# THE EFFECTS OF NET ENTANGLEMENT ON THE DRAG AND POWER OUTPUT OF A CALIFORNIA SEA LION, *ZALOPHUS CALIFORNIANUS*

Interactions between pinnipeds and fisheries can be broadly divided into two categories: the role of pinnipeds on the mortality of commercially important fish species and the effect of commercial fisheries on the dynamics of pinniped populations. Although the former has received considerable attention (Hirose 1977; Fiscus 1979, 1980; Matkin and Fay 1980; DeMaster et al. 1982), the importance of the latter has been addressed only recently (Shaughnessy 1980; Fowler 1982; Scordino and Fisher 1983[1]).

Fishery interactions may affect pinniped stocks through changes in prey abundance, incidental takes, or entanglement in discarded fishing gear and plastic packing bands. Scordino and Fisher (fn. 1) have shown that the number of entangled northern fur seals, *Callorhinus ursinus*, on the Pribilof Islands, AK, has recently increased, and now comprises 0.4% of the harvested animals. Fowler (1982[2]) reviewed existing data concerning the accumulation of plastic litter on beaches of several Alaskan islands. Using the number of net fragments found on shore as a rough estimate of the size distribution of material adrift at sea, he concluded that at least 60% are larger than those measured on fur seals. Because most nets found on these animals weigh <600 g, a significant mortality undoubtedly occurs at sea from entanglement in larger fragments.

This paper evaluates the hydrodynamic effect of net entanglement and documents the behavior of an entangled animal. A California sea lion was trained to allow itself to become entangled in a twine trawl net fragment and the subsequent rise in drag was measured. Increased energy consumption and swimming power requirements associated with dragging net fragments were calculated from these measurements. The results provide an initial basis for assess-

[1]Scordino, J., and R. Fisher. 1983. Investigations on fur seal entanglement in net fragments, plastic bands and other debris in 1981 and 1982, St. Paul Island, Alaska. Background paper submitted to the 26th Annual Meeting of the Standing Scientific Committee, North Pacific Fur Seal Commission, 33 p.

[2]Fowler, C. W. 1982. Entanglement as an explanation for the decline in Northern fur seals of the Pribilof Islands. Background paper submitted to the 25th Annual Meeting of the Standing Scientific Committee, North Pacific Fur Seal Commission, 24 p.

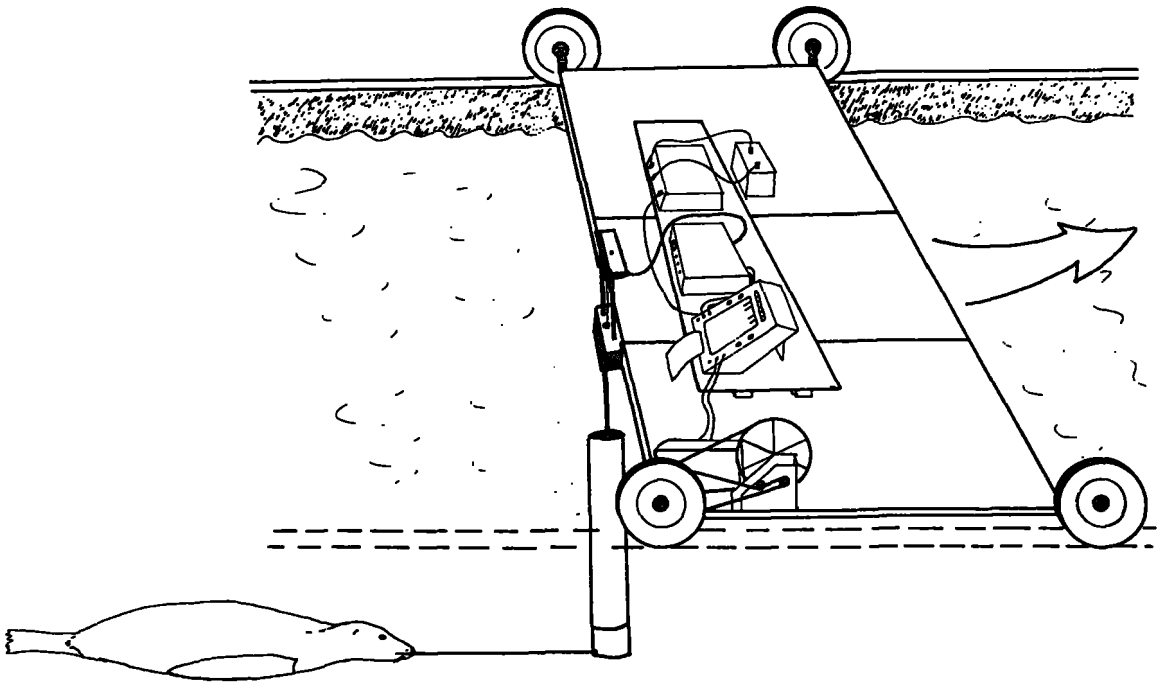

FIGURE 1.—Instruments and cart used in the drag experiments. The sea lion was towed passively underwater and the resultant force recorded. See text for further details.

ing the possible role of net entanglement on the mortality of pinnipeds at sea.

## Materials and Methods

A female California sea lion, *Zalophus californianus*, was used in this work. The animal was kept in large seawater holding tanks at Scripps Institution of Oceanography. Its weight (45 ± 0.5 kg) remained constant throughout the course of this study, conducted during April 1983.

To measure drag, the sea lion was trained to bite onto a neoprene mouthpiece and be towed through the water behind a moving cart (Fig. 1). The cart, powered by a variable speed electric motor, travelled around a circular "ring" tank which had a depth of 3.5 m and inner and outer diameters of 14.5 and 21 m, respectively. A line was connected to the mouthpiece and the other end secured to a load cell (Western Scale Co.) which produced a voltage output proportional to the amount of tension on the line. The tow line extended down from the load cell, through a streamlined strut and around a teflon pulley attached to the end of the strut (Fig. 1). The pulley, enclosed by a streamlined fiberglass housing, was set at a depth of 1 m (>3 body diameters) to eliminate surface wave effects on drag (Hoerner 1959).

Drag was measured by continuously recording the signal output from the load cell during each towing session. The signal was amplified and recorded on a Brush[3] 220 strip chart recorder (Gould Instruments). At the end of each session, the load cell was calibrated using a hand-held dynamometer. A tachometer, attached to one of the outer cart wheels, was used to determine cart velocity. This was simultaneously recorded on the strip chart. The sea lion's velocity, while it was being towed down the middle of the tank, was computed using the speed of the outer wheel and the tank's circumference. After each experiment the data were smoothed by eye and drag and velocity determined. Only steady traces which varied less than ±3% were analyzed. Drag was then converted to newtons by multiplying the kilogram force reading of the load cell by the acceleration of gravity.

Once the sea lion's drag without a net was measured, the animal was trained to place its head through an opening cut in the mesh of a 1/8-in (3.2 mm) nylon twine trawl net. The opening was near the center of the net which measured 1.4 m × 5 m, with a stretched mesh size of 19 cm. The net had a dry weight of 580 g. After several trials, the sea lion became accustomed to the procedure and would allow itself to be towed with the net trailing from its neck. The net was removed after each session.

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

## Results

Drag on the sea lion, both with and without the net, increased with velocity (Fig. 2). This rise, however, was significantly greater when the animal was entangled, with the difference between the two curves increasing throughout the range of speeds. At the highest velocity of 3.5 m/s, the entangled drag was 111 N greater than that of the free animal (Table 1). Therefore, to maintain a cruising speed of 2.0 m/s an animal of this size, entangled in a net with similar hydrodynamic characteristics, would experience the equivalent drag of a free animal swimming at speeds above 4 m/s.

Power that the sea lion must expend for swimming can also be calculated from these measurements. Since drag is a force, power output (in watts) is a product of drag times swimming velocity (Webb 1975): $P_0$ = drag × velocity. Table 1 shows the results of such calculations and the effect of the net on the sea lion's required output.

Power output is a measure of the mean rate of energy expended by the swimming muscles at a given velocity (Webb 1975). It does not, however, reveal the total energetic requirements of the sea

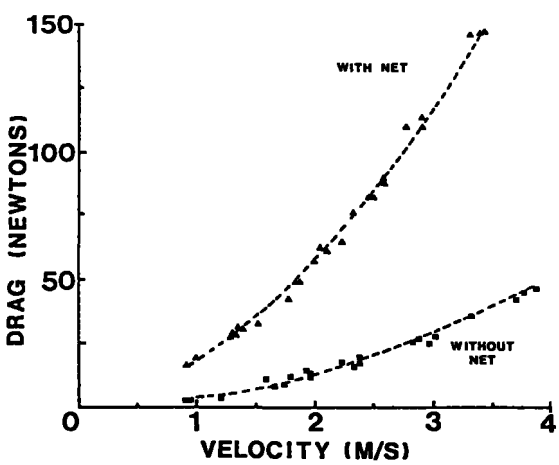


FIGURE 2.—Drag of a 45 kg sea lion with and withoug a net trailing from its neck. In both cases drag increased geometrically with speed. The regression equation with the net was 17.19 vel.$^{1.73}$, SEE (standard error of estimate) = 0.052. The equation for drag without the net was 2.93 vel.$^{2.06}$, SEE = 0.118.

TABLE 1.—The increase in drag and power output, and the estimated power input of the entangled sea lion. Drag with and without the net was calculated from the best fit regressions determined by the experiments. Power output was calculated by multiplying drag and the appropriate velocity. Weight specific power input is based on an efficiency (power out/power in) of 10%.

| | Velocity (m/s) | | | | | |
|---|---|---|---|---|---|---|
| | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | .3.5 |
| Drag (N) | | | | | | |
| Without net | 2.93 | 6.75 | 12.21 | 19.33 | 28.13 | 38.64 |
| With net | 17.19 | 34.66 | 57.01 | 83.87 | 114.97 | 150.11 |
| Power output (W) | | | | | | |
| Without net | 2.93 | 10.13 | 24.42 | 38.65 | 84.40 | 135.24 |
| With net | 17.19 | 51.99 | 114.02 | 167.74 | 344.91 | 525.39 |
| Power input (W/kg) | | | | | | |
| Without net | 0.7 | 2.3 | 5.4 | 8.6 | 18.8 | 30.0 |
| With net | 3.8 | 11.6 | 25.3 | 37.3 | 76.6 | 116.8 |

lion. Animals are not 100% efficient in converting metabolic energy to mechanical power needed for locomotion (Tucker 1975). Studies of penguins and fish which swim with their pectoral fins show that efficiency (power output/power input) varies between 5 and 15% (Webb 1973; Hui 1983). Female northern fur seals consume about 8 W/kg while at sea (Costa and Gentry in press). Using this number, the power output values estimated for the sea lion, and an assumed cruising speed of 2.5 m/s, an efficiency for fur seals of roughly 10% is obtained. Table 1 shows estimated energy requirements based on this efficiency for the sea lion with and without the net. Again it can be seen that to maintain a swimming speed of 2.5 m/s the sea lion would need to increase its metabolic expenditure by 50-fold, an impossibly high figure (Bartholomew 1977).

## Discussion

There is little doubt that for an animal of this size, entanglement in a 600 g net will substantially increase its chance of mortality at sea. Drag, and hence the power required for swimming, is increased by the presence of a net. As a result, these animals will swim slower, at a greater energetic cost than free animals. Drag of the net, which rises geometrically with velocity, will prevent activities requiring high speeds as would be the case if such animals engaged in the pursuit of rapidly moving or evasive prey species. Additionally, migration or travel to and from the rookery will be energetically more costly. It is likely, then, that once an animal becomes entangled in net fragments of this size or larger, it enters a state of negative energy balance.

The animal's size as well as the size of the net plays an important role in the amount of drag experienced. A larger net will present more surface area to the water. Since drag is dependent on surface area (Vogel 1981), larger net fragments will result in greater drag. Similarly, if two different-sized animals are entangled in nets of the same dimensions, the smaller will experience a larger relative increase in its drag and power requirements. If animals of different age classes encounter net fragments with equal probability, it is expected that the younger age classes will suffer a proportionally higher mortality.

Although starvation is undoubtedly the long-term result of net entanglement, other factors may have a more immediate effect. This was particularly evident during an observation of an actual entanglement. In the initial training phase of the sea lion, a net with a larger mesh size was used. At one point, while the net was floating in the water, the sea lion swam up from below and inserted its head through one of the mesh openings. Upon sensing the net around its neck it gave a strong backwards stroke, trying to retract its head. The backward movement brought some of the trailing net in front of it and when the animal then swam forward and dived underwater, another strand slipped onto its neck. This caused a violent reaction with the sea lion twisting and thrashing wildly. The twisting further entangled the animal and tightened the net. Within 1½ to 2 min the animal was completely entangled with three or four loops of mesh tight around its neck.

The net was so tight that an observer on the side of the tank was unable to pull it from the sea lion's head, and it was necessary to drain the holding tank. During this time, the animal swam around the tank barking and often thrashing about while trying to bite the net. This appeared to further tighten the net which, when finally removed, was so tight that a finger could not be slipped between the net and the animal's neck.

If the behavior of otariids at sea is similar to that exhibited by the entangled sea lion, then drowning may be another more immediate cause of mortality. Twisting and rolling could foul the foreflippers and prevent the animal from swimming. This seems particularly likely if it became caught in a larger net. Additionally, because the net was so tightly wrapped around the sea lion's neck, necrosis of the skin tissue and an open wound may have occurred within a matter of hours to a few days. Constant swimming could continue to tighten the net. Although several authors (Scordino and Fisher fn. 1) have speculated that neck wounds indicate a period of entanglement longer than 4 mo, these observations suggest that beached animals with open wounds may have become tangled only a few days prior to sighting.


### Acknowledgments

The sea lion was made available for this research by L. H. Cornell, Sea World of San Diego. The assistance provided by Phil Thorson and Terrie Williams in feeding and training the sea lion is gratefully acknowledged and appreciated. C. Fowler, J. Graham, G. Kooyman, and T. Williams provided useful comments on the manuscript.

This study was supported by NOAA grant 82ABC-02743 from the National Marine Mammal Laboratory to G. L. Kooyman.


### Literature Cited


BARTHOLOMEW, G. A.
1977. Energy metabolism. *In* M. S. Gordon (editor), Animal physiology: Principles and adaptations, p. 57-110. Macmillan Publ. Co., N.Y.

COSTA, D. P., AND R. L. GENTRY.
In press. Free ranging energetics of northern fur seals. *In* R. L. Gentry and G. L. Kooyman (editors), Fur seals: Maternal strategies on land and at sea. Princeton University Press.

DEMASTER, D. P., D. J. MILLER, D. GOODMAN, R. L. DELONG, AND B. S. STEWART.
1982. Assessment of California sea lion fishery interactions. Trans. N. Am. Wildl. Nat. Resour. Conf. 47:253-264.

FISCUS, C. H.
1979. Interactions of marine mammals and Pacific hake. Mar. Fish. Rev. 41(10):1-9.
1980. Marine mammal-salmonid interactions: a review. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific Ocean, p. 121-131. Oregon State Univ. Press, Corvallis.

FOWLER, C. W.
1982. Interactions of northern fur seals and commercial fisheries. Trans. N. Am. Wildl. Nat. Resour. Conf. 47:278-292.

HIROSE, P.
1977. Incidence of seal-damaged salmonids sampled from the lower Columbia river gillnet fishery, 1972-1976. Oreg. Dep. Fish Wildl., Inf. Rep. 77-4, 6 p.

HOERNER, S. F.
1959. Fluid-dynamic drag. Practical information on aerodynamic drag and hydrodynamic resistance. [Published by the author.] Midland Park, N.J. 416 p.

HUI, C. A.
1983. Swimming in penguins. Ph.D. Thesis, Univ. California, Los Angeles, 185 p.

MATKIN, C. O., AND F. H. FAY.
1980. Marine mammal-fishery interactions on the Copper river and in Prince William Sound, Alaska, 1978. Final Report to U.S. Marine Mammal Commission for contract MM8AC-013, 71 p. Publ. No. PB80-159536, Natl. Tech. Inf. Serv., Springfield, VA.

SHAUGHNESSY, P. D.
1980. Entanglement of Cape fur seals with man-made objects. Mar. Pollut. Bull. 11:332-336.

TUCKER, V. A.
1975. The energetic cost of moving about. Am. Sci. 63:413-419.

VOGEL, S.
1981. Live in moving fluids: The physical biology of flow. Willard Grant Press, Boston, MA, 352 p.

WEBB, P. W.
1973. Efficiency of pectoral-fin propulsion of *Cymatogaster aggregata*. *In* T. Y. T. Wu, C. J. Brokaw, and C. Brennen (editors), Swimming and flying in nature, Vol. 2, p. 423-1005. Plenum Press, N.Y.
1975. Hydrodynamics and energetics of fish propulsion. Fish. Res. Board Can. Bull. 190, 158 p.



STEVEN D. FELDKAMP

*Scripps Institution of Oceanography*
*Physiological Research Laboratory A-004*
*La Jolla, CA 92093*
Present address: *Long Marine Laboratory*
*University of California at Santa Cruz*
*Santa Cruz, CA 95064*


## NOTES ON THE LIFE HISTORY OF THE CATSHARK, *SCYLIORHINUS MEADI*

The catshark, *Scyliorhinus meadi* (family Scyliorhinidae) is a rare, poorly known species, easily identified by the eight dark saddle-like blotches along the dorsal surface. Springer (1966) first described *S. meadi* and Springer and Sadowski (1970) assigned it to subspecies status of *S. retifer*. In Springer's (1979) revision of the family, it was again given species status. At present only 10 immature specimens of *S. meadi* have been collected, seven males (180-490 mm in length), two females (235 and 385 mm in length), and one 190 mm specimen of unknown sex. This paper reports on the collection of an additional specimen of *S. meadi* and provides valuable life history information.

During a cruise aboard the RV *Delaware II* on 5