Entanglement of Cape Fur Seals (*Arctocephalus pusillus pusillus*) in South Africa

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Abstract

Global pollution is increasing, and marine mammals are commonly affected by the waste in the ocean. Endemic to the African continent, the pinniped species, Cape fur seal (*Arctocephalus pusillus pusillus*), are vulnerable to entanglement due to their curious nature and thick fur. Entanglement data were available from systematic photographic surveys of six colonies in South Africa (2019-2022) as well as opportunistic and citizen science records, photographs, aerial images and historical records from 1997 onwards. Overall, 314 cases of entangled seals were identified. As calculated from the systematic surveys, Baboon Point in Elands Bay (0.24% ± 0.78%, n = 7, with a 95% confidence interval) had the highest entanglement incidence. Seal Island in False Bay had the highest overall number of entanglements (50) and the highest mean number per survey (5.10 ± 0.46 number of entangled seals, n = 10), but this was also the largest colony assessed. Entanglement was observed the most in adults (61%, n = 189), with fishing materials being the primary cause of entanglements (40%, n = 59), specifically monofilament fishing lines (33%, n = 103). Although most entanglements were deemed 'sight' (67%, n = 100), 28 cases (19%) were considered 'severe,' likely impacting the health and welfare of affected individuals. Random Forest classification analysis identified the item of entangling material as an important predictor variable in terms of the severity level of the entanglement. The most common entangling material color was white (35%, n=82) followed by green (13%, n=30) and clear (7%, n=17) which may reflect the proportion of materials seals are exposed to, how they perceive them underwater, or their attraction to such colors. Aerial photographs showed higher efficiency in detecting entanglement cases than boat-based data where comparisons were possible. This is the first study to investigate entanglements of Cape fur seals in South Africa and highlights the need for correct disposal of waste, particularly that derived from the fishing industry, to mitigate its impacts on the welfare and conservation of marine fauna.

Keywords: Africa, Entanglement, Marine Pollution, Pinniped

1. Introduction and Literature Review

1.1 Marine Debris

Marine debris is of global environmental, social, and economic concern and can be divided into six main categories: plastic, paper, metal, textile, glass, and rubber (Agamuthu et al., 2019). Plastic makes up 60% to 80% of marine debris in mass (Derraik, 2002) and is rapidly produced due to its lightweight, durable, and inexpensive properties (Galgani et al., 2015). However, overuse and poor waste governance has led to it being the most abundant and persistent polluting man-made material in the ocean (Barnes et al., 2009; Parton et al., 2019). Over 14 million tons of plastic enters the marine environment every year (Agamuthu et al., 2019; UNEP, 2021; IUCN, 2021).

The accumulation of marine debris is considered a major threat to marine biodiversity (Baulch and Perry, 2014) and is known to impact an increasing number of species around the world (Gall and Thompson, 2015). Marine debris primarily impacts marine life through ingestion and entanglement (Gregory, 2009). In terms of impact and mortality, entanglement i.e., the trapping of an animal within anthropogenic debris, is likely a greater threat to marine mammals than ingestion of plastics (Gall and Thompson, 2015; Wilcox and Hardesty, 2016).

1.2 Entanglements

The entanglement of marine mammals in marine debris has been reported since the 1940s (Ryan, 2015) and since then records shave increased (Jepsen and de Bruyn, 2019). Moreover, entanglement is more difficult to mitigate and understand for marine than terrestrial wildlife, specifically to marine mammals (Gall and Thompson, 2015; Wilcox and Hardesty, 2016). The consequences of entanglement are similar across mobile animal species and in general, the survival rate of animals that are unable to disentangle themselves is compromised (Angliss and DeMaster, 1998). Animals may become caught on or in stationary objects by the entanglement material leading to exhaustion, starvation, and in the case of marine life possible drowning. Additionally, the animal may be entangled where their full range of motion is obstructed, hindering their ability to forage, resulting in malnutrition and starvation (Derraik, 2002). Further, injuries resulting from constriction by the entanglement can cause debilitating wounds which are prone to infection (Pemberton, Brothers and Kirkwood, 1992; Derraik, 2002; Jepsen and de Bruyn, 2019).

Most entangling material for marine mammals appears to be related to the fishing industry; ranging from monofilament lines, ropes, nets, and other fishing-related gear that enter coastal cities through nearby fishing activities (Laist, 1997; NOAA, 2014; Jepsen and de Bruyn, 2019). Plastic material manufactured in 'loops' such as those produced as linear filaments, straps, or ropes are most implicated in entanglement (Van der Hoop et al., 2017). Lost or dumped fishing gear is seen in much of the reported entanglement of pinnipeds (Lawson et al., 2015). This ghost gear moves great distances at sea and poses a great threat to other marine wildlife (Lawson et al., 2015), having affected over 40 species (mostly marine mammals) (Stelfox et al., 2016), with an estimated 640,000 tonnes accumulating in the ocean each year (Macfadyen et al., 2009). Other common marine plastic pollution includes plastic bags, nets, bottles, domestic and industrial packing material, and microplastics (Jepsen and de Bruyn, 2019), which originate from land-based sources or ships and enter the ocean via wind, rivers, illegal dumping or accidental lost at sea (Boucher and Friot, 2017). Coastal debris on shores from land-based sources or washed-up debris from surrounding coastal waters are other sources of possible plastic interaction with species distributed along coastal land (Islam and Tanaka, 2004; Curtis et al., 2021).

Of the 33 extant pinniped species (all of which are susceptible to entanglement), 22 (67%) have been recorded with entanglements (Jepsen and de Bruyn, 2019), with otariids (eared seals, including fur seals and sea lions) more likely to become entangled than phocids (true seals) (Laist, 1997). This is most likely due to the specific method of propulsion (Adam, 2009) and the increased fur thickness in otariids (MMC, 2022). Otariids expose their fore flippers as they propel themselves through water, increasing their chances of entanglement and additionally hindering their ability to free themselves from clung entangled material (Adam, 2009). Varying foraging ecologies and latitudinal distributions may further increase the susceptibility of entanglement among otariids (Costa, 1993; Levenson and Schusterman, 1999; Suaria et al., 2020).

Of these susceptible pinniped species, entanglement has shown to be of particular concern for young seals (Stelfox et al., 2016; Curtis et al., 2021), as they are attracted to marine debris due to their curiosity and playfulness (Derraik, 2002; Stelfox et al., 2016). Plastic loops easily slip onto their necks as they poke their heads through them, leaving material caught in their fur (Jepsen and de Bruyn, 2019) or appendages (Stelfox et al., 2016), sequentially leading to collars forming around growing pups, tightening around their bodies (Derraik, 2002), and/or cutting into their skin (Pemberton et al., 1992). A decline in populations, such as the Northern sea lion (*Eumetopias* *jubatus*) and the Hawaiian monk seal (*Monachus schauinslandi*), may have been exacerbated by the entanglement of young individuals in plastic debris (Henderson, 2001). Lower numbers of entangled adult seals may also be due to their larger body sizes decreasing their likelihood of getting caught in smaller debris (Laist, 1997), or the increased mortality of entangled younger seals, interrupting their development into entangled adults (NOAA, 2014). Declining entanglements or interactions with such debris in older age classes demonstrate possible learned experience in avoidance of floating debris, however this has yet to be studied in depth.

1.3 Cape Fur Seals

Cape fur seals (*Arctocephalus pusillus pusillus*: CFS) are the only pinniped endemic to the African continent (Riedman, 1990; Bonner, 1994) with an estimated 1.7 million individuals and 40 breeding colonies ranging from Ilha dos Tigres in Angola to Algoa Bay in South Africa (Kirkman *et al.*, 2013, 2016). The Cape fur seal population is listed as least concern on the IUCN red list (Kirkman *et al.*, 2016) with an estimated 40% of the species population in South Africa, breeding at 16 colonies (Kirkman *et al.*, 2013).

Cape fur seals are known as one of the top marine predators in southern Africa. Reports and tagging studies (Oosthuizen, 1991; Butterworth *et al.*, 1995) show these animals as generalist feeders with prey species ranging from pelagic to benthic marine species (Connan *et al.*, 2014; Kirkman *et al.*, 2016, Botha et al., 2020). As two-thirds of their prey is composed of commercially important fish species (Butterworth, 1991), interactions with fishing vessels and operations are common (Miller, Oosthuizen and Wickens, 1996; NOAA, 2014).

Cape fur seal breeding colonies are organized in harems, with mature males, also known as bulls, establishing their territories comprising of 10 to 30 females and their pups. Bulls defend their territory and harem for the entire breeding season from late October to the beginning of January (Riedman, 1990). Mothers give birth to a single pup between November and December, attending to their pup for 10-12 months, alternating between foraging trips to the sea and shore visits to nourish their pup with milk, before pups are weaned (Kirkman et al., 2016). Peak pupping occurs in the first week of December (Kirkman et al., 2016). Such biological characteristics are important to understand as breeding seasons play a role in the number of individuals from certain age classes that are present on hauled out seal colonies. Thus, influencing seal demographics that are affected by marine plastic pollution.

1.4 Study Objective

Despite the overwhelming amount of evidence of marine wildlife interacting with marine debris, specifically plastic pollution, the lack of spatial and temporal understanding, knowledge of the affected population proportions, search effort, and unsystematic reporting of problems limits mitigation and management efforts (Vegter et al., 2014; Gall and Thompson, 2015; Jepsen and de Bruyn, 2019).

Reports on plastic pollution and its effects on South African marine animals have mainly focused on sharks and seabirds (Grantham *et al.,* 2008; Petersen *et al.*, 2009) revealing fisheries bycatch as a primary implication. To date the limited and restricted access and challenging topography of CFS colonies, particularly island colonies, has hindered the thorough investigation in the impacts of marine plastic on CFS. Although there are records of CFS entanglements since 1998 under the Department of Environment, Forestry and Fisheries in the Cape Town Harbor, this data remains unpublished, leaving only one published record of seal entanglement in South Africa (Shaughnessy, 1980). This study summarizes reports from 1977-1979, ie. more than 50 years ago. As well as now being outdated, this study was restricted in geographic scope, integrating information from just three sites: Kleinzee, Seal Island in False Bay, and Geyser Rock near Gansbaai. Shaughnessy (1980), found that plastic straps, mostly blue, accounted for half the entanglements in 1977, followed by monofilament and trawl net, with trawl net and rope as the most frequently recorded objects. More recently and focusing on two CFS colonies in Namibia, Curtis et al. (2021) reported a 0.17% entanglement incidence, the equivalent of one animal in every 500. At these colonies Pelican Point and Cape Cross, in the Northern Benguela, fishing materials accounted for 53% of the entanglements documented, with monofilament fishing line (48%) and snoek line (40%) as the most common. However, packing straps (10%) were responsible for the most severe injuries in adult seals, suggesting a more sustained injury over a longer duration. Juvenile and male seals were more commonly entangled, with most entanglements observed around the neck (Curtis et al., 2021).

The Sea Search Research and Conservation (SSRC) team has carried out systematic surveys of seal colonies along the South African coast since 2019 to monitor the abundance and demographics of entangled Cape fur seals. These surveys have focused on spatial patterns at several colonies, the abundance of entangled seals, entanglement material, severity, color, and seal demographics affected by entanglements in marine debris. Until now, these data have not been comprehensively analyzed and this is the focus of the dissertation. This study aimed to fill the knowledge gap on the impacts of marine waste on Cape fur seals inhabiting South Africa. Specifically, I (1) investigated and conducted a geographic comparison of the entanglement incidences of Cape fur seals at six colonies along the South African coast, (2) investigated the age and sex demographics of Cape fur seals affected by entanglement, (3) investigated the type of material entangling Cape fur seals, (4) observed classification patterns between entanglement characteristics and their predictability of the entanglement outcome, in terms of severity, and (5) compared two methods of data collection in terms of detecting seal entanglement cases in South Africa. My main questions were:

1. Which colonies are most impacted by entanglement?
2. What demographics, ages and sexes, are most entangled?
3. What materials are most often found to entangle Cape fur seals?
4. Can certain entanglement characteristics or seal demographics predict the severity of an entanglement?
5. Is seal entanglement detection higher through aerial surveys or sea-level surveys?

This constitutes the first study in South Africa that explicitly assesses the impacts of marine debris on Cape fur seals at several colonies along the coast. My study is part of a larger project involving SSRC in observing the impacts of marine waste on top predators in Namibia and South Africa.

2. Methodology

2.1 Study Locations

The entanglement of Cape fur seals was investigated at six colonies along the Western Cape coast of South Africa (Figure 1, Table 1). The estimated population size of each colony is based on the most recent available published data. In the context of this study, and due to the understudied and variable South African Cape fur seal population, a colony, referred to in this study, is a colony irrespective of having breeding activity or not.

Table 1. Descriptive table of the six systematically surveyed colonies in South Africa.

Region	Colony	Breeding/non-breeding colony	Description	Coordinates	Estimated population size
Lamberts Bay	Bird Island	Breeding	Land colony next to a fishing harbor	32º08’96” S, 18º30’22” E	1500 seals (Strydom et al., 2022)
Elands Bay	Baboons Point	Non-breeding	Land colony	32º31’53” S, 18º31’53” E	500 seals
Hout Bay	Duiker Island	Breeding	Rocky island 100m from mainland	34º05’83” S, 18º32’69” E	6,000 seals (Ranahan, 2020)
False Bay	Partridge Point	Non-breeding	Rocky island 300m from mainland	34º25’60” S, 18º48’24” E	100 seals
False Bay	Seal Island	Breeding	Largest rocky island, 5.7km from mainland	34º13’74” S, 18º58’25” E	60,000+ seals (Fallows et al., 2016)
Mossel Bay	Seal Island	Breeding	Nature reserve rocky island 800m from mainland	34°09'04.6"S, 22°07'11.5"E	2,500 seals (Whale Watch SA, 2021).

2.2 Data Collection

2.2.1 Systematic Surveys

Colonies were visited between 2019 and 2022 to conduct systematic photographic surveys (Table 2) shown by Curtis et al. (2021) and Dicken et al. (2013) as a reliable, low-cost, and effective method for observing seal entanglements. Systematic entanglement surveys consisted of one-day photographic surveys focused on the colony in each region. A Canon Digital SLR camera with 100mm to 400mm lens was used for surveys. In four locations, surveys were conducted from a boat based platform, stationed close to the colony. However, at Lamberts Bay and Elands Bay the vantage point for surveys was land based with an average distance of 50m from the colony edge. Surveys comprised of one or more scans, termed as; a series of overlapping images at varied zoom and focal points of the colony, which on average took one to five minutes depending on the colony size. Scans differed depending on the location and angle of the photographer towards to colony. Scans were separated by spacer (blank) shots to demark the end of each focused period of data collection. If during the survey of a colony, an entanglement, scar or wound from an entanglement was sighted, a detailed series of photographs of the individual was taken to help identify the animal's demographics and entanglement characteristics. Entanglements were assessed in further detail during data analysis.

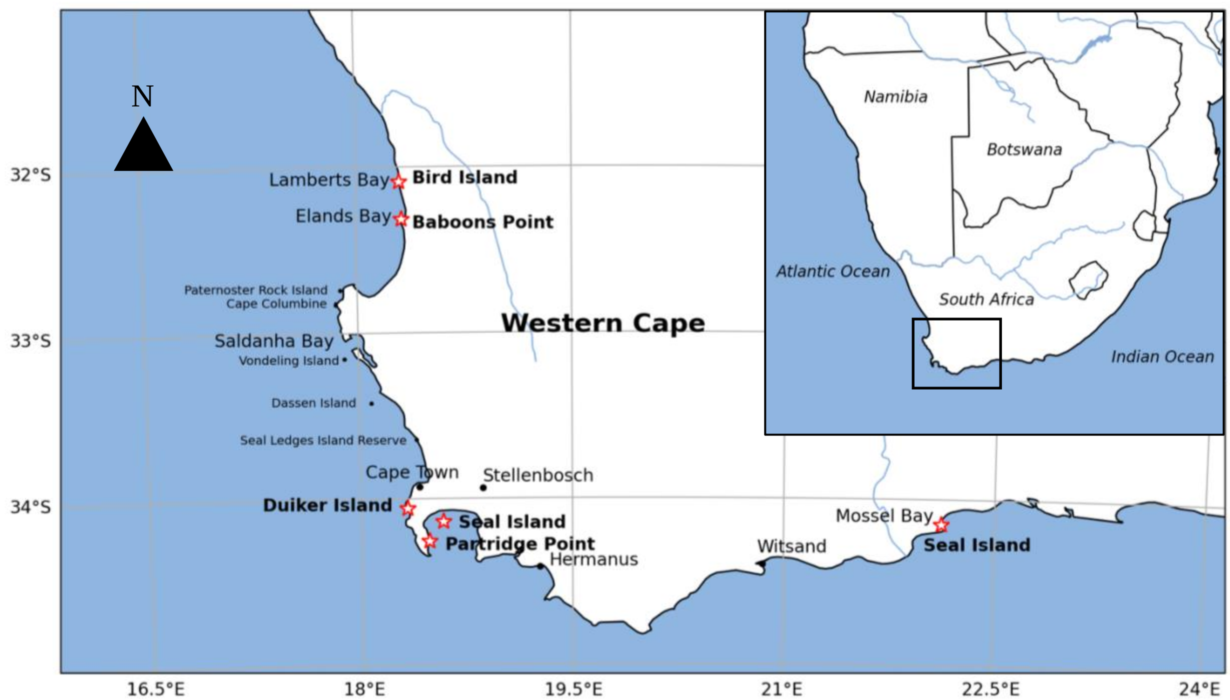

Figure 1. Site map of the Western Cape province in South Africa showing the six surveyed colonies: Bird Island, Baboon Point, Duiker Island, Partridge Point, Seal Island False Bay, and Seal Island Mossel Bay.

2.2.2 Aerial Surveys

For exploratory means, in addition to assessing the effectiveness of our data collection methods, we used *ad hoc* aerial survey data collected from gyrocopter flights taken along the South African west coast on October 30th, 2021. Aerial surveys consisted of scans from five seal colonies:

Paternoster Rock Island, Cape Columbine, Vondeling Island, Dassen Island, and Seal Ledges Island Reserve (Fig. 1). Entanglements captured through aerial images, using a Canon Digital SLR camera with a 100-400m lens, were converted to entanglement incidences and compared to systematic sea-based survey incidences for the same colony. Entanglements observed from aerial data, with respective entanglement characteristic and seal demographic data were added to the opportunistic dataset. Additional citizen science data of four aerial photographs at Duiker Island were analyzed for entanglements, noting, when possible, age cohorts, sex, entanglement material, severity, and color.

Table 2. Dedicated survey effort (number of surveys) to assess the entanglement of Cape fur seals at the six respective regions and colonies for each surveyed year, 2019-2022 (n = 49), in addition to the total number of surveys for each region.

Region	Colony	2019	2020	2021	2022	Total
Lambert's Bay	Bird Island	0	0	9	1	10
Elands Bay	Baboon Point	0	0	5	2	7
Hout Bay	Duiker Island	1	3	7	0	11
False Bay	Partridge Point	0	2	5	1	8
False Bay	Seal Island	2	1	7	0	10
Mossel Bay	Seal Island	0	0	3	0	3

2.2.3 Opportunistic and Citizen Science data

Opportunistic data were collected between November 2019 and February 2022 by the SSRC team during research outside of dedicated systematic surveys (i.e., when undertaking bioacoustics research). Opportunistic records also included entangled seals that were observed in seal colonies in other locations along the South African coast. Citizen science data on seal entanglements were also compiled. For contemporary records, a request (Appendix A) for seal entanglements was shared online between November 2021 and July 2022, where relevant scientists, volunteers, tour operators, wildlife scientists, and snorkelers could contribute entanglement records. Photos and records were then shared through the SSRC seal email Google Drive for easy access and organization. From such photos, entanglement characteristics and seal demographics were further observed, when possible, during data analysis. Entanglements recorded by citizen scientists did not include auxiliary information, such as the colony size.

Historical citizen science records, carried out by Cape Nature, from Lambert's Bay, at the Bird Island seal colony, from 1997 to 2002, were also included in the data analysis. These data were collected systematically, scanning the colony up to three times daily (with the minimum number of scans being once a day). These Bird Island historical observations provided 154 cases each respective material types, age classes, sexes, and description of the entanglement, including color and location.

2.3 Data Analysis

Before analyzing the data, rigorous quality control was carried out. This included checking through frames and scans that were adequate, in terms of photographic quality and closest distance from colony. An entanglement case was included where there was a visible obvious entangling item on the individual seals' body (check Appendix 11 for example cases). Throughout the data analysis process, any observed possible, uncertain, entanglement was noted separately for later, for further verification (see Appendix 2 for examples). Data were verified through repeated check by a single observer over time and between independent observers. Quality control was not possible for the historical records, but since data was collected from an experienced source (Vincent Ward, from Cape Nature), it was considered to be reliable and unbiased.

2.3.1 Geographic variation in entanglements

During surveys, one to five photographic scans were selected for further analysis. Such scans were selected based on a unique viewpoint of the colony, the smallest distance from the colony, and the highest quality photos. For the data analysis, Seal Island False Bay was noted as Seal Island.FB to discriminate between Seal Island Mossel Bay, which was noted as Seal Island.MB.

Both absolute numbers of entanglements and entanglement incidences were calculated per survey. The number of unique entanglements at each colony was assessed irrespective of the entanglement being observed in more than one scan of a survey. In addition to this, I generated information on entanglement incidence to facilitate comparison between colonies of different sizes. As frames may overlap (resulting in double counting), seals are mobile and those un-entangled are not individually distinctive, the entanglement incidence was calculated for each survey as the proportion of the entangled seals photographed per frame out of the number of entangled and non-entangled seals per frame. Potential 'double-counting' of certain seals was not problematic for the calculation of entanglement incidence, because both entangled and non-entangled seals were counted, making the incidence comparable between frames and colonies (Appendix 4 shows a schematic explanation).

As may seals could be photographed in each frame, the number of seals per frame was estimated by counting groups of seals ranging in numbers from 5, 10 to 20 seals in one group (Appendix 3 shows an example scheme of the estimation method). In frames with fewer than 5 seals, the exact number of seals was counted. This method of estimation was independently verified in a subset of data with known counts of seals in each frame and shown to be highly accurate (Appendix 10, using Pearson's product-moment correlation coefficient r = 0.89). Entanglement incidences per frame per scan were then calculated by using the number of entanglement individuals per frame divided by the estimated number of seals in that frame multiplied by 100 to reach a percentage value (an example calculation can be found in Appendix 5). Additionally, a regional entanglement incidence for Cape fur seals in South Africa was calculated by dividing the total number of seals photographed, across all surveys in all colonies, by the total number of entanglements, across all surveys in all colonies, and multiplied by 100. The entanglement incidence are a minimum estimate of the proportion of entangled seals as many seals are obstructed from view and thus potentially concealing both animals and entanglements.

For statistical geographic comparison, entanglement incident were compared between colonies using the entanglement incidence calculated for each survey and each colony (3 to 12 surveys per colony). Checking for normality and equal variances using a standard parametric Analysis of Variance (ANOVA) test (Appendix 6) in R studio (R package '*stats*' version 3.5.3; R Core Team, 2021), appeared to show normally distributed data after transforming the data by square rooting the entanglement incidences (seen in the qq-plot (b) and the frequency histogram (c)) and roughly equal variances (seen in the predicted entanglement incidence (%) vs residuals, plot (a)). Therefore, a parametric Analysis of Variance (ANOVA) test was run. Colonies with a small sample size were excluded from this statistical analysis, i.e. Mossel Bay, as the number of samples (in terms of surveys) was less than five (Riffenburgh, 2006). If a difference was found between the colonies, a Tukey's post-hoc test was used to identify the colonies that differed. All figures were created using the ggplot2 package in R studio (Wickham, 2016).

2.3.2 The demographics of entangled seals

I compared the demographic characteristics of entangled animals across age and sex classes using data from systematic photographic surveys, opportunistic, and citizen science data. A conservative assessment was made when assigning seals to age classes, so to reduce observation errors based on the observer timeframes and photographic quality. Therefore, all seals were classed into two groups: juveniles (<2 years) or adults (>2 years), a classification system that recognizes the more curious and energetic nature of young seals, making them more vulnerable to entanglement, compared to the larger (Kirkman et al., 2016) and wider-ranging ages (Warneke and Shaughnessy, 1985) of subadult and adult seals.

Classification of seal sex was difficult as photographic surveys of entangled seals do not always encapsulate the entire seal body, where specific body characteristics easily classify a seal's sex. Male seals were confidently assigned through visible external genitalia openings and or large prominent heads and bodies, which can be over four times the size of an adult female (Kirkman *et al.*, 2016). Females were assigned based on their slightly light greyish brown fur and contextual photos, such as weaning pups or visible nipples (Kirkman and Arnould, 2018). Where physical or contextual characteristics were ambiguous, the entangled seal was assigned as unknown sex. Following this, a comparison of the demographic characteristics of entangled animals across all data sources and geographic variation across the six colonies was carried out, excluding small sample sized colonies, using Pearson's chi-Squared goodness-of-fit test (alpha level 0.05).

2.3.3 Entanglement material and color

The entanglement material and color were recorded from all data sources. Entanglement material was classified by two separate categorical systems. The first system (A) comprised of five broad categories: fishing, industry, domestic, miscellaneous plastics, and unclassified (Table 3). This categorization allows comparison with recently published research from Southern Africa though is slightly modified from Curtis et al.'s (2021) version in that the categories are more explicitly divided in terms of the source of the entanglement material. The second entanglement material classification system (B) was created at a finer scale and was based on the direct item entangling the seal, with no assumptions of its origin (Table 4). Both methods were used for categorizing entanglement material in data collection, however, the entanglement item (B) was used for further data analysis. Historical citizen science records were excluded from material classification (A) as the material was classified solely on the direct item entangling the seal. The color of the entanglement item was also noted when possible. When color was not classified with 100% certainty, color was deemed unclassified.

The location of entanglement on the seals' body was also noted when clearly visible. Location was classified at the head if it was between the nose and the ears of the seal, which included mouth, eye, and cheek. If the entanglement was past the ear and above the flipper, the location of entanglement was classified at the neck. At and just below the flipper classified the location of entanglement at the shoulder. One historical entanglement record was noted below the flipper, the material observed embedded in the belly.

Table 3. Classification system A with material source categories and their associated descriptions.

Source	Description
Fishing	Materials that can be confidently and uniquely linked to fishing activity, both recreational and commercial.
Industry	Land and sea based industrial-related materials.
Domestic	Land based or dumped at sea household waste such as clothing or bags.
Misc. Plastics	Other miscellaneous plastics such as barrier tape, mesh.
Unclassified	All other materials of unknown origin.

Table 4. Classification system B with material item categories and their associated descriptions.

Item	Description
String/rope	Thin single polypropylene, cotton, hemp, or other braided material.
Packing Strap	Thin but tough plastic strap.
Monofilament	Thin fishing line.
Plastic Bag	Thin, flexible, plastic film, or plastic textile in the shape of a bag.
Net	Fused yarn looped or knotted at intersections with open spaces.
Hook	Fishing hook for baiting fish.
Unclassified	All other items which are unidentifiable.

Results from demographics and entanglement characteristics were statistically analyzed and compared between and among groups using Pearson's Chi-Squared goodness-of-fit test (R package '*stats*' version 3.5.3; R Core Team, 2021) for two-variable group comparisons (all with an alpha level of 0.05). For example, the item (B) was tested against the age of the seal for a possible association.

2.3.4 Predicting severity

The severity of entanglement was judged by the degree of constriction of the material and the type of wound caused. Entanglement scoring was recorded into five categories: nil (loose), slight (tight constriction but not breaking the skin); severe (cutting through the skin); very severe (cutting through skin and underlying fat layer); and carcass (seal dead likely due to entanglement) (Arnould and Croxall, 1995; Figure 2 taken from Curtis et al., 2021). Severity information was available in most cases, except where photographs were taken from a distance or poorly focused or no photograph was available.

I tested whether the severity of the injury resulting from entanglement could be predicted based on seal demographics, material characteristics and geographic location, using a Random Forest (RF) classification. RF was used to determine the best predictor variable for the severity level of entanglement cases (*randomForest*, Liaw and Wiener, 2002; R Core Team, 2021). This method is a robust classification method based on multiple decision trees, increasing the effectiveness of the model and the chances of making correct predictions (Yiu, 2019). In contrast to other decision trees, each tree in RF picks from a random set of features in node splitting forcing variation amongst the trees in the model, resulting in "lower correlation across trees and more diversification" (Yiu, 2019), also decreasing the chances of producing errors, therefore increasing the prediction accuracy. RF does not require assumptions of the distribution of variables (Breiman, 2001) and can deal with unevenly distributed observations (Chen et al., 2004), which is appropriate for the samples in this study.

Severity was used as the response variable as it is the resulting or outcome variable of an entanglement in addition to also being a measure of seal health which is a direct predictor for determining Cape fur seal well-being. Severity levels were only recorded where photographic data were available. 'Very severe' and 'severe' cases were pooled and combined under the 'severe' category due to sample size restrictions. Excluding three cases with undetermined severity levels, a total of 155 cases that were used in a Random Forest classification analysis. For comparison across international borders, recently collected data from Namibian seal colonies, dating from 2021 to 2022, was included in this classification analysis. This data was available from the NGO Ocean Conservation Namibia which collaborates with SSRC for the monitoring of Cape fur seal entanglements in Namibian colonies. I randomly selected 155 entanglement cases from the Namibian data set to use in the geographic comparison, again pooling the sever and very sever categories. The classification was therefore conducted on a dataset of 310 records, using the following explanatory variables: country (Namibia or South Africa), colony (the six South African colonies in addition to Namibian cases: Pelican Point, Cape Cross, and Other), material item (Table 3 categories in addition to five other items from Namibian cases: clothing, gasket, plastic wrap, saint joseph shark spike, and other), and age (classified under adult or juvenile categories). The sex and location of entanglement on the body were not included in this classification as there were too many cases with unknown sexes and the location of entanglement was not documented in Namibian cases. Although having a higher number of explanatory variables increases the robustness of the classification in Random Forest, such groups with too many unknowns would limit and decrease the accuracy of the results. Therefore, four explanatory variables were classified and tested as predictor variables for the severity of Cape fur seal entanglements.

Analyses were carried out using RStudio version 1.4.1106 (R Core Team, 2021) using the package *randomForest* (Liaw and Wiener, 2002). The percentage of data used for training the classification trees was 75% and based on my data set the number of trees was set to 1000 and the number of predictor variables (mtry) selected at each node at 4. The tuned classification trees gave the lowest out-of-bag errors in comparison to bagging and untuned trees (Appendix 7), therefore tuned trees were used for classification analysis. Each explanatory variable was classified according to its degree of contribution to the classification of severity levels using the Gini index. The classification rates indicated whether certain variables can be used to significantly predict the severity level of an individual Cape fur seal entanglement.

Additionally, severity levels of entanglement cases were tested for association with colony, age and sex demographics, and item and colour classes using Pearson's Chi-Squared goodness-of-fit test (all with an alpha level of 0.05). Yates' correction for continuity was used in cases were expected frequencies from chi-squared tests were less than five (Bobbitt, 2021).

Figure 2. Examples of severity types: A) nil B) slight, C) severe, D) very severe, E) carcass (Curtis et al. 2021).

3. Results

Overall, between September 2014 and February 2022, 158 entangled seals were identified from selected South African Cape fur seal colonies. Systematic colony surveys identified 104 unique entanglements, with the remaining entanglements observed through citizen science (n = 21, from public observers) and opportunistic (n = 36 of which 15 were from aerial surveys) data collection methods (Table 2).Additionally, 154 historical entanglement records were documented from Lambert's Bay between 1997 and 2002.

3.1 Geographic variation in entanglements

Between March 2019 and February 2022, 89 scans were processed from 49 dedicated systematic surveys (Table 4 and Appendix 8). The total number of photographs analyzed (n = 3071), ranged between 4 and 164 photographs per scan (mean 33 ± SD 39.40 frames). The number of scans per survey at each individual colony differed and ranged from 1 to 10. Each photographic scan consisted of several frames, ranging from 9 to 152 frames per scan. The time taken to analyze photographs post-survey depended largely on the number of photographs taken but was three minutes or less per frame. Duiker Island in Hout Bay had the highest number of surveys (12) followed by Bird Island and Seal Island False Bay (table 5).

The regional entanglement incidence for South Africa was 0.12% (± SD 0.32%). Entanglement incidences per colony are displayed in Figure 3, in addition to the descriptive statistics in Table 5 (Appendix 8 displays raw entanglement incidences per survey).

Table 5. Dedicated survey effort and results to assess the entanglement of Cape fur seals at six respective colonies including the number of surveys, scans, discrete entanglements (n = 104), the overall entanglement incidence, the standard deviation (SD), and the total effort in terms of the number of seals estimated (%).

Colony	No. Surveys	No. Scans	No. of discrete Entanglements	Incidence (%)	SD (%)	% of total effort
Birds Island	10	10	18	0.15	0.15	16
Baboon Point	7	20	11	0.24	0.78	6
Duiker Island	12	19	20	0.10	0.14	22
Partridge Point	7	15	2	0.05	0.12	5
Seal Island.FB	10	19	50	0.11	0.06	47
Seal Island.MB	3	6	4	0.12	0.03	4

Similar colony means and wide variation meant that entanglement incidences did not differ geographically across the six different colonies assessed (ANOVA, F = 1.189, df = 5, p-value = 0.33). Two outliers were observed at Baboon Point (Appendix 8, dates January 25, 2022 and February 2, 2022, with respective entanglement incidences of 2.05% and 0.955%).

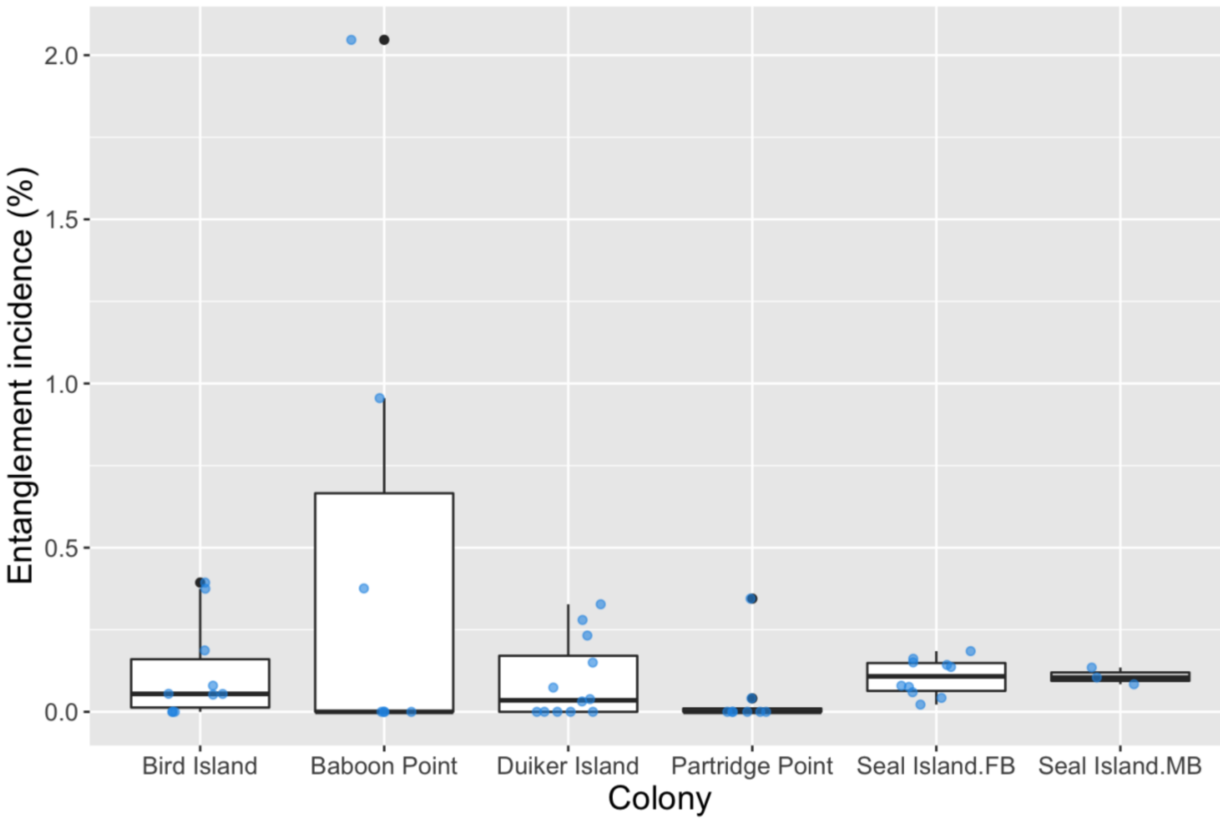

Figure 3. Entanglement incidence (%) for each colony systematically surveyed in South Africa. Entanglement incidences are binned into six bins, one for each colony, with the mean incidence shown by a black line, and blue dots representing surveys.

3.2 The demographics of entanglement

In cases where sex was confidently assigned, based on external characteristics described in the methods (56% were assigned, n = 131), there was a tendency for more females (73%, n = 96) to be entangled than males (female: male ratio 2.75). When excluding historical records, males were found more entangled than females (male: female ratio 1.15). Including cases from all data sources, adults were the most entangled age class (61%, n = 191), with 120 juveniles (38%), and three seals (1%) unclassified in terms of age.

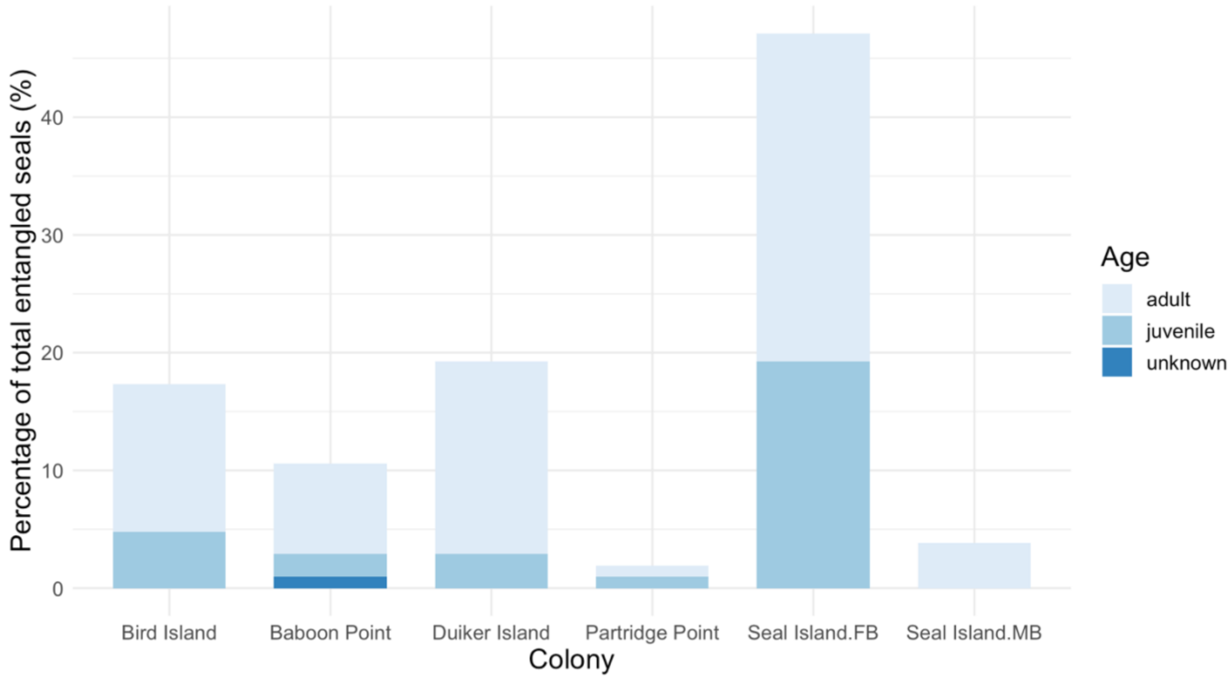

Figure 4. Percentage of entanglements for each age class at each systematically assessed colony (n = 103 cases).

From the systematic surveys, more adults were found entangled than juveniles (Fig. 4), most notably Duiker Island (85% adult cases), Bird Island (72% adult cases), and Baboon Point (72% adult cases). This trend was found at all colonies, with no statistical difference in the age composition of entangled seals between the six colonies assessed (Pearson's chi-Squared test for independence, X^2= 5.2606, df = 3, p-value = 0.154).

3.3 Entanglement material and color

Fishing materials were collectively the main entangling material in all cases (69%, n = 105), under classification system A. Other sources included industry (12%, n = 19) and domestics (3%, n = 5) and a large portion of the entangling material was unclassified (19%, n = 29). No cases fell under the misc. plastics. Under classification system (B), which focuses on material item and included cases from all data sources, monofilaments were the most common entanglement material (43%, n = 135 and 33%, n = 103 with certainty), followed by string/rope (21%, n = 65), packing strap (12%, n = 36) and net (10%, n = 32). Other items: hooks (2%, n = 7), plastic bags (2%, n = 6), and washers (less than 1%, n = 1), were found in fewer entanglement cases.

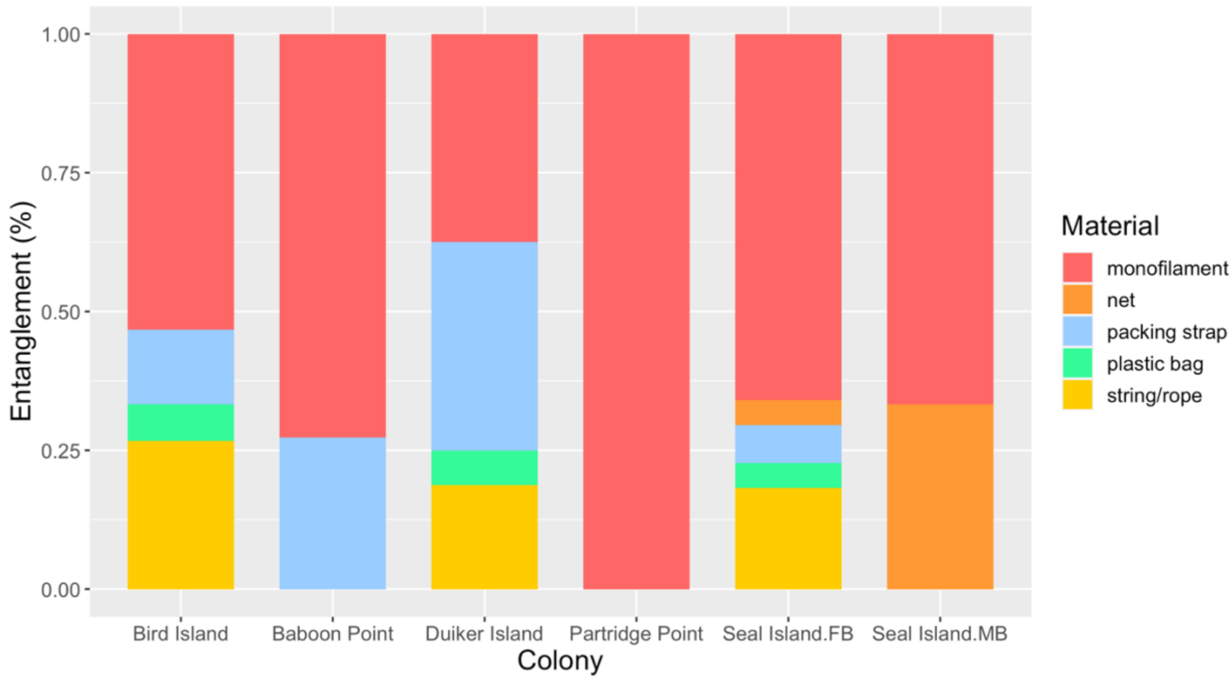

Figure 5. Entanglement item (%) associated with each of the six systematically surveyed colonies (n = 104 cases).

Monofilaments fishing line was the most common entangling item at all colonies assessed (Fig. 5). No significant associations existed between the six colonies and the entanglement item (Pearson's Chi-Square test for independence, $X^2 = 15.093$, df = 12, p-value = 0.236) however, Baboon Point, Partridge Point, and Seal Island Mossel Bay showed the lowest variety in material types. Figure 6 displays 90% of all entanglement cases by age class, as 10% (n = 30) were unclassified in terms of both age class and entanglement item. There was a significant difference among the two age classes in the distribution of entanglement items (Pearson's Chi-Square test for independence, $X^2 = 26.484$, df = 6, p-value < 0.001), with greater proportions of juveniles affected by net and plastic bag, compared to a greater proportion of adults entangled in monofilament.

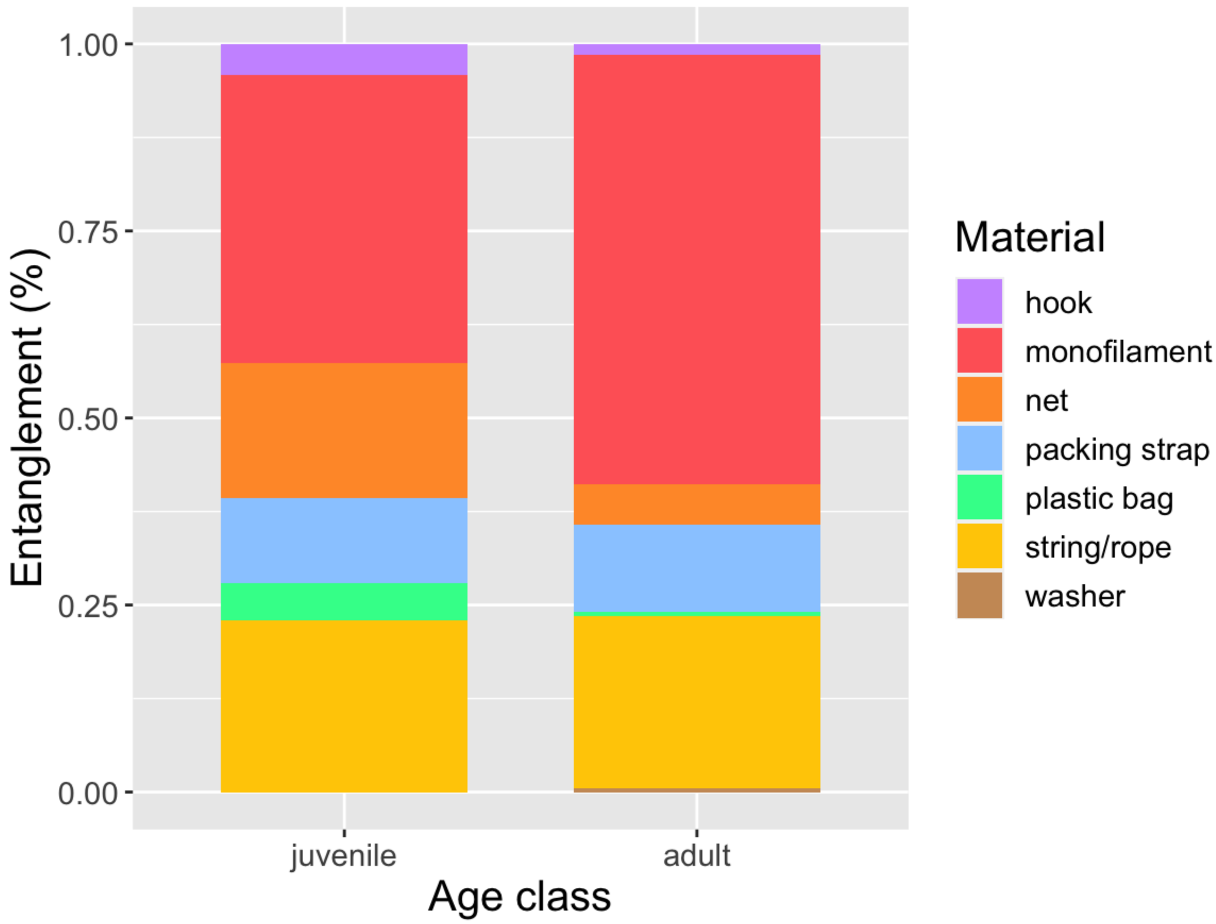

Figure 6. Entanglement cases (%) of items within associated age classes (n = 251 cases), using all data sources.

Regarding the entangling item (B) color, overall results indicate white as the most common color (35%, n = 83), followed by green (14%, n = 33), clear (8%, n = 18), and blue (6%, n = 14). Other item colors included: red (3%, n = 8), orange (3%, n = 6), black (3%, n = 6), yellow (2%, n = 5), beige (1%, n = 3), and grey (less than 1%, n = 1). In a quarter (25%, n = 60) of all cases, the material was uncertain or obstructed by fur and the color of the entangling item was unknown. Further analysis on color and any association between colonies, seal demographics and materials were not explored as sample sizes were too small. However, juvenile seals showed a high number of entanglements in green (9%, n = 23) material in comparison to adults (4%, n = 10), despite no significant association (Pearson's Chi-Square test for independence, $X^2 = 16.592$, df = 9, p-value = 0.056).

The location of the entangling item on affected individuals was documented in 99% of cases, from all data sources. The most observed location of a detected entanglement was around the neck (94%, n = 292). Other affected areas included the head (2%, n = 6), shoulders (4%, n = 12), and one historical case with the material embedded in the belly. Four examples of entanglements and associated demographics, and entanglement characteristics can be found in Appendix 11.

3.3.4 Predicting severity impact

Severity assessment was possible in most cases (98%, n = 155) across all data sources, excluding historical records from Lambert's Bay. Overall, the most observed effect of entanglement was 'slight' (67%, n = 100), followed by 'severe' (19%, n = 28), 'nil' (11%, n = 16) and 'very severe' (1%, n = 2). There were no entanglements under the 'carcass' severity level, however, there were two seals, one from a systematic survey at Baboon Point, the other from a citizen scientist at Brenton on Sea, that were found dead and entangled. However, in these cases, entanglement was not assessed as the primary cause of death and these cases were therefore not included in the 'carcass' severity classification level.

Despite the undetected significant relationship between severity and age classes, the entanglement tends to be more severe in adult cases (Fig. 7). Only two entangled seals, both of which were adults, were classified as very severe cases (1.4%) and three cases were classified as 'unknown' in terms of severity level. Testing for the surveyed colonies in terms of severity levels of entangled animals (Fig. 8) showed no significant relationship (Yate's correction for continuity, X^2= 2.269, df = 12, p-value = 0.999). Bird Island remains the only colony to have 'very severe' entanglements (1% of all recorded entanglements, n = 2).

Of the 158 entanglements, where both the entangling item and severity was classified (78%), the severity of the entanglement and the associated item (Fig. 9) showed a significant relationship (Pearson's Chi-Square test for independence, X-squared = 35.836, df = 15, p-value < 0.001). Entanglement cases with 'nil' severity levels showed the widest variety and the most proportionate distribution of cases in terms of material items. Monofilaments and string/rope items remain the only material with 'very severe' cases (with only 1 case for each item).

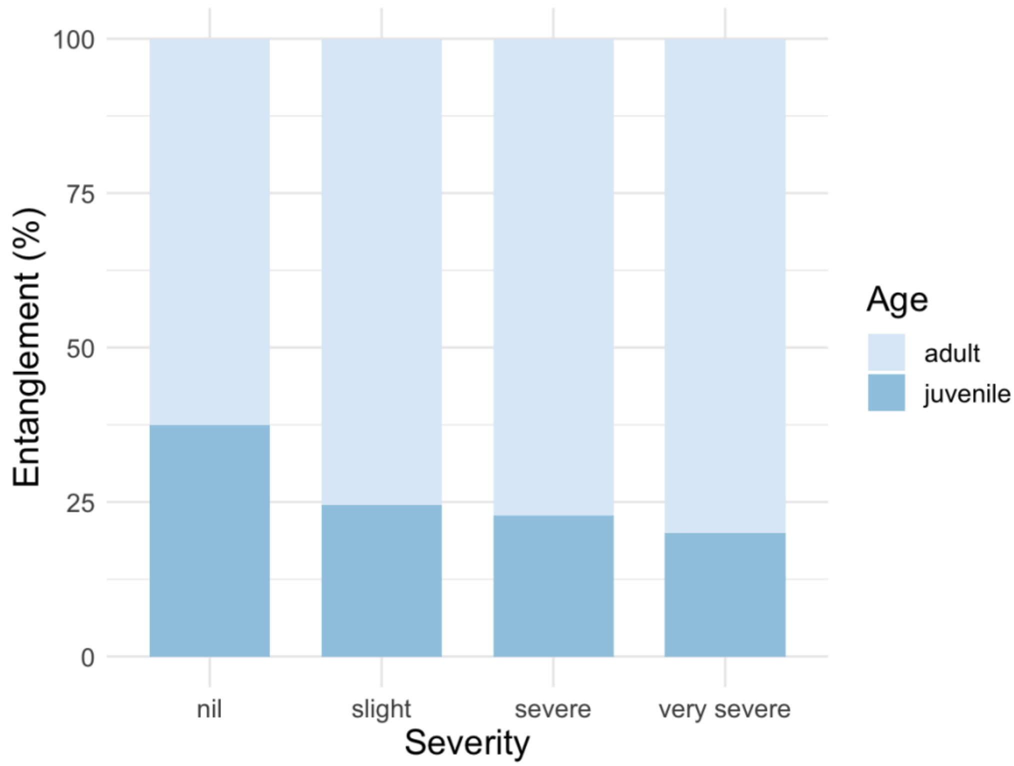

Figure 7. Percentage of entanglements (%) associated with each severity category and corresponding age class, using all data sources (n = 158 cases).

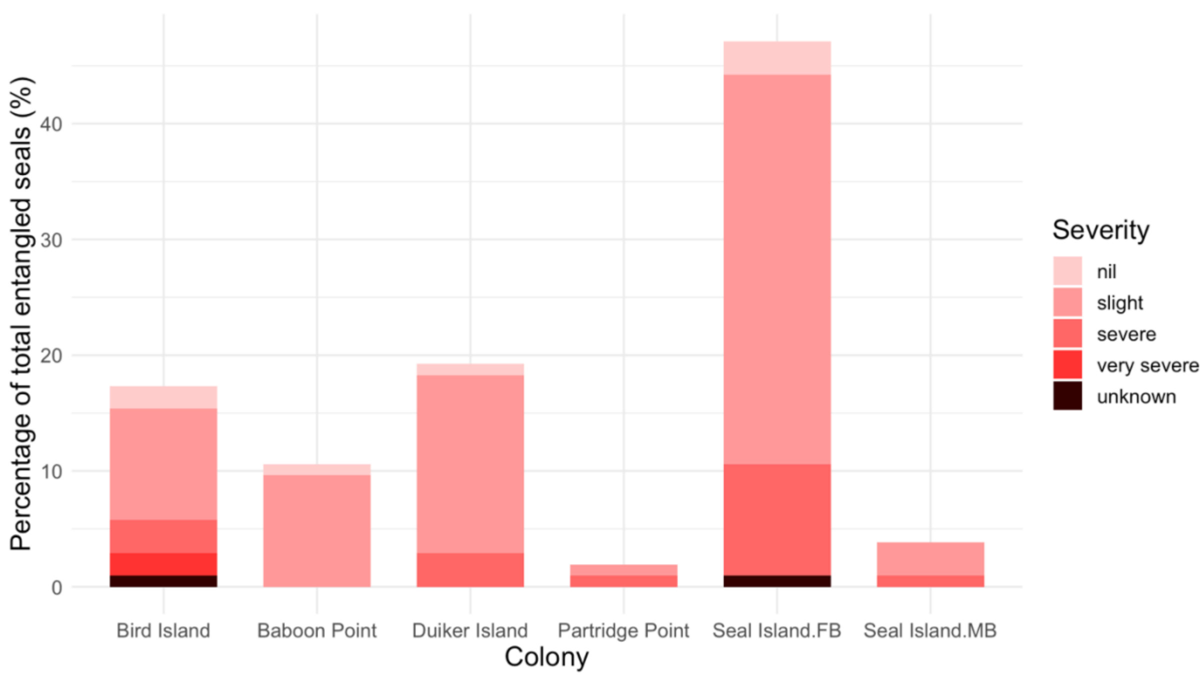

Figure 8. Percentage of total entanglements associated with each severity category at each systematically surveyed colony (n = 104 cases).

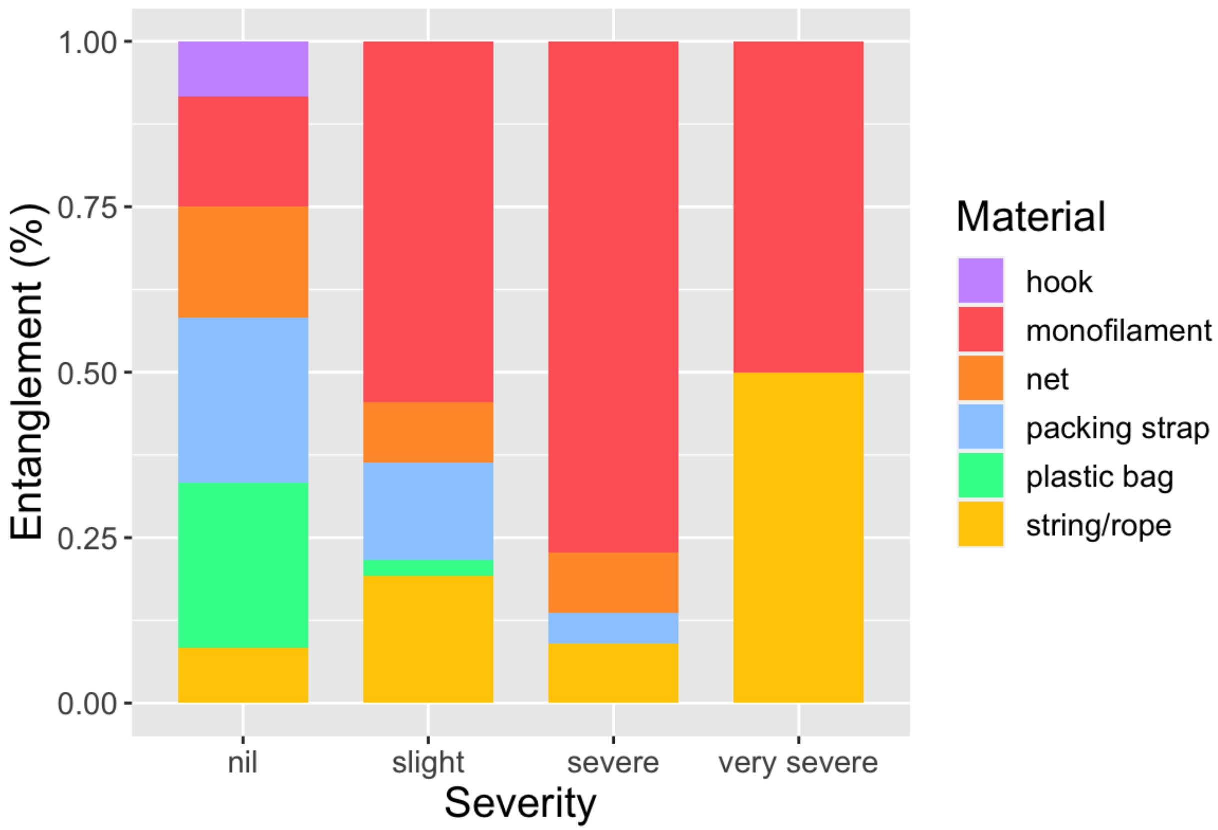

Figure 9. Percentage of entanglements (%) of the associated entanglement item with severity levels (n = 124 cases).

Using Random Forest classification analysis (Appendix 12), with a test accuracy of 53%, the entanglement material item contributed the most, out of all other explanatory variables, to the classification of the severity level of entanglements, followed by colony (both with mean decrease Gini index values greater than 15). The confusion matrix showed a high number of correct predictions (58%), where true labels matched predictor labels under the three severity levels classified (nil, slight, and severe), whereby 8 entanglement cases fell under 'nil' labels, 31 under 'slight' and 1 under 'severe'. Most other predicted cases were labeled under one level lower than the true level on the severity level classification. Age showed the lowest mean decrease Gini index value (5). The Mean Decrease Accuracy plot displayed a disproportionately high value for the country (with a mean decrease accuracy value greater than 35), where the material item was the second highest (with a mean decrease accuracy value less than 15), followed by the colony and finally by age (with a mean decrease accuracy value close to 0). This expresses how much accuracy the model loses by excluding this country variable. Ultimately, the material item of the observed entanglement case had the highest importance in the classification trees, and therefore, is an important predictor in determining the level of severity of an entanglement.

3.4 Survey method comparison

Aerial surveys detected a total of 15 unique entanglements (Table 6). During a boat-based survey in December 2021 zero entanglements were recorded at the Paternoster Rock Island colony. Therefore, a greater number of entanglement cases of Cape fur seals were detected through an aerial survey than through a boat-based survey of Paternoster Rock Islands within a similar period of the year.

Table 6. Ad hoc aerial survey effort to assess the entanglement of Cape fur seals on the west coast of South Africa including the number of surveys, number of scans, number of discrete entanglements (n = 15 total), overall entanglement incidence and the % total effort in terms of the estimated number of seals.

Colony	No. Surveys	No. discrete Entanglements	Entanglement incidence (%)	% total effort
Seal Ledges Island Reserve	1	1	0.04	11
Grotto Bay	1	0	0	7
Vondeling Island	1	2	0.05	20
Paternoster Rock Island	1	12	0.12	59
Cape Columbine	1	0	0	3

4. Discussion

Fishing material was identified as an important contributor to Cape fur seal entanglement around the South African coast. The geographic span of investigation on seal entanglements surveyed in this study is the first to be done in South Africa in such depth. From the 314 entanglements detected over 8 years, including the 154 historical records documented from 1997 to 2002, monofilaments were the most common entangling material of Cape fur seals with influences on the entanglement severity.

4.1 Geographic variation in entanglements

The overall entanglement incidence of South African Cape fur seals was 0.12%, comparable to the incidence observed in Namibia of 0.17% (Curtis et al., 2021). Other seal entanglement incidences, such as observed in a review by Jepsen and de Bruyn (2019), showed a global incidence of 0.37%, which was calculated throughout different seal colonies across the planet with a wide variety of methods and species. Incidences of 0.24% have been seen in *Arctocephalus gazella* (Hofmeyr et al., 2002), 1.9% in *Arctocephalus pusillus doriferus* (Pemberton et al., 1992; Butterworth, 2016), and 2.8% in *Arctocephalus forsteri* (Boren et al., 2006). The recorded incidences among the six colonies in this study ranged from 0.05 to 0.24%, falling within the range of incidences recorded in previous fur seal studies, with no significant differences detected between location. However, these incidences should be cautiously compared with other studies due to varying methods of data collection and incidence assessment in other studies.

Colony characteristic differences between South African and Namibian colonies may explain the slight differences in their respective entanglement incidences. Both Pelican Point and Cape Cross (in Namibia) are seal colonies on mainland coasts, whereas four out of the six colonies observed in South Africa are islands. A large portion of marine pollution is found on land specifically at beaches and coastal areas due to human population density and proximity to pollution sources (Rundgren, 1992; Beiras, 2018; Ryan, 2020). In a review by Ritchie and Roser (2018), coastlines are shown to harbor most of the accumulated plastic pollution in the world, with an estimation of 82 million tonnes of macroplastics washed up, buried, or resurfaced on the world's shorelines (Lebreton et al., 2018; Ritchie and Roser, 2018; Ryan 2020), 80% of which come from land-based sources (Ritchie and Roser, 2018; UNEP, 2019). This high accumulation of pollution on beaches increases possible encounters of litter with coastal inhabiting animals (Beiras, 2018), which may explain the slightly higher entanglement incidences and higher land-based pollution entanglement material in Namibian colonies, Cape Cross (0.17%) and Pelican Point (0.15%) (Curtis et al., 2021). Additionally, high incidences of entanglements have clearly been shown to result from the combination of human habitation and intense fishing activity or accumulation of marine debris through ocean currents (NOAA, 2014; Donohue et al., 2001; Perez-Venegas et al., 2021; Zavala-Gonzalez and Mellink, 1997; Galgani et al., 2015). Further investigation into ocean currents influencing pollution movements and sources on colonies in southern Africa should be carried out.

Recent sources also show that closer proximity to urban areas increases litter abundance in South Africa (Ryan, 2018; Ryan, 2020). Therefore, land-based colonies, or those that are closer to the mainland, are likely to be more impacted by pollution, specifically pollution from nearby urban activities. Apart from Baboon Point in Elands Bay, Bird Island in Lambert's Bay had the highest overall entanglement incidence in all South African colonies. The seal colony at Bird Island is land-based and next to a presently working fishing harbor. Additionally, as Lambert's Bay is situated on the cold upwelling west coast side of the country, nutrient-rich water establishes large-scale fishing and mariculture industries where seal encounters with such sources of pollution are more probable (Probyn et al., 2012; NOAA, 2014). Baboon Point in Elands Bay had the highest overall entanglement incidence, but also the highest variation in incidences. The reasons for which Baboon Point showed such high incidencs in two surveys could be justified by the size of the colony. Baboon Point has an estimated population of 500 seals, the second smallest colony in this study after Partridge Point, making it 120 times smaller than the largest colony in this study. Therefore, a single entanglement detected in more than one survey could have drastically skewed the overall entanglement incidence.

Seal Island False Bay had the highest number of entanglements and the highest mean entanglements per survey. This is expected as Seal Island False Bay was the largest colony surveyed in addition to having one of the highest number of surveys and scans (25% of all surveys and 21% of all scans) and was the most consistently visited colony out of the six with an average interval of 3.3 months between each survey. High entanglement incidences in False Bay could coincide with the substantial increase in human population in Cape Town, the nearest city, with more than double the population in 1980 (Statistics South Africa, 2016). This has intensified development and infrastructure in False Bay intensifying anthropogenic pressures (Pfaff, 2019). Despite this, the entanglement incidence at Seal Island (0.11%) has decreased more than three-fold from 0.34% of the harvested seals at Seal Island False Bay in the 1979 (Shaughnessy, 1980). This decline in entanglement incidences is consistent with decreases in plastic entanglement incidence in other regions in the world (Boren et al., 2006; Karamanlidis et al., 2008; Allen et al., 2012; Waluda & Staniland, 2013). Declines in the mean number of entanglements in Australian fur seals (*Arctocephalus gazella*) were seen from 1989 to 2013 which coincided with both the ban of unlicensed fishing around South Georgia and the legislation imposed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Waluda and Staniland, 2013). Additionally, Karamanlidis et al. (2008) have stated that fishing regulations around breeding areas have managed to eliminate the threat of accidental entanglement of monk seals. However, some seals have shown a decline in entanglement incidences due to increased effort or a growth in the seal population (Boren et al., 2006). The decline in entanglement incidences at Seal Island False Bay may be due to results from the National Environmental Management Waste Act which was put into place in 2008 and later amended (as the Waste Act) in 2014, which regulates packaging and plastic waste in South Africa. Additionally, this decline in entanglement incidences since the late 1970s is likely justified by our more conservative methods and calculations and the inflated harvested seal incidence rates, as entangled seals might be easier to harvest. This decline could also be attributed to the records of only harvested entangled seals recorded in the late 1970s (Shaughnessy, 1980), excluding non-harvested entangled seals. Harvested seals are immature seals (aged between eight to ten months, with some less than 10% in their second or third years), an age class that has been repeatedly shown more commonly entangled than older age classes (Shaughnessy, 1980; Croxall et al., 1990; Pemberton et al., 1992; NOAA, 2014; Lawson et al., 2015, Curtis et al., 2021).

4.2 The demographics of entanglement

Of all the animals taken from all data sources in this study, only 57% of all entanglements were assigned sex with certainty. This study has shown a slight tendency for entangled female seals than male seals. This is likely due the sex-skewed ratio of females in the global seal population and the volume of visiting female seals to colonies throughout the year (Kirkman *et al.*, 2016), contrasting with male seals, whose presence are limited to the breeding season. Additionally, behavioral differences, such as higher frequency of foraging trips in females, may have also influenced these results (Perez-Venegas et al., 2021). These results have also been visible in Northern fur seals in the Bering Sea (NOAA, 2014), where females constituted about half the number of recorded entanglement cases (Delong et al., 1990). Contrastingly, when historical records from this study are excluded, males were found slightly more entangled than females, which may be explained by the different data collection methods used. Historical records were collected through binoculars contrasting the photographic surveys carried out in my recent study, where records may have been biased towards seal morphology. Adult male seals can be up to four times larger than adult female seals (Kirkman et al., 2016) and are therefore more visible in photographs and likely easier to detect. This higher male to female ratio was also seen in Namibia (Curtis et al., 2021). Moreover, the sex demographic of entangled seals warrants future study as the sample size of known sexed individuals is small. Additionally, we cannot infer which sex is more at risk of being entangled as the overall proportion of female to male seals (both entangled and non-entangled) in each colony is unknown. Breeding and non-breeding colonies also differ in population demographics.

Although juveniles are found to make up a larger portion of the seal population (Lima and Páez, 1997; Wickens and York; 1997; Arnould et al., 2003; Dabin et al., 2004; Kuzin, 2010), adults were more commonly found entangled, contradicting Curtis et al. (2021), and the noteworthy higher number of entangled juveniles (67%) detected in Namibia. This additionally contradicts other studies where juveniles exhibited more entanglement cases, justified by their 'playful' and curious behavior (Croxall et al., 1990; Pemberton et al., 1992; NOAA, 2014; Lawson et al., 2015). However, discrepancies in the ages of entangled seals may arise from studies not always reporting age classes of entangled individuals. There are, however, studies that have observed higher numbers of entangled adult seals (Franco-Trecu *et al.*, 2017; Perez-Venegas *et al.*, 2021; Ayala, Castillo-Morales and Cárdenas-Alayza, 2022), which can be accounted for by differences in morphology and behaviour (King, 1983; Doidge, Croxall and Baker, 1984; Baker & Baker, 1988; Schliemann, 1990; Charrier, Mathevon and Jouventin, 2001). Different levels of pollution at sea, from currents or disposal incidences throughout the year, may also play a part in the different age classes being impacted by entanglements. A few studies have determined peaks in plastic pollution accumulation on South African beaches during summer months (December through January)

(Rundgren, 1992; Gregory and Ryan, 1997), which may play a role in increased entangled juvenile populations in breeding colonies. Additionally, the higher number of entangled adults may have resulted from data collection methods, as adults are more visible in photographs as they are much larger than juveniles.

Despite the differences in the characteristics of the six surveyed seal colonies in this study, no associated relationship between the colony and the age class of entangled seals was detected. This absence of a significant relationship between age class and colony shows consistency in the regional trend observed between occurrences in entangled juveniles and adults. However, this result may come from the inconsistent surveying of colonies over time, as breeding and non-breeding colonies are likely to display differences in age demographic composition throughout a year. Ultimately investigation of the age at which an individual seal becomes entangled, the amount of time a seal is entangled, and age classification of detected entangled seals is necessary and should be further carried out correspondingly for global comparison.

4.3 Entanglement material and color

More than 68% of all classified entangling material in this study came from fishing gear, making fishing materials by far the most common entanglement material source for South African Cape fur seals. These results are comparable with those of other studies (Croxall et al., 1990; Pemberton et al., 1992; Hanni and Pyle, 2000; Donohue et al., 2001; Page et al., 2004; Kimberly et al., 2009; NOAA, 2014; Lawson et al., 2015; Kühn et al., 2015; McIntosh et al., 2015; and Claro et al., 2019; Curtis et al., 2021) and to the volume of plastics present in the ocean. Over 20% of ocean plastics come from marine sources (LI et al., 2016), around half of which arises from fishing fleets, comprising of nets, lines, and abandoned vessels (Macfayden et al., 2009; LI et al., 2016).

The use of classifying the entangling material according to the item (B) was an improvement to the entanglement material classification system as a finer-scale categorization creates no assumptions about the source of the material and can thus be objectively analyzed. Monofilaments, or fishing lure or line, were the most common entangling material item, followed by string/rope, packing straps, and nets. Monofilaments are thin fine fishing lines easily obscured from view in the water and easily caught under the thick fur of a fur seal. Hence, it is important to keep in mind that this material could be the most common entangling material because of its large presence in the surrounding waters or because of the accessibility of its entangling material characteristics. However, results from entangling material analysis are comparable to the high proportion of fishing material that is present in coastal South African environments (Rundgren, 1997; Gregory and Ryan, 1997), suggesting that the high encounters of Cape fur seals with nearby fishing activities, vessels, and gear account for the prominent number of entanglement cases with fishing material.

Regarding seal demographics, nets were more common in juvenile cases than adults, which was also documented in Hawaiian monk seal entanglements (Henderson, 2001). This is likely due to the characteristics of netting material being large, having a small mesh size, being buoyant, and trailing. This, therefore, increases juvenile encounters from increased interactions with floating material and causes more strain on younger individuals from drag and increased energy expenditure underwater and on land (Feldkamp, 1985). Nets as trailing material may also hinder an individuals' ability to avoid predators such as sharks, and therefore make juveniles vulnerable to predation and other mortality factors (see Appendix 11b for an example entanglement case). Results from a study by Fowler et al. (1987) indicated that mortality increases with the total size of debris. Thus, juveniles caught in nets are less likely to reach adulthood. Fowler et al. (1987) additionally inferred that of all entangling material, net was the main source of mortality of the Northern fur seal population on the Pribilof Islands, similarly to for Australian fur seal entanglements (Pemberton et al.,1992). These results may also justify the higher number of adult seal entanglements observed in this study.

Color was classified in 51% of all entangling item cases, where white entangling items were disproportionately the most common color, followed by green and clear. White happened to be most common color for monofilaments, string/rope, plastic bags, and packing straps, which is proportionate to the most prevalent entangling material. Additionally, nets had a higher proportion of green nets and blue nets compared to the rest of the entangling items. Green nets were also the most common entangling material color in Australian fur seals (Lawson et al., 2015), which was justified by the large number of green trawl nets used by the fishing industry in and around Australian waters. String/rope items showed the most diverse range of colors, with up to nine different colors, followed by packing straps and monofilaments, each with six colors. This suggests that color does not play a role in what type of material the seal is more likely to get entangled in, as both these items were the most common materials for entanglement cases in this study. This was also concluded in Pemberton et al.'s study (1992), where a variety of colors of packing straps were detected determined by the variety of entangling material Australian fur seals faced. Additionally, juveniles showed a distinctly higher proportion of green entangling material than adults, which is likely justified by the higher number of nets. However, the function of color in driving patterns of entanglement is limited and few studies have discussed and observed the color of the entangling items and what that may mean for seal attraction or commonality in marine debris, in addition to assessing differences in attraction or eyesight of seals through maturation. Therefore, further investigation in this area is suggested.

Entanglements were most commonly seen around the neck of the individual, which is comparable to entanglements in Namibian colonies and other studies (Pemberton et al., 1992; Curtis et al., 2021). Most material easily loops around the individuals' neck getting caught in its' fur. Fewer cases were visible entangling individuals' flippers, which may be due to the drastic impact on the seals' activities and moveability, increasing its' energy expenditure, hindering its' ability to forage properly, and possibly leading to its starvation. Few seals were found to have entanglements around the head, which were likely less common because the individuals are more easily able to free themselves (Starr, 2020).

Several seals within this study were also seen with wounds or scars from previous entanglements. This suggests that either the material had detached, or the seal had been disentangled. Disentanglement of seals in South Africa is not very common, as most seals are on island reserves, and visitation of such areas or reserves is not permitted. The Victoria and Alfred Waterfront in Cape Town has a group of Cape fur seals in the harbor where a disentangling program in collaboration with the Two Oceans Aquarium works to disentangle seals. Disentanglement efforts seen in wounded or scarred seals highlights the need for these mitigation efforts when possible.

4.4 Predicting severity

Cape fur seals are listed as least concern under the Red List of Marine Mammals in South Africa (Kirkman et al., 2016) and populations in South Africa have seen slight growth trends since harvesting ceased in 1990 (Kirkman et al., 2013; Kirkman et al., 2016). Even so, most entanglement cases under all data sources were listed as 'slight' on the severity level, with no visible skin wounds, similar to results from Namibia (Curtis et al., 2021) and cases in South American fur seals (Franco-Trecu et al. 2017). These injuries have the potential to aggravate, cutting into the fat layer, which may lead to more severe cases causing wounds and or lesions or infections, ultimately leading to death. These 'slight' cases are thus still significant and dangerous. The relatively low number of 'very severe' cases is likely due to mortality from such entanglements, as the risk is higher, and therefore such cases are rarely observed due to increased time at sea (Fowler et al., 1987). This is also likely to be the reason for zero 'carcass' encounters. The carcass encounters observed at Baboon Point were not listed as entanglement cases as they were obviously not constricting the entanglement location, the neck of the seal. However, the entanglement could have enhanced the mortality risk of the seal and played a role in the cause of death.

The severity levels of entanglement cases for this study are a conservative estimate of severity due to difficulties in distinguishing through poor quality photographs or large distances from individuals. With more certainty in their classification, most 'severe' cases were identified through opportunistic and or citizen science photographs, indicating that proximity to animals in photographs increases severity assessment ability. This also aligns with results from the study in Namibia (Curtis et al., 2021), whereby 'severe' cases of entanglements were most common in close encounters. Croxall et al. (1990) also observed a higher proportion of obvious physical injury ('severe' or 'very severe') entanglement cases (30%) in Antarctic fur seals. However, the methodology from this study involved proximity to seal entanglement cases on land. Therefore, determining the severity of the entanglement is dependent on the method of observing an entanglement case. More studies are required to assess the progression of injuries in seals to fully understand the impacts of an entanglement and its wound status on the animals' welfare and survival.

Despite the absence of significant interactions with the other variables tested for in this study, the severity level of entanglements was found to be significantly associated with the entanglement item (B). Most entangling material showed a higher proportion of entanglement cases at 'slight' severity levels followed by 'severe' levels, with a significant association between groups. Monofilaments were represented at similar proportions at all levels indicating the ubiquitous effects of this material. String/rope material was disproportionally high in 'slight' cases. This is likely due to the rough clingy material of string or rope as it can grip sharp rocks and other surfaces making it easier for the entanglement to come loose. Packing strap material was also shown to be disproportionally high in slight cases, contrasting from Namibian cases where this material was most implicated in ‘severe’ cases (Curtis et al., 2021). However, this high number of ‘slight’ cases in packing straps is likely due to the packing straps’ high durability and commonly looped structure with sharp edges (Butterworth, 2016). This characteristically makes packing straps more prone to cut into flesh, likely leading to death, resulting in fewer high severity cases. However, these differences may also be a result from subjective assessments of severity levels.

The significant relationship between item (B) and severity was also determined in the Random Forest classification analysis, whereby the item (B) was distinctly the most influential predictor variable of an entanglements’ severity level. This suggests that the outcome, the severity level, of an individual’s entanglement is dependent on what item, this individual was entangled in. Following the item (B) as a predictor variable, the colony, the geographic location, also showed high predictability under the RF classification trees. This suggests that the severity level of an entangled individual will likely depend on its geographic location in terms of observed seal colonies. Therefore, mitigation efforts in terms of the type of plastic pollution entering the ocean in addition to the geographic location of sensitive areas (such as seal colonies) will greatly reduce the severity level of Cape fur seal entanglements in South Africa and Namibia.

To investigate explanatory variables for severity levels as the outcome of an entanglement case further corresponding data collection and studies need to continue within South African colonies. Additional variables that might play a role in influencing the severity of an entanglement such as foraging depth, time and range, duration of entanglement, pollution source, known sex class, etc., should additionally be observed in the future. The duration of an entanglement was not observed in this study, however, is likely to greatly influence the severity level of an entanglement. This could be inferred to the age class of the entangled seal as age classes have different exposure times to entanglement material, whereby juvenile seals have a shorter exposure time than adult seals. However, due to possible discrepancies in age classes due to collection methods, it would be greatly influential to additionally observe the duration of entanglements in the future. Understanding the variables that are influencing the outcome of entangled seals can inform us on where to properly place mitigation efforts to better reduce the impacts of plastic pollution on the well-being of seals.

4.5 Survey method comparison

This study highlighted the important methodological considerations for studying entanglements. Systematic photographic surveys of a colony taken to represent its' entanglements was effective, as previously seen (Dicken, Bradshaw and Smale, 2013; Curtis *et al.*, 2021), with photographs offering a quick, low-cost option, amidst reliable and non-invasive methods that can be stored indefinitely. Within this study, the benefit of using photographic surveys from ground level allowed for multiple perspectives of the same colony (as proven in Appendix 9). Land versus boat surveys were limited to the location of the seal colony. Despite the sea conditions and movement during boat-based surveys, several subsets of the colony were observed during a boat-based survey as the boat can move around the colony, giving a more holistic representation. During land-based surveys the photographer was limited to one vantage point, where they are constrained to a sub-set view of the colony. However, during land-based surveys, the photographer was able to take their time in surveying the colony and take multiple scans with less effort and distractions of being on a boat and dealing with sea conditions. Photos were also of higher quality, with more stable conditions on the static ground and opportunistic entanglements were also detected with increased time visiting land-based seal colonies.

A higher number of entanglements were observed through aerial surveys when compared with boat-based photographic surveys at Paternoster Rock Island. An aerial view of a seal colony is more representative of that colony, fewer seals are hidden behind other seals and or rocks, depending on the colony, allowing for visibility of entire seal bodies, making age classes, material type, color, and severity also easier to classify. However, these results are not comparable as such surveys were carried out at different times of year and limited comparisons were made. Nevertheless, despite legal restrictions and potential for disturbances (López and Mulero-Pázmány, 2019), applying methods of aerial photographs has been repeatedly effectively applied in marine research (Schofield *et al.*, 2019; Kelaher *et al.*, 2020; Raoult *et al.*, 2020; Pirotta *et al.*, 2022). This method overcomes the biases of sea-based photographic surveys. Drones are cost-effective, time-efficient and can be used at higher frequencies with less disturbance (Claro et al., 2019; Pirotta et al., 2022). Ultimately, it is important to integrate new technology and methods that improves our understanding of ecological operations, such as population monitoring, when used in conjunction with conventional methods to maintain relevance to historical datasets (Christman et al., 2022).

4.5 Recommendations and future directions

Aerial surveys and the use of photographs to identify entanglement cases is recommended for future studies for efficient entanglement identification and ease of archiving. An increased number of surveys at all colonies, including the biggest Cape fur seal colony in South Africa, Kleinzee, is necessary, in addition to more consistent visits of other colonies throughout the year. Long-term monitoring will allow for more reliable comparisons between and among colonies in addition to detecting possible seasonal differences before, during, and after breeding seasons. Colonies with a notably high number of entanglements, such as at Seal Island in False Bay, are worth visiting for disentanglement efforts. The Two Oceans Aquarium in Cape Town has developed a method for disentangling seals from afar using a dart gun with promising results (Two Oceans Aquarium, 2021). This however is only a short-term solution to reduce animal suffering. Long-term solutions include changing underlying policies in plastic waste and handling, at sea and on land, in addition to changing human habits of plastic consumption.

Despite the growing Cape fur seal populations in South Africa (Kirkman et al., 2013 and 2016), 'slight' entanglements have the potential to aggravate and lead to population decline as in South America (Perez-Venegas et al., 2021) and the Bering Sea (NOAA, 2014). However, rather than focusing on the population impact from entanglements in these seals, this study focused on the impacts of entanglement in terms of the welfare and the general conservation of Cape fur seals in South Africa. Moreover, it is important to further investigate whether such entanglements recorded in South Africa come from active fishing gear or from disposed ghost gear, in addition to using severity levels as outcome predictors for entanglement cases in future studies. This will allow proper and appropriate mitigation in underlying policies targeting either fishing communities, companies, or organizations in the addition to the proper disposal of plastic pollution at sea and on land.

The primary source of entanglements is the individual encounters with fishing gear, therefore mitigating marine life entanglements will require interventions to reduce interaction with fishing gear and activities. In addition to the numerous suggestions from Laist (1997), the most supported suggestions addressing the prevention of abandoned, lost, or otherwise discarded fishing gear (ALDFG) by the UNEP and FAO include: documenting entanglement incidences; recovering lost gear; tagging, and or marking gear; using GPS or technology to map and detect gear; payment incentives for old or retired fishing gear; biodegradable nets and gear; and reduced effort

(Macfayden et al., 2009). Wilcox and Hardesty (2016) also underline three ways of reducing the probability of ghost-fishing gear getting lost, by, for example, creating biodegradable nets; increasing the chances of recovering lost gear, by mapping losses; and marking nets. There are many other suggestions in creating alternative or upgraded fishing gear such as using acoustics (Gearin et al., 1994; Jefferson and Curry, 1996) or making biodegradable nets from cotton (Cho, 2011) or seaweed (Herlekar, 2015).

Fisheries management is additionally extremely important. Efforts in policy changes do have the potential in reducing the impact of plastic pollution that ends up in the ocean (NOAA, 2014), such as Annex V in MARPOL (Annex V of MARPOL 73/78, 1978). Annex V sought to eliminate and reduce waste dumping into the sea from ships, which was possibly a variable that led to a 50% reduction in trawl net entanglements observed in 1988 (Ribic et al., 1994). Additionally, acts such as the Conservation Measure 63/XII for the Reduction in Use of Plastic Packaging Bands, which was put forward in 1993 and restricts the use of packing straps, are examples of important steps taken towards reducing marine animal entanglement. Reducing fishing effort and vessels, in addition to regulating mesh sizes, are other ways in lowering the chances of entanglements (Jepsen and de Bruyn, 2019). However, policy changes and regulations that prohibit or try to manage waste dumping and fishing activities in the ocean are difficult to enforce and monitor in certain areas of the world. Additionally, these suggestions only tackle waste at sea, whereas land-based debris such as domestic plastics requires separate mitigation efforts. These efforts may include changing global consumerism and business habits, using more sustainable practices, and improving waste disposal and recycling management.

Cape fur seals are a sentinel marine animal for studying the impacts of plastic pollution in marine ecosystems. They breed and rest on land in large groups allowing for easy access and observation efforts. Observing entanglements in seals that are hauled out on land are good indicators of the surrounding environmental conditions. Effects of marine debris on seals can also indicate possible impacts on other marine animals that are more difficult to monitor, such as pelagic deep-diving species, i.e., cetaceans that spend little time at the surface (NOAA, 2014). Further investigation of such marine animals is essential in understating the greater impacts of marine plastic pollution on ocean life.

4.6 Conclusions

In summary, results from this study support the worldwide perspective that fishing material is the primary source of seal entanglements. The entanglement material was classified as the most influential predictor in terms of the outcome of an entanglement. Although ‘slight’ entanglements were notably the most common severity category, there is potential for serious progression of severity levels with wounds and lesions leading to death. Entanglement incidences amongst South African colonies were slightly lower than Namibian colonies, however, were still significant and relevant in terms of impacts on individual seals’ health and wellbeing. The combination of systematic photographic and aerial surveying methods allowed for efficient analysis of animal entanglement characteristics and case demographics. As indicator species, generalist feeders, and opportunistic animals, Cape fur seals can assist in understanding how the effects of marine debris, specifically plastic pollution, impact the ecosystem. Therefore, future work should focus on 1) the continued long-term monitoring of the various sources and types of marine debris that negatively affects organisms, 2) assessing the proportional impacts of marine debris in comparison to other potential factors stressing organisms or populations, such as climate change, changes in food availability and disease, and 3) examining temporal and spatial patterns of entangled individuals in marine debris. Thus, the health and wellbeing of marine animals and the ocean in terms of marine plastic pollution can continue to be assessed and properly addressed.

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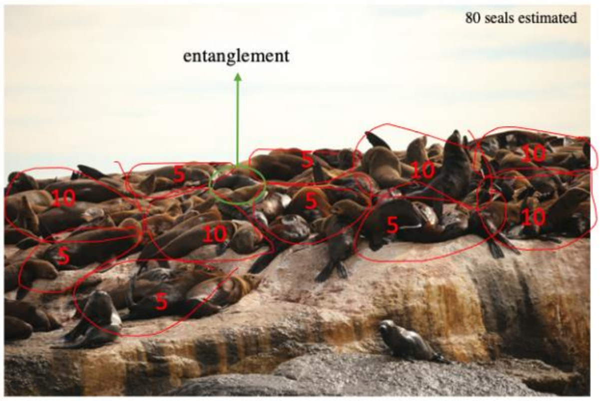
Appendix 1. Data request poster for citizen science entanglement photographs.

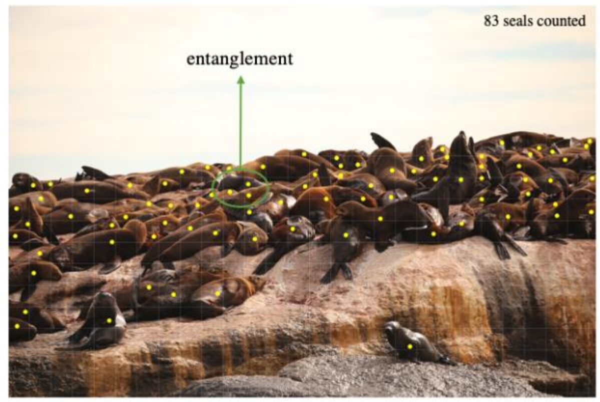
Appendix 2. Examples of non-entangled seals.

2a) Non-entanglement sample 1. This seal could be mistaken for as entangled however just displays an entanglement scar.

2b) Non-entanglement sample 2. This seal could be mistaken for as entangled around the neck; however, the positioning of the head and body create an illusion of entanglement when it is simply a body roll.

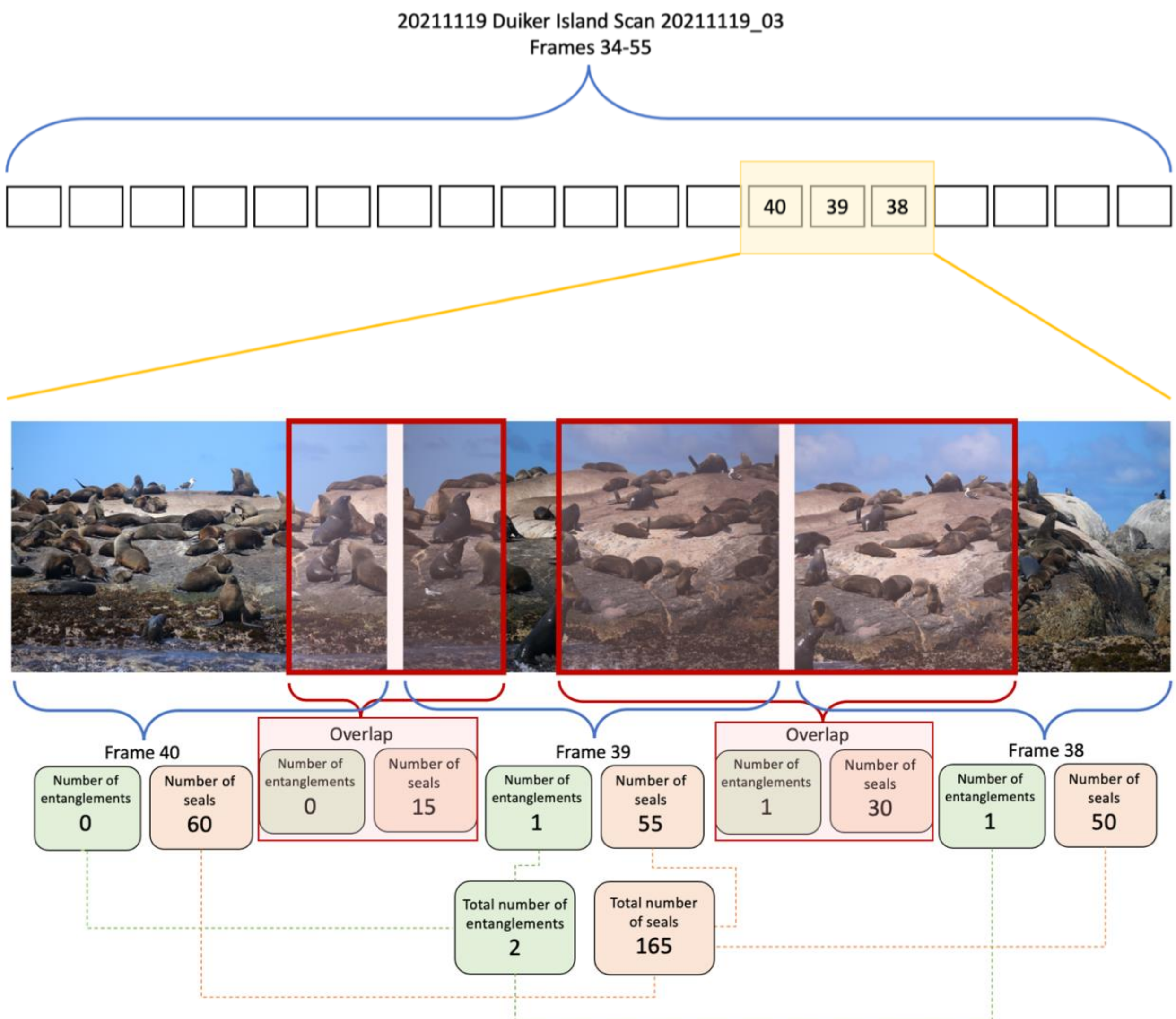
Appendix 3. Scheme illustrating method comparison between estimating the number of seals per frame versus counting the number of seals per frame. This frame was taken from a survey at Duiker Island in Hout Bay on the 10th of January 2022.





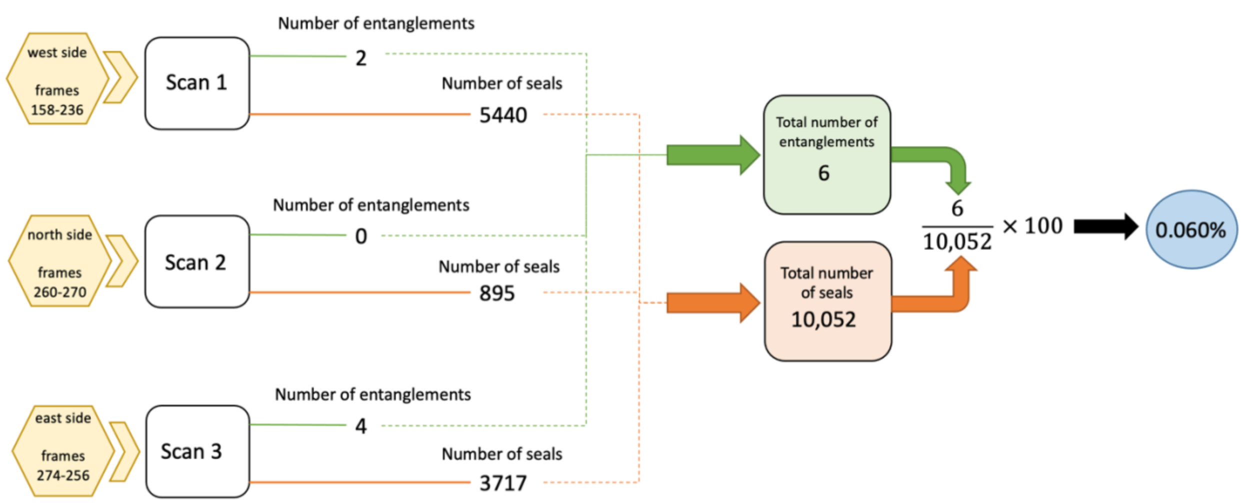
Appendix 4. Example scan explaining the overlapping of frames.

This scheme displays an example scan (20211119_03 from Duiker Island) on the 19th of November, 2021. This scan consisted of frames 34 to 55, frames 38, 39, and 40 displayed below, showing visible overlapping of seals. This double counting of both entangled and non-entangled seals is disregarded as the overall entanglement incidence of the survey will be unobstructed. The sum number of seals and entanglements was calculated for these three overlapping frames just as an example, however, the total number of seals and entanglements is summed within each scan and then for the overall survey to then calculate the entanglement incidence for that survey (check Appendix 6 for an example of one survey consisting of three separate scans). The entanglement incidence would then be the total number of entanglements (2) divided by the total number of seals (165), multiplied by 100 to give an incidence of 1.21%.



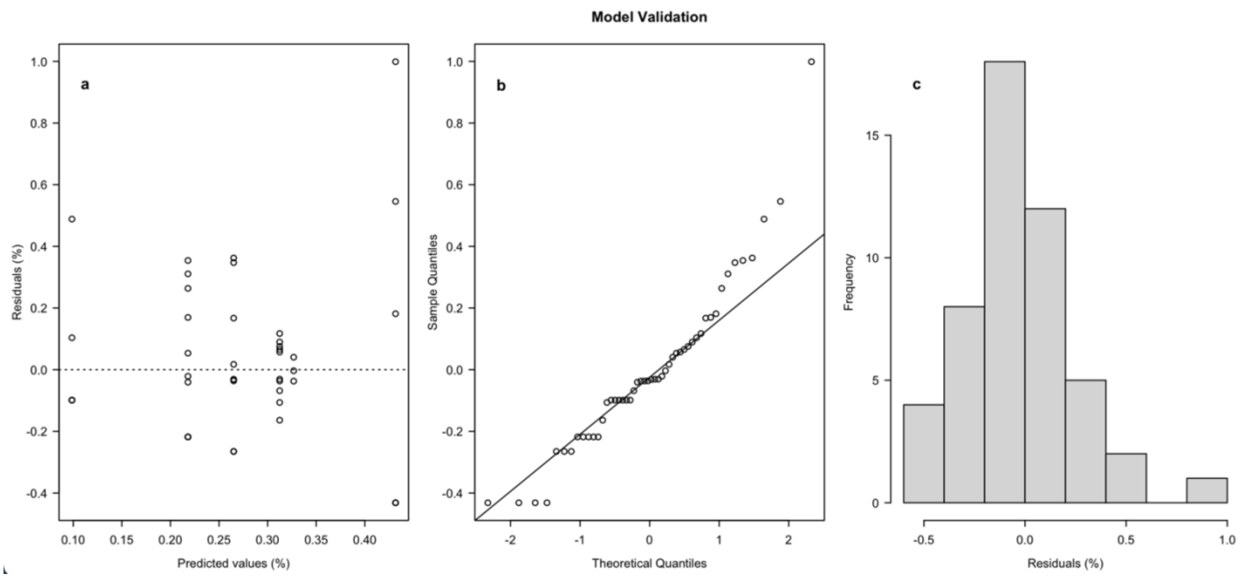
Appendix 5. Example of the entanglement incidence calculation.

The following scheme represents one survey, Scan ID 20210213 at Seal Island False Bay, where three individual photographic scans were taken and used for analysis. Each scan differed based on the unique viewpoint of the colony and therefore comprised of a unique number of frames. For each frame, per scan, the total estimated number of seals was noted in addition to the number of entangled seals observed for each frame. The total number of seals in each scan was summed among all scans of that survey, in addition to the total number of entanglements of that survey. The total number of entanglements in the survey was divided by the total number of seals, which was then multiplied by 100 to obtain an overall entanglement incidence for the survey.

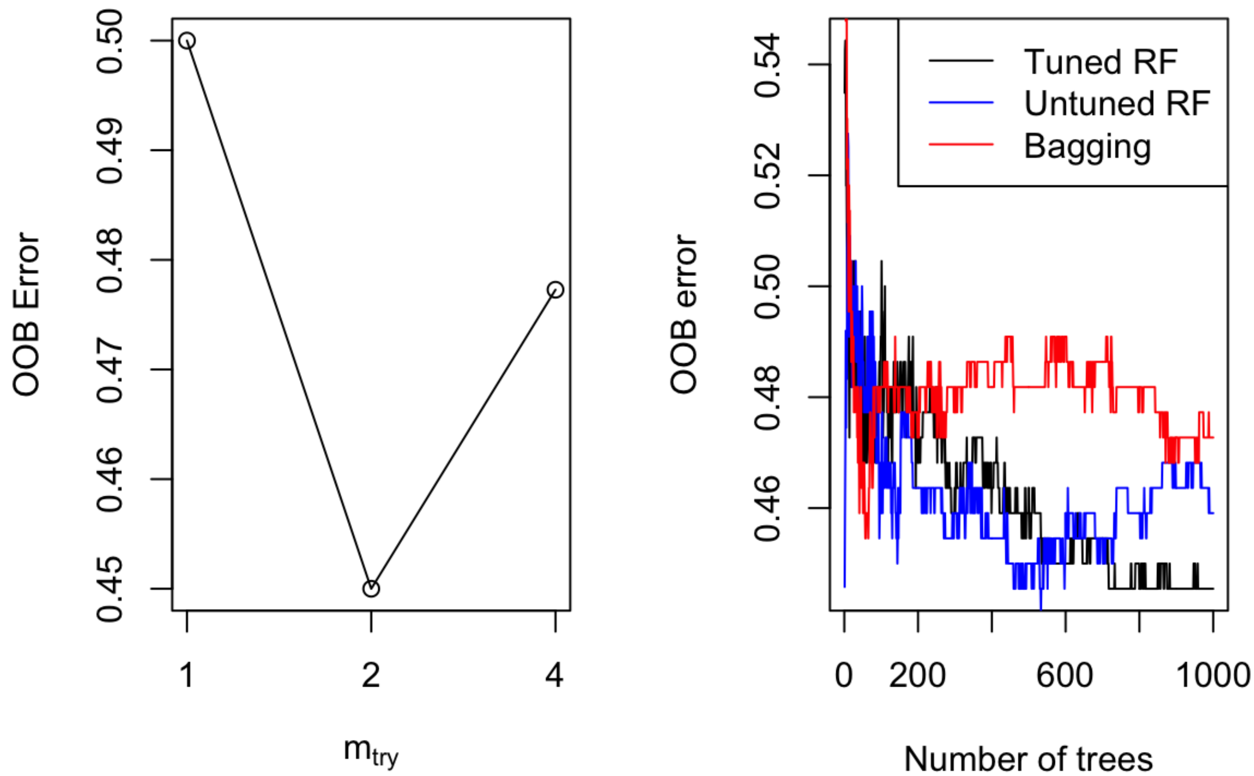


Therefore, 0.060% represents the entanglement incidence for the survey of the seal colony on Seal Island in False Bay on the 13th of February 2021.

Appendix 6. Model validation displaying (a) residuals over the predicted entanglement incidences (%), (b) qq-plot of sample qualities and theoretical qualities, and (c) a histogram of the frequency of residuals (n=49).



Appendix 7. Random Forest out-of-bag (OOB) error results. Figures displaying the tuned OOB errors and the OOB error for the number of trees for each Random Forest, Tuned RF (for tuned classification), untuned RF (for untuned classification), and Bagging (for bagged classification).



Appendix 8. Calculated entanglement incidences (%) for each survey, including the region and colony, the survey date with the respective estimated number of seals and number of entanglements observed (n = 49).

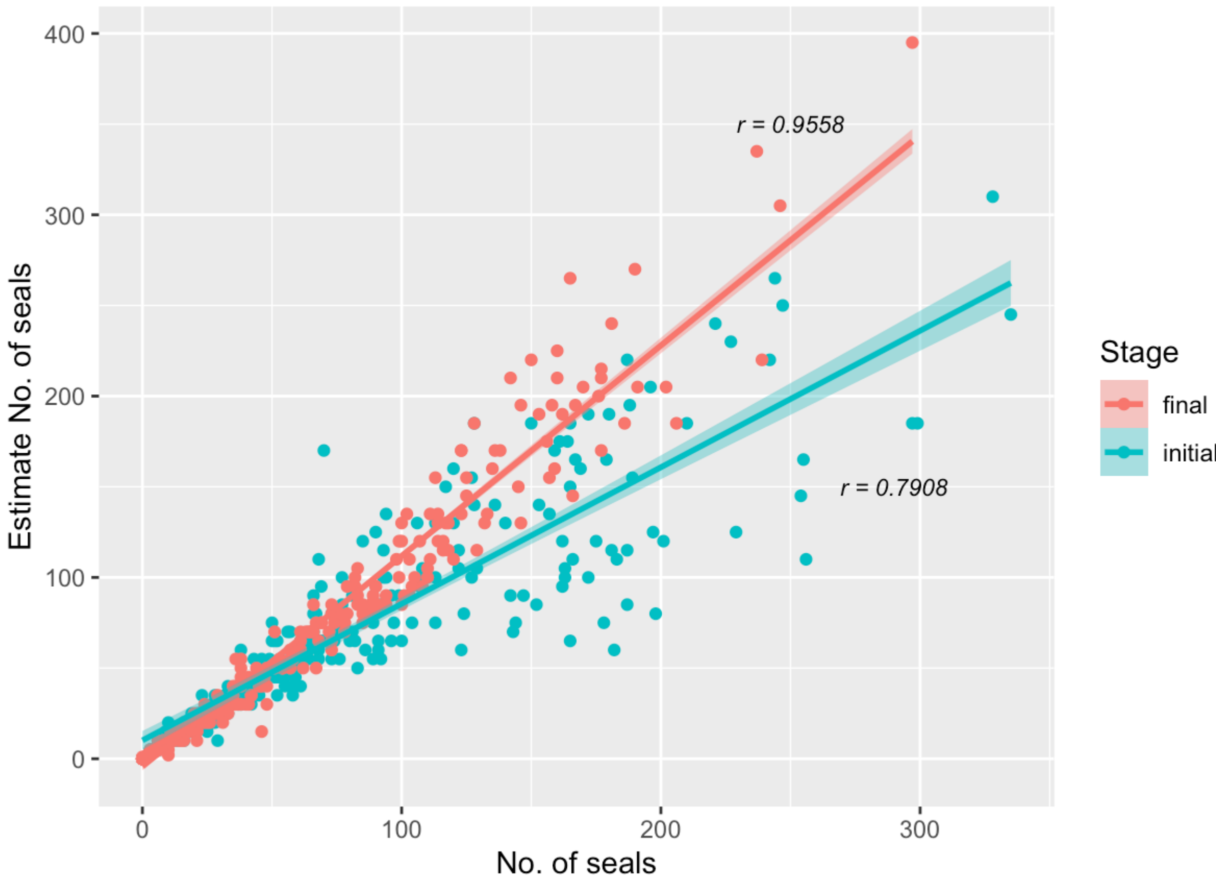
Region	**Colony**	Survey date	**Estimate no. of seals**	**No. of entanglements**	**Entanglement incidence (%)**
Lamberts Bay	Bird Island	20210426	1778	7	0.39
Lamberts Bay	Bird Island	20210427	2150	0	0.00
Lamberts Bay	Bird Island	20210428	1825	1	0.05
Lamberts Bay	Bird Island	20210429	2675	5	0.19
Lamberts Bay	Bird Island	20210430	1840	1	0.05
Lamberts Bay	Bird Island	20210501	2510	2	0.08
Lamberts Bay	Bird Island	20210922	3817	2	0.05
Lamberts Bay	Bird Island	20210923	4266	16	0.38
Lamberts Bay	Bird Island	20211020	1174	0	0.00
Lamberts Bay	Bird Island	20220202	1015	0	0.00
Elands Bay	Baboons Point	20210922	902	0	0.00
Elands Bay	Baboons Point	20210923	1330	5	0.38
Elands Bay	Baboons Point	20211019	2540	0	0.00
Elands Bay	Baboons Point	20211020	2274	0	0.00
Elands Bay	Baboons Point	20220125	684	14	2.05
Elands Bay	Baboons Point	20211218	985	0	0.00
Elands Bay	Baboons Point	20220202	314	3	0.96
Hout Bay	Duiker Island	20191122	666	1	0.15
Hout Bay	Duiker Island	20200313	985	0	0.00
Hout Bay	Duiker Island	20201019	3608	0	0.00
Hout Bay	Duiker Island	20201027	2710	2	0.07
Hout Bay	Duiker Island	20210403	1841	0	0.00
Hout Bay	Duiker Island	20210421	1194	0	0.00
Hout Bay	Duiker Island	20210505	1620	0	0.00
Hout Bay	Duiker Island	20210509	1430	4	0.28
Hout Bay	Duiker Island	20211006	2583	1	0.04
Hout Bay	Duiker Island	20211109	6344	2	0.03
Hout Bay	Duiker Island	20211119	3664	12	0.33
Hout Bay	Duiker Island	20220110	3445	8	0.23
False Bay	Partridge Point	20200730	230	0	0.00
False Bay	Partridge Point	20200806	371	0	0.00
False Bay	Partridge Point	20210518	510	0	0.00
False Bay	Partridge Point	20210821	804	0	0.00
False Bay	Partridge Point	20210909	904	0	0.00
False Bay	Partridge Point	20211031	2441	1	0.04

False Bay	Partridge Point	20211231	580	2	0.34
False Bay	Partridge Point	20220109	694	0	0.00
False Bay	Seal Island.FB	20190330	3780	3	0.08
False Bay	Seal Island.FB	20191018	8780	12	0.14
False Bay	Seal Island.FB	20200730	4331	8	0.18
False Bay	Seal Island.FB	20210213	10052	6	0.06
False Bay	Seal Island.FB	20210413	5260	4	0.08
False Bay	Seal Island.FB	20210416	4525	1	0.02
False Bay	Seal Island.FB	20210504	4705	2	0.04
False Bay	Seal Island.FB	20210508	9800	14	0.14
False Bay	Seal Island.FB	20210909	5316	8	0.15
False Bay	Seal Island.FB	20211031	8040	13	0.16
Mossel Bay	Seal Island.MB	20210321	2965	4	0.13
Mossel Bay	Seal Island.MB	20210322	1191	1	0.08

Appendix 9. Scheme illustrating two scans of the same survey at seal colony of Partridge Point in False Bay on the 31st of December 2021. In Frame 213 an entanglement is visibly detected however in Frame 221 the location of the entanglement on the same seal is hidden behind another seal and the entanglement is not visible. This displays the utility of using multiple scans for one survey to appropriately depict the entanglements of a colony.

Frame 213 – scan 1 | Frame 221 – scan 2

Appendix 10. Scatter plot displaying both the initial (n = 256) and the final (n = 340) stages in the estimation of the number of seals per frame versus the true number of seals per frame.



Appendix 11. Example entanglement photos.

11a) Entanglement sample 1. Male adult seal with a severe entanglement of a white monofilament around the neck. This was an opportunistic entanglement taken on the 22nd of November, 2019, at the Hout Bay Harbour by M. Terreri.

11b) Entanglement sample 2. Juvenile seal with a slight entanglement in a green net around the neck. This was a citizen science entanglement case taken by S. Hoerbst at Geyser Rock in Gansbaai in 2015.

11c) Entanglement sample 3. Adult seal with a slight entanglement of a white monofilament at the shoulder. This was an entanglement recorded at a systematic photographic survey of Bird Island in Lambert's Bay on the 23rd of September 2021. The photograph was taken by M. Ramilo Henry.

11d) Entanglement sample 4. Juvenile seal with a nil entanglement of a white plastic bag around the neck. This was an entanglement recorded at a systematic photographic survey of Seal Island in False Bay on the 30th of March 2019. The photograph was taken by S.Elwen.

Appendix 12. Random Forest classification results. Figures displaying the decrease in accuracy by mean accuracy and decrease in node impurity by mean Gini index for four explanatory variables in terms of severity of entanglement cases.