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Entanglement of Steller Sea Lions in Marine Debris and Fishing Gear on the Central Oregon Coast from 2005–2009 †

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Abstract: Entanglement in marine debris and fishing gear is an increasing problem for the world's pinnipeds and a contributing factor in Steller sea lion (*Eumetopias jubatus*) injury and mortality. From 2005–2009, we surveyed (n = 389 days) two haul-outs on the central Oregon coast containing a combined median of 402 animals (range 33–1240, or ca. 1–19% of the Oregon coast population). We recorded 72 individuals entangled in marine debris (n = 70) or with ingested salmon hook-and-line fishing gear (n = 2). Of the identifiable neck entanglements, black rubber bands were the most common neck-entangling material (62%), followed by plastic packing bands (36%), nets (1.2%), yellow rubber bands (0.4%), and a flying disc (0.4%). The estimated prevalence of entanglement for individuals in Oregon was 0.34%. Juveniles were the most frequently entangled age class (60%), followed by adult females (28%), and subadult males (12%). Supply chain and industry-based solutions are needed to prevent entangling debris from entering the ocean, along with eliminating, modifying, or cutting entangling loops of synthetic material.

Keywords: Steller sea lion; *Eumetopias jubatus*; marine debris; entanglement; Oregon; packing bands; rubber bands; Lose the Loop

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1. Introduction

Entanglement of marine mammals in marine debris and derelict fishing gear is a growing problem in the world's oceans. The number of marine species reported entangled in or with ingested marine debris has grown from 267 species in 1997 [1] to 557 species in 2015 [2] and 914 species in 2020 [3]. Plastics and related synthetic materials have replaced natural fibers in the fishing industry, primarily due to their low cost, light weight, durability, and strength [4]. Land-based plastics entering the ocean are also a major contributor to entanglement and ingestion of marine species. Jambeck, et al. [5] calculated that 275 million metric tons (MT) of plastic waste was generated in 192 coastal communities in 2010, 4.8 to 12.7 metric tons of which entered the ocean. Without waste management changes, the cumulative quantity of plastic waste that may enter the ocean from land is predicted to increase by an order of magnitude by 2025 [5]. Synthetic materials are less likely to sink, last longer once discarded or lost, and are harder for marine organisms to escape from once entangled [4]. Entangling marine debris causes suffocation, drowning, lacerations, infection, strangulation, and increased energy expenditure (e.g., while dragging large fragments of net), resulting in mortality. Because many marine species are either rarely observed or die at sea as a result of their entanglements, accurately estimating the prevalence of entanglement and mortality is difficult and likely underrepresented. Previous studies of pinnipeds indicate that the probability of sighting entangled animals on land is reduced by their increased time spent at sea and lower survival rates caused by their entanglements [6,7].

Increasing concern over plastics in the ocean led to the introduction of Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), which prohibits the at-sea disposal of plastic wastes. Annex V was formally adopted in 1988 and has been ratified by more than 70 nations. However, illegal dumping of plastics is difficult to enforce and continues to be a threat to marine life.

Entanglement of pinnipeds in marine debris is increasing and is now reported in 85.7% of otariid species and 62.5% of phocid species globally [3]. Although, entanglements are reported more often for otariids than phocids, the prevalence of entanglement varies considerably from 0.1% to 7.9% of species surveyed [8,9]. Comparison among studies, however, is complicated by multiple factors, including methods used to calculate the prevalence of entanglement and age composition of the population being studied. For example, the majority of entanglements frequently occur with pups and juveniles [10–13], likely as a result of their curiosity as they seek out and interact with entangling debris [4].

The Steller sea lion (*Eumetopias jubatus*) occurs from central California along the Pacific Rim to Japan [14,15]. Because of unexplained widespread population declines of more than 80% in Alaska, Steller sea lions were first listed under the Endangered Species Act (ESA) in 1990 [16,17]. In 1997, the population was divided into two distinct population segments, listing the eastern distinct population segment (DPS), which includes Oregon, as threatened and the western DPS (west of 144° W longitude) as endangered. In 2013, the eastern DPS was delisted under the ESA but maintains protection under the Marine Mammal Protection Act. Along the Oregon coast, Steller sea lions occupy two rookeries at Rogue Reef and Orford Reef and use eight additional haul-out sites, including Sea Lion Caves and Cascade Head.

Entanglement in marine debris and fishing gear has been shown to contribute to Steller sea lion injury and mortality [12,18,19]. Although Steller sea lion entanglement results have been reported in northern Southeast Alaska, British Columbia, and northern Washington [12,20], our study provides the first report of Steller sea lion prevalence of entanglement in Oregon. The goal of this study was to provide baseline data on entanglements affecting Steller sea lions in the southern portion of their range. Our objectives were to: (1) determine sources of marine debris entangling Steller sea lions; (2) estimate the prevalence of entanglement for the central coast Oregon Steller sea lion population; (3) estimate the sex and age class of entangled Steller sea lions by entanglement type; (4) determine what actions can be taken to reduce entanglements of Steller sea lions off Oregon; and (5) compare results to Steller sea lions entangled in Alaska and Washington.

2. Materials and Methods

We collected entanglement data during Steller sea lion studies at Sea Lion Caves (44.1167° N, 122.133° W) from 2005–2009 and at Cascade Head (45.072° N, 124.009° W) from 2005–2007 (Figure 1; data file available in Supplementary Materials). Sea Lion Caves is privately owned and operated and includes a natural Basalt rock, amphitheater-shaped cave approximately 37 m high and 91 m long. There also are rocky haul-outs to the north and south of the cave entrance. Steller sea lions use the cave primarily from November through August and haul-outs outside the cave from January through August. Cascade Head haul-out is a series of cobble cove beaches used by Steller sea lions, California sea lions (*Zalophus californianus*), and harbor seals (*Phoca vitulina*) intermittently throughout the year.

We observed Steller sea lions in the field from November through April 2005–2007 for at least four hours per day approximately two days per week during daylight hours. Observers used 8× or 10× binoculars and a spotting scope ($16 - 48 \times 60$) to observe animals. Each haul-out was continuously scanned throughout each observation period to look for branded and entangled Steller sea lions. We attempted to digitally photograph (Nikon 70s, Nikon Corporation, Thailand) all entangled Steller sea lions from a variety of different angles to match individuals within and between years. We deployed six remotely operating video cameras from April 2008 through August 2009 at Sea Lion Caves to observe Steller sea lions. Six IQeye 5.0 megapixel video cameras (Vicon, San Juan Capistrano, CA, USA) mounted within waterproof, pressurized Videolarm (Kintronics, Ossining, NY, USA) housings were installed within Sea Lion Caves and overlooking a haul-out outside the cave. Cameras were set at one frame per second (FPS) using IQvision software. Using NetDVR software, we programmed cameras to operate from 0800–1900 (times varied by daylight hours) seven days per week. Cameras were on the same circuit as all other electrical equipment at Sea Lion Caves and the start and end times of the cameras were dictated by when the staff turned electrical equipment on and off each day. Video signals were sent via Category 5 cable (24 gauge, solid conductor, twisted-pair cable). Power was run through 14-gauge two-conductor wire. We ran wires through the conduit to a main building, which housed an internet-connected, desktop computer with attached external hard drives. We saved images to the main computer during the day and backed-up to four 750 MB external eSATA (SEAGATE, Carson, CA, USA) hard drives every night. This technology allowed us to observe Steller sea lions in their natural habitat without disturbance using the same protocol as during in-person observations.

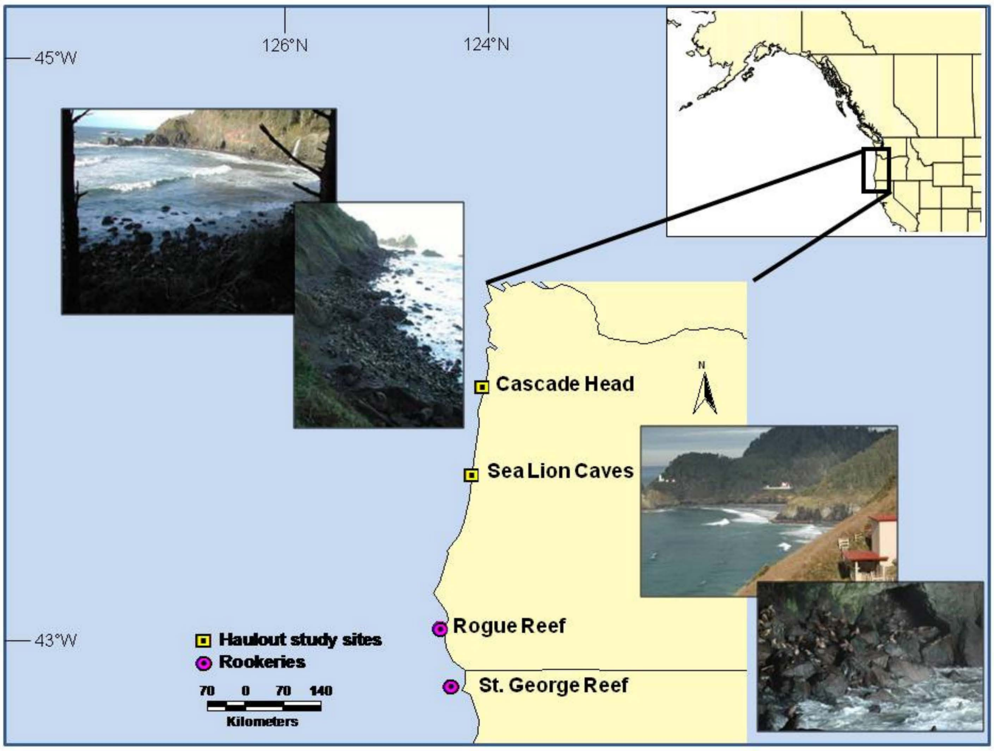

Figure 1. Map depicting Oregon haul-outs where Steller sea lions were observed during 2005–2009. Rookeries indicate where Steller sea lions were branded as pups.

We used two sets of external hard drives alternately at Sea Lion Caves and switched every two or three weeks so that images could be downloaded between visits. We conducted observations of Steller sea lions via the archived video images using NetDVR software running on a desktop computer. Via internet connection to the video cameras, we recorded date, camera start time, end time, and amount of hard drive storage capacity used daily.

When an entangled individual was observed we recorded: type of entanglement (e.g., neck entanglement, hook and/or ingested fishing gear), description of entangling material (e.g., white plastic packing band, black rubber band, and salmon flasher (lure)), severity of entanglement or ingested gear, age class (adult, subadult, and juvenile), sex (if able to determine), and behavior (e.g., nursing pup, etc.). Adult females were classified as age $\geq$ 4 years, adult males as $\geq$9 years, subadult males as 4–8 years, and juveniles as 0 year to <4 years. When possible, we compared known-aged (tagged or branded) animals to an entangled animal to help us estimate age of the entangled animal. We conducted abundance and composition (age and sex) counts of Steller sea lions in person in the field from 2005–2007 and at 11:00 each day for images recorded from video cameras from 2008–2009. Additional data collected included: date, location, observers, photographer, start and end times, and weather. We entered photographs of entangled individuals into a database along with detailed information about each individual.

To determine the prevalence of entanglement, we first divided the total number of entangled Steller sea lions counted on a haul-out by the total number of Steller sea lions on that haul-out. We then calculated a mean of means for each haul-out site then a grand mean for both sites.

We determined population level effects of entanglements using published equations to estimate population size based on pup counts [17,21,22]. This method uses the total pup count in a given year $\times$ 1.10 to account for 10% of pups missed during surveys. Using life tables, Calkins and Pitcher [21] estimated the ratio of total animals to pups in a stationary population would be about 4.5:1. Sensitivity analyses [22] indicated that for a population increasing at 3.1% (the rate of increase for the Oregon Steller sea lion population during the study period), the ratio could be as low as 4.2:1 if the increase was due to elevated fecundity, or as high as 5.2:1 if the increase was due to reduced juvenile mortality. Therefore, we multiplied the prevalence of entanglement by the low and high range of the estimated population size in Oregon for 2009 to estimate the number of Steller sea lions entangled at one point in time.

3. Results

Median counts of Steller sea lions, excluding pups, were 318 (range 31–876) individuals at Sea Lion Caves and 85 (range 2–364) individuals at Cascade Head during 389 survey days. We recorded a total of 72 individuals entangled in marine debris or having ingested salmon hook-and-line fishing gear. Steller sea lions with neck entanglements (n = 70) were much more common than those with salmon fishery hook-and-line gear (n = 2). Of the 70 individuals with neck entanglements, we were unable to identify 29% (n = 21) of the entangling materials. The source of the remaining neck entanglements could not be identified because the entangling material was either too deeply embedded in the neck or the quality of the image was not clear enough to determine what the material was. Of the 21 identifiable neck entanglements (Figure 2), black rubber bands (Figure 3) were the most common entangling material (62%), followed by plastic packing bands (36%; Figure 4), nets (1.2%; Figure 5), yellow rubber bands (0.4%), and a flying disc (0.4%). Two individuals were observed with salmon hook-and-line gear (flashers/lures) hanging from their mouths, indicating a swallowed hook (Figure 6). Severity codes (Table 1) for Steller sea lions were based on Croxall, et al. [23] using the terms nil (loose), slight (snug constriction but does not break skin), severe (cutting through skin), and very severe (cutting through skin and underlying fat). The majority of the neck entanglements were very severe (71%) or severe (5%), with the entangling material cutting through skin (Table 1). Black rubber bands comprised the majority (42.7%) of severe neck entanglements, followed by plastic packing bands (34%), unknown (22.4%), and swallowed hooks with flashers/lures hanging from the mouth (0.9%; Table 1). The majority of very severe neck entanglements were unidentifiable (55.6%), followed by plastic packing bands (33.3%), and nets (11.1%; Table 1).

Overall, the prevalence of Steller sea lion entanglement for Sea Lion Caves and Cascade Head was estimated as 0.34% (SE = 0.030). Juveniles were the most frequently entangled age class (60%), followed by adult females (28%), and subadult males (12%; Figure 7).

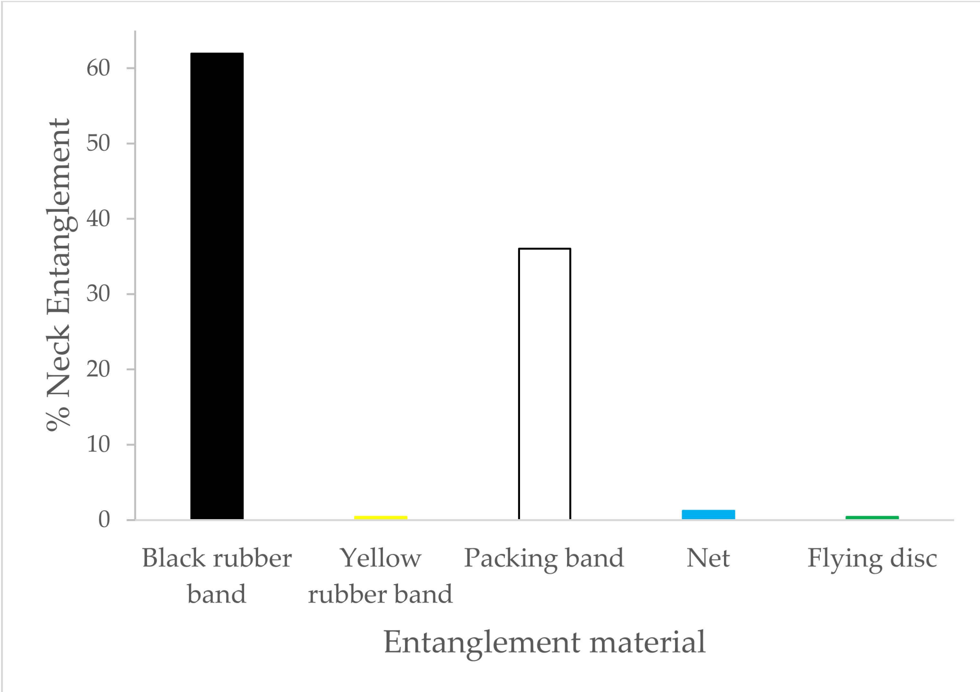

Figure 2. Percentage of identifiable Steller sea lion neck entanglements (n = 49) observed by entanglement type during surveys at Sea Lion Caves and Cascade Head haul-outs in Oregon during 2005–2009.

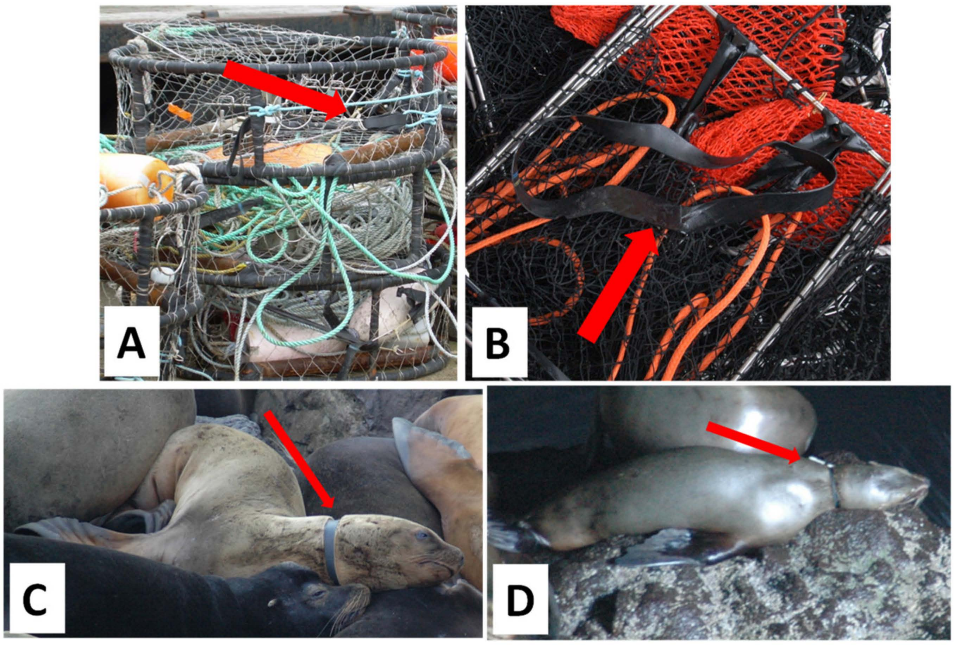

Figure 3. Examples of (**A**) commercial Dungeness crab pot with attached black rubber band, (**B**) loose rubber band lying on top of recreational crab pot aboard vessel underway, (**C**) juvenile Steller sea lion with black rubber band neck entanglement at Cascade Head, Oregon, and (**D**) juvenile Steller sea lion with black rubber band and attached white plastic hook neck entanglement at Sea Lion Caves, Oregon. Red arrows point to black rubber bands in each photo.

Based on the prevalence of entanglement of 0.34% and a population size of Steller sea lions in Oregon of between 6241 and 7726 in 2009, we determined that there was a minimum of between 21 and 26 visibly entangled Steller sea lions on the central Oregon coast in 2009 at any one point in time.

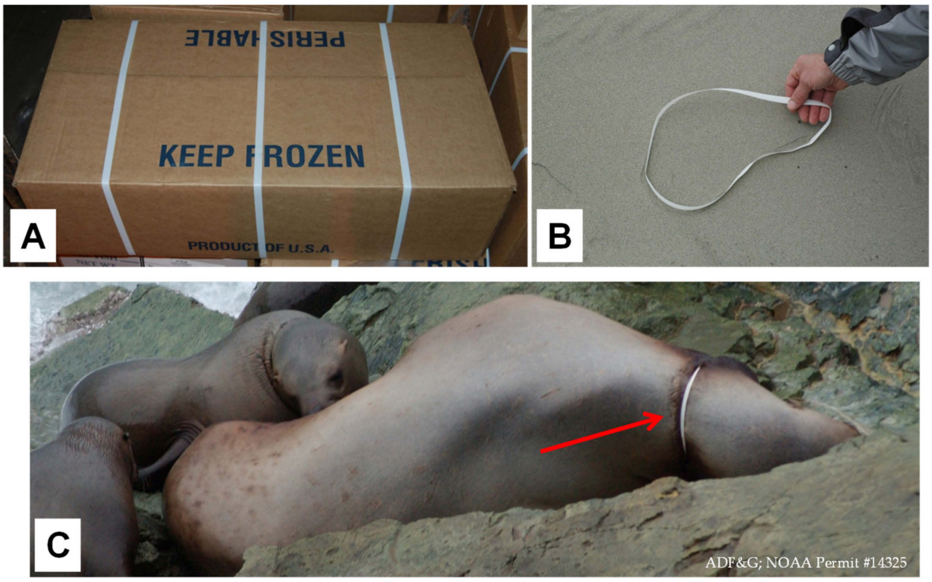

Figure 4. Examples of (**A**) plastic packing bands on fish bait box, (**B**) plastic packing band washed up on a beach in Newport, Oregon, and (**C**) adult female Steller sea lion with plastic packing band around neck (indicated by red arrow).

Figure 5. Juvenile Steller sea lion entangled in large net of unknown origin at Sea Lion Caves, Oregon.

Figure 6. Example of (**A**) Salmon fishery flashers (lures) sold in a typical marine supply store, and (**B**) Steller sea lion that has swallowed a hook indicated by flasher lodged tightly against mouth.

Table 1. Codes used to depict entanglement or ingestion severity and percentage of the degree of entanglement severity (overall and by entangling material within each severity category) of Steller sea lions observed from 2005–2009. Neck-entangling materials: PB = packing band; BRB = black rubber band; YRB = yellow rubber band; FD = flying disc; FL = flasher/lure; U = unknown.

Degree of Severity	Description	Percentage of Steller Sea Lion Neck Entanglement Severity Overall (and by Entangling Material within Each Severity Category)
D1	NIL: Neck entanglement loose; exerting no pressure	1% (0.5% PB, 0.5% FD)
D2	SLIGHT: Neck entanglement tight but not breaking the skin	23% (80.3% BRB, 11.8% PB, 1.3% YRB, 1.3% Net, 5.3% U)
D3	SEVERE: Neck entanglement material cutting through skin; swallowed hook or hook with flasher attached	71% (42.7% BRB, 34.0% PB, 0.9% FL, 22.4% U)
D4	VERY SEVERE: Neck entanglement material cutting through skin, blubber, and at times muscle; fluids from swallowed hook visible from mouth; likely to cause death	5% (33.3% PB, 11.1% Net, 55.6% U)

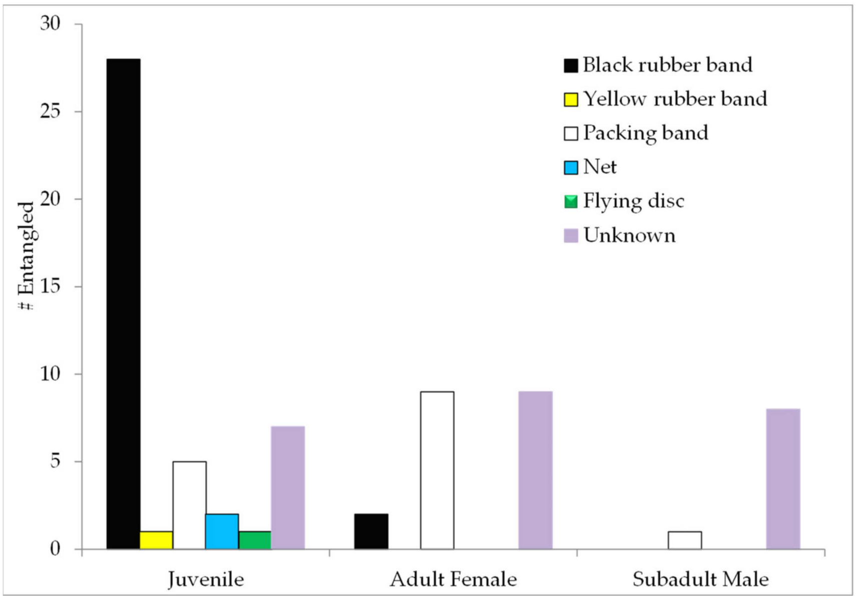

Figure 7. Number of juvenile, adult female, and subadult male Steller sea lions entangled by entanglement material observed during surveys in Oregon during 2005–2009.

4. Discussion

This study was the first to report on live Steller sea lion entanglements in Oregon. The results indicate that the majority of entangling debris affecting Steller sea lions in Oregon is fishery-based. Moreover, the highest percentage of entangling debris is from black rubber bands, most often used in commercial and recreational Dungeness crab (*Metacarcinus magister*) fisheries and other pot fisheries. There may be other sources of black rubber bands, but after extensive discussions with fishing industry participants, including the Oregon Dungeness Crab Commission, crab fishing was identified as the most likely source. The second most common entangling debris is from loops of plastic packing bands, often used on shipping and bait boxes. Less frequently observed entanglements included nets, yellow rubber bands (used by mariners to hold cuffs of raingear tight) and a plastic flying disc. The only ingested materials observed were salmon fishery flashers hanging from the mouth, indicating that the individual swallowed a hook.

We were surprised to find that the majority of Steller sea lion neck entanglements observed during this study were a result of black rubber bands. We observed 62% of individuals entangled in black rubber bands during our five-year study at two haul-out sites compared with 30% of Steller sea lions entangled in black rubber bands in an eight-year study at 78 haul-out sites in Southeast Alaska and northern British Columbia [12] and only 7.8% of Steller seas lions entangled in black rubber bands at four haul-out sites in northern

Washington [20]. Though we do not fully understand why the prevalence of entanglement in black rubber bands is so much higher in Oregon, the most likely explanation is that the Steller sea lions are becoming entangled in loose, floating rubber bands that were lost overboard. It may also be possible that the Steller sea lions are somehow becoming entangled in the pots themselves. During the time of this study, an estimated 10% or 10,000 of the crab pots fished during the season [24] were lost each year in Oregon. Pots may break free in rough seas, be cut by the propellers of passing vessels, tangled up with seaweed, or snagged on other, older derelict gear. Some Dungeness crab pots lost during the 2006–2007 fishing season were recovered four years later in the Northwestern Hawaiian Islands [25]. The Oregon Department of Fish and Wildlife implemented multiple regulations to reduce the amount and impact of derelict crab gear and has initiated crab gear research and retrieval programs [24], but the fact remains that there are thousands of derelict crab pots that risk contributing to marine mammal entanglements. Although it is difficult to determine how Steller sea lions could become entangled in rubber bands attached to derelict pots, we cannot rule out this possibility.

Plastic packing bands were the second most common neck entanglement for Steller sea lions during this study as opposed to being the most common neck entanglement for Steller sea lions in Southeast Alaska, northern British Columbia [12], and northern Washington [20]. However, of our incidental observations of California sea lions in Oregon (primarily on the docks in Newport, Oregon), plastic packing bands were the most common identifiable neck entanglement as they also were for California sea lions on the northern Washington coast [20]. Plastic packing bands continue to be widely reported as a cause for pinniped neck entanglements globally [10,13,26,27]. One source of packing bands is from bait boxes used on fishing vessels. Two industry outreach campaigns in the South Atlantic and South Pacific Oceans were successful in reducing the use and loss at sea of packing bands and encouraged fishers to cut the bands to prevent entangling loops [7,27]. The ultimate solution is to eliminate the use of plastic packing bands or use a quickly biodegradable material to secure bait boxes and other items that currently use packing bands. Using a biodegradable band would not only eliminate the risk of entanglement but would also reduce the amount of plastic in the marine environment.

We only observed two Steller sea lions with ingested salmon hook-and-line gear from either commercial and/or recreational salmon fisheries at Sea Lion Caves. We also identified additional occurrences of ingested salmon hook-and-line gear by Steller sea lions on Rogue Reef (Figure 1) in southern Oregon using images from a remote camera installed at Rogue Reef Steller sea lion rookery (Oregon Department of Fish and Wildlife unpubl. data). Interestingly, the prevalence of ingested fishing gear was extremely low compared with Southeast Alaska and northern British Columbia [12], where 80% of ingested hook gear was from salmon hook-and-line fisheries and slightly lower than northern Washington [20], where 13.6% of Steller sea lions and 6.3% of California sea lions had ingested salmon hooks with flashers. Ingestion of salmon hook-and-line gear has also been commonly reported off California and associated with dead-stranded animals [19,28]. Therefore, it is unclear whether the few observations during our study do indeed reflect a low prevalence of ingestion with salmon hook-and-line gear or a need for additional sampling in other areas of the state where more commercial and recreational salmon hook-and-line fishing occurs.

We found Steller sea lion prevalence of entanglement (0.34%) to be within the range of other pinniped studies worldwide (0.1–7.9%) [8,9,23,29], higher than the 0.26% reported for Steller sea lions in Southeast Alaska and northern British Columbia [12] and slightly lower than the 0.41% reported for Steller sea lions in northern Washington [20]. However, it is extremely important for those studying pinniped entanglement to be consistent not only in their terminology but also in how they present their results. The word "rate" is often associated with reporting the prevalence of entanglement, but is incorrectly used, as there is no rate involved in the analysis. To continue to compare and track the prevalence of entanglement over time among species and regions, we must strive to be consistent in our analysis and our terminology.

The prevalence of entanglement and population level effects calculated for Steller sea lions is likely to be underestimated for several reasons. First, the likelihood of observing all entangled individuals is poor. Because of reduced survival and possibly more time spent at sea, entangled individuals are less likely to be sighted and resighted onshore as individuals that are not entangled [6,7,29,30]. Second, sea lions may die at sea as a result of their entanglements before being observed on land. We observed a juvenile Steller sea lion at Sea Lion Caves entangled in a large blue net (Figure 5), which we believe caused the individual to drown. We saw this individual during two consecutive days then saw pieces of a dead Steller sea lion floating in the cave the next day. Although this observation is circumstantial, it seemed unlikely that the individual could have become free from this large and heavy net. Third, external evidence of ingestion may not exist or may be lost over time. For example, some fishing gear (i.e., hooks and lines) may be ingested entirely or external pieces eventually break off, thus not visible to observers.

Just as observed in a study in Southeast Alaska and northern British Columbia [12], juvenile Steller sea lions were the most frequently observed age class entangled in marine debris in Oregon. Higher numbers of entanglements among younger age classes are frequently reported for pinnipeds [8,23,31,32]. Juvenile pinniped curiosity and play appear to be important factors causing animals to seek out and interact with entangling debris [4]. This was apparent in our study as we observed a plastic toy flying disc with a hollow center floating in the water in Sea Lion Caves. Several juvenile Steller sea lions swam around the disc, poking at it with their noses until one young Steller sea lion picked it up in his teeth, began playing with it, and eventually swam right through the hole of the disc and it became stuck around his neck. Flying discs with hollow centers have become an increasing source of entanglement in the United Kingdom (Sue Sayer, Cornwall Seal Group, personal communication, https://www.cornwallsealgroup.co.uk/2022/05/solid-discs-only/ (accessed on 28 April 2022)) and caused the near decapitation of a grey seal (*Halichoerus grypus*). Neck entanglements are especially lethal to juvenile animals because as a sea lion or seal grows, the entangling material tightens, eventually strangling the animal or causing secondary infection.

The global quantity and diversity of entangling materials emphasizes the need for continued education campaigns that increase awareness of the impacts of marine debris and solutions to reduce entangling marine debris. Prevention of debris entering our waterways is the key to reducing entanglements. One such collaborative effort is the international Pinniped Entanglement Group (https://pinnipedentanglementgroup.org/ (accessed on 28 April 2022)), which focuses on pinniped entanglement prevention, outreach and education, exploring innovative disentanglement techniques, and rescue. It is also important that researchers work together with social scientists to: (1) determine the sources of items entangling pinnipeds; (2) identify if items are lost intentionally or accidentally; and (3) determine if outreach efforts actually make a difference so that time and funding are used more wisely.

In our study area, the priority is to reduce the number of rubber bands and plastic packing bands entering the ocean. As a first step, we met with the Oregon Dungeness Crab Commission, Oregon Sea Grant, and several commercial crab fishermen to discuss possible solutions toward reducing Steller sea lion entanglements. As a result of this collaboration, the Oregon Dungeness Crab Commission agreed to: (1) include our "Lose the Loop"™ slogan (encouraging the cutting and proper discarding of entangling loops that could potentially end up as marine debris) on laminated signs, electronic, and print material; (2) ask commercial crab fishermen to tie knots in rubber bands used on crab pots to reduce the diameter of loops (idea of Jeff Feldner, fisherman and Oregon Sea Grant extension agent); and (3) reduce loss of black rubber bands from going overboard by using a retaining clip and keeping loose bands off the deck. These are simple first steps to reduce entanglements of Steller sea lions in marine debris. Ultimately, we need to come up with additional innovative solutions to reduce both loops and plastic in the marine environment by using biodegradable materials.

At the time of this study, response to live entangled Steller sea lions was rare. A young Steller sea lion entangled in a trawl net in Sea Lion Caves was disentangled, but only because it was anchored by the net in the rocks and was directly in front of a public viewing area. Historically, remote sedation using a Zolazepam–Tiletamine combination ("Telazol") of large pinnipeds was risky because the animals might enter the water after darting and risk drowning or suffocation [33]. In recent years, however, a new combination of medetomidine, midazolam, and butorphanol provides effective sedation of otariids without inhibiting normal respiratory functions [34,35], greatly reducing the risk of mortality if the animal enters the water before capture. This advancement has greatly improved capture success of otariids [34–37]. While having a method to disentangle Steller sea lions is a positive step, it is expensive and requires a very experienced response team. Therefore, we should continue to focus our efforts on preventing entangling materials from entering our waterways in the first place.

Continued monitoring of Steller sea lion populations is necessary to assess the impact of marine debris on the vital rates and population trends of Steller sea lions in the North Pacific. It is critical to work with all stakeholders, including manufactures, social scientists, fisheries, resource managers, and local communities, to eliminate the threat of entangling marine debris to Steller sea lions and all marine life. Studies such as ours provide a baseline from which to compare the success of these sustained efforts.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/oceans3030022/s1, Spreadsheet S1.

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

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