Proceedings of the

International Marine Debris Conference

Derelict Fishing Gear and the Ocean Environment

AUGUST 6–11, 2000

HAWAI‘I CONVENTION CENTER

HONOLULU, HAWAI‘I

NATIONAL MARINE SANCTUARIES

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION · NOAA · U.S. DEPARTMENT OF COMMERCE

Proceedings of the

INTERNATIONAL MARINE DEBRIS CONFERENCE
ON DERELICT FISHING GEAR AND THE OCEAN ENVIRONMENT

The Hawaiian Islands Humpback Whale National Marine Sanctuary and its partners acknowledge and thank Senator Daniel K. Inouye for his vision and support of the conference.

August 6-11, 2000

Hawai'i Convention Center

Honolulu, Hawai'i

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FOREWORD

The International Marine Debris Conference on Derelict Fishing Gear and the Ocean Environment was convened to address the Pacific-wide nature of lost and discarded fishing gear and its impacts on protected species, coral reefs, and the marine environment.

The conference attempted to address the problem of derelict fishing gear at its source. Evaluation of netting removed from coral reefs during multi-agency cleanup efforts in the Northwestern Hawaiian Islands indicated to National Marine Fisheries Service (NMFS) officials at the Honolulu Laboratory that the majority of recovered debris was not originating locally but rather from other fisheries operating in the North Pacific, including Asia and Alaska.

Bob Rock, Marine Debris Communications Committee

Artist Robert Lyn Nelson (left) and President of the Ocean Futures Society Jean Michel Cousteau (right) during the unveiling of the Conference poster.

Funding for the conference was provided by the U.S. Congress to the National Oceanic and Atmospheric Administration's Hawaiian Islands Humpback Whale National Marine Sanctuary. Congress charged the agency with the overall organization of the conference and with the directive to bring together a diverse group of individuals from industry, government, and the public sector to assess the Pacific-wide nature of derelict fishing gear and develop specific recommendations and strategies for action.

The conference convened in Honolulu, Hawai'i on August 6-11, 2000. Representatives from across the Pacific came together to share ideas and develop a list of recommendations and detailed strategies for action including Chile, Taiwan, Japan, Australia, New Zealand, American Samoa, and Micronesia.

Among the recommendations were calls for:

- an international action plan,
- greater attention to marine debris issues by members of the International Maritime Organization and various UN Regional Seas Programs, and
- public and private partnerships to assist in the implementation and compliance of international agreements and guidelines.

This proceedings document is a compilation of the papers, speaker presentations, and recommendations developed by the conference participants. We hope that the recommendations will be shared amongst colleagues and that collaborative multi-agency and international efforts will continue to produce solutions to this problem.

Naomi McIntosh
Conference Organizer
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MAHALO NUI LOA TO ALL INDIVIDUALS WHO CONTRIBUTED THEIR TIME AND EFFORT

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Bob Rock, Marine Debris Communications Committee

Likeke Bell opens the Conference by blowing the pu (conch shell). Seated left to right on the platform are conference speakers Honolulu Mayor Jeremy Harris, Jim Cook (WESPAC), and James Coe (NMFS) and conference hosts Kitty Simonds (WESPAC) and Allen Tom (HIHWNMS).

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INTRODUCTION

On August 6-11, 2000 the Hawaiian Islands Humpback Whale National Marine Sanctuary, along with its multi-agency partners, sponsored the International Marine Debris Conference on Derelict Fishing Gear and the Ocean Environment. The objectives of the conference were to: (1) review sources and impacts of derelict fishing gear; (2) assess and identify new technology for mitigation and prevention; (3) establish international and national partnerships; (4) increase international and national public awareness; and (5) develop recommendations for future actions.

Bob Rock, Marine Debris Communications Committee

The Hawai'i Convention Center, scene of the International Marine Debris Conference.

To help stimulate ideas and recommendations on these matters, six issue papers were distributed to participants prior to the conference. The issue papers served to form a foundation for discussions within each of six separate working groups examining policy and legal issues, impacts of marine debris, source identification, industry considerations and actions, monitoring and removal, and education and outreach.

The conference was convened to bring together representatives from government and academia as well as environmental and industry groups to evaluate past, present, and future mitigation efforts. A total of 278 individuals participated from 20 countries and 15 states. Twenty-eight speakers were invited to give oral presentations and share their research findings on the scope of the derelict fishing gear problem and current efforts aimed at addressing the issue. U.S. Senators Daniel K. Inouye and Daniel K. Akaka, U.S. Representatives Neil Abercrombie and Eni Faleomavaega, and Under Secretary on Oceans and Atmospheres and Director of NOAA Dr. D. James Baker were among those invited to share their views on issues associated with marine debris. In addition and in conjunction with the conference, August 6-12 was proclaimed Marine Debris Awareness week in the state of Hawai'i by Governor Benjamin Cayetano. Mayor Jeremy Harris also proclaimed Marine Debris Education week for the City and County of Honolulu to urge all citizens to play an active role in solving the problems of marine debris.

Bob Rock, Marine Debris Communications Committee

International Marine Debris Conference participants enjoy a luau on the grounds of Bishop Museum.

Based on the issue papers and other papers presented at the conference, a list of recommended actions were developed for each of the six focus topics. Consequently, conference participants detailed thirty priority recommendations and strategies for future action. These recommendations underscore the importance of international cooperation in addressing the derelict fishing gear issue in the North Pacific Ocean.

What follows is a summary of the information, ideas, and recommendations presented and developed at the conference to reduce the impact of derelict fishing gear on the ocean environment.

ECOLOGICAL EFFECTS OF MARINE DEBRIS: THE EXAMPLE OF NORTHERN FUR SEALS

Charles W. Fowler, Program Leader for the Systemic Program
Management Studies Program, Alaska Fisheries Science Center,
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ABSTRACT

It is impossible to make a complete list of the environmental impacts of the current human population, a population that is a thousand-fold larger than the mean population of other similar-sized mammals. One set of influences has involved our use of the seas for food and the resulting changes in marine environments. Humans harvest fish at rates that are ten to one thousand-fold larger than the mean rates of consumption by other mammalian predators. Among the many consequences are the effects of the gear used. To accomplish harvests of such magnitudes we have developed new technologies, including the development and use of plastics to make nets. In spite of the durability of plastics, fragments of fishing gear are lost, torn away, or discarded. These fragments join debris generated elsewhere, including the effluents from rivers and streams that carry garbage lost or discarded in terrestrial settings, all of anthropogenic origin and destined to impact the marine environment.

Numerous studies have been published, and several symposia have been held, to characterize and measure the effects of marine debris. Plastics often accumulate in the digestive systems and cause the death of birds, turtles, and various filter feeding species. Many fish, birds, and mammals become entangled and die. This paper uses the effects of marine debris on northern fur seals (Callorhinus ursinus) that breed on the Pribilof Islands in Alaska as an example of the general problem of marine debris. Entanglement in marine debris by northern fur seals results in reduced growth rates, altered feeding behavior, injury, impaired maternal care, and mortality. The population level consequences of such factors were manifested in a decline that occurred in the late-1970s and early-1980s.

Much has been done to tackle the larger problem of marine debris. But if we were to consider all of the cases for marine species like that of the northern fur seal, studied or not, we would be left with an important question: Can we address the issues behind and beyond the problem of debris? They involve changes in the quality and quantity of food supplies, other aspects of fur seal population dynamics, and effects on other species. More research is needed and any conclusion regarding the effects of marine debris on any one species is not basis for neglecting research or management regarding other problems. Supporting the current human population results not only in the problem of marine debris, but in many other problems in both marine and terrestrial environments.

INTRODUCTION

Industrial fishing helps provide food for a human population that is well above the normal range of natural variation for population size among species of similar body size (Fowler and Perez, 1999). Having occupied more of the earth's surface than any other mammalian species, we rely on the fishing industry to supply significant portions of our food from the marine environment. Marine fishery harvests are being taken at rates that are one to three orders of magnitude more than the average consumption rates among other mammalian consumers of the same resources, mostly through commercial fishing (Fowler, 1999; Fowler and Perez, 1999; Fowler et al., 1999). Such harvests have numerous secondary or indirect effects, some of which show in the initial documentation of their effects on ecosystems (e.g., Pauly et al., 1998; Hall, 1999; Kaiser and de Groot, 1999). We have very little understanding of the consequences of such changes to the future of the various species involved, including ourselves. It is important to recognize that there are repercussions to what we are doing, especially those that may result in risks for future generations. These include the effects of the technologies that make such harvests possible.

One technology that has made it possible to harvest fish at current rates was the development of plastics, particularly those used in nets that were introduced in the 1940s and 1950s and became prevalent by the 1960s. Numerous review articles and books serve as sources of information about the effects of plastics in various environments, including their influence on various elements of the marine environment (e.g., Shomura and Yoshida, 1985; Alverson and June, 1988; Shomura and Godfrey, 1990; Coe and Rogers, 1997). Ghost fishing (Breen, 1990; Hall, 1999) has direct effects on species of economic interest as well as both their prey resources and predators. Entanglement and ingestion of plastic debris have been documented as factors contributing to the mortality of numerous species, including many marine turtles, sea birds, and marine mammals (e.g., Laist, 1997). Plastics from worn or discarded fishing nets are one of the main sources of debris involved in the entanglement of marine mammals.

Between the mid-1970s and the early-1980s the population of northern fur seals on the Pribilof Islands experienced a decline from which it has not recovered. This decline occurred a few years after a peak was observed in the portion of juvenile males seen entangled in the commercial harvest. Concern generated when the problem was first recognized and gave rise to a number of studies to examine the effects of marine debris on individual fur seals and attempts to measure the effect on their population.

The entanglement of northern fur seals is one of many examples of the kinds of environmental effects of a human population so abnormally large in comparison to other species. This particular effect is the result of the use of plastics in fishing, shipping, and other activities in support of this population and is one example of the many effects of commercial fishing in that regard.

EFFECTS OF MARINE DEBRIS ON NORTHERN FUR SEALS

Northern fur seals (as well as other pinnipeds around the world, Fowler, 1988; Laist, 1997) become entangled in marine debris of various types, nearly all of which ends up encircling their necks (with some around their heads or shoulders and upper bodies). Most is netting of various kinds (predominantly trawl net fragments, but also seine and gill net material), plastic packing bands, and twine or ropes of various kinds (see Fowler et al., 1994 and Stepetin et al. 2000 for an accounting of the kinds of items found on northern fur seals, and further references regarding this issue). Presumably, most of the entanglement occurs as a result of curious play with such materials (Bengtson et al., 1988) and is therefore a problem of greater consequence to younger seals than it is for the adults.

The history and details of the study of entanglement of northern fur seals, as summarized below, is documented in a variety of reports and documents, some of which are referred to in overview papers of Fowler (1987), Fowler et al. (1990) and Laist (1997). The monitoring of marine debris on northern fur seals continues (Stepetin et al., 2000), thus offering the opportunity for continued analysis in the future.

BEHAVIORAL EFFECTS

Being entangled in debris reduces the ability of fur seals to swim. Their activities are altered so that more time is required for finding food and for resting, resulting in less time for other activities such as returning to breeding colonies to nurse pups. In the process, feeding cycles and diving behavior are affected.

For example, Feldkamp et al. (1989) found that captive northern fur seals exhibited a marked reduction (75% for the circumstances of their study) in the time fur seals spend swimming when they are entangled (as compared to normal conditions with no debris to impede their movement through the water). Entangled animals spent more time resting (138% more in the Feldkamp study) than they did without debris.

Yoshida et al. (1990a) also conducted studies on captive northern fur seals in a marine aquarium and found that entanglement inhibited activity in general. In this study, debris of 1 kg and 2 kg masses were placed on two adult female fur seals and radio transmitters were attached with nylon harnesses, including one on a control seal. The behavior of all three seals was monitored with receivers that recorded their activity. Average total daily active periods were 9.6 h/day for the control, 4.1 h/day for the seal entangled in 1 kg of netting and 1.4 h/day for the seal in 2 kg of netting. Activity was similar among all three seals after removal of the debris.

Another behavioral factor affected by entanglement is the cyclic foraging patterns among both male and female northern fur seals. During the breeding season, females leave their breeding colonies to feed and then return to nurse their pups.

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These are cycles that are repeated for a number of weeks after the pups are born (Gentry, 1998). A study of the effects of entanglement on females was conducted in 1985 (DeLong et al., 1988). Forty females were fitted with radio transmitters, all from the Zapadni Reef breeding colony on St. Paul Island in the Bering Sea. Twenty were entangled in 200 g pieces of trawl webbing of 23 cm mesh and the other twenty served as controls. These seals were then monitored continuously with a programmable receiver and chart recorder to determine whether they were present or absent from the breeding colony. Furthermore, visual scans were conducted daily between July 22 and October 13. The mean duration of the trips to sea for the entangled and control seals in this study is illustrated in figure 1. As can be seen, the feeding trips for entangled seals were roughly twice the length of those for the controls.

Similar work with juvenile males showed that they also exhibit altered feeding cycles (Bengtson et al., 1989). Cycle length was increased by being entangled, consistent with the results of studies on females, and more time was spent on land, an option probably not so available to females whose pups depend on them for food.

The diving behavior of entangled northern fur seals is also affected. For example, entangled seals do not dive as deep as they would otherwise. Bengtson et al. (1989) used data from time depth recorders attached to seals to compare the diving behavior of three entangled seals with that of three control seals, all juvenile males captured and tagged in 1986 on St. Paul Island. The debris on the entangled seals was, in all cases, less than 1 kg in weight. The results indicated that the entangled seals made about the same number of dives as did the control seals, but the entangled seals did not dive as deep as the controls did. When diving to any particular depth, the entangled seals spent more time during their dives than did the control seals. Thus, the depth and duration of dives was altered by being entangled, but no change in the frequency of dives was detected in this study. Entangled seals made longer and more shallow dives than seals without the effects of debris.

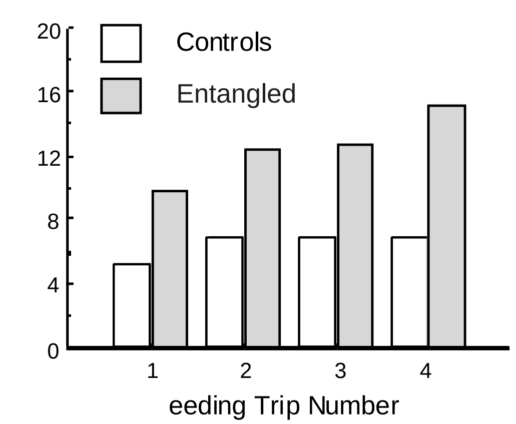


Figure 1
A comparison of the mean length of feeding trips for entangled female northern fur seals fitted with radio transm itters and for seals fitted only with radio transmitters, for the first four feeding trips in the study (from DeLong et al., 1988).

ENERGETIC DEMANDS

The energetic drain on seals caused by the drag of entangling debris is greater than the drag a seal experiences while swimming normally. Studies by Feldkamp et al. (1989) showed that fur seals of 4 to 17-months of age spent twice as much energy swimming at 1.1 m/s with 200 g of entangling trawl net compared to seals without debris. This is consistent with work on California sea lions (Zalophus californianus) in which it was shown that individuals entangled in 400 g pieces of net experienced a four-fold increase in energetic demands. As would be expected, both studies showed that energetic demands increase with swimming speed and the size of the entangling debris.

These conclusions are supported by the work of Yoshida et al. (1990b) who observed a decrease in swimming speed in relation to an increase in the size of entangling debris in their study with captive animals. Net fragments of six different sizes (0.5 to 3.0 kg) were placed on the necks of eight fur seals (two males, six females) in an aquarium and their swimming speed was recorded using visual observations of each individual while swimming over measured distances. Another measure employed in this study was that of the time required to capture fish. Consistent with the studies reported above, the time required increased in a relationship that was nearly a linear function of net size. The mean time to catch live fish for control seals was about 15 seconds whereas seals entangled in 3 kg of netting required an average of about 157 seconds. Thus, being entangled contributes to a decrease in foraging efficiency. Entangled seals spend more energy swimming, consume less in the time during which they forage, and have less energy available for swimming.

WOUND DEVELOPMENT

Of all the seals that get entangled, a few are entangled in debris that is sufficiently small enough for them to capture food, grow, and survive to be seen in studies to monitor entanglement. However, the resulting growth in body size of these seals produces pressure against entangling debris. The wear of movement, in combination with this pressure, results in growing wounds and infections. Fowler and Baba (1991) summarized the data on wound size for entangled male seals sighted in research on seals observed after 1983. Some of these seals were involved in studies in which the debris was purposely left on the animals (to estimate mortality caused by entanglement). Twelve entangled seals were initially sighted without observable wounds and then were resighted again in the following year. After one year of being entangled, three of these seals had no wounds, one showed the initial phases of wound development, and the remaining eight had full 360° wounds around their necks. Another eight had wounds that were less than 360° when first encountered and were then sighted on one or more occasions in subsequent years. All but one of these had developed full 360° wounds by the first (n = 5) or second (n = 2) year following the initial observation.

GROWTH RETARDATION

Based on the results of studies on energetics, it is no surprise that entangled fur seals either lost weight or there was a reduction in their growth rates; some of which may be attributable to the effects of wounds and infections caused by entangling debris.

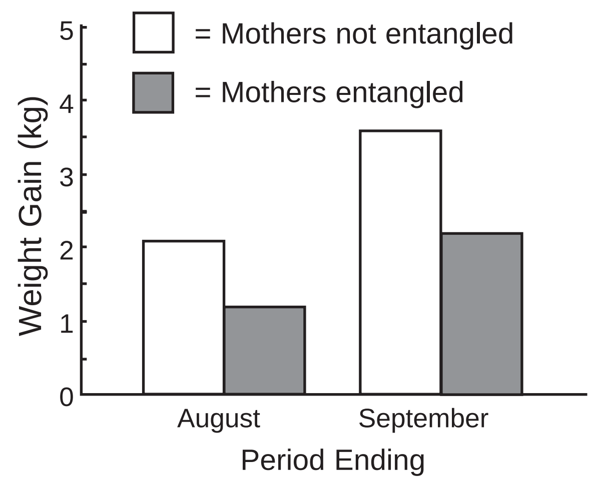
Table 1 shows the weights of juvenile male seals taken in the commercial harvest of 1982 (Scordino and Fisher, 1983). The mean weights of all entangled seals with wounds were less than those for the controls (not entangled). In two cases, entangled seals with no wounds (ages two and three) showed mean weights less than the controls and in all cases the entangled seals with wounds showed mean weights less than entangled seals with no wounds. If there were no difference in growth, the probability of this combination of observed differences (or more extreme) occurring is less than 0.10. As reported in Scordino and Fisher (1983), there were cases in which entangled males were observed with very obvious stunted growth.

Table 1. Body mass (kg) of juvenile male fur seals of four different age categories taken during the commercial harvest of 1982, St. Paul Island, Alaska (from Scordino and Fisher, 1983).

	Age (years)			
Entanglement category	2	3	4	5
Controls	21.4	28.5	35.3	50.9
Entangled (no open wounds)	21.3	27.8	36.0	52.8
Entangled (with open wounds)	14.7	26.6	32.2	44.5

DeLong et al. (1988) also found indirect effects on the growth of pups whose mothers were entangled. In addition to monitoring the 40 adult females (20 entangled females and 20 control females), the pups from each of the two groups were also marked and weighed. The first weights for these pups were obtained in July at their first capture. Pups from each group were subsequently recaptured and weighed again in August and a third time in September. Pups nursed by control females gained a mean of 2.1 kg (n = 19) between the first and second weighing and 3.6 kg (n = 14) between the second and third. By comparison, the surviving pups of the entangled females gained an average of 1.2 kg (n = 12) and 2.2 kg (n = 7) for the same periods (figure 2).

Figure 2
Comparison of the gain in mass observed from July to August, and from August to September, for two groups of fur seal pups: 1) those whose mothers were entangled (n = 12, 7), and 2) those whose mothers were free of entangling debris (n = 19, 14), (from DeLong et al., 1988).



MORTALITY

Individual northern fur seals die as a result of the effects of entanglement, as would be expected on the basis of the impacts reviewed above. Starvation, exhaustion, infection, greater vulnerability to predators, and diseases are all involved to one extent or another. Knowing this emphasizes the importance of assessing the extent of mortality rates, especially in view of its potential importance at the population level. Various studies have examined this issue for northern fur seals.

In the study by Delong et al. (1988), entangled females and their pups were monitored over the course of the 1985 season to determine the indirect effects of entanglement. DeLong et al. (1988) indicated that 3 out of 17 entangled adult female seals failed to return from their first trip to sea. Four failed to return after their second trip, and two more did not return after their third trip. Thus, over half (9 of the 17) failed to return within the first three trips to sea, a period of time less than about two months. By contrast, only one of the 20 control seals did not return, her failure occurring on the fourth trip to sea. Such observations can be explained either by behavioral changes or mortality. In either case the pups suffered higher mortality.

DeLong et al. (1988) conducted surveys and monitoring again in 1986 to test the hypothesis that adult female seals from the entangled group from the 1985 study would be resighted in the same proportion as seals from the control group. During weekly surveys conducted in July, August, and September of 1986, 12 females from the control group, and two females from the entangled group were resighted. Both of the females from the entangled group were animals that had lost their entangling debris during 1985; none of the 17 that retained their debris in 1985 were resighted in 1986.

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DeLong et al. (1988) concluded that the females that did not return in 1985 either abandoned their pups or died at sea. Mortality probably prevented the observation of those not sighted again in 1986.

DeLong et al. (1988) also report significant indirect effects on survival of pups (before weaning and during the time that they depend on their mother's milk) that are attributable to the entanglement of their mothers. Of the pups born to the 17 females that retained their entangling webbing, only 6 were alive at the end of the study the first season, while 19 of the 20 pups from the control females survived. Thus, even when an entangled adult female is capable of returning to nurse her pup, the pup's chances of surviving are reduced.

Other studies of entanglement and its effects on the northern fur seal population involved juvenile male northern fur seals. Between 1985 and 1992, 153,850 juvenile male seals were sampled in surveys (referred to as roundups that involved sampling with replacement, Bengtson et al., 1988; Fowler and Ragen, 1990; Fowler et al., 1990; Fowler and Baba, 1991). Entangling debris was left on the sampled seals (n = 265) when they were encountered during the first three years of this study, and each entangled seal was tagged along with two control seals of similar body size. After the first three years, debris was removed from entangled seals when they were encountered. In years subsequent to the initial marking, the ratio of the proportion resighted for each group was used to calculate an estimated survival of both entangled and disentangled seals (Fowler et al., 1990). This survival was expressed as a fraction of normal survival (i.e., survival of the control seals). Figure 3 shows the declines in the portion of each group of seals resighted by year of recapture subsequent to their release.

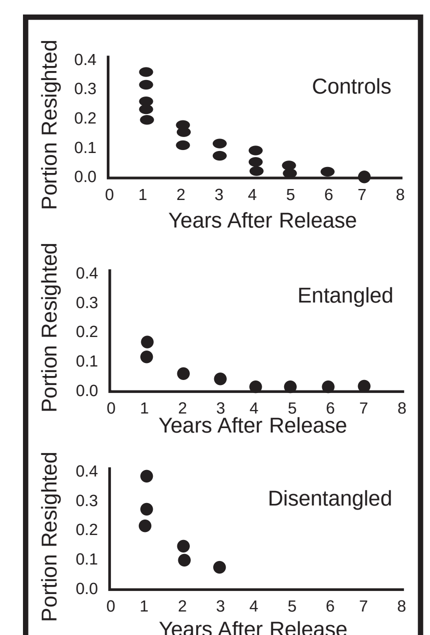

Figure 3
The fraction of seals resighted subsequent to release in samples from St. Paul Island, Alaska, from 1986 through 1992, that were never entangled (top panel), entangled (middle panel), or had entangling debris removed (lower panel), (updated from Fowler et al., 1999).

PRESENTATIONS

The relative rates of recapture clearly indicated a marked effect of entanglement on survival. Analysis of the data presented graphically in figure 3 resulted in an estimated survival for entangled seals that is about one-half that of the survival they would normally experience (an instantaneous mortality rate caused by entanglement of about 0.69, Fowler et al., 1990; Fowler et al., 1994). Disentangled seals experienced a survival about 93% of that for controls (Fowler et al., 1994), thus indicating that removal of debris has a marked effect in preventing mortality, but some residual effects of entanglement seem to remain, nevertheless.

POPULATION EFFECTS

Studies such as those above contributed to information to help measure the effects of entanglement among northern fur seals at the population level, and emphasized the importance of doing so. It became clear that the animals surviving to be observed in small debris represented only a small fraction of those that became entangled. Most had died and were never seen because almost all seals in larger fragments of net appeared to have either died or left the reproductive population after less than one year in the experimental studies reviewed above.

The timing of the decline between the mid-1970s and the early-1980s corresponded to a period during which the population effects of earlier entanglement would have been expected had there been population models such as were produced later (Swartzman, 1984; Fowler, 1982; Reed et al., 1987; French et al., 1989; Reed et al., 1989; French and Reed, 1990). This timing led to the concern that prompted the studies reviewed above and placed emphasis on examining population level effects in a variety of ways.

Several alternative approaches were employed to examine the degree to which mortality caused by entanglement has been influential in the dynamics of the northern fur seal population, especially that of the Pribilof population. These included: (1) various modeling studies; (2) several analyses of data on observed entanglement rates in correlation with population change; and (3) estimates of mortality rates caused by entanglement after accounting for various factors such as the unobserved entanglement and mortality involving large debris.

Modeling began with the work of Fowler (1982) where it was concluded that the effects of entanglement should be considered as a factor in the decline in fur seal numbers observed in the late-1970s. Swartzman (1984) and Swartzman et al. (1990) then developed models that showed the plausibility of mortality from entanglement as a primary cause of this decline. These models were more sophisticated than that of Fowler (1982) by including age structure (Fowler, 1987). Other modeling work (Reed et al., 1987; French et al., 1989; Reed et al., 1989; French and Reed, 1990) resulted in similar conclusions.

They showed that entanglement-caused mortality could clearly account for population trends observed between the early-1970s and mid-1980s. This work also demonstrated the possibility that a decline in observed entanglement rates (even a 20% reduction) might result in a stabilizing of the Pribilof Islands population (the population has been relatively stable since the early-1980s following the peak in observed entanglement rates in the early- to mid-1970s). Thus, among the many alternative factors known to contribute to mortality, entanglement has been the only factor for which there was a demonstrable change with a magnitude and timing that corresponded with the decline. These modeling efforts clearly established the plausibility of entanglement as the primary factor contributing to the decline between the mid-1970s and early-1980s, keeping in mind that the effects of other factors continued to play their roles.

Other studies also support the conclusion that entanglement caused mortality was a primary factor in the decline of fur seals on the Pribilof Islands in the late-1970s and early-1980s. Some of these studies used information on correction factors to account for the variety of factors that prevent most mortality from being directly observed. These factors included age, to account for the fact that small entangled seals would not be seen (they could not return to the breeding islands if they were entangled and do not return under normal circumstances in any case). The most significant factor is the size of debris; as demonstrated in other work, seals entangled in large fragments of trawl netting cannot return to the islands to be observed during entanglement surveys. Further considerations involved the effects of sex, natural (nonentanglement related) mortality, and other characteristics of entangling debris (e.g., mesh size and type). Such factors were combined to estimate the mortality rate caused by debris within the fur seal population as a whole. These efforts resulted in an estimated entanglement-related survival of about 0.85 (an instantaneous mortality rate of about 0.16) among younger age groups. Thus, these studies indicate that there was an extra mortality rate of about 15% per year that was attributable to the effects of entanglement (Fowler et al., 1990). This estimate applied to conditions of an observed entanglement rate of about 0.4% among the juvenile males. The corresponding extra mortality of the higher entanglement rates observed in the early- to mid-1970s would be more than enough to explain the decline in population in the late-1970s. Such results added to the difficulty of ruling out the conclusion that entanglement was a primary factor.

Similar results emerged in studies of the correlation between the rate of change in the fur seal population and observed entanglement rates (Fowler, 1985; Fowler, 1987). The independent variable in most such studies was the entanglement rates observed a few years earlier when mortality would remove (or prevent the reproduction of) females that would normally have been recruited to the reproductive population. Figure 4 shows one such relationship, extended from earlier work to take advantage of more recent data and cover the period from 1967 to 1991 (for entanglement rates) and 1971 to 1996 (for rates of change). Data after 1994 can not be used yet because rates of change beyond 2000 are not available. As predicted by earlier modeling work, the reduction in entanglement rates observed recently has corresponded with a relatively stable population (little change has been observed in the numbers of pups born in the Pribilof population of fur seals since the early-1980s). The entanglement rates observed in recent years have remained at about 0.2% (Robson et al., 1997; Stepetin et al., 2000), and such observation can be used in future correlative analysis when the corresponding rates of change are available.

The results of this component of studies on population effects of entanglement (as shown in figure 4) indicate that entanglement results in the equivalent of a mortality rate of about 15% spread over the entire population. This is seen in the difference between the rate of change at an entanglement rate of zero (8% per year increase) and that at the highest rates of observed entanglement (about a 7% or 8% per year decline).

Another correlative study looked at the mortality unexplained by the relationship between pup survival and juvenile survival (the first 20 months of life at sea, Fowler, 1985, 1987) between 1950 and 1965. This relationship appeared to break down in the late-1960s through the mid-1970s at a time when entanglement rates were observed to increase. Multiple correlation analysis resulted in an estimated additional mortality of 15% at an entanglement rate of 0.4%, again sufficient to have been the primary cause of the decline between the mid-1970s and early-1980s at the higher entanglement rates observed in the early-1970s. Other correlative studies are presented in Fowler (1985).

The consistency of results in the modeling work, the estimated mortality rates, and the correlation analyses led Fowler (1985, 1987) to conclude that the decline in fur seal numbers observed in the late-1970s, and the failure to recover in the early 1980s, can be attributed to the effects of entanglement. Much as the decline between the 1950s and late-1960s can largely be attributed to the effects of the harvest of females (York and Hartley, 1981). A similar conclusion was reached by Fowler et al. (1990). This conclusion comprises the basis for management action as mortality rates of 15% for fur seals cannot be within the normal range of natural variation of mortality caused by other species (e.g., Fowler et al., 1999). It should be obvious that the significant effects of entanglement are confined primarily to the period when observed entanglement rates are highest (i.e., the period between the early-1970s and early-1980s), although we cannot rule out lingering effects, nor that the low levels of entanglement observed currently are not having unmeasured effects.

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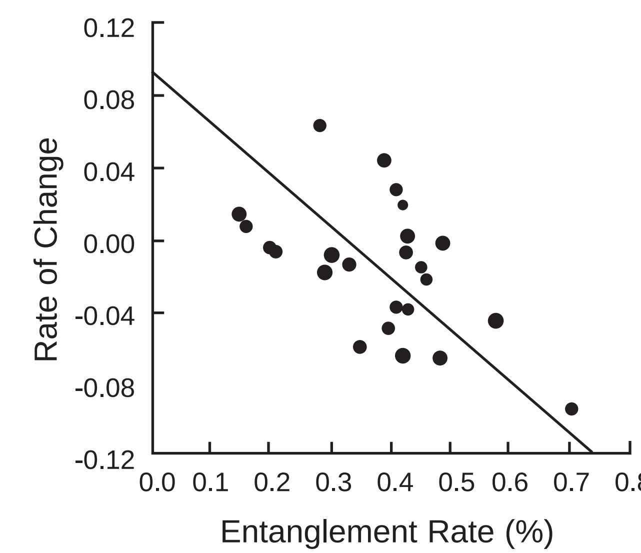

Figure 4
The correlation between the rate of change in numbers of pups born from 1972 to 1996 (based on a running mean of 3) and the entanglement rate observed among subadult male northern fur seals from 1967 to 1991 (i.e., with a lag of 5 years, based on data available at the National Marine Mammal Laboratory, Seattle, WA; see Fowler, 1987).

DISCUSSION

Commercial fishing is a complex process with many effects on the various species within marine ecosystems. There is little doubt that marine debris is one of these factors. The effects identified for fur seals and their population on the Pribilof Islands are not alone.

Although it is likely that the decline in the late-1970s may not have occurred without the effects of entanglement caused mortality, other factors can not be ignored. During the decline, other factors had their normal effects in contributing to natural mortality. Other factors may have involved other anthropogenic effects. For example, such factors could easily include a reduction in the carrying capacity (Fowler and Siniff, 1992), especially in the years following the more prominent effects of entanglement. In spite of its apparent prominence for a restricted period of time, it would be a critical mistake to ignore other effects of over fishing, contaminants, or global climate change, especially at times of low entanglement rates. Although the effects of the commercial harvest of female northern fur seals were probably greatest during the 1950s to the late-1960s (York and Hartley, 1981), lingering effects could well extend into later periods (Fowler, 1995). We cannot use information that indicates that entanglement was, and may still be, a serious problem to divert attention from such matters. Research on the effects of changes in the composition (Merrick, 1995), depletion, and redistribution of resources is imperative because their effects could easily be significant at any time. All problems that can be identified and measured need to be addressed to fulfill the tenets of adequate management (Fowler et al., 1999).

In focusing on measuring the effects of marine debris as one such problem, for at least one period of time, it is clear that the combined effects of factors such as wounds and altered behavior contribute to mortality and its resulting population-level effects for northern fur seals. From a management point of view, the burden of proof now lies not in proving that there are population-level effects, but that there are not (Mangel et al., 1996; Dayton, 1998). The same would be the case for the genetic effects of harvesting (Fowler, 1995), or a reduction in carrying capacity (Fowler and Siniff, 1992). Much is now being done to mitigate the problems of marine debris (e.g., Debenham and Younger, 1991; Coe and Rogers, 1997). In view of the information we have on northern fur seals, in combination with information on other problems created by marine debris, it is important to undertake management action, including beach cleanups, and the discarding of waste netting in ports (Debenham and Younger, 1991; Alverson and June, 1988). A wide variety of such efforts are in place, including educational programs to address the issue (National Research Council, 1995; Coe and Rogers, 1997).

The collective effects of marine debris are staggering in their magnitude if we consider all of the species that may be affected by marine debris, not to mention the problems observed in terrestrial settings. The role of plastics in the marine debris problem must be considered in the context of the good they serve (in many areas, e.g., packaging, medicine, fishing, entertainment, apparel, protective gear, and instrumentation). Ultimately, the following questions must be asked: Is the good outweighed by the long-term consequences of the global problems and in the marine environment in particular? What if these problems are only the small tip of a very large iceberg in parallel with the few surviving entangled fur seals left to be observed after the mortality experienced by so many others? Behind the magnitude of the problems observed is one very important factor: the magnitude of the human population. Plastics and other debris are, in part, the result of technology that has allowed (even promoted) the growth of the human population to its current size. Can the current human population be sustained in view of its many consequences? Only one of these effects is apparent in the small example provided by the effects of marine debris. And only one example of this larger problem is seen in the effects of a few kinds of debris on northern fur seals.

We have been fortunate with northern fur seals because their life history characteristics and breeding behavior have made it a convenient species for studying the effects of marine debris. In spite of the limitations of data on northern fur seals, our success in studying this species has been made possible by their annual return to the breeding islands where they are seen in large numbers. In these locations they have been available for field studies, particularly studies of the effects of marine debris. If we had the opportunity to study in equivalent detail the physiology, behavior, and population dynamics of all species similarly affected, it is clear that the extent and nature of the effects of marine

debris would be better appreciated. Affected species would include: filter feeders that filter microscopic plastic particles from marine waters; birds that use plastics to construct their nests and feed their young; and other species that are effected by ghost fishing, entanglement, and ingestion (Coe and Rogers, 1997; Shomura and Yoshida, 1985; Shomura and Godfrey, 1990). Such studies would need to be expanded to include the effects of chemicals released during the breakdown of plastics, and chemicals concentrated by plastics that have surfaces to which the molecules of such substances are attracted.

Based on what we have learned from the northern fur seal example, will we know how to solve the underlying problems even if we understood all that there is to understand about debris, and all of the species it affects? Short-term superficial attempts to solve the problem of debris have their own unintended consequences. For example the initial manufacture of plastics requires energy that results in carbon dioxide to contribute to problems such as global warming, and mitigation through recycling plastics only adds to such problems. Other alternatives pose other problems. Landfills to dispose of plastics require both energy and space, both of which we are using at abnormal rates compared to other species (Fowler and Perez, 1999). Incineration results in unwanted by-products. Every way we turn, there are consequences to our actions. These are seen, in their most painfully obvious way, if we contemplate giving up the use of plastics entirely. But the question remains: Is our use of plastics for their short-term benefits overshadowed by much larger long-term consequences that future generations will experience?

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I would like to thank the many colleagues with whom I have worked over the past two decades for their efforts in the research on entanglement and its effects on northern fur seals. A complete list of people is beyond the scope of this paper, but most are found as authors of the papers in the literature cited below. Society owes them a debt of gratitude for their help in understanding the magnitude of the problem of marine debris. I greatly appreciate their work and dedication. I would particularly like to thank Jim Coe, Gary Duker, Jean Fowler, James Lee, Rolf Ream, Bruce Robson, and Jeremy Sterling for insightful and helpful comments in their reviews of previous drafts.

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ECONOMICS OF LOST FISHING GEAR

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INTRODUCTION

"The homilies of economists never change."[2]

Six years ago at the Third International Conference on Marine Debris, the papers on economics made four important points: (1) debris on beaches decreases the prosperity of a community as well as the ecosystem (Smith, 1997); (2) moral suasion only goes so far (Sutinen, 1997); (3) a waste management model may be a good way to identify points of intervention for reducing the social costs of marine debris (Laska, 1997); and (4) a cost-benefit perspective has much to offer in attacking the issue of marine debris (Kirkley, 1997).

Aside from debris on the beaches, it did not seem-based on the conference report-that much quantitative information was available on the economic cost of marine debris, and that would seem to be the same today.[3] Hopefully we will learn to the contrary during this conference.[4]

Why does it seem that little has been learned about the costs of marine debris? I think it is because of the wide-open and elusive nature of the ocean, the long time horizons between loss and impacts, and the socialization of private costs into the commons that are our oceans. And because, if there is no change in institutional and regulatory structure concerning lost fishing gear, there is no behavioral change for economics to evaluate. I will identify some areas for further economic analysis later in this paper. A simple comprehensive accounting of the costs of marine debris would be useful, but this is an applications problem waiting for a public policy initiative.

In this morning's talk, I would like to summarize an economic perspective on lost fishing gear, but I cannot claim to be any type of expert. My "expertise," if you want to call it that, will be in applying economic and political theory, spiced with a little time using commercial fishing methods aboard a NOAA research vessel, and some familiarity with what are important economic and operational issues to fishing boat owners and captains. What I have to say won't be very brilliant. Hopefully, it will be helpful just to remember some first principles.

PRIVATE VS. SOCIAL COSTS AND BENEFITS

To begin, let us consider the direct cost of replacement of lost fishing gear to the vessel owner (a cost frequently shared by the crew). Lost fishing gear represents a negative externality in the production of seafood, and this negative externality is generalized to the rest of society. Avoiding the loss of fishing gear represents a specific cost to fishing vessels in terms of capital and operating expenses, allocation of labor time, the risk of retrieval, and opportunity cost of lost fishing time (during replacement or retrieval). The fishing vessel