from the fishing/boating industry.

4.1. Yearly Trends

Our study reports on 145 cases of phocids affected by marine debris from 2010 to 2020 in the Netherlands. We compared our results with two previous studies on reported entanglements around the Dutch coast: Osinga and colleagues [15] reported 77 strandings of animals affected by marine debris from 1979 to 2008 (2.7 strandings per year); the 2010 SCP internal communication [25] reported 54 strandings over a 25-year period from 1985 to 2010 (2.2 strandings per year). This study (13.2 stranding per year) found that the number of yearly entanglements seems to have quadrupled since these reports were written, representing a clear and significant increase in the number of animals entangled in marine debris. It is important to note, however, that Osinga and colleagues [15] only reported strandings of dead animals, whereas this study and the 2010 SCP internal communication [25] reported on both live and dead strandings. Moreover, our study reports on strandings from all three Dutch rehabilitation centers, whereas the two previous studies only reported stranding data from SCP; hence, the current numbers must be interpreted with caution when comparing with the two previous studies.

4.2. Species Differences

4.2.1. Number of Entanglements

When comparing species, we found that the incidence of entanglements in gray seals is more than four times higher than that in harbor seals (Figure 2), even though, in 2016, the Dutch population of harbor seals was three times as large as the population of gray seals [23,31]. Our results are in line with those of the 2010 SCP internal communication [25], which reported a 2.6-fold higher incidence of entanglements in gray seals than in harbor seals, but contradict the results of Osinga and colleagues [15], who reported a 3.5-fold higher likelihood of entanglement in harbor seals. Nevertheless, the results obtained by Osinga and colleagues [15] should be interpreted with caution because most of the cases they reported were categorized as inferred by-catch. They defined inferred by-catch as dead animals found without a net and without external physical evidence of contact with fishing gear, but which always met all the following criteria: (1) fish (remains) in the stomach or intestines, (2) good nutritional condition, (3) no other significant pathological findings, and (4) the presence of lung edema. We believe that such cases do not necessarily suggest by-catch, because no further histopathological examination of carcass tissues was performed, potentially missing acute diseases without clear macroscopic alterations such as acute bronchopneumonia, cardiovascular problems, and septicemia, among others. This suggests that the higher incidence of reported entanglements in harbor seals was likely over-represented by Osinga and colleagues [15]. We thus propose that future studies only include cases of confirmed by-catch to avoid possibly inflating the number of reported entanglements, as conducted in the current report.

Comparing our results with previously published data, we found that, regardless of the location, gray seals still suffer more from entanglements than harbor seals [32,33]. Our gray seal yearly entanglement rate (0.3%) was considerably lower than the entanglement rates (3.6–5.0%) reported in the United Kingdom [34]. Similarly, our yearly entanglement rate for harbor seals (0.04%) was lower than rates (0.05–0.09%) reported in California in the mid-1980s [35]. However, these results should be interpreted with caution because none of the studies used the same methodology for reporting entanglements (e.g., only looking at haul-out sites) and calculating yearly entanglement rates.

4.2.2. Stranding Distribution

Gray seal breeding grounds are located on the islands of Vlieland, Terschelling, and the sandbanks in between both islands [36], which corresponds to the locations with higher stranding rates in this study (Figure 1b). Gray seals are known for their playful behavior [37,38]. They generally forage in deeper waters further away from their haul-out sites and eat larger prey [36,39]. The combination of playful behavior and foraging preferences may bring gray seals closer to active fishing grounds, increasing the number of interactions with fisheries, and subsequently increasing the likelihood of becoming entangled.

Harbor seals were stranded more frequently on the coastlines of South Holland and North Holland. However, we cannot explain this particular finding as their distribution along the Dutch coast is relatively homogeneous [39]. The higher incidence of ingested debris, such as fishing lines and hooks, found in harbor seals may be explained by their preference to forage in shallower waters and eat smaller-sized prey that is often targeted by recreational fishing [39].

In the Netherlands, the habitat of both species is constantly affected by anthropogenic activities, such as fishing [23,24]. In fact, Hastie and colleagues [40] showed that gray seals take foraging decisions based on the amount of fish available and the risks associated with sound exposure (i.e., aversiveness to anthropogenic noise). These behavioral changes may affect their foraging efficiency, potentially increasing the number of interactions with fishing boats and causing an increased risk of entanglement [40,41].

4.3. Age Differences

We find that juveniles of both species are more affected by marine debris than adults or pups (Figure 2). Young pinnipeds, particularly gray seals, tend to be more playful and curious than older individuals [20,37,38,42]. Juveniles tend to swim further away from their known haul-out locations to avoid competition with older individuals and explore new feeding grounds [43,44]. These age-related behavioral differences may explain the higher incidence of entanglements found in younger animals. Young animals are also the most affected by entanglements in other European locations, such as Ireland [32] and Germany [33].

4.4. Entanglements

4.4.1. Type of Entanglement

For both species, the most common external entanglements were located around the neck (Figure 3). However, this type of entanglement may have been over-represented in this study because these occurrences are easier to spot from boats or from the beach. To establish that an animal has ingested debris, further diagnostic procedures, such as radiography, are required. This could potentially have contributed to an under-representation of ingested debris.

4.4.2. Origin and Type of Debris

The most common material found causing entanglements originated from fishing activities, particularly fishing nets (Figure 4). This aligns with findings of the last Marine litter Wadden Sea Quality Status Report [4], which states that the majority of litter items found on beaches, such as plastic nets and ropes, are frequently used for fishing. Marine debris can be diverse, but because of its properties (resistant, durable, flexible, accessible, etc.), plastic debris is the most abundant [4,6,17]. In fact, five out of the nine seals that ingested marine debris in our study had swallowed fishing lines made of a synthetic plastic material called nylon. The direct effects of swallowed fishing line have been described before [12,20]; however, a potential indirect effect should be considered. Over time, large pieces of plastic can break down into smaller pieces due to the effect of waves, currents, and sunlight [45]. These small plastic particles, known as microplastics, can act as anchors for certain pollutants and toxins (e.g., persistent organic pollutants—POPs—or bis-phenol A). If these plastics are ingested, the pollutants they hold can leach out of them [45]. Once inside of an organism, these toxic substances accumulate in its body tissues because they cannot be metabolized. Individuals may suffer from a range of impairments, including endocrine disruption, growth inhibition, and impaired reproduction [1,46–49]. Moreover, the body tissue concentration of environmental pollutants increases at higher levels in the trophic food chain in a process known as biomagnification [50]. Seals, which are the apex predators of the Wadden Sea, are thus likely already exposed to higher levels of pollutants [49]. It is, however, unknown whether the ingestion of plastic debris further accelerates the uptake of environmental pollutants in seal body tissues.

In addition to the composition of the debris, the shape of the debris may also play a role in the incidence of entanglements. Debris that resembles the shape of a seal's prey could trigger a foraging behavior, potentially increasing the number of interactions with the debris, and consequently, the chances of becoming entangled. For example, the shape of a rope may resemble a sand eel (typical prey of gray and harbor seals [51,52]).

4.4.3. Data Collection Standardization

Although not all entangled animals are in need of rehabilitation, some entanglements may result in lesions that require medical treatment, as demonstrated by the case of a young gray seal (see the Supplementary Materials). The survival of such affected individuals is dependent on the quality of the intensive care provided, emphasizing the importance of rehabilitation efforts. Unfortunately, due to the lack of consistency among stranding reports, no further analysis was conducted based on the severity of the wounds. Forney and colleagues [53] developed a classification system of the severity of entanglement injuries in marine mammals, which we tried to apply in this study. According to this approach, the majority of our reported cases fell into the serious injury category, but we found that if immediate action could be taken and the entangled marine debris was removed on-site, serious injuries could be completely avoided. With this in mind, the authors have adapted Forney et al.'s [53] classification system based on our experience in seal rehabilitation. In doing so, we propose a comprehensive and standardized method for reporting and classifying entangled animals, which will facilitate data collection and improve on-site decision-making (see the Supplementary Materials).

5. Conclusions

In conclusion, we have shown that the numbers of entanglement cases are rapidly increasing around the Dutch coast. There may be several reasons for the increasing numbers of reported entanglements found in this study. First, the observed increase may be directly related to increased interactions with marine debris due to the higher abundance of waste found in our oceans [4,10,17,21,22]. Despite both gray and harbor seals having healthy populations in the Wadden Sea [23], the combined effects of anthropogenic threats, such as the increased abundance of marine debris, higher levels of environmental pollution (e.g., noise and microplastics), and increased interactions with fisheries, could, in the long run, become an important risk to the survival of these populations. There is thus an urgent need to keep developing public programs and implement governmental policies which aim to protect the marine environment. For example, initiatives such as the "Bins on Boats" are proving very successful in reducing the amount of boat-generated litter [54]. Second, the recent advice issued by the Scientific Advisory Committee on the rehabilitation of seals in the Netherlands states that "injured animals are to be assisted or rehabilitated if the injuries have been caused by direct human activities" [31], potentially resulting in increased public awareness of how local marine wildlife may be affected by environmental debris. Third, the heightened will to help animals in need combined with the widespread use of new technologies in recent years, such as smartphones and social media (e.g., WhatsApp), may have facilitated contact with rehabilitation centers, increasing the number of reported entanglements. Although public awareness is increasing and policies aimed at protecting the Dutch marine environment are being developed and implemented, it is currently unknown whether these efforts will be enough to ensure healthy and sustainable populations of gray and harbor seals in the years to come.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/oceans3030026/s1, Figure S1. Yearly numbers of reported entanglements and/or debris ingestion in gray seals grouped by (a) age, (b) sex, (c) stranding location, and (d) origin of the entangling debris. Figure S2. Yearly numbers of reported entanglements and/or debris ingestion in harbor seals grouped by (a) age, (b) sex, (c) stranding location, and

(d) origin of the entangling debris. Table S1. Form for Collecting Entanglement Data. Table S2. Classification of entanglement lesions based on observed injuries. Reference [55] is cited in the Supplementary Materials.

Author Contributions: Conceptualization, A.S.-C. and K.d.R.; methodology, A.S.-C. and K.d.R.; software, A.S.-C. and K.d.R.; validation, A.S.-C. and K.d.R.; formal analysis, A.S.-C. and K.d.R.; investigation and data collection, A.S.-C., N.G., J.H. and M.G.; analysis, A.S.-C. and K.d.R.; resources, A.S.-C., A.R.-G., J.H., M.G. and N.G.; data curation, A.S.-C., K.d.R. and N.G.; writing—original draft preparation, A.S.-C. and K.d.R.; writing—review and editing, A.S.-C., K.d.R., S.V., A.R.-G., M.G., J.H. and N.G.; visualization, A.S.-C. and K.d.R.; supervision, A.R.-G.; project administration, A.S.-C.; funding acquisition, K.d.R., M.G., J.H. and A.R.-G. All authors have read and agreed to the published version of the manuscript.

Funding: The Sealcentre Pieterburen, A Seal, and Ecomare, funded the seal stranding scheme and supported A.S.-C., A.R.G., S.V., N.G., M.G. and J.H. KdR was supported by the FWO project "Interactive vocal rhythms" G034720N awarded to Bart de Boer.

Institutional Review Board Statement: No ethical statement was required for the data collected for this study because it was part of the normal data collection of strandings and sightings in the Netherlands and no further animal experimentation was carried out. The animals accepted for rehabilitation underwent the necessary medical care and no unnecessary handling occurred.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to confidentiality.

Acknowledgments: The authors want to thank Sonia Velez Jimenez and Victor Romero Cazorla for their help on collecting and organizing the data, and Aline Joustra for creating the figures. We would like to thank all members and volunteers of Sealcentre Pieterburen, A Seal, and Ecomare for their continued support in this research. The authors would also like to thank three anonymous reviewers for their constructive comments on this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Agamuthu, P.; Mehran, S.B.; Norkhairah, A.; Norkhairiyah, A. Marine Debris: A Review of Impacts and Global Initiatives. *Waste Manag. Res.* **2019**, *37*, 987–1002. [CrossRef] [PubMed]
2. Sheavly, S.B.; Register, K.M. Marine Debris & Plastics: Environmental Concerns, Sources, Impacts and Solutions. *J. Polym. Environ.* **2007**, *15*, 301–305. [CrossRef]
3. Laist, D.W. Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and Ingestion Records. In *Marine Debris*; Coe, J.M., Rogers, D.B., Eds.; Springer Series on Environmental Management; Springer: New York, NY, USA, 1997; pp. 99–139. [CrossRef]
4. Fleet, D.M.; Dau, K.; Gutow, L.; Schulz, M.; Unger, B.; van Franeker, J.A. Marine Litter. In *Wadden Sea Quality Status Report 2017*; Common Wadden Sea Secretariat: Wilhelmshaven, Germany, 2017.
5. Galgani, F.; Fleet, D.; van Franeker, J.; Katsanevakis, S.; Maes, T.; Mouat, J.; Oosterbaan, L.; Poitou, I.; Hanke, G.; Thompson, R.; et al. *Marine Strategy Framework Directive—Task Group 10 Report: Marine Litter*; Office for Official Publications of the European Communities: Luxembourg, 2010. [CrossRef]
6. Rochman, C.M. The Story of Plastic Pollution from the Distant Ocean Gyres to the Global Policy Stage. *Oceanography* **2020**, *33*, 60–70. [CrossRef]
7. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056 (accessed on 5 March 2022).
8. Kuo, F.J.; Huang, H.W. Strategy for Mitigation of Marine Debris: Analysis of Sources and Composition of Marine Debris in Northern Taiwan. *Mar. Pollut. Bull.* **2014**, *83*, 70–78. [CrossRef]
9. Perez-Venegas, D.J.; Valenzuela-Sánchez, A.; Montalva, F.; Pavés, H.; Seguel, M.; Wilcox, C.; Galbán-Malagón, C. Towards Understanding the Effects of Oceanic Plastic Pollution on Population Growth for a South American Fur Seal (Arctocephalus Australis Australis) Colony in Chile. *Environ. Pollut.* **2021**, *279*, 116881. [CrossRef]
10. Gall, S.C.; Thompson, R.C. The Impact of Debris on Marine Life. *Mar. Pollut. Bull.* **2015**, *92*, 170–179. [CrossRef]
11. Costa, R.A.; Sá, S.; Pereira, A.T.; Ângelo, A.R.; Vaqueiro, J.; Ferreira, M.; Eira, C. Prevalence of Entanglements of Seabirds in Marine Debris in the Central Portuguese Coast. *Mar. Pollut. Bull.* **2020**, *161*, 111746. [CrossRef]
12. Parga, M.L. Hooks and Sea Turtles: A Veterinarian's Perspective. *Bull. Mar. Sci.* **2012**, *88*, 731–741. [CrossRef]

13. Steen, D.A.; Hopkins, B.C.; van Dyke, J.U.; Hopkins, W.A. Prevalence of Ingested Fish Hooks in Freshwater Turtles from Five Rivers in the Southeastern United States. *J. Wildl. Rehabil.* **2014**, *34*, 17–24. [CrossRef]
14. Fossi, M.C.; Panti, C.; Baini, M.; Lavers, J.L. A Review of Plastic-Associated Pressures: Cetaceans of the Mediterranean Sea and Eastern Australian Shearwaters as Case Studies. *Front. Mar. Sci.* **2018**, *5*, 173. [CrossRef]
15. Osinga, N.; Shahi Ferdous, M.M.; Morick, D.; García Hartmann, M.; Ulloa, J.A.; Vedder, L.; Udo de Haes, H.A.; Brakefield, P.M.; Osterhaus, A.D.M.E.; Kuiken, T. Patterns of Stranding and Mortality in Common Seals (Phoca Vitulina) and Grey Seals (Halichoerus Grypus) in The Netherlands between 1979 and 2008. *J. Comp. Pathol.* **2012**, *147*, 550–565. [CrossRef]
16. Sayer, S.; Hockley, K.; Allen, R. Entanglement and Its Effects on Grey Seals (Halichoerus Grypus) 2000 to 2013 Cornwall and North Devon, UK. In *World Animal Protection Commissioned Report*; World Animal Protection: London, UK, 2015; p. 50.
17. Butterworth, A. A Review of the Welfare Impact on Pinnipeds of Plastic Marine Debris. *Front. Mar. Sci.* **2016**, *3*, 149. [CrossRef]
18. Allyn, E.M.; Scordino, J.J. Entanglement Rates and Haulout Abundance Trends of Steller (Eumetopias Jubatus) and California (*Zalophus californianus*) Sea Lions on the North Coast of Washington State. *PLoS ONE* **2020**, *15*, e0237178. [CrossRef]
19. Dau, B.K.; Gilardi, K.V.K.; Gulland, F.M.; Higgins, A.; Holcomb, J.B.; St Leger, J.; Ziccardi, M.H. Fishing Gear-Related Injury In California Marine Wildlife. *J. Wildl. Dis.* **2009**, *45*, 355–362. [CrossRef]
20. Laist, D.W. Overview of the Biological Effects of Lost and Discarded Plastic Debris in the Marine Environment. *Mar. Pollut. Bull.* **1987**, *18*, 319–326. [CrossRef]
21. Barnes, D.K.A.; Galgani, F.; Thompson, R.C.; Barlaz, M. Accumulation and Fragmentation of Plastic Debris in Global Environments. *Philos. Trans. R. Soc. B Biol. Sci.* **2009**, *364*, 1985–1998. [CrossRef]
22. Høiberg, M.A.; Woods, J.S.; Verones, F. Global Distribution of Potential Impact Hotspots for Marine Plastic Debris Entanglement. *Ecol. Indic.* **2022**, *135*, 108509. [CrossRef]
23. Brasseur, S. *Stranding and Rehabilitation in Numbers: Population Development and Stranding Data on the Dutch Analysis of New Data from a Public Database*; Wageningen Marine Research Report, No. C108/17; Wageningen Marine Research: Wageningen, The Netherlands, 2018. [CrossRef]
24. Jensen, L.F.; Teilmann, J.; Galatius, A.; Pund, R.; Czeck, R.; Jess, A.; Siebert, U.; Körber, P.; Brasseur, S. Marine Mammals. In *Wadden Sea Quality Status Report 2017*; Common Wadden Sea Secretariat: Wilhelmshaven, Germany, 2017.
25. Hekman, R.; Osinga, N. *Fishnet Entanglement in Common Seals (Phoca vitulina) and Grey Seals (Halichoerus grypus) Stranded on the Dutch Coast, 1985–2010*; Sealcentre Pieterburen Internal Communication; Sealcentre Pieterburen: Pieterburen, The Netherlands, 2010.
26. Harms, C.A.; Greer, L.L.; Whaley, J.; Rowles, T.K. Euthanasia. In *CRC Handbook of Marine Mammal Medicine*; Gulland, F.M.D., Dierauf, L.A., Whitman, K.L., Eds.; CRC Press: Boca Raton, FL, USA, 2018; pp. 675–691.
27. Pugliares, K.R.; Bogomolni, A.; Touhey, K.M.; Herzig, S.M.; Harry, C.T.; Moore, M.J. *Marine Mammal Necropsy: An Introductory Guide for Stranding Responders and Field Biologists*; Woods Hole Oceanographic Institution: Falmouth, MA, USA, 2007; p. 133. [CrossRef]
28. Jefferson, T.A.; Webber, M.A.; Pitman, R.L. Pinnipeds. In *Marine Mammals of the World*, 2nd ed.; Jefferson, T.A., Webber, M.A., Pitman, R.L., Eds.; Academic Press Elsevier: London, UK, 2015; pp. 358–522.
29. Meyers, R.A.; Bowen, W.D.; Stobo, W.T. *Duration of Pelage Stages of Grey Seal, Halichoerus grypus, Pups*; Research Document 97/11; Department of Fisheries and Oceans, Canadian Stock Assessment Secretariat: St. John's, NL, Canada, 1997.
30. Renouf, D. *Behaviour of Pinnipeds*, 1st ed.; Springer Science & Business Media: Dordrecht, The Netherlands, 1991.
31. van der Zande, A.N.; van Alphen, J.J.M.; Goodman, S.J.; Meijboom, F.L.B.; Stegeman, A.J.; Thompson, D.; Kuindersma, W.; Latour, J.B. *Advice of the Scientific Advisory Committee on Seal Rehabilitation in The Netherlands*; Record Number 535588; Wageningen Environmental Research: Wageningen, The Netherlands, 2018.
32. Cosgrove, R.; Gosch, M.; Reid, D.; Sheridan, M.; Chopin, N.; Jessopp, M.; Cronin, M. Seal Bycatch in Gillnet and Entangling Net Fisheries in Irish Waters. *Fish. Res.* **2016**, *183*, 192–199. [CrossRef]
33. Unger, B.; Herr, H.; Benke, H.; Böhmert, M.; Burkhardt-Holm, P.; Dähne, M.; Hillmann, M.; Wolff-Schmidt, K.; Wohlsein, P.; Siebert, U. Marine Debris in Harbour Porpoises and Seals from German Waters. *Mar. Environ. Res.* **2017**, *130*, 77–84. [CrossRef]
34. Allen, R.; Jarvis, D.; Sayer, S.; Mills, C. Entanglement of Grey Seals *Halichoerus grypus* at a Haul out Site in Cornwall, UK. *Mar. Pollut. Bull.* **2012**, *64*, 2815–2819. [CrossRef]
35. Stewart, B.S.; Yochem, P.K. 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.* **1987**, *18*, 336–339. [CrossRef]
36. Brasseur, S.; Aarts, G.; Kirkwood, R. *Habitat Quality for Grey Seals in the Dutch Wadden Sea*; Report Number: C090/14; Institute for Marine Resources & Ecosystem Studies (IMARES): Wageningen, The Netherlands, 2014.
37. Surviliene, V.; Rukšenas, O.; Pomeroy, P. Play Behavior of Wild Grey Seals (Halichoerus grypus): Effects of Haulout Group Size and Composition. *Aquat. Mamm.* **2016**, *42*, 144–161. [CrossRef]
38. Wilson, S. Juvenile Play of the Common Seal (*Phoca vitulina* vitulina) with Comparative Notes on the Grey Seal (*Halichoerus grypus*). *Behaviour* **1974**, *48*, 37–60. [CrossRef]
39. Aarts, G.; Cremer, J.; Kirkwood, R.; van der Wal, J.T.; Matthiopoulos, J.; Brasseur, S. *Spatial Distribution and Habitat Preference of Harbour Seals (Phoca vitulina) in the Dutch North Sea*; Report Number C118/16 (ISSN 1566-7197); Wageningen Marine Research: Wageningen, The Netherlands, 2016. [CrossRef]

40. Hastie, G.D.; Lepper, P.; McKnight, J.C.; Milne, R.; Russell, D.J.F.; Thompson, D. Acoustic Risk Balancing by Marine Mammals: Anthropogenic Noise Can Influence the Foraging Decisions by Seals. *J. Appl. Ecol.* **2021**, *58*, 1854–1863. [CrossRef]
41. Erbe, C.; Dunlop, R.; Dolman, S. Effects of Noise on Marine Mammals. In *Effects of Anthropogenic Noise on Animals*; Slabbekoorn, H., Dooling, R.J., Popper, A.N., Fay, R.R., Eds.; Springer Science + Business Media: New York, NY, USA, 2018; pp. 277–309. [CrossRef]
42. Page, B.; McKenzie, J.; McIntosh, R.; Baylis, A.; Morrissey, A.; Calvert, N.; Haase, T.; Berris, M.; Dowie, D.; Shaughnessy, P.D.; et al. 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.* **2004**, *49*, 33–42. [CrossRef]
43. Oates, S.C. Survival, Movements, and Diet of Juvenile Harbor Seals along Central California. Master's Thesis, San Jose State University, San Jose, CA, USA, 2005.
44. Carter, M.I.D.; Russell, D.J.F.; Embling, C.B.; Blight, C.J.; Thompson, D.; Hosegood, P.J.; Bennett, K.A. Intrinsic and Extrinsic Factors Drive Ontogeny of Early-Life at-Sea Behaviour in a Marine Top Predator. *Sci. Rep.* **2017**, *7*, 15505. [CrossRef]
45. Andrady, A.L. Microplastics in the Marine Environment. *Mar. Pollut. Bull.* **2011**, *62*, 1596–1605. [CrossRef]
46. Desforges, J.P.; Hall, A.; Mcconnell, B.; Rosing-Asvid, A.; Barber, J.L.; Brownlow, A.; de Guise, S.; Eulaers, I.; Jepson, P.D.; Letcher, R.J.; et al. Predicting Global Killer Whale Population Collapse from PCB Pollution. *Science* **2018**, *361*, 1373–1376. [CrossRef]
47. Jepson, P.D.; Deaville, R.; Barber, J.L.; Aguilar, À.; Borrell, A.; Murphy, S.; Barry, J.; Brownlow, A.; Barnett, J.; Berrow, S.; et al. PCB Pollution Continues to Impact Populations of Orcas and Other Dolphins in European Waters. *Sci. Rep.* **2016**, *6*, 18573. [CrossRef]
48. Kannan, K.; Blankenship, A.L.; Jones, P.D.; Giesy, J.P. Toxicity Reference Values for the Toxic Effects of Polychlorinated Biphenyls to Aquatic Mammals. *Hum. Ecol. Risk Assess.* **2000**, *6*, 181–201. [CrossRef]
49. de Swart, R.L.; Ross, P.S.; Vos, J.G.; Osterhaus, A.D.M.E. Impaired Immunity in Harbour Seals (*Phoca vitulina*) Exposed to Bioaccumulated Environmental Contaminants: Review of a Long-Term Feeding Study. *Environ. Health Perspect.* **1996**, *104* (Suppl. 4), 823–828. [CrossRef] [PubMed]
50. Nelms, S.E.; Galloway, T.S.; Godley, B.J.; Jarvis, D.S.; Lindeque, P.K. Investigating Microplastic Trophic Transfer in Marine Top Predators. *Environ. Pollut.* **2018**, *238*, 999–1007. [CrossRef] [PubMed]
51. Hall, A.J.; Watkins, J.; Hammond, P.S. Seasonal Variation in the Diet of Harbour Seals in the South-Western North Sea. *Mar. Ecol. Prog. Ser.* **1998**, *170*, 269–281. [CrossRef]
52. Hammond, P.S.; Hall, A.J.; Prime, J.H. The Diet of Grey Seals Around Orkney and Other Island and Mainland Sites in North-Eastern Scotland. *J. Appl. Ecol.* **1994**, *31*, 340–350. [CrossRef]
53. Forney, K.A.; Cole, T.V.N.; Eagle, T.; Angliss, R.; Long, K.; Barre, L.; Van, L.; Borggaard, A.D.; Rowles, T.; Norberg, B.; et al. *Differentiating Serious and Non-Serious Injury of Marine Mammals: Report of the Serious Injury Technical Workshop 10–13 September 2007, Seattle, Washington*; NOAA Technical Memorandum NMFS-OPR-39; National Oceanic and Atmospheric Administration: Washington, DC, USA, 2008.
54. Kusmanoff, A.M.; McIntosh, R.R.; Boag, S.; Bekessy, S.A. "Bins on Boats", a Behaviourally-Based Intervention to Curb Marine Pollution in Bass Strait, Australia. *Conserv. Sci. Pract.* **2022**, *4*, e12659. [CrossRef]
55. Merck Laboratories. *The Merck Veterinary Manual*, 10th ed.; Kahn, C.M., Line, S., Eds.; Merck & Co., Inc.: Kendallville, IN, USA, 2010; p. 2945.