A STUDY OF THE EFFECTS OF COMMERCIAL FISHING DEBRIS ON *CALLORHINUS URSINUS* FROM BREEDING ISLANDS IN THE WESTERN PACIFIC

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ABSTRACT

In this paper, data and analyses are presented concerning the incidence of entanglement among the northern fur seal, *Callorhinus ursinus*, from the breeding islands of the western Pacific. This work was undertaken to further explore the degree to which waste disposed from fishing vessels is a source of mortality for this species. Based on the available data, estimates of the minimum proportion of various age and sex groups entangled within the population are produced. Historical data show that injuries caused by fishing nets shreds (66%), ropes (20%), fishing line (8%), and packing bands and collars made of other materials (6%) are contributing to the mortality of northern fur seals. The incidence of entanglement, and therefore the resulting mortality among the Tyuleniy (Robben) Island population, is higher than for the population on the Komandorskie (Commander) Islands. The higher incidence of entanglement on Robben Island may be related to declines in the population on that island in comparison to the relative stability on the Commander Islands, where the incidence of entanglement is less.

BACKGROUND

The intensity of exploitation of living marine resources increases annually (Moiseev 1979). The number of fishing fleets increases correspondingly (Yerukhimovich and Yefremenko 1985). Increasing intensity in fishing brings with it various negative effects on the environment. One of the aspects of this influence is the pollution of the ocean with scraps of fishing gear, packing materials, and other waste from the commercial fisheries, directly threatening many marine organisms. Fish, seabirds, reptiles, and marine mammals get entangled in such materials and die (DeGange and Newby 1980; Fowler 1982, 1985, 1987; Kuzin 1985; Shomura and Yoshida 1985).

A determination of the extent of the negative influence of commercial fishing waste and pollution in the ocean is not possible for the majority of marine organisms. But the continuous and systematic observation of

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

northern fur seals, returning each year to their hauling grounds (near the breeding colonies) after wintering in the ocean, provides the opportunity to determine the number of individuals entangled in marine debris. The resulting data allow for the calculation of estimates of the extent of damage caused by marine debris resulting from loss and discard by commercial fisheries as well as other human activities.

From the historical data, the kinds of debris found on entangled seals is known. Of the total number of entangled seals on Robben Island, 66% are entangled in fragments of fishing nets. Another 20% are found entangled in ropes, 8% in fishing line, and 6% in packing bands and collars made of other materials of commercial fishing waste (Kuzin 1985). Fowler's data (1982) showed that in the Pribilof Island population as many as 50,000 seals may die annually as a result of injuries caused by foreign objects. Over a life time, entanglement may cause the death of 15% of a cohort (Fowler et al. 1990). Similar estimates for other populations of fur seals, however, are unavailable.

In order to obtain estimates of entanglement-related mortality for populations of fur seals on both Robben and the Commander Islands, the statistical data presented annually to the Northern Pacific Fur Seal Commission regarding the incidence of entanglement among northern fur seals on hauling grounds are used.

METHODS

For estimating the effects of commercial fishing debris on fur seal populations, we have used the data from the commercial harvest of bachelor seals (2- to 5-year-old males, also referred to here as juvenile males). These data were collected by counting the total and the number of entangled male seals in the commercial harvest for each year from 1975 to 1986 on both Robben Island and the Commander Islands (Table 1). All entangled seals were of the same size category as the remaining seals taken in the harvest. These harvests were conducted during the months of June and July of each year, and all entangled seals were killed along with the other seals taken. Seals with scars only were not counted as entangled such that the counts included only male seals observed with entangling debris. Entangling debris found on the seals was then identified and frequencies were tabulated for each category of debris. Pieces of monofilament gillnet were included in the category of net shreds along with pieces of trawl net debris.

With the data on total numbers taken in the harvest and the counts of entangled seals among them, collected as described above, the incidence of entangled animals among the juvenile males (2 to 5 years old) was determined by dividing the number of entangled seals taken by the total in the harvest for each year and location.

For other age groups and sex groups of seals, data are not available from their primary concentrations on the breeding rookeries. However, data have been recorded for entangled individuals from these categories, as noted for seals found on hauling grounds. Thus, the percent of all entangled animals found on hauling grounds that fall into each category

Table 1.--Number of juvenile male fur seals taken and the incidence of seals entangled in debris in the commercial harvest by year and location (breeding islands in the western Pacific).

	Number harvested		Number entangled		Percent entangled	
Year	Robben	Commander	Robben	Commander	Robben	Commander
1975	2,500	1,730	27	30	1.08	1.73
1976	2,569	2,768	69	68	2.68	2.46
1977	4,069	2,766	69	66	1.69	2.39
1978	3,188	3,032	81	32	2.54	1.06
1979	2,933	2,524	33	13	1.13	0.52
1980	3,107	2,544	26	44	0.83	1.73
1981	3,613	5,117	113	35	3.12	0.76
1982	2,924	5,075	124	75	4.20	1.48
1983	2,582	5,717	24	34	0.92	0.59
1984	2,322	5,294	35	37	1.50	0.70
1985	459	5,097	4	47	0.87	0.92
1986	2,034	--	34	--	1.67	--
Total	32,300	41,664	639	481	1.97	1.15

can be determined. The categories used in this study are: mature males (older than 6 years), half-mature males (or "half bulls," 6 years of age), bachelors (younger than 6 years), females, and pups. Since exact ages are not known, the numbers in each age category are determined on the basis of experienced judgment.

To analyze the data resulting from the field work described above, a method for estimating lower bounds of the proportion of each age-sex class was developed. The following is an explanation of the procedure used.

As mentioned above, the empirical data are for a population consisting of several categories or age-sex groups. One category is represented by data for which the incidence of entanglement can be clearly determined (i.e., the bachelor males, which will be represented by subscript j). The other groups (e.g., pups, females) are those for which we wish to have estimates of the incidence of entanglement. These groups will be represented by subscript i.

To develop a procedure for estimating the proportion of seals entangled in each group, their total numbers in the population as a whole are defined as P_i. The total for the bachelor males is defined as P_j. The proportion entangled (or incidence of entanglement) is defined as C_i and C_j, respectively, for each of the two categories, so that the numbers entangled are C_iP_i and C_jP_j. Of these, a proportion of each category is seen, a proportion defined as α (α_i and α_j, respectively) so that the actual numbers of entangled animals seen on land are $\alpha_iC_iP_i$ and $\alpha_jC_jP_j$ for

the two cases. It is assumed that the probability of seeing an entangled animal of any category is the same as the probability of seeing a nonentangled animal of the same category or that entanglement does not influence the probability of being seen. This may be summarized as follows:

Category	Total population	Fraction entangled	Numbers entangled	Proportion seen	Entangled animals seen
i	P_i	C_i	C_iP_i	α_i	$\alpha_iC_iP_i$
j	P_j	C_j	C_jP_j	α_j	$\alpha_jC_jP_j$

The desired estimate is of C_i, knowing C_j. This can be accomplished by dividing the number of entangled animals seen from category i ($\alpha_iC_iP_i$, for which there are data) by the number of animals seen in category j ($\alpha_jC_jP_j$, also for which there are data) and multiplying this ratio by $C_j(\alpha_jP_j \ / \ \alpha_iP_i)$:

$$(\alpha_iC_iP_i \ / \ \alpha_jC_jP_j) \ C_j \ (\alpha_jP_j \ / \ \alpha_iP_i) \ - \ C_i$$

For this equation to produce the correct estimate (disregarding the statistical aspects of the problem), then, it is seen that either values for α_iP_i and α_jP_j must be known (which they are not) or their ratio must be known. If this ratio were 1.0, the number of the two segments seen would be equal.

Based on observations on hauling grounds, the total number of seals in the bachelor category is always larger than the total for each of the other categories listed in Tables 2 and 3. (Here we refer to the total present, not the number of entangled seals seen.) Because of this, the equation above can be used by assuming $(\alpha_jP_j \ / \ \alpha_iP_i) > 1.0$ to determine lower bounds to the entanglement rates for the categories other than for bachelors. The value of the expression $(\alpha_jP_j \ / \ \alpha_iP_i)$ will always be greater than 1.0 since α_jP_j (the number of bachelor males seen on hauling grounds) is always greater than the number seen for other groups. Thus, the expression used to produce estimated lower bounds for the proportion entangled for groups other than bachelor males is:

$$C_i > N_iC_j \ / \ N_j$$

where:

C_i is the proportion of animals of the age-sex group in question that are entangled;

$N_i = \alpha_iC_iP_i$ is the number of entangled animals of the age-sex group in question as observed at the hauling grounds;

C_j is the proportion of bachelors that are entangled; and

$N_j = \alpha_jC_jP_j$ is the number of entangled bachelors observed at the hauling grounds.

Table 2.--Number and percent of entangled fur seals falling in various age and sex categories as observed at hauling grounds on Robben Island.

	Bulls		Half bulls		Bachelors		Females		Pups		Total	
Year	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1974	4	1.5	10	3.8	115	43.4	136	51.3	--	--	265	100
1975	--	--	--	--	27	77.1	8	22.9	--	--	35	100
1976	2	2.2	1	1.1	69	71.2	21	22.6	--	--	93	100
1977	2	2.8	--	--	69	97.2	--	--	--	--	71	100
1978	53	18.0	47	15.9	58	19.7	135	49.9	1	0.3	294	100
1979	16	19.2	9	10.8	16	19.3	42	50.6	--	--	83	100
1980	1	0.8	4	3.5	102	88.7	8	6.9	--	--	115	100
1981	11	15.7	5	7.1	19	21.1	32	45.7	3	4.3	70	100
1982	4	3.2	5	4.3	65	52.4	50	40.3	--	--	124	100
1983	12	12.4	--	--	13	13.4	72	74.2	--	--	97	100
1984	16	18.4	5	5.7	18	20.7	47	54.0	1	1.1	87	100
1985	10	10.8	--	--	31	30.0	61	59.8	--	--	102	100
1986	5	6.8	2	2.4	19	22.9	53	63.9	4	4.8	83	100
1987	10	13.5	8	10.8	13	17.5	43	58.1	--	--	74	100
Total	146	9.2	96	6.0	634	39.8	708	44.4	9	0.6	1,593	100
Calculated minimum percent of entangled individuals:												
		0.45		0.30		[a]1.97		2.19		0.03		

[a]From Table 1.

RESULTS

The numbers of seals taken in the commercial harvests on Robben Island and the Commander Islands, and the numbers of entangled seals among them are shown in Table 1 for 1975 through 1986. Also shown is the resulting incidence of entanglement expressed as a percent of the harvest. The number of entangled seals from the other categories, as observed on the hauling grounds, are shown in Table 2 for Robben Island, and Table 3 for the Commander Islands. Tables 2 and 3 also show the fraction of the total number of entangled animals observed as accounted for by seals in each category. Thus, the totals of the categories are each 100% for all observed entanglement, by year and island.

The results of calculations to determine the lower bounds to estimates of the percent entangled among each age-sex group of northern fur seals are presented in the last lines of Tables 2 and 3. The proportion of the total population which is entangled depends on the fraction of the population comprised by each of the age-sex categories. However, it can be seen that the lower bound for the overall entanglement rate must be between 0.03 and

Table 3.--Number and percent of entangled fur seals falling in various age and sex categories as observed at hauling grounds on the Commander Island.

	Bulls		Half bulls		Bachelors		Females		Pups		Total	
Year	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1974	--	--	--	--	--	--	--	--	--	--	--	--
1975	1	2.9	2	5.7	13	34.1	19	54.3	--	--	35	100
1976	--	--	--	--	--	--	--	--	--	--	--	--
1977	8	9.4	11	12.9	25	29.4	30	35.3	11	12.9	85	100
1978	--	--	--	--	--	--	--	--	--	--	--	--
1979	63	26.8	2	2.0	126	53.6	41	17.4	5	2.1	237	100
1980	26	24.1	--	--	40	37.0	39	36.1	3	2.8	108	100
1981	21	15.9	7	5.3	85	64.4	19	14.4	--	--	132	100
1982	17	12.2	16	11.5	81	58.3	25	17.9	--	--	139	100
1983	36	39.1	5	5.4	20	21.7	31	33.7	--	--	92	100
1984	--	--	--	--	--	--	--	--	--	--	--	--
1985	--	--	--	--	--	--	--	--	--	--	--	--
1986	13	27.7	3	6.4	21	44.6	10	21.3	--	--	47	100
1987	--	--	--	--	--	--	--	--	--	--	--	--
Total	185	21.1	46	5.3	411	46.9	214	24.5	19	2.21	875	100
Calculated minimum percent of entangled individuals:												
	0.52		0.13		[a]1.15		0.59		0.05			

[a]From Table 1.

2.19% for Robben Island and between 0.05 and 1.15% for the Commander Islands. These estimated lower bounds cover the period from June through August (3 months), the time during which seals are seen on the hauling grounds.

DISCUSSION

It is natural that some seals that are entangled in commercial fishing waste die at sea without being seen on land, especially in the areas where seals from the western Pacific overwinter (Pacific Ocean and Sea of Japan in the Japanese, Korean, and American exclusive economic zones). However, data concerning entanglement rates and mortality for these areas are not available. In Fowler's (1985, 1987) work and Fowler et al. (1990), information is presented as a basis for accounting for unseen mortality at sea. After accounting for debris that is too large for seals to return to land, mesh sizes that pups become entangled in, and the mortality rates observed in large debris, as many as 30 to 35 seals per year may die for each one that is observed alive. The effects of the size composition of debris at sea has not been considered in its effects on seal populations of the

western Pacific. Neither have the effects of mesh size. However, in view of the levels of entanglement presented in Tables 2 and 3, it is clear that an even lower ratio of unseen mortalities to observed entanglement would be necessary to achieve similar levels of mortality thought possible for the Pribilof population. Further data on the size composition (by weight and mesh) of debris from beaches and pelagic habitat in the western Pacific will be necessary to extend this evaluation of the potential effects of marine debris on the mortality of fur seals.

There is a very important observation to be noted in the data in Tables 2 and 3, an observation that deserves to be emphasized. At the Commander Islands, the incidence of entanglement among seals is lower than at Robben Island. Among bachelors, the incidence of entanglement is 1.7 times as high on Robben Island as on the Commander Islands. The minimum level of entanglement for females is almost four times as high. The importance of this observation comes from the fact that this may be one of the reasons why the Commander Island seal population did not decrease in recent years, while other populations declined. This emphasizes the need for further information on the composition of debris (by weight and mesh size) to determine if there are differences between the western and eastern Pacific. Such differences might explain the divergence in dynamics between the population of fur seals on the Commander Islands (no recent declines) and the Pribilof Islands (a decline in the late 1970's).

If mortality due to entanglement is as high in the western Pacific as is thought possible for the Pribilof population, as many as 3.7 to 6.7 thousand seals die from entanglement annually. In the North Pacific as a whole, then, as many as 60,000-65,000 northern fur seals may die due to the discard and loss of gear and debris from commercial fisheries. Those figures are 1.7-2 times higher than the figures of the potential annual harvest of juvenile male northern fur seals in the U.S.S.R. and the United States.

It is known that 60% of the Robben Island seals, 5-6% of the Pribilof seals, and 28-30% of the Commander Island seals winter in Japanese waters (Ashchepkov and Kuzin 1986). Cooperative efforts involving all interested countries seem necessary for studying the problem of the pollution of the ocean by commercial fishing waste. The existing fisheries-oriented scientific associations among the Pacific countries provide the opportunity for their leadership to inform fisheries organizations about the sources of debris and the volume of the damage caused by commercial fishing to marine resources. The solving of this problem depends on how soon and how completely sailors and fishermen realize the seriousness of marine pollution and that the discard of debris is contrary to international regulations.

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