AN ABSTRACT OF THE THESIS OF

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Title: Population Dynamics, Annual Food Consumption, Movements, and Dive Behaviors of Harbor Seals, *Phoca vitulina richardsi*, in Oregon.

Abstract approved: Signature redacted for privacy.
Bruce R. Mate

Number of harbor seals, counted on 32 haul-out areas in Oregon, increased by 6 - 8.8 % per year from 1975 - 1983. Percent of seals in bays has increased an average 1.8%/year, from 47% in 1975 to 61% in 1983. Along the central Oregon coast, harbor seals were most abundant during January and April. Four environmental factors, height of low tide, amount of rain, wind speed, and wave height, were correlated significantly with number of harbor seals on land. A greater precentage of radio-tagged harbor seals were found on land during summer and spring counts ($\overline{X}$ = 53.1%), than during autumn and winter ($\overline{X}$ = 9.2%). There were an estimated 9,023 - 20,018 harbor seals in Oregon during winter 1985.

The results of experiments with captive harbor seals indicated that only 25 - 34% of some fish species (e.g.

Engraulis mordax, Clupea harengus, and Thaleichthys pacificus) was represented as otoliths in feces, whereas with other species it was 80%. Over 80% of the otoliths were excreted within 24 h of ingestion. Mean reduction in otolith length ($\bar{X}$ = 27.5%, SD = 10.3) was not significantly different among fish species.

Harbor seals caught in Oregon (n = 214) were an average 126 cm in length and 55.7 kg in mass. Average dive duration for six individuals ranged from 1.0 min (SD = 0.7) to 3.1 min (SD = 1.8). Maximum dive duration was 11.4 min. Radio-tagged individuals moved as far as 280 km, but 92% of time were found within 8 km of the release site.

Harbor seals fed primarily on fishes of 8 - 15 cm standard length. Generally they consumed smaller fish in spring and summer and larger fish during fall and winter. Juvenile fishes (e.g. Parophrys vetulus and Citharichthys sordidus) were probably consumed by harbor seals in estuaries, whereas adults were eaten in the ocean. In 1980, 5 species of fishes, Leptocottus armatus (721.4 metric tons), Clupea harengus (451.4 metric tons), Cymatogaster aggregata (440.8 metric tons), Parophrys vetulus (427.8 metric tons), and Glyptocephalus zachirus (332.6 metric tons), comprised 42.5% of a total 5,584.9 metric tons of fish estimated consumed by harbor seals in Oregon.

Population Dynamics, Annual Food Consumption, Movements, and Dive Behaviors of Harbor Seals, *Phoca vitulina richardsi*, in Oregon.

by

James T. Harvey

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This dissertation is dedicated to the memory of my mother, and to the inspiration provided by my father.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

POPULATION DYNAMICS, ANNUAL FISH CONSUMPTION, MOVEMENTS, AND DIVE BEHAVIORS OF HARBOR SEALS, PHOCA VITULINA RICHARDSI, IN OREGON

CHAPTER 1

INTRODUCTION TO HARBOR SEAL-FISHERIES CONFLICTS

Competition of pinnipeds with man for marine resources has contributed to recent interest in food habits of these marine mammals. Their large size and carnivorous habits can lead to serious conflicts with commercial- and sport-fishery interests. Marine mammals can affect prey abundance and size distribution (Power and Gregoire, 1978). For example, in some parts of its range, the sea otter (Enhydra lutris) is one of a few marine species thought of as a keystone species, because of its dramatic effects on structuring the nearshore community (Dayton, 1975; Estes and Palmisano, 1975). Those characteristics that enable pinnipeds to be efficient predators have led them to be of concern to fisherman and fisheries.

Direct effects of pinniped predation on fisheries along the west coast of North America involve damage to gear and catch. Gear damage, resulting from entanglements, has occurred in pelagic gill-net fisheries by California sea lions (Zalophus californianus; Miller et al., 1983), and in trawl fisheries for pollock (Thergra chalcogramma) by northern sea lions (Eumetopias jubatus; Loughlin and Nelson, 1986). Pinnipeds, especially California sea lions, are responsible for damaging salmon (Oncorhynchus sp.) catches in hook and line fisheries (Briggs and Davis, 1972; DeMaster et al., 1982; Roffe and Mate, 1984). Harbor seals (Phoca vitulina) cause damage to salmon caught in gill nets (Beach et al., 1985; Mate, 1980). The conflicts between marine mammals and fisheries have resulted in several workshops (Beddington et al. 1985; Contos, 1982; Mate, 1980).

More recently, the indirect impact of marine-mammal predation on populations of commercial fishes has been studied. Marine mammals are regarded as competitors with man for fish resources. Effects of pinniped predation on salmon (Brown and Mate, 1983; Gearin et al., 1986; Hirose, 1977; Roffe and Mate, 1984), and sea otter consumption of molluscs (Costa, 1978) have received the greatest attention. There has been little discussion of effects of pinniped predation on noncommercial fish species other than descriptions of food habits of pinnipeds.

Although estimates of food consumed by pinniped populations have been made for various locations (Antonelis and Perez, 1984; Condy, 1981; Lavigne et al., 1985; Perez and Mooney, 1986), there have been no attempts to quantify the consumption of specific fish species off

Oregon. These data are important to assess the effects of pinniped predation on the fish community, and commercial stocks of fishes off Oregon. In the Bering Sea, marine mammals may remove more of the biomass of commercial fish species than the fishery itself (Laevastu et al., 1980; McAlister, 1981), and have the potential of affecting the dynamics and characteristics of fish populations (Power and Gregoire, 1978).

Harbor seals may number more than 300,000 in the eastern North Pacific (U.S. Dept. Commerce, 1986), are one of the most abundant species of pinnipeds, and have been implicated in many conflicts with fisheries (Contos 1982; Mate 1980). *Phoca vitulina richardsi* is distributed along the west coast of North America from central Baja California to Bristol Bay, Alaska, including the Aleutian and Pribilof Islands (Bigg, 1981). This subspecies is generally confined to the littoral zone, and is seen most commonly on nearshore rocks or tidal lands within bays or estuaries. In British Columbia, males averaged 1.61 m standard length and 87 kg in mass, whereas females averaged 1.48 m and 65 kg (Bigg, 1969*a*). Pups are 0.6 m in length and 7 kg mass at birth, and are born May - August in Washington, and progressively earlier to the north and south (Bigg, 1969*b*). Harbor seals usually become sexually mature at 3 - 5 years of age. Females mate soon after a 3 - 6 week period of lactation.

Harbor seals are opportunistic carnivores, and feed primarily on benthic fishes (e.g. Pleuronectidae, Bothidae, and Cottidae), rockfishes (Sebastes sp.), small schooling fishes (e.g. Clupeidae, Osmeridae, and Engraulidae), and occasionally on salmon (Salmonidae) and lamprey (Petromyzontidae; Brown and Mate, 1983; Graybill, 1981; Imler and Sarber, 1947; Pitcher, 1980a; Roffe and Mate, 1984; Spalding, 1964). Although investigators have addressed the impact of harbor-seal feeding on commercial species such as salmonids, a regional study of harbor-seal predatory impact on all fish species is needed.

Managers of marine resources recently have been directed, through such legislation as the Marine Mammal Protection Act of 1972, to consider the health and stability of the ecosystem in developing management practices. To effectively manage fish populations and to regulate the influence of fishing activities on pinniped populations, an understanding of the trophic ecology of pinnipeds is necessary. Researchers use trophic models to generate explicit questions regarding how systems function, to suggest topics for which data are insufficient, and to provide preliminary estimates of energy flow through a system. The trophic model presented in this dissertation is used in a similar manner.

This dissertation is a compilation of studies regarding the ecology of harbor seals in Oregon. One goal of this research is to estimate the annual consumption of fishes by harbor seals in Oregon. Factors that contribute to this estimate include number, spatial distribution, size, food habits, and energetic requirements of harbor seals in Oregon. These factors are investigated in the following five chapters of this dissertation.

In Chapter 2, I examine annual trends in abundance and distribution of harbor seals in Oregon. Aerial counts of harbor seals between 1975 and 1983 were used to determine changes in abundance, and distribution of haul-out sites. In Chapter 3, counts of harbor seals on 10 haul-out sites along the the central Oregon coast were used to examine monthly trends in abundance of harbor seals, and to evaluate which environmental factors affected the number of seals resting on land. In this chapter, I also investigated what proportion of harbor seals were on haul-out sites during counts. Radio-tagged individuals, located during counts along the coast, were used to determine the portion of the population not observed during counts (i.e. not on land). To more reliably estimate abundance of harbor seals, a correction factor was developed from the proportion of tagged harbor seals on land during a count.

Researchers have often used fish otoliths and cephalopod beaks, found in pinniped feces, to determine the number and size of prey eaten. In chapter 4, I examine errors associated with this technique. I fed captive harbor seals a known number and size of fish and cephalopod to test the hypothesis that the number and size of fishes and cephalopods eaten are not significantly different from those estimated based on otoliths and beaks collected in feces. I also examined the passage rates of otoliths through seals.

In Chapter 5, I examine the dive characteristics, movements, and activity patterns of radio-tagged harbor seals in Oregon. These data were used to determine time harbor seals spend in water and on land.

In Chapter 6, I estimate the number and biomass of fish species consumed by harbor seals in Oregon during 1980. Otoliths collected from seal feces are used to determine size of prey consumed. Linear regressions of fish length and weight on otolith length and weight are generated to estimate prey size. An estimate of annual fish consumption by harbor seals is compared to estimates of fishing and natural mortality for some fish species.

CHAPTER 2

POPULATION DYNAMICS AND DISTRIBUTION OF HARBOR SEALS, *PHOCA VITULINA*, IN OREGON.

The harbor seal, *Phoca vitulina*, is one of five species of pinnipeds that commonly occurs in Oregon. Although they are the most abundant and ubiquitous pinniped in the state, found in most bays, estuaries, and on many offshore rocks, there is only one published account of their statewide distribution and abundance (Pearson and Verts, 1970). Pearson and Verts (1970) conducted four counts from land and one aerial count of harbor seals along the Oregon coast in 1967 - 1968, and concluded that there were fewer than 500 harbor seals in Oregon. There have been numerous recent studies of harbor seal abundance at specific haul-out sites (locations where pinnipeds are found on land) along the coast (Bayer, 1985*b*; Brown and Mate, 1983; Graybill, 1981; Mate, 1977; Roffe and Mate, 1984), but no recent reports of their statewide distribution and abundance.

More than 3,800 harbor seals were killed in Oregon between 1925 and 1972 by a state-hired seal hunter and bounty hunters (Pearson, 1969). The number of harbor seals in Oregon was probably reduced, and harbor seals were harassed from inshore areas where they rested. Harassment and killing of harbor seals was significantly reduced after 1972, when the Marine Mammal Protection Act was passed. Protection of harbor seals has probably resulted in an increase in abundance and redistribution of animals into bays and estuaries. These hypotheses were tested in this study.

The objectives of this study were to determine the location and use of haul-out sites, and change in abundance of harbor seals in Oregon from 1975 - 1983.

METHODS

Aerial counts of seals on land along the entire Oregon coast were performed annually in a high-winged Cessna 172 or 182 in June, July, or August from 1975 - 1983 (Fig. 1). Counts of harbor seals from 1975 to 1976 were conducted by Mate (1977), thereafter by B. Mate, R. Brown, and me. Counts were conducted approximately 2 h before low tide to maximize the number of seals visible on haul-out sites (Schneider and Payne, 1983; Terhune and Almon, 1983). The entire coastline usually was scanned during annual counts to determine locations of harbor seals ashore. Whenever harbor seals were first observed in a specific location it was recorded, generally this location was observed in subsequent counts. Haul-out sites with more than approximately five individuals were

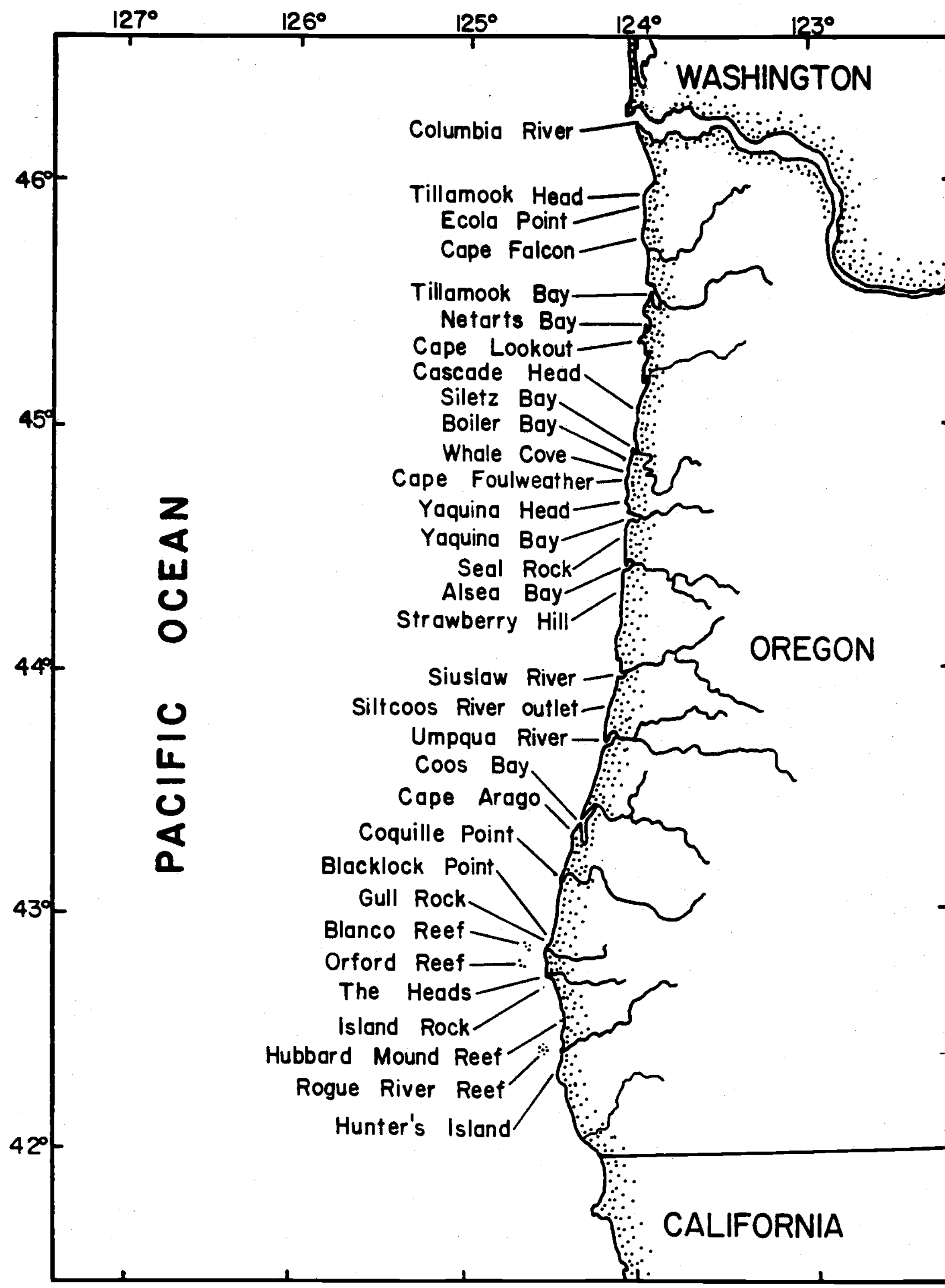

Fig. 1.--Thirty-two sites along the Oregon coast where harbor seals were observed on land.

photographed from an altitude of 215 - 305 m with a hand-held 35-mm camera and 300-mm or 70- to 210-mm zoom lens. Generally, photographs were taken within 15^{o} of vertical. The image of seals on land was projected either on a blackboard or painted glass, and each seal counted. Individuals were designated by a mark on the projected image to avoid duplicating counts.

Counts required two days; flights were made from Newport to the north or south on consecutive days. Counts at some haul-out sites were not possible because of inclement weather.

Trends in abundance of harbor seals in Oregon were assessed using counts of harbor seals at 14 haul-out sites (Table 1). Counts of harbor seals at these 14 sites were used because were observed most years, contained nearly 90% of harbor seals enumerated during yearly counts, and these sites represented an equal number of ocean and bay haul-out habitats (7 each).

There were nine complete counts of harbor seals along the entire coast made between June and August in each of 9 years that provided information for interannual comparisons. The July 1981 count, however, was flown during suboptimum conditions, when the tide was nearly high at some locations. This most likely led to the low count for that year, therefore in subsequent discussions of trends in harbor seal abundance, data from 1981 are

Table 1.--Counts of harbor seals on 32 haulout areas (listed from north to south) along the Oregon coast, based on aerial censuses during the summer months between 1975 and 1983. Hyphens designate no count was taken. Each area is designated as an offshore (O), shoreline (S), or estuarine (E) haul-out habitat. Twelve haul-out sites were counted on most flights and are designated with a asterik.

Haul-out site		Month and year of count								
Location	Habitat	July 1975	July 1976	June 1977	June 1978	July 1979	July 1980	July 1981	August 1982	June 1983
Columbia River*	E	--	145	152	307	4	356	194	65	153
Tillamook Head	S	--	8	25	49	110	0	--	115	112
Ecola Point	S	--	--	4	0	0	--	--	0	--
Cape Falcon	S	--	60	102	0	0	0	31	55	15
Tillamook Bay*	E	312	85	247	367	385	279	203	545	527
Netarts Bay*	E	24	--	23	44	54	16	48	207	167
Cape Lookout	S	23	--	--	0	20	15	10	11	0
Cascade Head	S	--	--	31	27	18	28	3	0	0
Siletz Bay	E	--	--	43	0	0	0	0	0	0
Boiler Bay	S	--	--	--	--	--	--	--	--	8
Whale Cove	S	--	--	--	--	--	--	0	--	19
Cape Foulweather*	O	50	25	18	0	38	64	49	11	30
Yaquina Head	S	--	--	11	13	55	4	0	54	50
Yaquina Bay	E	0	--	0	0	--	19	0	0	0
Seal Rock	S	--	0	0	0	--	--	0	6	0
Alsea Bay*	E	71	0	1	0	0	119	148	251	193
Strawberry Hill*	S	10	0	46	33	75	52	70	75	86
Siuslaw River*	E	0	0	10	4	0	20	0	121	60
Siltcoos outlet	S	53	--	25	--	--	--	--	0	--
Umpqua River*	E	454	443	596	464	382	549	210	280	774
Coos Bay*	E	113	35	--	85	95	35	117	222	233
Cape Arago*	S	670	125	425	530	483	440	104	985	683
Coquille Point*	O	91	106	61	81	79	62	55	75	120
Blacklock Point	S	--	--	--	--	8	--	--	9	--
Gull Rock	O	0	55	--	83	88	--	78	80	75
Blanco Reef	O	0	0	--	49	37	148	23	24	0
Orford Reef	O	60	0	0	0	15	--	19	75	0
The Heads	O	--	--	0	0	14	24	--	--	35
Island Rock	O	0	--	6	0	--	--	--	11	--
Hubbard Md. Reef*	O	--	90	126	182	0	98	100	20	166
Rogue Reef*	O	133	236	201	211	6	189	0	184	212
Hunter's Island*	O	180	151	148	49	106	--	84	30	15
Totals for 14 haul-out sites designated with *:		2,108	1,441	2,054	2,357	1,707	2,279	1,382	3,071	3,419
Percent of total count:		(93.9)	(92.1)	(89.3)	(91.4)	(82.4)	(90.5)	(89.4)	(87.5)	(89.8)

excluded. A linear regression was used to assess trends in counts of harbor seals on the 14 haul-out sites. Two counts were conducted in June 1983; unfortunately this is the only information available regarding variability of counts within a year.

RESULTS

Harbor seals were counted on 32 haul-out sites along the Oregon coast (Fig. 1). Haul-out sites were usually separated by at least 1 km, and included many locations where harbor seals rested on land. Three types of habitats on land were used by seals: estuarine sand and mud flats exposed during low tides; remote, rocky, mainland shoreline; and offshore rocks and islands. Some unique sites included a grassy plateau in Alsea Bay accessible only during high tides, a seldom used boat dock in Siletz Bay, and a shoreline location (Strawberry Hill) where people could observe seals from across a 20-m surge channel. Nine haul-out sites were estuarine habitats, 13 were shoreline, and 10 offshore. Ninety percent of offshore haul-out sites were located in the southern portion of the state (south of Strawberry Hill), whereas the other haul-out habitats were primarily in the northern portion of the state (66.7% of estuarine and 69% of shoreline habitats were north of Strawberry Hill).

Most seals ($\bar{X}$ = 89.8%/year, SD=3.7) were counted at 14 sites (Table 1). Numbers of seals at Cape Arago, Umpqua River, and Tillamook Bay averaged 22.1, 20.6, and 14.7% of the total statewide count, respectively. The greatest number of seals on any area was 985, recorded at Cape Arago in July 1982. The second largest concentration was 774 individuals in the Umpqua River in June of 1983.

Counts at specific haul-out sites varied dramatically among years (Figs. 2a and 2b). Offshore and shoreline haul-out sites had the greatest interannual variability, particularly at Cape Arago and Rogue Reef, although counts also fluctuated widely in the Columbia River (Fig. 2a). Few offshore or shoreline sites had a detectable trend in seal abundance; an exception was Hunters Island where counts of harbor seals declined. Counts at 83% of bay haul-out sites rose dramatically in 1982 and 1983 (Figs. 2a and 2b). Based on counts at the 14 haul-out sites observed most frequently (Table 1), the proportion of harbor seals counted in bays increased from 47% in 1975 to 61% in 1983, an average increase of approximately 1.8% / year (Fig. 3).

There was a trend of increasing counts of harbor seals from 1975 - 1983. Counts of harbor seals on 14 haul-out sites increased significantly at an average rate of 8.8% / year (t = 3.42, r^2 = 0.81, $P < 0.01$; Fig. 4). Counts of harbor seals were not made at 2 sites in 1975,

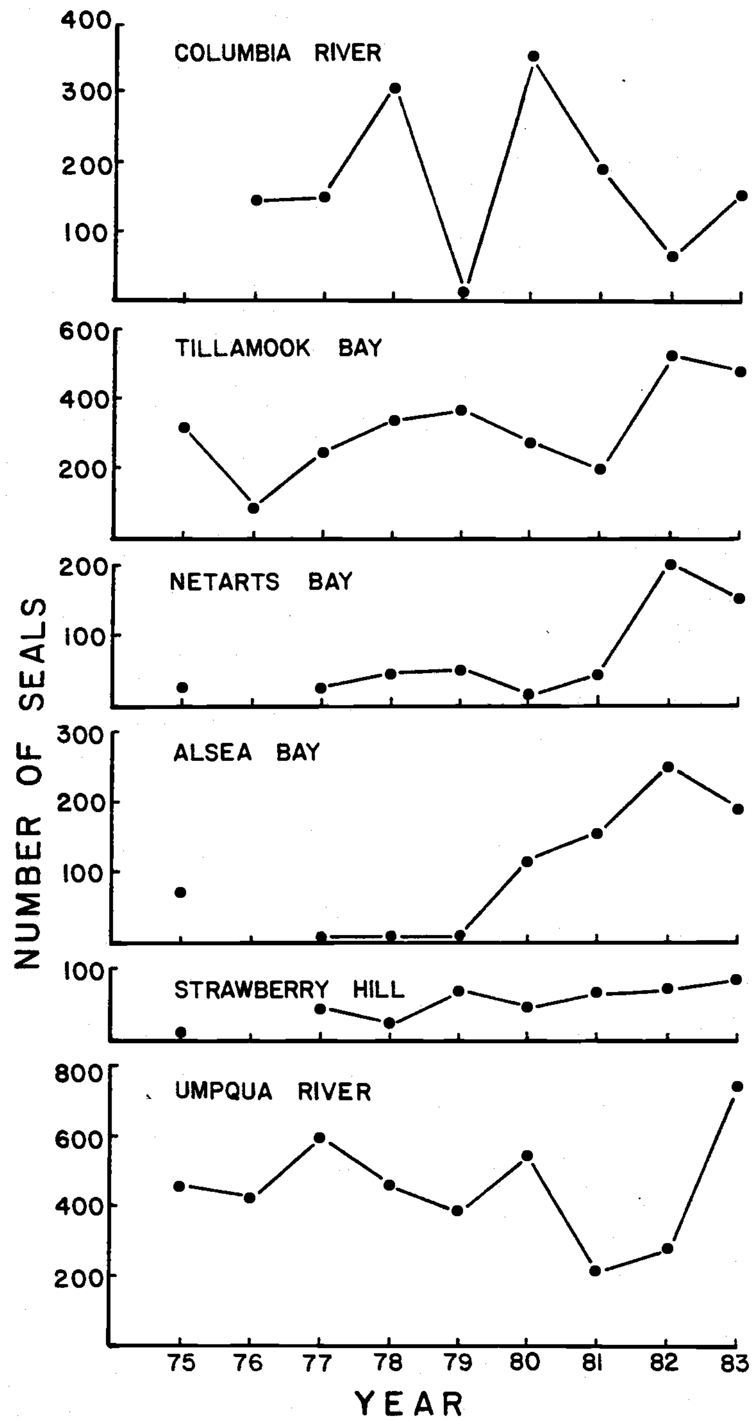

Fig. 2a.--Number of harbor seals on land at six locations in Oregon from 1975 - 1983.

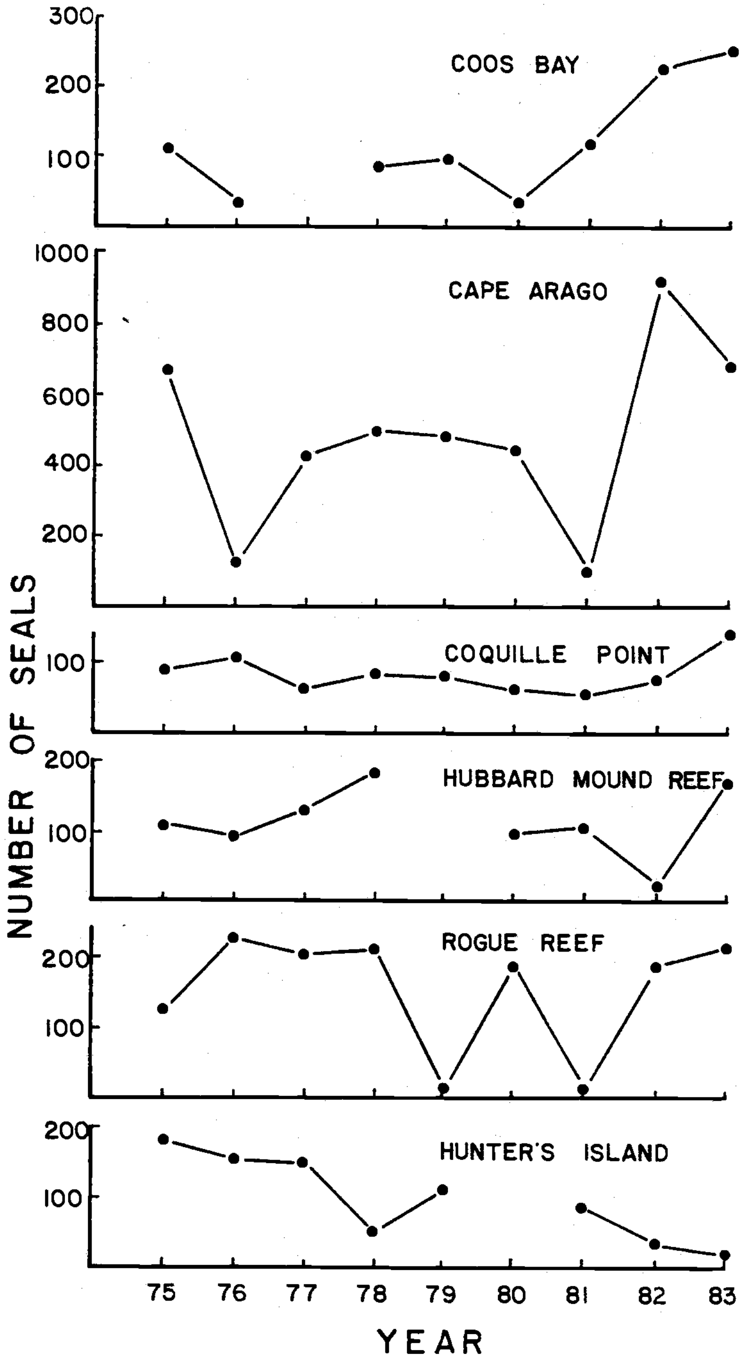

Fig. 2b.--Number of harbor seals on land at six locations in Oregon from 1975 - 1983.

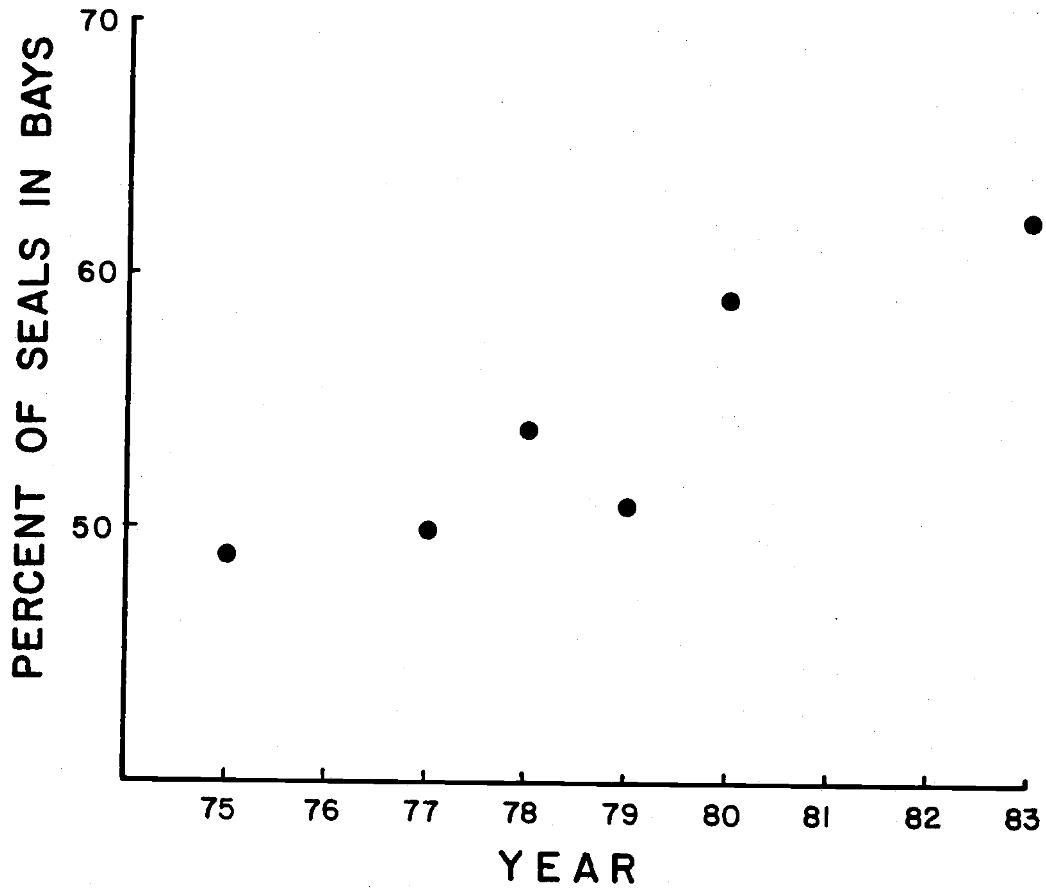

Fig. 3.--Changes in percent of harbor seals counted on bay haul-out sites in Oregon from 1975 - 1983.

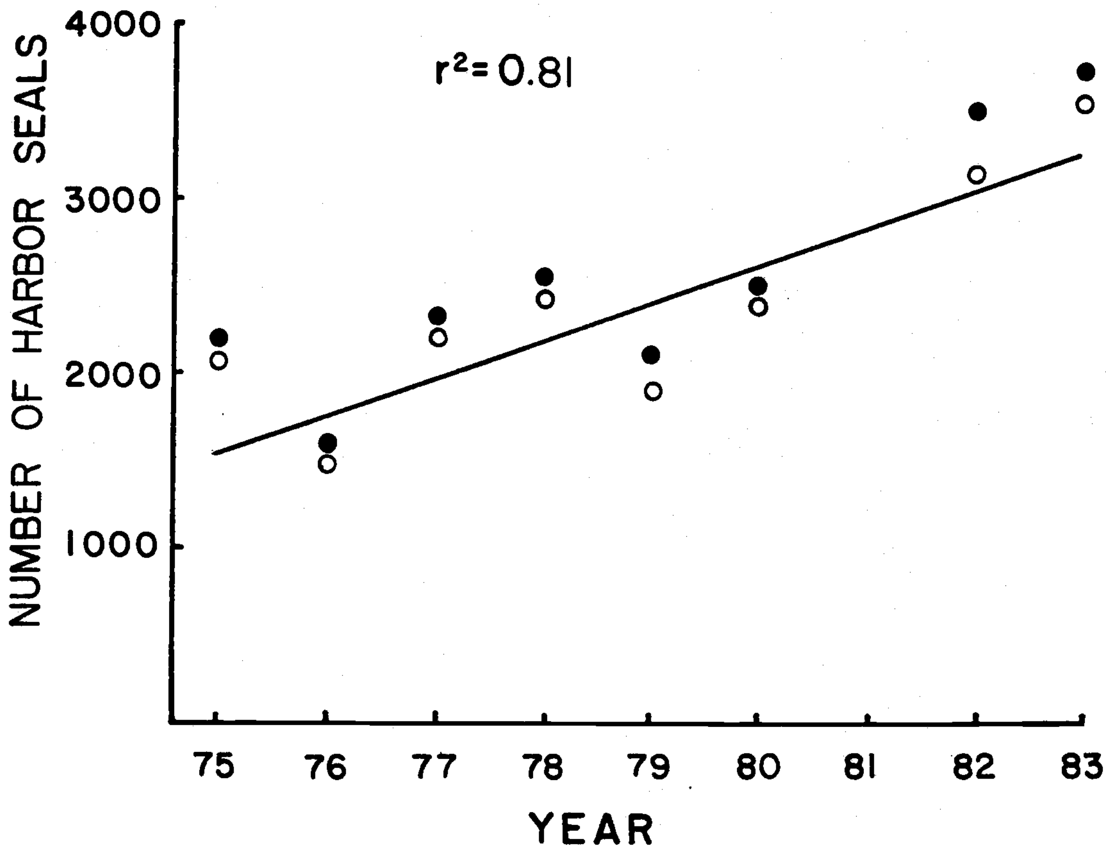

Fig. 4.--Total number of harbor seals on land in Oregon from 1975 - 1983, excluding 1981 (●). Number of harbor seals on land at 14 sites most frequently counted (○); line is fitted to (○).

and at 1 site in 1976, 1977, and 1980. Counts of harbor seals on all haul-out sites along the coast increased at an average 6.0% / year ($\underline{t}$ = 4.10), $r^2 = 0.90$, $P < 0.01$; Fig. 4). Two counts of harbor seals were made in June 1983 (3,739 and 3,565 individuals), and were different by only 4.7% (174 harbor seals).

DISCUSSION

Aerial counts have inherent problems in assessing pinniped populations, such as: inability to count all animals (i.e. some animals are missed and others are in the water), effects of the aircraft on pinniped behavior, and weather restrictions on time of counts (Eberhardt et al., 1979; Estes, 1976; North-Griffiths, 1974; Packard et al., 1985). Aerial counts in Oregon were conducted during summer months under relatively consistent environmental conditions (i.e. weather safe for aircraft and clear enough to photograph seals on land). Although the entire 1981 count of harbor seals was not conducted during a low tide, all other counts were performed under similar conditions. Therefore, it seems appropriate to assess interannual variation of population trends from these counts.

Conclusive evidence of increasing abundance of harbor seals in Oregon is lacking because within-year variability was not determined. Two counts made in June 1983 were similar, but there were no data to compare variability in counts throughout the summer during a year. Bayer (1985b), however reported no significant difference in counts of harbor seals in Yaquina Bay during the summers of 1977 - 1982. Counts of harbor seals on land may fluctuate dramatically from day to day especially in response to disturbance and environmental factors (Ling et al., 1974; Chapter 3). The observed trends in abundance may therefore be caused by: chance; proportionately less harbor seals ashore during counts in early years and greater numbers in later years; immigration, harbor seals moving north from California or south from Washington; or an actual increase of harbor seals in Oregon. Because there was no systematic bias in counts of harbor seals throughout the years, I assumed trends in abundance were not related to progressive refinement of methods.

Increasing counts of harbor seals in Oregon from 1975 - 1983 probably represent an increase in abundance because previous counts were less than during this period, new haul-out sites are being used, and counts since 1983 are greater than previous years. Estimates of 250 harbor seals on offshore rocks in Oregon during 1967 (U.S. Bureau Sport Fisheries and Wildlife, 1966 - 1977), and 500 during 1968 (Pearson and Verts, 1970) are well below counts during 1975 - 1983. Although these earlier efforts to count harbor seals on land probably did not cover all haul-out sites, the number of harbor seals counted at particular sites were less than recent counts at these locations. In addition, counts of harbor seals in Oregon since 1983 have continued to increase at a rate similar to that reported for 1975 - 1983 (R. Brown, Oregon Department of Wildlife, pers. comm.). Between 1975 and 1978, harbor seals used an average of 16.3 haul-out sites, compared with an average of 30.3 haul-out sites from 1980 to 1983. Increased number of harbor seals may force some individuals to inhabit other areas for rest and food. The increased use of different haul-out sites, together with the increasing count of harbor seals since 1967 provide evidence for an increase in abundance of harbor seals in Oregon. This increase principally occurred in bays and estuaries, and may be from immigration (a consequence of reduced harassment) and recruitment.

Harbor-seal abundance in Oregon may be increasing because the closure of bounties for this species and the enactment of the Marine Mammal Protection Act of 1972 (PL 92-522) have restricted harassment and killing of marine mammals allowing immigration and increased reproduction. An increase in harbor-seal abundance after 1972 might be expected if the population had been reduced, and there was less harassment.

Reduction in harbor-seal abundance in Oregon and Washington before 1972 may have been caused by control programs initiated by these states in response to perceived conflicts between marine mammals and fisheries (Newby, 1973). Seal-control programs, such as bounties and hired hunters, were in operation between Alaska and Oregon between 1914 and 1972, and resulted in the deaths of approximately 146,000 harbor seals (Mate, 1980). Many harbor seals turned in for bounty in southern Oregon, however, may have been killed in northern California (B. Mate, pers. comm.). The number of harbor seals claimed for bounty probably was lower than the actual number killed. In some areas approximately 40% of harbor seals killed sank and were not recovered (Scheffer and Slipp, 1944).

Harbor-seal populations were further affected because a large portion of the animals were harassed from protected bays and estuaries (Newby 1973). Pregnant females use protected areas of estuaries for birthing and caring for pups (Brown and Mate, 1983; Beach et al., 1985). If these areas are important in the reproductive cycle of this species, then harassment in bays may have effectively lowered the reproductive rate.

A 6 - 9% average annual increase in the population of harbor seals off Oregon since 1975 is consistent for recovering populations of pinnipeds (Eberhardt and Siniff, 1977), and with other regions. Harbor seals in the region near Humboldt Bay, California, increased from 6 in 1966 to 311 in 1973 (Loughlin, 1978). Payne and Schneider (1984) reported an average rate of increase of 11.9% per year for harbor seals using a Massachusetts haul-out site between 1972 and 1983. In contrast, there were no increases in harbor-seal abundance reported in San Luis Obispo Co., California (1972-1976), San Francisco Bay, California (1972-1980), Point Reyes, California (1976-1984), or in Yaquina Bay, Oregon (1977-1983; Allen and Huber, 1984; Bayer, 1985b; Fancher and Alcorn, 1982; Wade, 1981). Harbor seals in central California possibly were not subject to as much mortality as those between Alaska and Oregon, therefore harbor-seal abundance is stable. The numbers of harbor seals in California and Yaquina Bay may have remained stable because of increased human activity, and a lack of undisturbed haul-out sites of suitable size.

The evidence presented here indicates an increase in harbor-seal abundance in Oregon since 1973. The greatest increase in counts, however, occurred after 1981. Counts of harbor seals in Oregon represent trends in abundance and are minimum estimates of population size.

CHAPTER 3

DYNAMICS OF HARBOR-SEAL ABUNDANCE ON HAUL-OUT SITES IN CENTRAL OREGON.

Harbor seals commonly are found on land during periods of rest (Schneider and Payne, 1983; Terhune and Almon, 1983). The number of seals on land may be related to seasonal factors such as pupping, food availability, and pelage molt (Brown and Mate, 1983; Graybill, 1981; Loughlin, 1978; Stewart, 1981), or to daily factors such as wave action, stage of tide, time of day, air temperature, and disturbance (Bayer, 1985b; Brown and Mate, 1983; Ling et al., 1974; Stewart, 1981; Sullivan, 1979). Schneider and Payne (1983) concluded that tidal stage and disturbance were correlated with the number of seals on a haul-out site in Massachusetts, whereas sea state, cloud cover, and wind speed were not related to harbor-seal abundance. Although many aerial and land counts of harbor seals have been conducted in Oregon, there have been no attempts to quantify what factors may affect the number of harbor seals on land. These data are necessary to determine optimal times to count harbor seals.

Seasonal abundance of harbor seals in the northern and southern portions of Oregon have been reported, but there has been no such study, other than in Yaquina Bay (Bayer, 1985b) of harbor seals along the coast of central Oregon. Ocean and bay haul-out sites are found along the central coast, which makes this area suitable for a study of seasonal use of both habitats by harbor seals.

The aggregated distribution of pinnipeds on land, changes in use of haul-out sites through time, and variation in the number of animals on haul-out sites through time contribute to a large statistical variance associated with counts of pinnipeds (Estes, 1976). As Estes (1976) stated:

> "... studies of natural history, particularly those oriented toward activity and behavior, could help estimate bias and increase precision in estimates of population abundance for most species of marine mammals. For if we understand such things as patterns of individual and group activity (if, in fact, these patterns are simple enough for us to understand), then temporal variation in detectability could be accounted for".

It is clear that only a portion of the total population of harbor seals is located on haul-out sites during a land or aerial count (Pitcher and McAllister, 1981; Stewart and Yochem, 1983); the abundance estimates are, therefore, less than the actual population size. Many researchers used the maximum count of harbor seals on land as a best estimate of population size. An estimate of the actual population size is needed to calculate the effects of harbor seals predation on fishes.

The objectives of this paper were to determine: (1) seasonal abundance and land use of harbor seals along the coast of central Oregon; (2) those factors that control number of seals on land, and thereby develop guidelines on optimal conditions necessary for reliable counts; and (3) the proportion of seals on land during counts.

METHODS

Harbor-seal counts.--Dates of harbor-seal counts were chosen at random, (discounting days that counts could not be completed during low tide and daylight) and on a weekly basis, to distribute counts throughout the entire study period. Harbor seals at 10 haul-out sites between Siletz Bay (44°55'N, 124°01'W) and Strawberry Hill (44°14'N, 124°07'W) were counted one to 10 times/month between July 1983 and September 1985 (Fig. 1). Counts of harbor seals along this portion of the coast were conducted in a single low-tide period, and all haul-out sites were visible from the road. Counts began 1 h before low tide at Strawberry Hill and preceded northward until the final count was made at Siletz Bay approximately 1 h after low tide. The tide is progressively later to the north, therefore comparisons could be made between counts because counts of harbor seals at each location were made at nearly the same time relative to low tide.

Numbers of harbor seals at each location were counted by using 10- by 50-mm binoculars or a 10 - 60-X spotting scope. Temperature (^{o}C), rain (amount of precipitation in mm), wind speed (m/s), wind direction, and cloud cover (% cover) were recorded by personnel at the Newport airport (centrally located in the study area) within 1 h of the low tide during each count. Wave height was determined by use of a wave-metering device housed at the Hatfield Marine Science Center, Newport, Oregon. This devise was calibrated to measure wave heights for a 10-min period every 6 h. The largest wave, during a 6-h period closest to the time of a count of harbor seals, was multiplied by 0.80 to determine the average top 10% of wave heights (Zopf et al., 1976). Time and height of low tides was that predicted for the dock at the Hatfield Marine Science Center. Haul-out sites were within 300 m of the observation location, therefore, weather did not affect the ability to reliably count number of harbor seals on land.

Counts of harbor seals were transformed using the equation:

$\sqrt{\text{count} + 1}$ (Snedecor and Cochran, 1980). Correlation and a multiple regression were used to evaluate which environmental factors were responsible for explaining the variability in seal abundance (Neter and Wasserman, 1974). The null hypothesis was that there was no relationship between counts of harbor seals and environmental conditions. These conditions included height of low tide, wave height, wind speed, cloud cover, air temperature, day of week (weekday or weekend), and month.

Proportion of harbor seals on land.--The proportion of harbor seals on land during a count was determined by monitoring the location and activities of radio-tagged individuals. Twenty-six harbor seals were captured and radio-tagged in Yaquina Bay during July (n = 1), August (n = 1), and September (n = 2) 1983, in Alsea Bay (n = 6) and Yaquina Bay (n = 6) during August 1984, and in Alsea Bay (n = 10) during April 1985. Radio tags were affixed to the pelage of the head with an epoxy adhesive (Fedak et al., 1982). Because the radio tag was placed on the top of the head, signals could be monitored when harbor seals were on land or at the water's surface. Individuals were identified by unique radio frequencies between 148 and 150 MHz. Radio signals were received from a maximum distance of 8 km when the receiver was on land, and 16 km when in an aircraft.

During each count, seals with radio tags were located by continually listening to a receiver system that monitored each tag frequency for a 2 s period. Harbor seals usually spend more than 25 s on the surface after a dive (Chapter 5), therefore a tagged seal could usually located on most occasions, if it was within reception range. Some radio-tagged harbor seals probably were not located during counts, although they were present in the study area during the survey. Either they were underwater when the receiver was within reception range, were too far offshore (out of reception range), or were behind an obstruction that prevented reception. Location of radio-tagged harbor seals also was determined during 21 aerial counts of pinnipeds along the Oregon coast from September 1984 to July 1985. Radio-tagged harbor seals resting out of water were distinguished by a continuous signal from the radio tags, and identified in the water by the presence of intermittent signals. Location, time, signal strength, and whether the animal was on land or in the water were noted for each tagged seal located during a count.

The proportion of counts during which a radio-tagged harbor seal was located on land was transformed using an arcsine square-root transformation. These data then were used in a 2 by 2 contingency table (Snedecor and Cochran, 1980) to test for differences between tagged harbor seals from: (1) Yaquina and Alsea Bays in 1984, (2) 1984 and 1985 (Alsea Bay), and (3) females with and without pups (Alsea Bay in 1985).

If behaviors of tagged seals were representative of all seals in the area, the proportion of tagged harbor seals on land during a count was an estimate of the proportion of the population counted. A correction factor was calculated as one divided by the monthly average of proportion of tagged harbor seals on land during a count. Monthly averages were used because no radio-tagged harbor seals were located on land during some counts, therefore the reciprocal was infinity. The variance of the corrected counts was calculated as the product of two dependent variables (Goodman, 1960).

Corrected counts were calculated as follows:

Corrected count = count X (1 / $\bar{X}$ of monthly proportion of tagged harbor seals on land during a count).

RESULTS

Harbor-seal counts.--Ninety-seven counts of harbor seals on haul-out sites from Siletz Bay to Strawberry Hill were completed between July 1983 and September 1985. Peak numbers of seals were observed in January, August, and September (Fig. 5). Low counts were recorded in March and November. Counts ranged from two (1 November 1984) to 622 (20 August 1985) within the study area and averaged 326 (CI = 26.9) for all years and months. Counts often varied dramatically between consecutive counts; for example, there was a 923% increase from 52 seals counted on 5 September 1984 to 532 individuals counted on 12 September

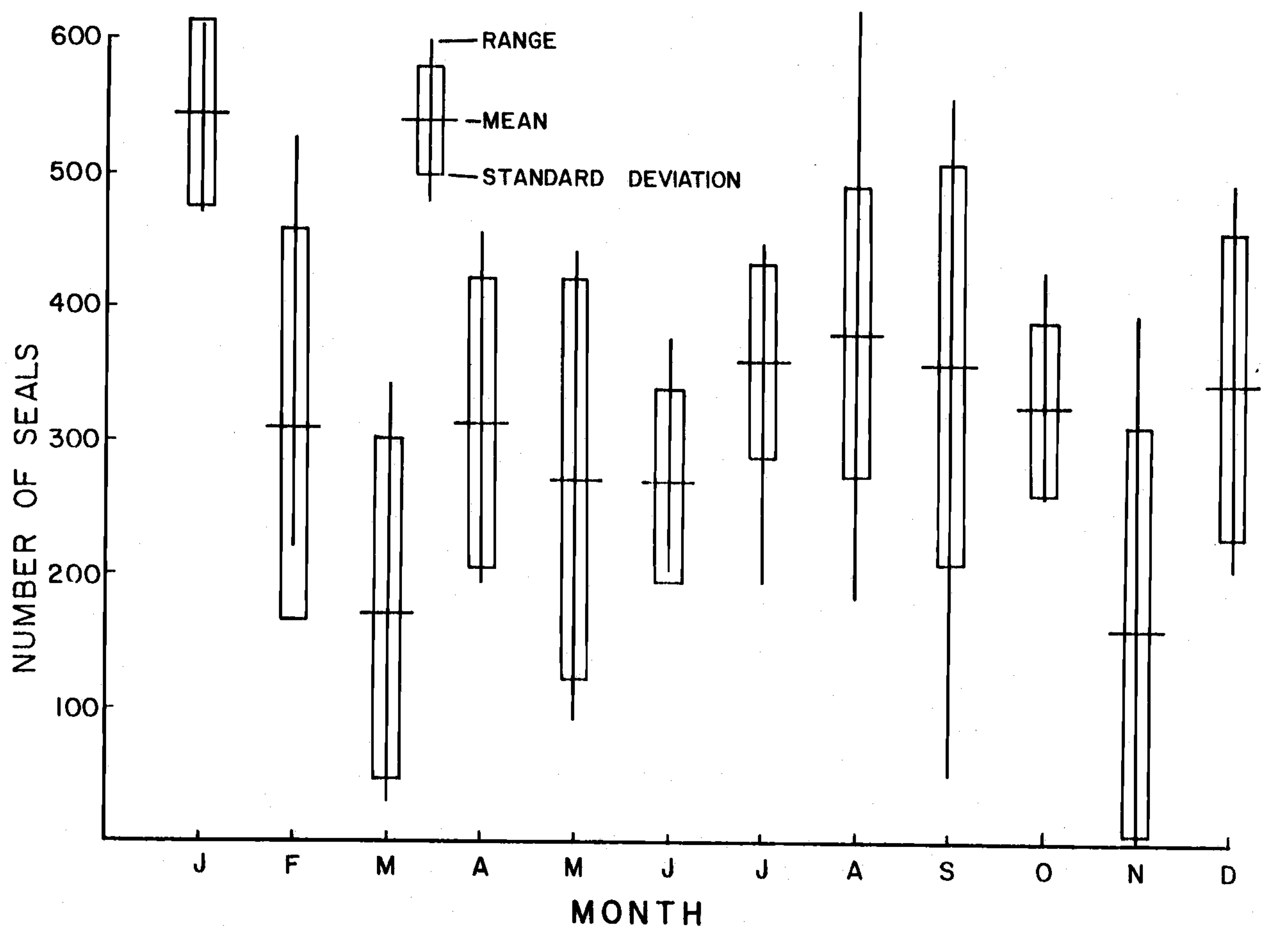

Fig. 5.--Monthly mean, standard deviation, and range of number of harbor seals on land at 10 sites along the central Oregon coast from 97 counts made July 1983 through September 1985.

1984, and a decrease of 630% from 526 seals on 25 January 1985 to 72 seals on 4 February 1985. There was no seasonal pattern of variation in counts (Fig. 5). Counts made in January, however, varied the least (CV = 12.8%), whereas those recorded in November varied the greatest (CV = 96.7%, Table 2). Alsea Bay had the greatest number of seals ($\bar{X}$ = 106.4, SD = 15.4), whereas Boiler Bay averaged only 1.4 harbor seals (SD = 0.7, Table 2).

Numbers of seals counted at ocean (Cape Foulweather, Otter Rock, Yaquina Head, Seal Rock, and Strawberry Hill) sites were correlated positively with counts at bay (Siletz, Boiler, Yaquina, and Alsea bays and Whale Cove) sites (r = 0.292, $P < 0.01$). Counts of seals on haul-out sites in the ocean were correlated positively with time of day (i.e. increased number of harbor seals in afternoon), temperature, and height of low tide (r = 0.372, 0.309, and 0.300, respectively; $P < 0.01$), and negatively with rain and wave height (r = -0.485 and -0.346; $P < 0.01$). The number of seals on haul-out sites in bays was correlated negatively with time of day, wind speed, height of low tide, amount of rain, day of week (i.e. fewer harbor seals counted during weekends than weekdays), and wave height (r = -0.437, -0.365, -0.358, -0.328, -0.281, -0.277, respectively; $P < 0.01$). A greater proportion of harbor seals was on land in bays during the spring, approximately equal numbers in the bays and ocean during summer, and

Table 2.--Summary statistics, mean, minimum, and maximum, standard deviation (SD), and coefficient of variation (CV) of counts of harbor seals on land between Siletz Bay and Strawbwerry Hill, Oregon. The number of counts (n) and summary statistics are given for each month and location.

Location	n	$\overline{X}$	Minimum	Maximum	SD	CV
Siletz Bay	97	26.3	0.0	106	30.2	1.15
Boiler Bay	97	1.4	0.0	16	3.7	2.44
Whale Cove	97	25.4	0.0	85	23.4	0.92
Cape Foulweather	97	8.1	0.0	40	11.3	1.39
Otter Rock	97	16.8	0.0	57	16.8	0.78
Yaquina Head	97	48.5	0.0	123	32.6	0.67
Yaquina Bay	97	5.1	0.0	35	8.7	1.71
Seal Rock	97	12.2	0.0	34	8.2	0.67
Alsea Bay	97	106.4	0.0	264	76.5	0.72
Strawberry Hill	97	71.5	0.0	138	34.4	0.48
TOTAL CENSUSES	97	326.4	2.0	622	133.7	0.41
Month						
January	3	545.7	469	607	70.3	0.13
February	4	309.3	221	526	146.1	0.47
March	5	172.8	32	345	127.8	0.74
April	6	312.8	195	455	109.9	0.35
May	4	270.5	90	441	151.2	0.56
June	6	266.0	203	373	71.7	0.27
July	17	360.1	194	443	73.8	0.21
August	18	380.6	182	622	111.3	0.29
September	15	357.3	52	559	152.0	0.43
October	7	324.0	265	428	64.2	0.20
November	7	158.9	2	396	153.6	0.97
December	5	342.4	206	496	114.3	0.35

more seals were on haul-out sites in the ocean during winter (Fig. 6).

Total counts of harbor seals within the study area were correlated negatively with height of low tide, amount of rain, wind speed, and wave height ($P < 0.01$). Low tides of -0.15 to 1.0 m generally corresponded with higher counts.

Environmental variables were not significantly correlated with each other ($P > 0.05$), and were analyzed together with total counts in the regression model. Four variables, height of low tide, amount of rain, wind speed, and wave height, explained 65.8% of the variability in total number of seals counted ($P < 0.01$). Other variables (time of day, temperature, wind direction, month, day of week, and cloud cover) did not contribute significantly to an evaluation of the total count of seals.

Proportion of harbor seals on land.--Radio tags were attached to 26 harbor seals (four males and 22 females) in Yaquina and Alsea Bays, three of which were never relocated after release (Table 3). One tag was functional for a minimum of 288 days; average duration of known tag operation was 131.6 days ($SD = 84.1$). Radio tags probably remained attached to harbor seals and functional for many days after they were last located. Radio tags were glued to the pelage of seals, and were expected to fall off before the time of molt (August - September). Therefore,

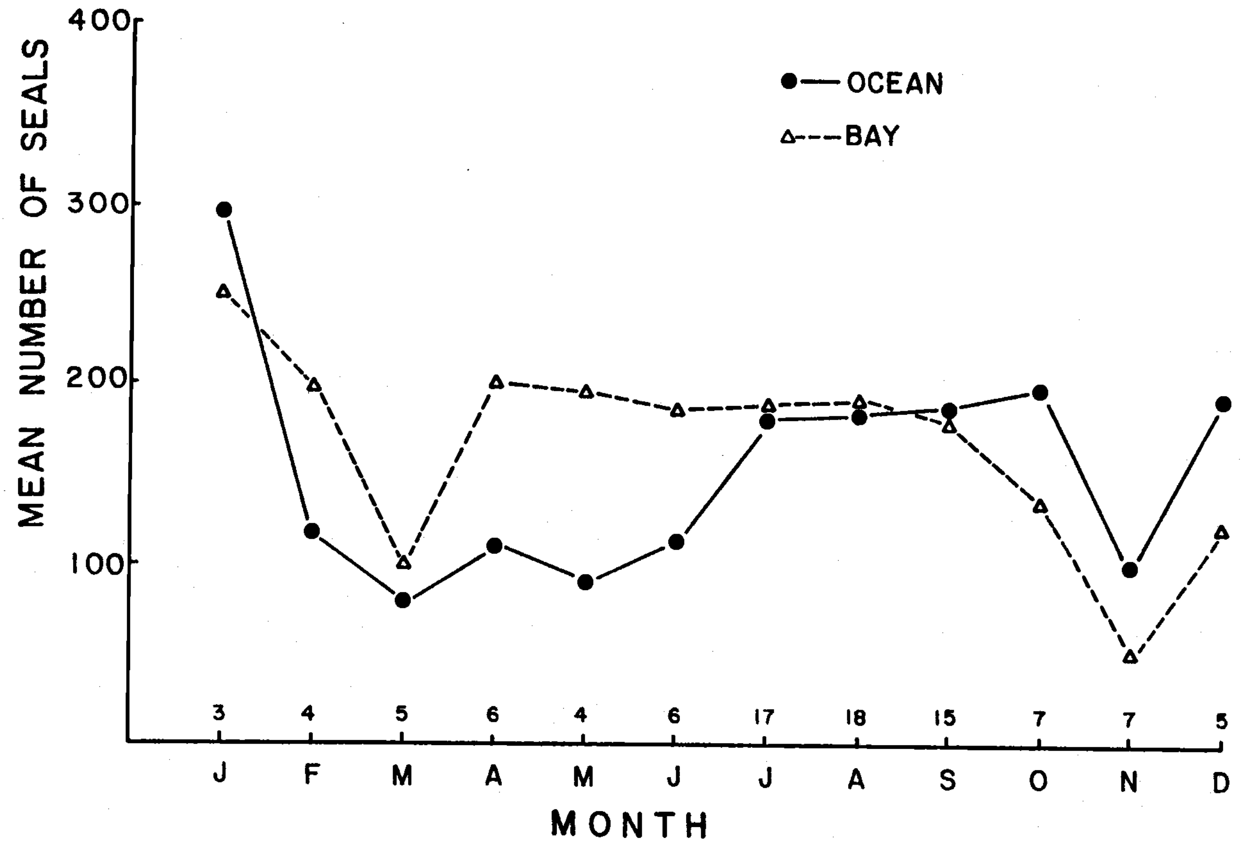

Fig. 6.--Monthly mean number of harbor seals at ocean (●) and bay (△) haul-out sites along the central Oregon coast from July 1983 - September 1985. Number of counts is given above each month.

Table 3.--Number of times tagged harbor seals were located, number of times (percent of total in parentheses) harbor seals were found on land or in water, and minimum duration of tag operation, for 26 seals radio-tagged in Yaquina and Alsea Bays from 1983 - 1985. Duration of known operation of radio tags is given with location where harbor seals were tagged.

Seal No.	No. times located	No. times on land (%)	No. times in water (%)	Tag operation (days)
July - December 1983 (Yaquina Bay)				
880	26	3 (11.5)	23 (88.4)	71
720*	10	0 (0.0)	10 (100.0)	42
620	4	1 (25.0)	3 (75.0)	98
600	2	1 (50.0)	1 (50.0)	42
August 1984 - June 1985 (Yaquina Bay)				
211*	9	2 (22.2)	7 (77.8)	112
280	13	2 (15.4)	11 (84.6)	288
343	40	2 (5.0)	38 (95.0)	189
380	40	5 (12.5)	35 (87.5)	189
400	14	1 (7.1)	13 (92.9)	244
420	38	9 (23.7)	29 (76.3)	196
August 1984 - May 1985 (Alsea Bay)				
241*	18	6 (33.3)	12 (66.7)	243
260	32	11 (34.4)	21 (65.6)	254
302*	0	0 (0.0)	0 (0.0)	0
322	23	7 (30.4)	16 (69.6)	127
363	44	6 (13.6)	38 (87.5)	248
440	18	4 (22.2)	14 (77.8)	196
April - July 1985 (Alsea Bay)				
060	0	0 (0.0)	0 (0.0)	0
150	0	0 (0.0)	0 (0.0)	0
170	3	3 (100.0)	0 (0.0)	41
530**	13	7 (53.9)	6 (46.1)	71
560	5	4 (80.0)	1 (20.0)	49
700	4	2 (50.0)	2 (50.0)	58
720**	12	7 (58.3)	5 (41.7)	72
730	9	5 (55.6)	4 (44.4)	50
750	7	6 (85.7)	1 (14.3)	61
770**	17	12 (70.6)	5 (29.4)	85

* designates males
** designates females known to have had a pup

12 harbor seals radio-tagged during their molt in August 1984 had the greatest chance of carrying tags for a full year; their tags were functional for an average of 176.3 days (Table 3). Radio tags remained on females tagged in Alsea Bay during April 1985 for an average of 60.9 days, an expected period because molt commenced approximately 100 days after tagging. Radio tags on harbor seals tagged in Yaquina Bay in July 1983 remained attached for an average of 63.2 days, although they were tagged late in the summer (Table 3).

Nine radio-tagged harbor seals were located during aerial counts outside the area where land counts were conducted. One individual was located 8 mo after capture on Rogue Reef, Oregon (265 km south of the tagging location), and another as far north as Grays Harbor, Washington (280 km from the tagging location). Interchange between two adjacent bays (Yaquina and Alsea) was evident because five radio-tagged harbor seals used both bays during the study.

Individual radio-tagged harbor seals were located as many as 44 occasions during land counts (Table 3). Percent of counts that a tagged harbor seal was on land varied among individuals, and ranged from 0 to 100%. Proportion of times a tagged harbor seal was on land during a count was not significantly different between harbor seals tagged in Yaquina Bay in 1983 and 1984 ($\underline{X}^2 = 0.03$, $\underline{P}$ >

0.01). Tagged seals in Yaquina Bay ($\bar{X}$ = 14.3%) were on land during counts less frequently than harbor seals tagged in Alsea Bay ($\bar{X}$ = 22.3) during 1984 (X^2 = 7.05, P < 0.01). The proportion of counts that radio-tagged females with pups were on land was not significantly different from that of tagged females without pups in Alsea Bay during 1985 (X^2 = 1.18, P > 0.05). Females tagged in Alsea Bay in the spring of 1985 were on land a greater proportion of counts than the females tagged in this bay during fall 1984 (X^2 = 31.82, P < 0.01).

The percent of tagged harbor seals on land during counts was least between October and February ($\bar{X}$ = 9.2%), therefore, correction factors were highest during this time ($\bar{X}$ = 16.5, range = 5.8-34.5). During March - July, the percent of radio-tagged seals on land during each count was greatest ($\bar{X}$ = 53.1%, SD = 31.9), and correction factors were correspondingly low ($\bar{X}$ = 2.5, range = 1.0-4.3; Table 4). Radio-tagged harbor seals were not located in August, and only one tagged seal was found in July. There was no correlation between the proportion of tagged seals on land during a count and the number of seals on land (P > 0.05).

Mean number of harbor seals in the study area, estimated from counts and correction factors, during October - February was 4,976 (SD = 2,482) individuals. This figure is 9.5 times the average maximum count, and

Table 4.--Number of counts per month (n), percent of tagged seals on land, and corrected counts of harbor seals along the central Oregon coast during 1983 - 1985. Corrected counts are derived by multiplying census counts by a monthly correction factor. The correction factor (CF) is the reciprocal of the monthly average of the percent of tagged seals on land during counts.

Month	n	% of tagged harbor seals on land		CF	Corrected Count			
		$\bar{X}$	SD		$\bar{X}$	SD	minimum	maximum
January	5	17.4	11.0	5.8	3,323	409	2,695	3,804
February	6	4.2	10.2	23.8	10,179	5,126	5,262	15,810
March	7	23.8	30.2	4.2	1,137	827	134	2,164
April	5	23.3	32.5	4.3	767	411	201	1,187
May*	4	52.3	26.9	1.9	517	289	172	843
June*	4	82.5	23.6	1.2	348	97	252	452
July*	1	100.0	0.0	1.0	272	0	100	100
August	0							
September	8	36.7	27.4	2.7	876	468	142	1,553
October	5	11.2	11.0	8.9	2,745	490	2,366	3,572
November	7	2.9	0.1	34.5	5,478	5,298	69	13,655
December	5	10.5	17.4	9.5	3,154	1,089	1,962	4,724

* months when mostly females retained radio tags.

14.9 times the average count during this time period. During March - September, mean estimated number of harbor seals in this same region was 608 individuals, which is only 1.7 times the average maximum count (375.6), and 2.7 times the average count of seals on land during this period.

To estimate number of harbor seals in Oregon I used two counts of harbor seals conducted in January and March 1985 (R. Brown, pers. comm.), and applied the correction factor determined for that month. These counts were used because they represented counts of harbor seals on all haul-out sites in Oregon during a period when I had developed correction factors. There were an estimated 20,671 (3,564 X 5.8; SD = 13,079) harbor seals in Oregon during January, and 17,182 (4,091 X 4.2; SD = 21,802) in March of 1985. Abundance also was determined using estimates of harbor-seal abundance in central Oregon (Siletz Bay - Strawberry Hill) and the proportion of individuals in this area during the statewide count. Using these figures, I estimated there were 20,018 (SD = 2,464) individuals in Oregon during January, and 9,023 (SD = 6,567) during March 1985.

DISCUSSION

Harbor seal counts.--Along the west coast of North America, greatest counts of harbor seals on land occur during spring and summer months when animals are pupping and molting. This has been reported for San Miguel Island, off southern California (Stewart, 1981), along the coast of central California, (Allen and Huber, 1984; Allen et al., 1984; Fancher and Alcorn, 1982), and off northern California, (Herder, 1986; Loughlin, 1978; Sullivan, 1979). In Oregon, greatest counts of harbor seals occurred in September through April in the Rogue River (Roffe and Mate, 1984), but between May and July near Coos Bay (Graybill, 1981). Seasonal abundance of harbor seals in the Rogue River is unique, because seals use one particular haul-out site during winter and at night when human disturbance is minimal (Roffe and Mate, 1984). Pups were not observed in the river, therefore pupping is assumed to occur elsewhere (Roffe, 1980). Bayer (1985b) reported peak counts of seals in Yaquina Bay between August and September, the time of molt. In northern Oregon, peak numbers of harbor seals were found in Netarts Bay from September through November, whereas in nearby Tillamook Bay the greatest numbers were found from June through September (Brown and Mate, 1983). In Washington, the greatest numbers of seals were reported from May through October, pupping and molting periods (Everitt and Jeffries, 1979; Everitt et al., 1981).

A second increase in numbers of seals on land during the winter, observed in the present study, has only been reported elsewhere in San Luis Obispo Co., California (Wade, 1981), Klamath River, California (Herder, 1986), and Yaquina Bay (Bayer, 1985b). Most investigators have only counted harbor seals in bays or estuaries, and may have missed a winter increase in harbor seals found on haul-out sites in the ocean.

There may be a winter increase in harbor-seal abundance ashore because: (1) they are energetically stressed during winter, and seek land for rest, or (2) food is abundant nearshore and they need less time to forage. Intuitively, it seems that seals would seek protected bays and estuaries during winter, if rough sea conditions make feeding and resting difficult in the ocean. This appears not to be the case in Oregon. A greater proportion of seals used bays during the spring pupping season, approximately equal numbers were in oceans and bays during molt, and a greater percentage of seals were in the ocean during winter (October - January). A greater proportion of harbor seals use bays during spring because these areas provide shelter and food for pups and molting adults.

Increased number of harbor seals on land during winter may have resulted from decreased time needed to forage.

During winter, some fishes, such as herring (Clupea harengus) and eulachon (Thaleichthys pacificus), enter estuaries to spawn, and could serve as prey for seals (Bayer, 1985b). Because the total biomass of fishes in estuaries declines in winter there probably is not an adequate quantity and quality of appropriately-sized prey in bays for most harbor seals to remain during winter (Bayer, 1981; Chapter 6).

Aside from the seasonal increases associated with pupping and molting, height of low tide explained the greatest amount of variability in daily counts of harbor seals. The greatest numbers of seals ashore are recorded during low tides (Allen et al., 1984; Bayer, 1985b; Everitt and Braham, 1980; Graybill, 1981; Ling et al., 1974; Sullivan, 1980). The influence of tidal height on numbers of seals on land has only been reported by Roffe (1980), and is critical in designing census methodology and understanding behaviors of seals. High low tides do not offer the seals much time to remain out of water at haul-out sites in Oregon. Consequently, the numbers of seals counted at these times were low. Counts of seals, recorded during extremely low tides, also were relatively low because some haul-out sites became inaccessible when water receded too far vertically or horizontally from the site. Additionally, low tides below mean low water were excellent times for clam digging, resulting in disturbance to seals at certain locations. Off central Oregon, the greatest number of seals, therefore, were recorded when the low tide was between -0.3 and +1.0 m.

Other factors cited as influencing numbers of seals on land were: wave action (Bishop, 1967; Loughlin, 1978; Wade, 1981), air temperature (Ling et al., 1974), disturbance (Bayer, 1985b; Loughlin, 1978; Renouf et al., 1981; Terhune and Almon, 1983), and time of day (Allen et al., 1984; Stewart, 1981). At exposed haul-out sites, wave action was sufficient to eliminate or reduce available area for resting. The result was lower numbers of seals during periods of high surf conditions (Bishop, 1967; Wade, 1981). Air temperature was identified as a factor in controlling numbers of harbor seals on land in Newfoundland (Ling et al., 1974) and Massachusetts (Schneider and Payne, 1983). In more temperate marine climates, air temperature generally does not fall below water temperature, and may not affect harbor seals on land. Water conducts heat more effectively than air, so seals may be able to conserve heat on land. Because harbor seals inhabit nearshore areas, the influence of human activity on their behaviors is more acute than on other pinniped species. Use of secluded beaches and offshore rocks reduces disturbance, but human activity and corresponding disturbance certainly affects counts. Although disturbance of harbor seals on land was not recorded in the present study, lower counts during weekends and negative low tides could be the result of increased human activity at those times.

Number of harbor seals was greatest in the afternoon in some areas where there was adequate space throughout the tidal cycle, and human disturbance was low (Allen et al., 1984; Everitt et al., 1980; Stewart, 1981). In other areas, including my study area, there was no correlation between numbers of harbor seals on land and time of day (Roffe and Mate, 1984; Terhune and Almon, 1983). There were few available haul-out sites off Oregon that can be used by harbor seals during high tide, therefore time of low tide determines when harbor seals use haul-out sites.

In general, the number of seals using ocean and bay haul-out sites fluctuated similarly to environmental factors. It seems that bay haul-out sites were used most frequently in the morning hours and at lower tides. Ocean haul-out sites, conversely, were used more in the afternoon and at moderately low tides. Bay haul-out sites were subject to greater human disturbance, especially in the afternoon, and these haul-out sites had less vertical relief. With much less human disturbance, seals in the ocean therefore may rest on shore after morning feeding forays. This pattern is similar for harbor seals on the Channel Islands (Stewart, 1984; Stewart and Yochem, 1983). Ocean haul-out sites generally had greater vertical relief, providing more opportunities for animals to rest on land at higher low tides.

In other studies of multiple variables that may affect numbers of harbor seals on land, Schneider and Payne (1983) reported stage of tide, air temperature, and wave intensity to have the greatest influence on numbers of seals. Their study period (November-May), however, did not extend through the summer months when peak numbers of seals would be expected during pupping and molting. In addition, the study site was limited to an offshore, rocky portion of the Massachusetts coast. Ling et al. (1974) reported stage of tide and air temperature were correlated with number of harbor seals, whereas cloud cover and wind velocity were not related. Therefore, factors responsible for influencing number of seals on land may differ with habitat and seasons.

<u>Proportion of harbor seals on land during counts</u>.--Estimates of the size of pinniped populations are affected by errors associated with the sampling technique (e.g. aerial or land counts), and behavior of the pinnipeds (Smith, 1973). Eberhardt et al. (1979:18) stated: "The main unresolved problem in direct counts of marine mammals centers around development of reliable correction factors to adjust visual counts to provide an estimate of total numbers." The use of radio-telemetry seems to be the best method to determine the relationship between maximum

counts and actual numbers of individuals in an area. Floyd et al. (1979) used radio-tagged deer to assess the numbers of individuals uncounted during counts; only a few researchers have used this technique on harbor seals.

A greater proportion of tagged harbor seals were found on land during spring and summer counts, than during fall and winter counts. Pitcher and McAllister (1981) reported radio-tagged harbor seals on Tugidak Island, Alaska were on land an average of 50% of days in June when harbor seals were counted, whereas during August they were on land an average of 40% of days. They did not discuss the time interval used to check for radio-tagged individuals. Ten (four females, six males) radio-tagged harbor seals on San Nicolas Island, California were on land an average of 65% of days in May, 58% in June, and 41% in July (Stewart and Yochem, 1983). On San Miguel Island, 18 (four females, 14 males) radio-tagged harbor seals were on land an average of 35% of days from 24 October to 6 December (Stewart and Yochem, 1983). Twelve radio-tagged seals (eight males, four females) in the Klamath River, California were on land on an average of 56.4% of days in April, and 65.1% in May (Herder, 1986). There was no significant difference in number of harbor seals on land among months or between sexes. In Oregon, an average 2.9 - 23.8% of radio-tagged harbor seals (4 males, 23 females) were on land during counts in October - March, whereas

23.3 - 100% were on land during counts in April - September. A great variability in percent of radio-tagged harbor seals on land throughout the year was not observed by other investigators because their studies were not conducted the entire year.

If the percent of tagged animals on land is to be used as a correction factor for estimating abundance, then it should be determined at the time counts are made. During counts of harbor seals in Oregon, the location of tagged seals (i.e. in the water or on land) was determined within a 5 - 10 min period. In other studies, tagged harbor seals were designated as on land if they came ashore any time during a day. The percent of radio-tagged harbor seals designated as on land is probably greater with increased amounts of time used to locate individuals, and abundance would therefore be overestimated. Counts of harbor seals on land, whether by eye or from photographs, are usually made within a brief period of time, and it it is then that correction factors need to be determined. The data of Pitcher and McAllister (1981) are also difficult to use in determining a correction factor because they eliminated individuals known to be nonresidents or were away for prolonged periods. The data they report, therefore, were biased toward resident seals that may rest on land more frequently. Tagged harbor seals that did not rest on land were often not sampled.

Yochem et al. (1987) have reported data comparable to that presented in this study. They found that 11 - 19% of radio-tagged harbor seals were on San Miguel Island during one-hour intervals throughout the day. These data were collected between October and December 1982. They used these data to estimate that 2,168 harbor seals were using the island then. During these months in Oregon, an average 8.2% of radio-tagged harbor seals were found on land during counts. These values are much less than the 35 - 65% of days harbor seals were reported on land elsewhere (Herder, 1986; Pitcher and McAllister, 1981; Stewart and Yochem, 1983).

Radio-tagged harbor seals are more easily located on land than in water. I probably overestimated the proportion of tagged harbor seals on land during counts because individuals in water were less likely to be sampled. Correction factors used were therefore minima.

The great variability in use of haul-out sites by harbor seals is reflected in the large variance associated with corrected counts. A larger sample size of harbor seals of all ages and sexes would be needed to more precisely determine estimated abundance. Harbor seals should be tagged in various locations because there are differences in how harbor seals use haul-out sites.

Estimates of harbor-seal abundance were made using a model similar to the "Petersen method" of mark-recapture for a closed population (Seber, 1982). The following assumptions must hold to calculate a suitable estimate of population size: (1) the population is closed, (2) all animals must have equal probability of being caught, (3) marking does not affect recapture, (4) each individual has an equal possibility of being recaptured, (5) marks are not lost, and (6) all marks are reported at recapture. Only radio-tagged individuals that were located, either in the water or on land, were used in estimates of population size. The recaptured (tagged individuals that were located) individuals formed the second sample, and any movements into or out of the study area were irrelevant because I used only those individuals located. Therefore, immigration and emigration could occur, without distorting estimates of abundance. The use of radio-tags as marks allowed all tagged individuals to have an equal probability of recapture, eliminated unknown tag loss as a bias, and insured all marks were reported.

It was assumed that capture, handling, and placement of a radio-tag on a harbor seal did not significantly alter its behavior. This seems reasonable because radio-tagged harbor seals were seen on land with other individuals within 6 h of tagging. In estimating population size based on correction factors developed from radio-tagged individuals, it was assumed that the tagged individuals are a representative sample of the population.

This assumption remains untested. All harbor seals tagged in the present study were caught in bays along the central Oregon coast. Although there is documented movement of seals between offshore and bay haul-out sites, differences in behavior of harbor seals in these two habitats was not been determined sufficiently. The assumption was that there was no difference in use of haul-out sites by harbor seals in bays and offshore, and that the observed proportion of radio-tagged harbor seals on land during a count represented the proportion of all seals on land in the study area. This assumption can be tested by capturing and tagging seals on offshore haul-out sites, and monitoring their movements and behaviors.

There is some evidence (i.e. no correlation between proportion of tagged harbor seals on land and counts of all harbor seals on land) that tagged harbor seals were not behaving as other individuals. The lack of a correlation of numbers of tagged and untagged harbor seal on land was probably a result of the great variability in use of haul-out sites by all individuals.

Estimates of harbor-seal abundance in Oregon were between 9,023 and 20,671 individuals, however the variability associated with these figures was great. Because monthly correction factors were highly variable, estimates of harbor-seal abundance in Oregon were imprecise. Estimated abundance of harbor seals was 2.2 -

5.8 times actual counts made in winter 1985. The number of harbor seals in Oregon is certainly greater than actual counts, however, the magnitude of this difference is equivocal. Estimates of harbor-seal abundance should improve with increased knowledge of temporal and spatial variation in counts of harbor seals throughout the state, and by improving our estimates of correction factors.

CHAPTER 4

ASSESSMENT OF ERRORS ASSOCIATED WITH PINNIPED FECAL SAMPLING.

Fecal samples are a valuable source of information on food habits of pinnipeds because many samples can be collected quickly, with little effort, and without harm to the animals. Undigested hard parts of prey, primarily fish otoliths and cephalopod beaks, have been collected from feces, and their distinctive morphology used to identify taxa of prey eaten by pinnipeds (Antonelis et al., 1984; Brown and Mate, 1983; Frost and Lowry, 1981; North et al., 1983; Pitcher, 1980b). The dense calcium carbonate structure of otoliths and chitin of beaks is resistant somewhat to digestion.

The length and mass of fishes and cephalopods are correlated positively with the length of their otoliths and beaks (Appelbaum and Hecht, 1978; Casteel, 1974; Clarke, 1980; Southward, 1962; Templemann and Squires, 1956; Wolff, 1982). These relationships were used to estimate the size of prey species consumed by pinnipeds (Brown and Mate, 1983; Frost and Lowry, 1981; North et al., 1983).

Some investigators have assumed that all fish otoliths and cephalopod beaks pass through the alimentary canal in equal proportions to the number eaten, and that otoliths and beaks are not reduced in size significantly. If true, number and size of prey consumed may be estimated by enumerating and measuring otoliths and beaks from feces. Unfortunately, these assumptions have not been tested adequately for any pinniped species and their prey (Jobling and Breiby, 1986).

The primary objectives of this study were: (1) to determine the change in number and size of otoliths and beaks passed through the digestive system of captive harbor seals (*Phoca vitulina*), (2) to compare differences in size reduction of otoliths and beaks among prey species and harbor seals, and (3) to estimate the rate of passage of otoliths and beaks. These data are needed to determine the number and size of prey species consumed by harbor seals as estimated using otoliths and beaks from feces. A secondary objective was to determine the location and degree of digestion of otoliths within the three main regions of the pinniped alimentary canal (i.e. stomach, small intestine, and colon).

METHODS

Six captive harbor seals were obtained in groups of two from three aquaria in Washington and Oregon. They were 4 - 8 years of age, and 36 - 86 kg body mass. The seals were fed either Atlantic herring (<u>Clupea harengus harengus</u>) or eulachon (<u>Thaleichthys pacificus</u>) twice daily at a rate of approximately 5 - 10% of their body mass/day. It was assumed that this schedule simulated the feeding regime of harbor seals in the wild, because harbor seals in Oregon rest on shore during periods of low tide, and consequently have the opportunity to feed at least twice a day during high tides. The quantity of food was sufficient for the harbor seals to slightly gain weight during the course of the experiments.

An experimental trial consisted of feeding harbor seals a meal of fishes or cephalopods of known mass (g), and standard length (cm) or mantle length (cm). The availability of prey species fluctuated throughout the study; therefore, the 14 species of experimental prey (Table 5) were not always the same for each pair of seals. The experimental fish and cephalopods represented the major taxa and size classes consumed by seals off Oregon (Brown and Mate, 1983; Graybill, 1981; Roffe and Mate, 1984), and simulated the natural food habits of this species.

Harbor seals were housed as pairs in a 10- by 20- by 2-m outdoor cement tank, located at the Hatfield Marine Science Center, Newport, Oregon. The tank was filled to a depth of 1.5 m with 40,000 l of seawater, and was equipped with a 4- by 4-m platform to which the seals had

Table 5.--Linear relationship between left otolith length (LOL) and right otolith length (ROL), or left otolith weight (LOW) and right otolith weight (ROW) and standard length (SL) of fish species. Regression equations for cephalopod species (L. opalescens and L. pealei) are given for mantle length (ML) or weight (WT) of squid regressed on upper rostral length (URL) and lower rostral length (LRL). Species are listed in alphabetical order. Also given are the coefficient of determination (r^2), and number (N) of otoliths collected for the regression. ND indicates no data available.

Species (Common name)	Regression Equation	r^2	N	Otolith Robustness
Anoplopoma fimbria (sablefish)	SL=5.28(LOL)+1.31 SL=5.30(ROL)+1.25	0.96 0.97	79 79	0.15
Clupea h. harengus (Atlantic herring)	SL=5.00(LOL)+0.95 SL=5.04(ROL)+0.90	0.73 0.72	81 78	0.08
Cymatogaster aggregata (shiner perch)	SL=1.72(LOL)-0.49 SL=1.72(ROL)-0.50	0.96 0.96	69 68	0.33
Glyptocephalus zachirus (rex sole)	SL=4.38(LOL)-0.25 SL=4.29(ROL)+0.49	0.68 0.66	49 46	0.77
Hypomesus pretiosus (surf smelt)	SL=9.61(LOW)+8.38 SL=11.94(ROW)+7.19	0.78 0.65	9 9	0.14
Leptocottus armatus (staghorn sculpin)	SL=2.27(LOL)-1.24 SL=2.44(ROL)-1.84	0.77 0.85	30 24	0.23
Loligo opalescens[1] (Pacific market squid)	ML=54.3(URL)+42.2 ML=60.8(LRL)+32.4	0.79 0.74	ND ND	
Loligo pealei (Atlantic market squid)	WT=141.2(URL)-213.8 WT=142.3(LRL)-174.2	0.25 0.22	20 20	
Microgadus proximus (Pacific tomcod)	SL=1.67(LOL)-2.91 SL=1.65(ROL)-2.72	0.95 0.95	45 44	0.68
Microstomus pacificus (Dover sole)	SL=4.24(LOL)+3.75 SL=4.46(ROL)+2.84	0.69 0.65	63 67	0.44
Parophrys vetulus (English sole)	SL=3.57(LOL)-1.83 SL=3.69(ROL)-2.44	0.96 0.95	112 110	0.31
Salmo gairdneri (rainbow trout)	SL=6.14(LOL)-3.16 SL=6.64(ROL)-4.74	0.88 0.92	28 25	0.14
Sebastolobus alascanus (shortspine thornyhead)	SL=1.34(LOW)+9.11 SL=1.35(ROW)+9.04	0.89 0.89	61 63	0.86
Thaleichthys pacificus (eulachon)	SL=4.47(LOL)-1.89 SL=4.26(ROL)-1.00	0.72 0.70	91 89	0.12

[1] Regression equation taken from Wolff (1984).

continuous access. Seawater was pumped from Yaquina Bay, and averaged 9.4 ^{0}C, and 31.4 $^{0}/_{00}$ salinity. At intervals of 3 - 6 days, the water in the tank was siphoned off to a depth of 0.2 m without loss of fecal material that had settled to the bottom; feces were filtered through a 0.5 mm sieve inserted in the drain as the remaining contents of the tank were removed. Experimental meals were fed to harbor seals between 12.5 and 144 h before the tank was first cleaned during a trial. The tank was cleaned at least three times before an experimental meals of the same prey species was fed to harbor seal pairs. At the end of each set of experiments with a pair of seals, the tank was cleaned thoroughly to insure no otoliths or beaks were present in the tank when a new pair of harbor seals were obtained.

Fecal samples were stored for approximately 1 day in an emulsification mixture (Treacy and Crawford, 1981), and washed gently through a series of three sieves (2 mm, 1 mm, and 0.5 mm; Murie and Lavigne, 1985). Otoliths were sorted, stored dry in vials, and later identified, enumerated, measured, and weighed. Otolith length (nearest 1 mm) was measured parallel to the sulcus from the anterior tip of the rostrum to the posterior edge using either a microscope and ocular micrometer at 6 X magnification, or hand-held calipers. Otoliths were weighed to the nearest 0.1 mg on a digital Mettler balance. Left and right otolith lengths and weights were determined separately, and otoliths with obvious broken edges were not measured. Squid beaks were stored in 50% isopropyl alcohol. The upper and lower rostral and hood lengths were measured to the nearest 0.1 mm under a microscope (10 X) equipped with an ocular micrometer, as described by Clarke (1962).

The ability to recover otoliths from the tank was tested by randomly introducing 8, 10, and 16 otoliths (3 - 12 mm), from _Anoplopoma_ _fimbria_, _Sebastes_ _melanops_, and _Cymatogaster_ _aggregata_ in mixed numbers for each trial, into the tank on 3 separate days. Seals were present in the tank during these trials, and the tank was cleaned within 5 h of dispersing the otoliths of known number and size. All but one, a 5.0-mm otolith from _A_. _fimbria_ and representing 3% of total number of otoliths, were recovered in the cleaning immediately following dispersal. Therefore, it was assumed that all otoliths excreted were retrieved in the subsequent draining and cleaning of the tank.

The estimated size of fish or cephalopod eaten by captive harbor seals was determined from measurements of otoliths and beaks collected from fresh fishes and cephalopods. A least-squares linear regression was used to describe the otolith length or weight to fish length relationships for both left and right otoliths (Table 5).

This same method was applied to measurements of upper and lower squid beaks and mantle lengths. Otolith robustness (otolith weight/otolith length) was calculated for each fish species used.

For each trial I calculated the percent of fish recovered, that was the number of a particular prey species fed harbor seals divided into the estimated number as determined by the greatest number of left or right otoliths or upper and lower beaks recovered in feces, multiplied by 100. Trials using the same prey species were separated by 2 - 3 weeks to assure that all hard parts had been excreted before another trial began. Five species of fish (shiner surfperch, C. aggregata; rex sole, Glyptocephalus zachirus; shortspine thornyhead, Sebastolobus alascanus; English sole, Parophrys vetulus; and rainbow trout, Salmo gairdneri) were common to all experiments and used to evaluate differences in percentage of recovered otoliths among fish species or among pairs of seals. The percent of recovered fish was transformed using an arcsine transformation (Zar, 1984). An analysis of variance was used to test for significant differences within groups (i.e. percent of otoliths recovered differs among fish species) and among groups (i.e. percent of otoliths recovered differs among pairs of seals).

A Student's t-test was used to evaluate the null hypothesis that there was no difference between the actual mean length of fish eaten and that estimated from measurements of collected otoliths. The size distribution of fish actually fed to seals and the estimated distribution based on collected otoliths were compared by use of a Kolmogorov-Smirnoff test. Otolith robustness was regressed on percent reduction to determine if the size of otolith was related to the underestimation of fish length.

The passage rate of otoliths was calculated by the difference between the time of ingestion and recovery of otoliths and beaks in feces. Only maximum passage rates were determined, because the tank was only drained at 3 - 6 day intervals. For each seal pair and fish species, the cumulative percent of otoliths recovered was calculated for each subsequent cleaning.

To determine the location and amount of digestion occurring in separate parts of the alimentary canal, 29 harbor seals, incidentally killed in commercial gill nets in the Columbia River during 1986, were sampled. Within 2 - 8 h of death, stomachs, small intestines, and colons were removed from seals and frozen. Gastrointestinal samples were thawed several months later, and contents were washed through a series of sieves of 3, 2, 1.5, and 0.5 mm mesh size. Otoliths were stored dry in vials, and later identified, measured, and weighed. A one-way analysis of variance was used to test the hypothesis that there was no significant reduction in average length or weight of otoliths collected in the three regions of the alimentary canal. A Kolmogorov-Smirnoff goodness-of-fit test was used to detect differences in frequency distributions of otolith length and weight for each region of the alimentary canal.

RESULTS

Estimated number of prey eaten (percent recovered).-- Sixty-one feeding trials, with a specific fish or cephalopod species fed to seals as an experimental meal, were conducted during 2 years. Fifty-four percent of the 673 fish and 37% of the 35 cephalopods fed harbor seals were represented as otoliths or beaks in feces.

Recovery rates varied greatly for some prey species and seal pairs (Table 6). For example, the recovery rates of *C. aggregata* were 28.6, 57.1, and 100.0 for three trials with harbor seal pair # 3, whereas the recovery rates of this species varied less for seal pair # 1 (50.0, 53.3., and 57.1). Percent of prey recovered for all prey species was 67.1 (SD = 30.6), 50.6 (SD = 32.9), and 63.3 (SD = 34.8) for the three pairs of harbor seals.

There was no significant difference in recovery rate for five fish species common to experiments among the three pairs of harbor seals ($F = 0.64$, $P > 0.01$). There was, however, a significant difference in recovery rates

Table 6.--Number of fish and cephalopods fed to three pairs of harbor seals during feeding trials. The estimated number is based on the greatest number of left or right otoliths, or upper or lower beaks collected in feces, and percent recovered is the proportion of number of prey estimated to number of prey actually fed.

Species	Trial	Pair 1			Pair 2			Pair 3		
		Number		%	Number		%	Number		%
		Fed	Estimated	Recovered	Fed	Estimated	Recovered	Fed	Estimated	Recovered
Fishes										
Anoplopoma fimbria	1	1	1	100.0	7	0	0.0			
Cymatogaster aggregata	1	12	6	50.0	10	3	30.0	14	4	28.6
	2	15	8	53.3	13	11	84.6	14	14	100.0
	3	14	8	57.1	14	10	71.4	14	8	57.1
Clupea harengus	1				11	6	87.5			
	2				10	1	10.0			
	3				11	0	0.0			
Glyptocephalus zachirus	1	5	4	80.0	8	8	100.0	16	15	93.8
	2	2	0	0.0	7	5	71.4	12	11	91.7
	3	3	3	100.0	20	16	80.0	21	18	85.7
Hypomesus pretiosus	1				20	11	55.0			
Leptocottus armatus	1				10	5	50.0	20	8	40.0
	2				18	4	22.2	20	6	30.0
	3							19	17	90.0
Microstomus pacificus	1	6	6	100.0	6	4	66.7			
Microgadus proximus	1							20	12	60.0
	2							20	14	70.0
	3							19	17	89.5

Table 6.--(Cont.,p.2)

Species	Trial	Pair 1			Pair 2			Pair 3		
		Number		%	Number		%	Number		%
		Fed	Estimated	Recovered	Fed	Estimated	Recovered	Fed	Estimated	Recovered
<u>Parophrys vetulus</u>	1	8	5	62.5	7	2	28.6	15	1	6.7
	2				14	0	0.0			
<u>Sebastolobus alascanus</u>	1	8	8	100.0	9	8	88.9	4	4	100.0
	2				8	5	62.5	8	8	100.0
	3				8	7	87.5			
<u>Salmo gairdneri</u>	1	6	5	83.3	6	4	66.7	1	1	100.0
	2	12	10	83.3	12	8	66.7	12	2	16.7
	3				12	2	16.7	12	7	58.3
<u>Thaleichthys pacificus</u>	1	10	5	50.0				25	2	8.0
	2	10	4	40.0				19	2	10.5
	3	12	8	66.7						
Cephalopods										
<u>Loligo opalescens</u>	1	14	2	14.3						
<u>Loligo pealei</u>	1				12	2	16.7	9	9	100.0

among the five fish species used (F = 3.835, P < 0.01). The lowest average recovery rates were for small fishes such as juvenile P. vetulus (24.4), C. harengus (32.5), and T. pacificus (35.0), whereas recovery rates were greater for larger fishes (e.g. S. alascanus, M. pacificus, and G. zachirus).

Recovery rates were significantly greater for fish species with more robust otoliths than for species with thinner otoliths (t = 3.80, P < 0.01; Fig. 7a).

Estimated size of prey eaten (percent size reduction).--Estimated length of fishes, based on lengths of otoliths from feces, was significantly less than the length of fishes fed harbor seals in 39 (76.5%) of 51 trials (Table 7). For four of six trials with S. alascanus there was no significant difference between estimated length of fish and actual length of fish fed harbor seals. Estimates of mantle length of cephalopods, based on measurements of beaks in harbor seals feces, were not significantly different from the lengths of cephalopods fed to harbor seals (Table 7).

No significant reduction in otolith lengths were found, either among pairs of seals or among fish species (P > 0.01). For all fish species, the length was underestimated by an average of 27.5% (SD = 13.8), when comparing the length of fish fed to harbor seals and that determined from otoliths collected in feces. In addition,

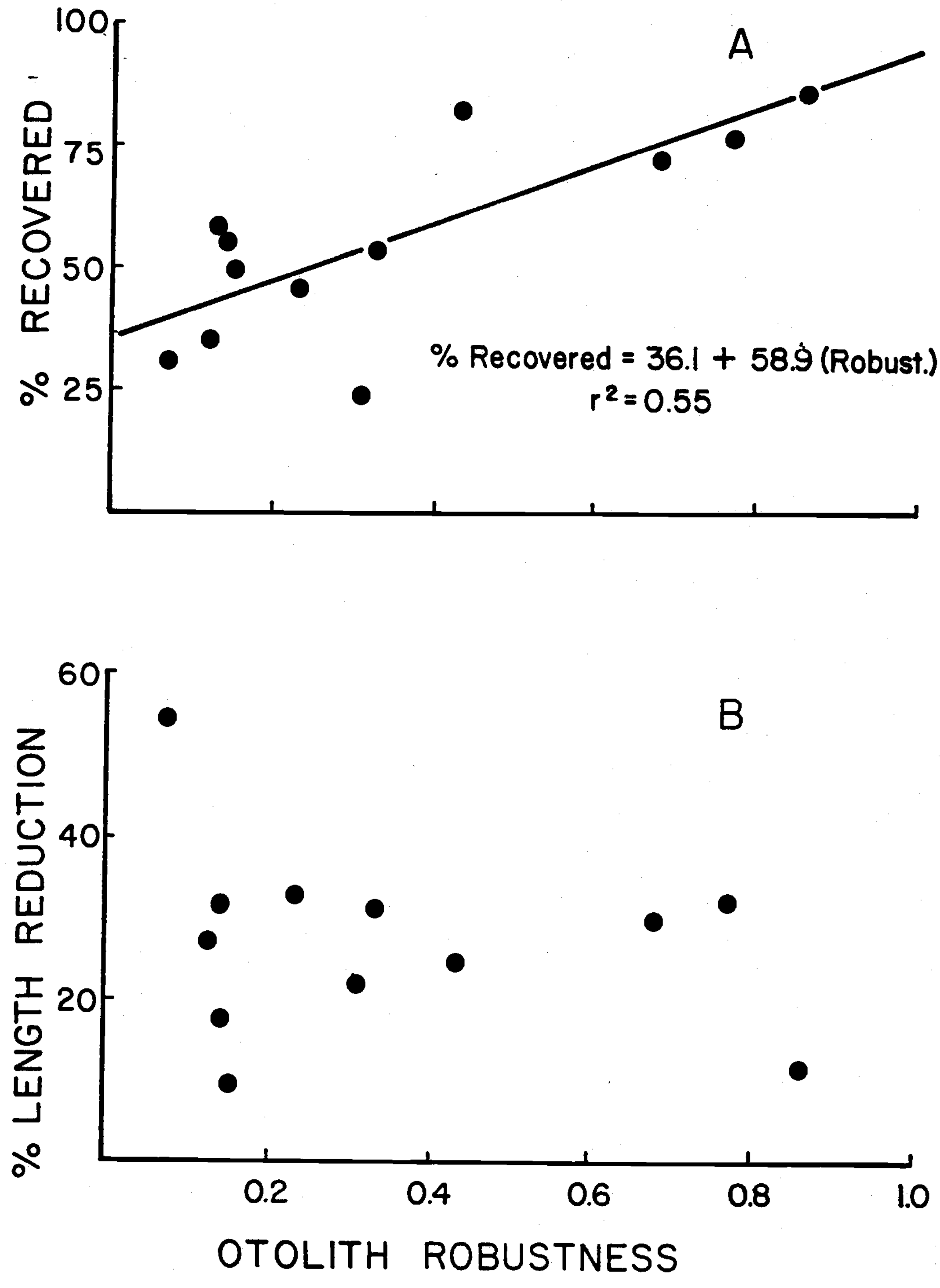

Fig. 7.--Linear relationship between percent of otoliths recovered in harbor-seal feces and otolith robustness (otolith length/otolith weight) for 12 species of fish (A), and percent reduction in otolith length compared with otolith robustness (B).

Table 7.--Mean standard length (mantle length) and standard deviation of fish (cephalopod) species fed to harbor seals and that estimated based on measurements of otoliths (beaks) collected in feces. A t-test was used to test for differences in mean lengths of prey fed seals and estimated from measurements of otoliths and beaks.

		Mean standard length (cm) and standard deviation (SD) of prey species					
		Pair 1		Pair 2		Pair 3	
Species	Trial	Fed (SD)	Estimated (SD)	Fed (SD)	Estimated (SD)	Fed (SD)	Estimated (SD)
Fishes							
Anoplopoma fimbria	1	19.0 (0.0)	20.8 (0.0) NS				
Cymatogaster aggregata	1	10.1 (0.6)	7.5 (3.5) *	6.2 (0.2)	4.9 (1.1) **	9.8 (1.1)	5.6 (3.5) **
	2	9.5 (0.8)	6.0 (2.5) **	9.4 (1.1)	6.0 (1.6) **	8.8 (1.1)	6.3 (2.0) **
	3	10.0 (0.8)	8.1 (1.1) **	10.2 (0.6)	5.8 (2.5) **	10.0 (0.9)	5.5 (1.6) **
Clupea harengus	1			21.2 (2.3)	18.4 (2.6) *		
	2			22.1 (2.3)	17.0 (0.0) NS		
Glyptocephalus zachirus	1	22.6 (1.0)	21.2 (2.3) NS	22.9 (1.6)	18.1 (2.6) **	23.8 (1.2)	19.2 (2.4) **
	2	21.9 (1.0)	14.7 (9.2) NS	22.2 (1.5)	15.0 (2.9) **	22.3 (1.1)	11.5 (1.8) **
	3			23.5 (1.3)	18.5 (4.1) **	23.9 (1.2)	16.6 (4.1) **
Hypomesus pretiosus	1			13.1 (0.5)	10.8 (1.5) **		
Leptocottus armatus	1			11.1 (0.6)	7.8 (1.8) **	11.5 (0.7)	7.7 (2.6) **
	2			11.0 (0.9)	7.4 (0.4) **	11.8 (1.0)	6.5 (2.6) **
	3					11.1 (1.3)	8.4 (1.7) **

Table 7.--(Cont., p.2)

Species	Trial	Pair 1 Fed (*SD*)	Pair 1 Estimated (*SD*)		Pair 2 Fed (*SD*)	Pair 2 Estimated (*SD*)		Pair Fed (*SD*)	Pair Estimated (SD)	
		Mean standard length (cm) and standard deviation (SD) of prey species								
Microgadus proximus	1							12.2 (0.7)	6.5 (2.0)	**
	2							12.7 (1.8)	8.3 (2.0)	**
	3							12.4 (1.1)	6.1 (1.5)	**
Parophrys vetulus	1	10.1 (0.5)	8.6 (1.3)	*	9.1 (1.0)	7.6 (1.9)	NS	8.7 (0.7)	5.3 (0.0)	**
Sebastolobus alascanus	1	21.2 (1.1)	13.6 (6.4)	**	22.7 (1.4)	28.0(10.9)	NS	21.3 (2.1)	20.1 (4.0)	NS
	2				21.2 (0.9)	17.8 (6.6)	NS	21.3 (1.4)	15.0 (4.4)	**
	3				21.2 (1.8)	19.2 (6.1)	NS			
Salmo gairdneri	1	22.7 (1.4)	16.3 (6.8)	NS	24.7 (1.9)	23.6 (2.2)	NS	23.9 (1.4)	14.0 (0.0)	**
	2	24.3 (2.1)	13.8 (4.5)	**	24.4 (1.2)	17.4 (6.3)	**	24.6 (1.0)	12.0 (5.5)	**
Thaleichthys pacificus	1	17.0 (1.5)	11.9 (5.5)	*				16.0 (1.3)	9.9 (2.2)	**
	2	16.2 (1.9)	11.2 (4.6)	*				15.0 (1.4)	11.6 (3.7)	**
	3	14.6 (1.3)	12.4 (4.1)	NS						
Cephalopods:										
Loligo opalescens	1	10.0 (1.5)	11.9 (0.3)	NS						
Loligo peali	1				22.8 (5.5)	21.4 (5.9)	NS	17.0 (3.5)	21.6 (3.9)	NS

NS indicates not significant
* *t*-test significant at 0.05 probability level
** *t*-test significant at 0.01 probability level

there was no significant relationship between the robustness of the otolith and percent reduction in fish length (_t_ = 0.088, _P_ > 0.01; Fig. 7b).

Comparing mean length of fish fed to harbor seals with estimated lengths determined from otoliths from feces may be biased if smaller otoliths are not recovered or are digested completely. To evaluate this bias, the frequency distribution of estimated lengths of _C_. _harengus_ was compared with the frequency distribution of actual lengths of _C_. _harengus_ fed to one pair of harbor seals. The two distributions were not significantly different in shape, however, the distribution of estimated lengths was displaced to the left (_P_ > 0.01; Fig. 8). Therefore, differences in mean standard length between estimated and fed, represent the average amount of digestion to all otoliths, and are not biased because smaller otoliths were not recovered.

Estimates of passage rate.-- Otoliths and beaks from experimental prey were collected in feces 13 - 1,007 h after harbor seals had eaten the fish. Fifty-two (7.4%) of 698 otoliths and beaks were not recovered within 100 h after ingestion. These few, longer recovery times probably result from hard parts that remained in the tank through subsequent cleaning. Generally, greater than 90% of the otoliths and beaks were recovered within 24 h of an experimental meal (Fig. 9). In one trial, otoliths of _S_.

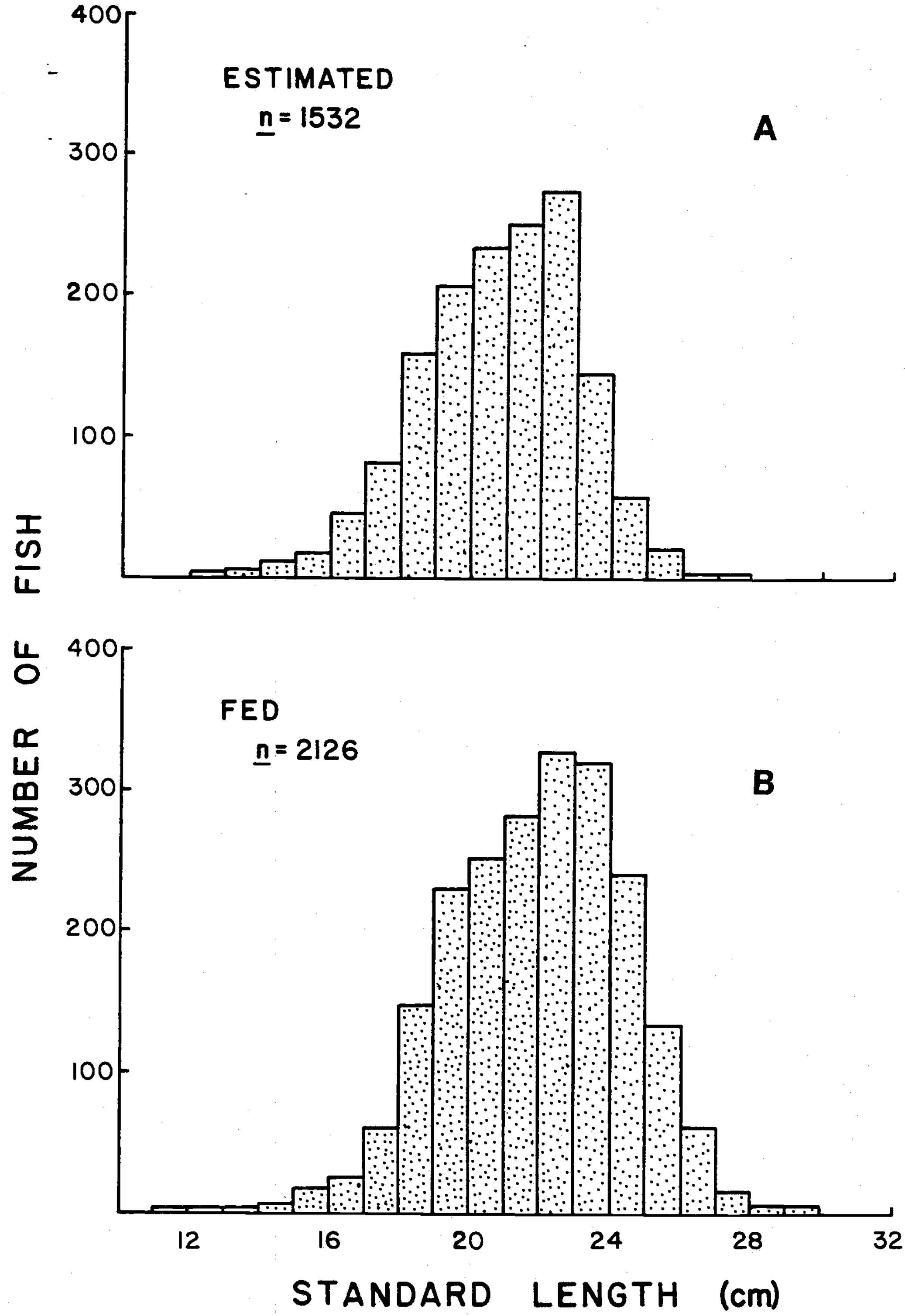

Fig. 8.--Frequency distributions of standard length of herring, Clupea harengus, fed to harbor seals (A), and standard length estimated from measurements of otoliths collected from harbor seal feces (B).

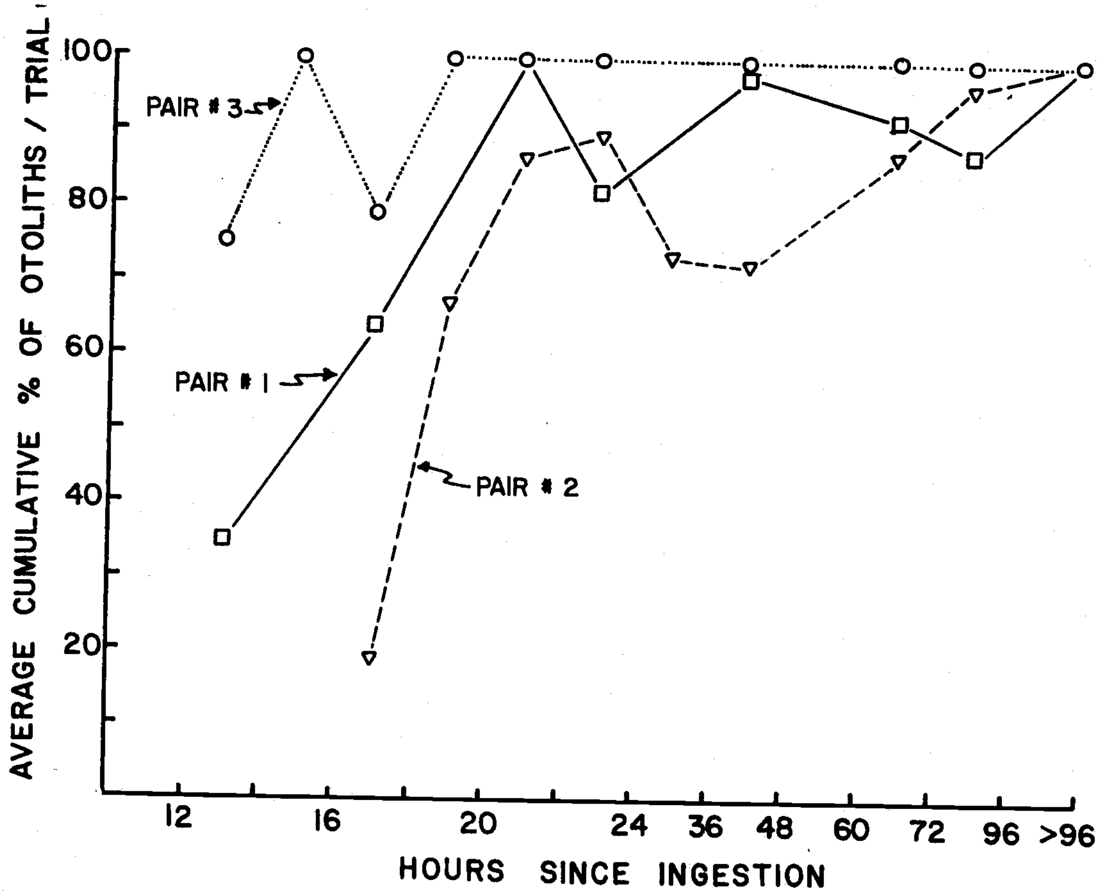

Fig. 9.--Average cumulative percent of otoliths recovered from feces of three pairs of harbor seals since the time of fish ingestion.

alascanus were recovered in feces 12.5 h after these fish were eaten.

Location of otolith digestion.--Twenty-seven of 29 harbor seals collected in gill nets had at least one otolith in the digestive tract. Although these harbor seals contained otoliths representing other species of fishes, eulachon otoliths comprised greater than 97.4% of the total number collected. In determining the location and degree of digestion within the alimentary canal, only eulachon otoliths were considered.

There was no significant difference in the number of otoliths collected among the stomach, small intestine, and colon of harbor seals ($X^2 = 6.85$, $P > 0.01$). There was no significant difference in average length of eulachon otoliths collected in these three regions of the alimentary canal ($F = 1.43$, $P > 0.01$). In addition, the frequency distributions of otolith length were identical for these three regions (Fig. 10). The weight of eulachon otoliths found in in the lower regions (small intestines and colon) was significantly less than the weight of otoliths found in the stomach ($F = 5.24$, $P < 0.01$).

DISCUSSION

Estimated number of prey recovered.--There have been no past studies of otolith digestion in pinnipeds that are

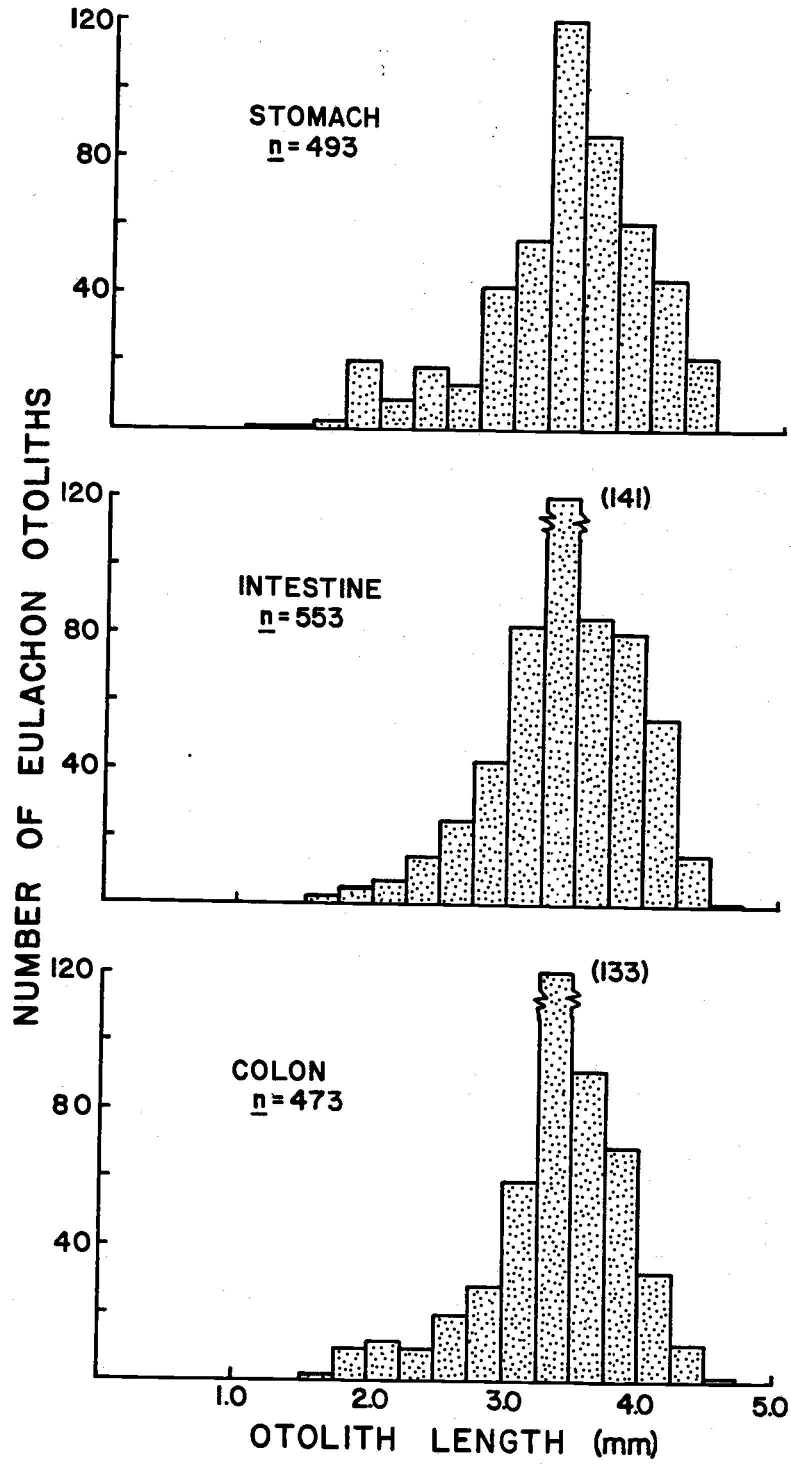

Fig. 10.--Frequency distribution of eulachon (Thaleichthys pacificus) otolith lengths collected from the stomach, small intestine, and colon of 27 harbor seals in the Columbia River.

comparable in methodology to the present study. Investigators have confined pinnipeds to small, dry enclosures to facilitate collection of feces, and reported that most fish otoliths ingested by pinnipeds were digested completely. Hawes (1983) fed northern anchovy (Engraulis mordax), jack mackerel (Trachurus symmetricus), and Pacific mackerel (Scomber japonicus) to a 1.5-year-old California sea lion (Zalophus californianus), and recovered only 6, 35, and 18%, respectively, of the otoliths in the feces. In a similar study, three length-classes of herring were fed to one captive harbor seal; otoliths from only the largest size class (30-35 mm TL) were recovered (da Silva and Neilson, 1985). Although the seal ingested an average of 15, 30.5, and 90 otoliths per feeding for each of the three size classes of fish, respectively, only two otoliths were recovered. I found recovery rates of otoliths for most species of prey to be greater than reported in these studies. Pinnipeds that are relatively inactive in enclosures, may have reduced passage rates of material through the digestive system, therefore increased digestion of otoliths (Grunewald and Tucker, 1985; Hellebrandt and Tepper, 1934). In preliminary experiments I found passage rates of otoliths were greater when harbor seals were confined to a small (2 by 2 m) dry enclosure, rather than the large water-filled tank. This is corroborated by studies of Murie and Lavigne

(1986), in which they estimated 57 - 82% of C. harengus otoliths were undigested by free-swimming phocid seals, although this is based on examinations of stomach and intestinal contents, and not feces.

Differences in percent of otoliths recovered among studies may be explained partially by considering the species of fish used as prey. In the present study, only 32.5% of C. harengus otoliths were recovered in feces, probably because they are relatively thin, and more likely to be completely digested. The low percentage of otoliths recovered by Hawes (1983) and da Silva and Neilson (1985), therefore, is a function of the greater susceptibility of C. harengus and E. mordax otoliths to complete digestion and relative inactivity of the animals. Their findings are probably not indicative of recovery rates for all prey species of harbor seals.

Estimated size of prey eaten.--Assessing the effects of pinniped gastric fluids on the digestion of otoliths can be divided into in vivo experiments, involving captive animals (da Silva and Neilson, 1985), and in vitro laboratory experiments on otoliths (Hawes, 1983; Jobling and Breiby, 1986; McMahon and Tash, 1979). The lengths of the two C. harengus otoliths recovered (4% of the total fed) by da Silva and Neilson (1985) were reduced by 26.% and 12.9%, respectively. North et al. (1983) made a subjective assumption that there was a 20% loss in length of fish otoliths collected from Antarctic fur seal (Arctocephalus gazella) feces in South Georgia by comparing sizes of otoliths collected in feces with otoliths from fresh fish.

McMahon and Tash (1979) immersed otoliths of green sunfish (Lepomis cyanellus) in a 0.01N HCl (pH of 2.0 to 2.5) acid solution, and found they were identifiable to species after 12 h, but completely dissolved after 24 h. Hawes (1983) reported that 28% and 12% of the length of C. harengus and T. symmetricus otoliths, respectively, were digested after 9 h in a 1.8 pH solution of HCL acid. Complete digestion occurred in 11 and 15 h for C. harengus and T. symmetricus, respectively. L. opalescens beaks never decreased in size. Otoliths from Melanogrammus aeglefinus and C. harengus dissolved at a rate of 0.17 and 0.37 mm/h, respectively, in a solution of HCL with a pH of 1.09 (Jobling and Breiby, 1986).

Fish lengths were underestimated by an average of 27.5%; although variable among species, there were no significant differences. Generally, larger, more robust otoliths were less digested than smaller, thinner otoliths. Correspondingly, the estimated size of those fish with large otoliths, based upon length of otoliths from feces, more accurately represented the actual size of the fish fed to seals. Squid beaks did not significantly decrease in size, and therefore can be used to reliably estimate the size of cephalopod eaten by harbor seals.

Otolith passage rates.--Helm (1984) reported an initial defecation time, measured by the first appearance of dye in the feces, of 5 h for two harbor seal pups. These results are similar to the 6 h reported by Havinga (1933) in a comparable study. These rapid movements of material through the digestive tract are unique considering the great length of the intestinal tract of pinnipeds (Helm, 1983), but both involved studies of immature individuals and passage of liquid material, both of which would produce greater passage rates.

Otoliths were absent from stomachs of captive phocid seals killed 12.4 h after feeding, and first appeared in the colon after 8.9 h (Murie and Lavigne, 1986). These seals were allowed to swim normally before being killed, but were starved for 24 h before feeding.

Based on the average cumulative percent of otoliths recovered for all trials, I concluded that over 90% of otoliths were excreted within 24 h, and otoliths that apparently remained in the alimentary tract for greater than 3 days likely were retained in the small intestine and colon before being excreted. If otoliths had remained in the stomach for over 13 h, they probably would have been digested completely. Otoliths from feces, therefore represent fish eaten within the last day, however, approximately 10% may have been eaten before this time.

Factors affecting otolith digestion and passage.--The hypothesis, that there is no difference between the number and size of fish eaten by seals and the number and size of fish estimated from otoliths recovered in feces, was refuted in the present study. Most otoliths are partially or completely digested. The amount of otolith digestion is dependent upon such internal factors as: the amount and acidity of gastric fluids, rate of gastric emptying (i.e. time required for stomach contents to pass into the small intestine), and movement of otoliths through the stomach. Increased exercise may accelerate gastric emptying, as I have observed with harbor seals in containers (Hellebrandt and Tepper, 1934; Grunewald and Tucker, 1985). Secondary factors that may influence otolith digestion are age and size of animal and ambient temperature.

Complete digestion of otoliths is most likely the result of prolonged exposure to acidic solutions, a consequence of decreased gastric emptying or otolith retention in the stomach. Most otolith digestion occurs in the acidic solution of the stomach. Otoliths are not dissolved further in the digestive tract because sodium bicarbonate neutralizes the acids at the beginning of the small intestine (Guyton, 1981). This is supported in my study by the equal size of eulachon otoliths removed from the stomach, small intestine, and colon of harbor seals. Similarly, Frost and Lowry (1980) found no difference between lengths of otoliths collected in stomachs and intestines of ribbon seals (*Phoca fasciata*). Murie and Lavigne (1986) fed herring to 13 captive seals (10 grey seals (*Halichoerus grypus*), 2 harp seals (*P. groenlandica*), and 1 ringed seal (*P. hispida*), and found 100% of otoliths in the stomachs of those animals killed within 3 h of feeding; no otoliths were collected in the stomachs 12.4 h after feeding. The time required for gastric emptying, up to 13 h in some cases, is an important factor which affects both size and number of otoliths recovered in feces.

Estimates of species, number, and size of prey can be obtained by collecting hard parts of prey in pinniped feces. In most cases, the number and size of prey would be underestimated unless these biases were assessed. Experiments with other pinniped species are needed if their food habits are determined from fecal samples.

CHAPTER 5

MOVEMENTS AND DIVE PATTERNS OF RADIO-TAGGED HARBOR SEALS, *PHOCA VITULINA*, IN OREGON.

For many years, researchers of harbor-seal biology and behavior have confined their observations to those times when the animals were ashore (Knudston, 1974; Sullivan, 1980; Terhune, 1985). Some information on individual movements and waterborne behaviors could be inferred from trends in estimates of abundance and collection of individuals. These types of data, however, are difficult to collect on free-ranging individuals.

Recent advances in radio-telemetry and attachment methodology provided the opportunity to monitor activities of individual harbor seals for long periods (Brown and Harvey, 1981; Fedak et al., 1982). Although movements of harbor seals were inferred based on locating individuals ashore with radio-tags attached to their ankles (Beach et al., 1985; Brown and Mate, 1983; Pitcher and McAllister, 1981) and for untagged seals near land (Allen, 1985), there have been no studies of their daily activities in water.

The objectives of this study were: (1) to determine dive characteristics of harbor seals in the nearshore environment, (2) to determine patterns in daily activity, and (3) to determine local and regional movements of tagged seals along the Oregon coast.

It was hypothesized that dive duration would be greater when harbor seals were in the deeper, offshore water than when they were active in shallow bays. It also was hypothesized that all tagged harbor seals would rest on land during each low tide.

METHODS

Harbor seals were captured in the water adjacent to haul-out sites in Yaquina, Alsea, and Coos bays, Oregon using a 24- by 12-m net with 20- or 35-cm stretch meshing (Brown and Mate, 1983). Radio tags were attached to the pelage on the posterior portion of the head of 28 harbor seals using an epoxy adhesive (Fedak et al., 1982). Each radio tag operated on a different frequency (148 - 150 MHz), and the attachment and radio-tag were designed to operate for 9 - 12 months.

Activities of seven radio-tagged individuals were monitored from land for various periods between 1983 and 1985. Placement of the radio tag on the head provided a strong and reliable signal each time the animal surfaced to breathe. Radio signals could be monitored to 8 km when receivers were on land, and to 13 km when receivers were in aircraft. Duration of each surfacing and dive were recorded to the nearest 1 s using a digital watch. Dive durations were limited arbitrarily to greater than 5 s because this eliminated brief artificial dives that were actually interruptions in the signals while the animal was still at the surface (e.g. water breaking over the antenna, head tilted backwards with antenna in water). Alterations of data because of this constraint on dive duration were performed on only 10 (0.6%) dives, and this did not influence results greatly. Tagged harbor seals may have occasionally surfaced without detection, although this probably happened infrequently.

During 95 surveys to count harbor seals along the central Oregon coast (Siletz Bay - Strawberry Hill), radio-tagged harbor seals were identified and located using a receiving system in an automobile. Twenty-two flights were conducted along the entire Oregon coast to locate radio-tagged harbor seals. A receiver connected to a strut-mounted yagi antenna was monitored continuously for radio-tag frequencies throughout the flights. The location, time, position of the harbor seal (i.e. on land or in water), and weather conditions were noted when each tagged individual was located.

RESULTS

Mean duration of dives for individual harbor seals ranged from 0.97 min (58 s;SD=0.68) to 3.1 min (SD=1.80; Table 8). The maximum recorded dive was 11.35 min.; three seals had at least one dive in excess of 10 min. There were significant differences in average duration of dives among seals (F = 10.2 , P < 0.01). Most dives recorded were less than 1 min. Aside from dives of less than 1 min duration, seal 488 had 138 (dives of 5.5 - 10.5 min, whereas seal 880, had 69% of longer dives between 1 and 5.5 min (Fig. 11). Seal 383 appeared to have a frequency distribution of dive durations intermediate to seals 488 and 880. There was no significant difference in mean dive time for seal 488 between bay and ocean activities (Mann-Whitney U test, P > 0.05).

Average duration of surfacings for different tagged harbor seals ranged from 0.34 min (SD = 0.15) to 0.6 min (SD = 0.45). Duration of surfacings generally were 30 - 40 s, and there were no significant differences in duration of surfacings among seals (P > 0.01).

Three harbor seals (383, 880, and 488) were tracked continuously for 20, 20, and 24 h, respectively. These harbor seals spent 10 - 19% of time resting onshore; the remainder of time was spent in water. These three harbor

Table 8.--Mean ($\overline{X}$), standard deviation (SD), and maximum duration of dives and surface activity (in min) for seven harbor seals radio-tagged in Oregon, 1983 - 1985. *n* is number of dives and surfacings.

	Seal identification						
	383	488	600	620	720	880	808
Dive (min)							
n	213	561	42	83	122	574	51
$\overline{X}$	2.66	3.04	3.10	2.31	1.39	2.55	0.97
SD	1.88	2.46	1.80	1.84	1.17	1.76	0.68
maximum	11.35	10.41	7.35	7.35	4.6	10.90	1.98
Surface (min)							
n	216	568	45	88	127	601	51
$\overline{X}$	0.60	0.41	0.36	0.36	0.37	0.39	0.57
SD	0.45	0.34	0.15	0.30	0.28	0.32	0.32
maximum	2.65	3.65	0.78	1.83	1.23	3.75	1.13

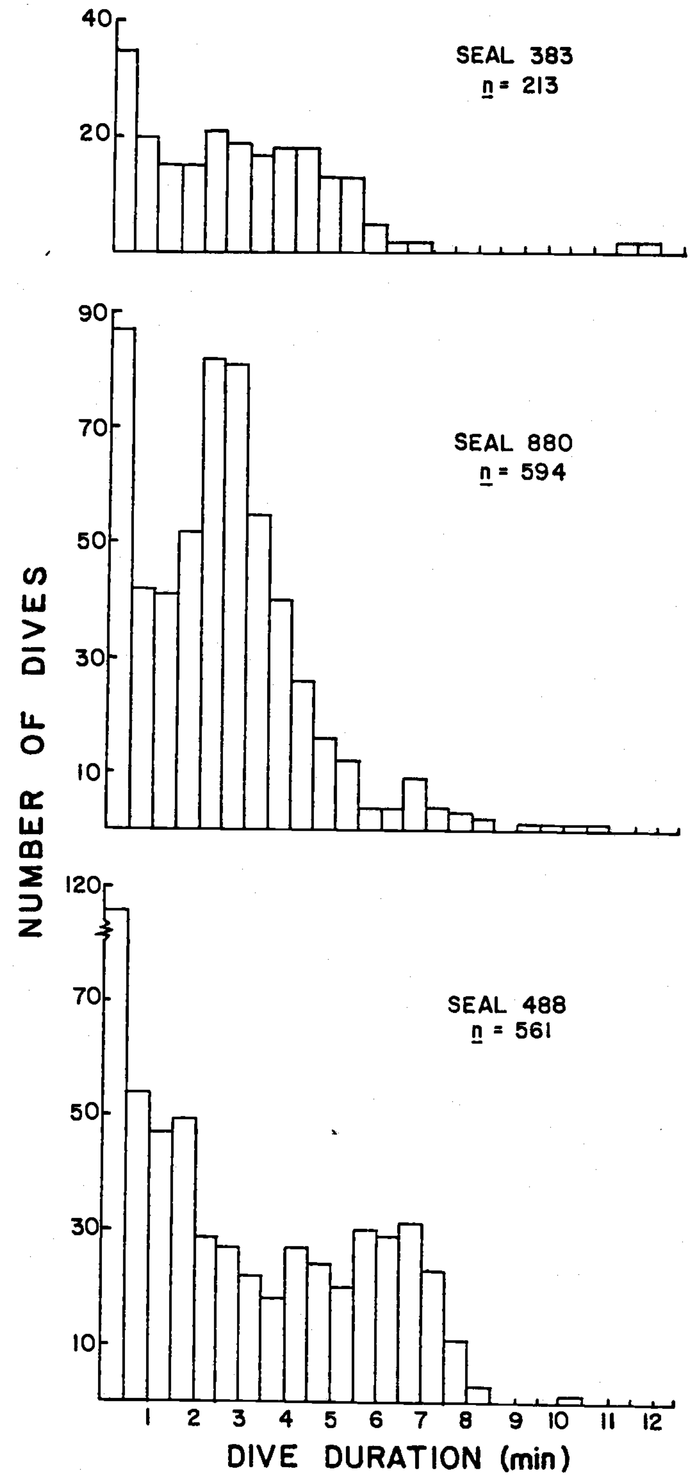

Fig. 11.--Frequency histogram of dive duration for three radio-tagged harbor seals in Oregon.

seals spent 50, 70, and 100% of time in the bay in which they were tagged; sometimes moving 9 km up the estuary.

Twenty-four of 26 seals radio-tagged since 1983 were located at least once after their release; three were never found. Relocated harbor seals were found near the release site (within 8 km) an average of 92% of the time. Thirteen seals always were found within 8 km of where they were released (Table 9). Individuals moved as far as 280 km north to Grays Harbor, Washington, and 250 km south to Rogue Reef, Oregon (Fig. 12). Although this sample contained only four males, there appeared to be no propensity for a particular sex to move greater distances.

DISCUSSION

Harbor seals have remained underwater for 28 min during forced dives (Scholander, 1940). Because these seals were forced to dive until they struggled, natural dives in the wild were not expected to last as long. Recent physiological studies (Hochachka, 1981) suggest that the longer dives of 10 - 11 min by Oregon harbor seals are within their aerobic capabilities.

Radio-tagged harbor seals were in shallow bays throughout most of time they were monitored, and dives were of short duration. Duration of dives was not significantly greater when seal 488 was in the ocean,

Table 9.--Date, location, sex, and weight of 27 harbor seals captured and radio-tagged in Oregon, 1983-1985; number of times the animals were located after tagging, in and outside the vicinity of the release site (within 8 km); and percent of times the seals were located within the region of the release.

					NO. TIMES LOCATED			
SEAL	DATE	LOCATION	SEX	WT(kg)	TOTAL	IN	OUT	%IN
600	7/83	Yaquina	F	----	2	2	0	100
620	7/83	Yaquina	F	----	4	4	0	100
720	7/83	Yaquina	M	63.0	10	9	1	90
880	7/83	Yaquina	F	75.0	26	18	8	69
211	8/84	Yaquina	M	93.5	9	9	0	100
241	8/84	Alsea	M	116.0	20	13	7	65
262	8/84	Alsea	F	93.5	32	31	1	97
302	10/84	Alsea	M	52.5	0	0	0	---
322	8/84	Alsea	F	99.0	22	22	0	100
343	8/84	Yaquina	F	67.0	40	39	1	98
363	8/84	Alsea	F	43.5	45	41	4	91
383	8/84	Yaquina	F	77.0	40	40	0	100
402	8/84	Yaquina	F	----	14	12	2	86
422	8/84	Yaquina	F	68.7	39	39	0	100
441	8/84	Alsea	F	80.5	18	16	2	89
057	4/85	Alsea	F	120.5	0	0	0	---
154	4/85	Alsea	F	71.5	2	0	2	0
168	4/85	Alsea	F	106.0	3	3	0	100
532	4/85	Alsea	F*	93.0	16	16	0	100
560	4/85	Alsea	F	87.5	5	4	1	80
698	4/85	Alsea	F	79.0	5	3	2	60
720	4/85	Alsea	F*	91.5	12	9	3	75
730	4/85	Alsea	F	90.0	11	11	0	100
752	4/85	Alsea	F	99.0	10	10	0	100
772	4/85	Alsea	F*	81.0	19	19	0	100
488	7/85	Coos	F	63.0	22	22	0	100
808	7/85	Coos	F	70.0	11	11	0	100

* female seen with pup

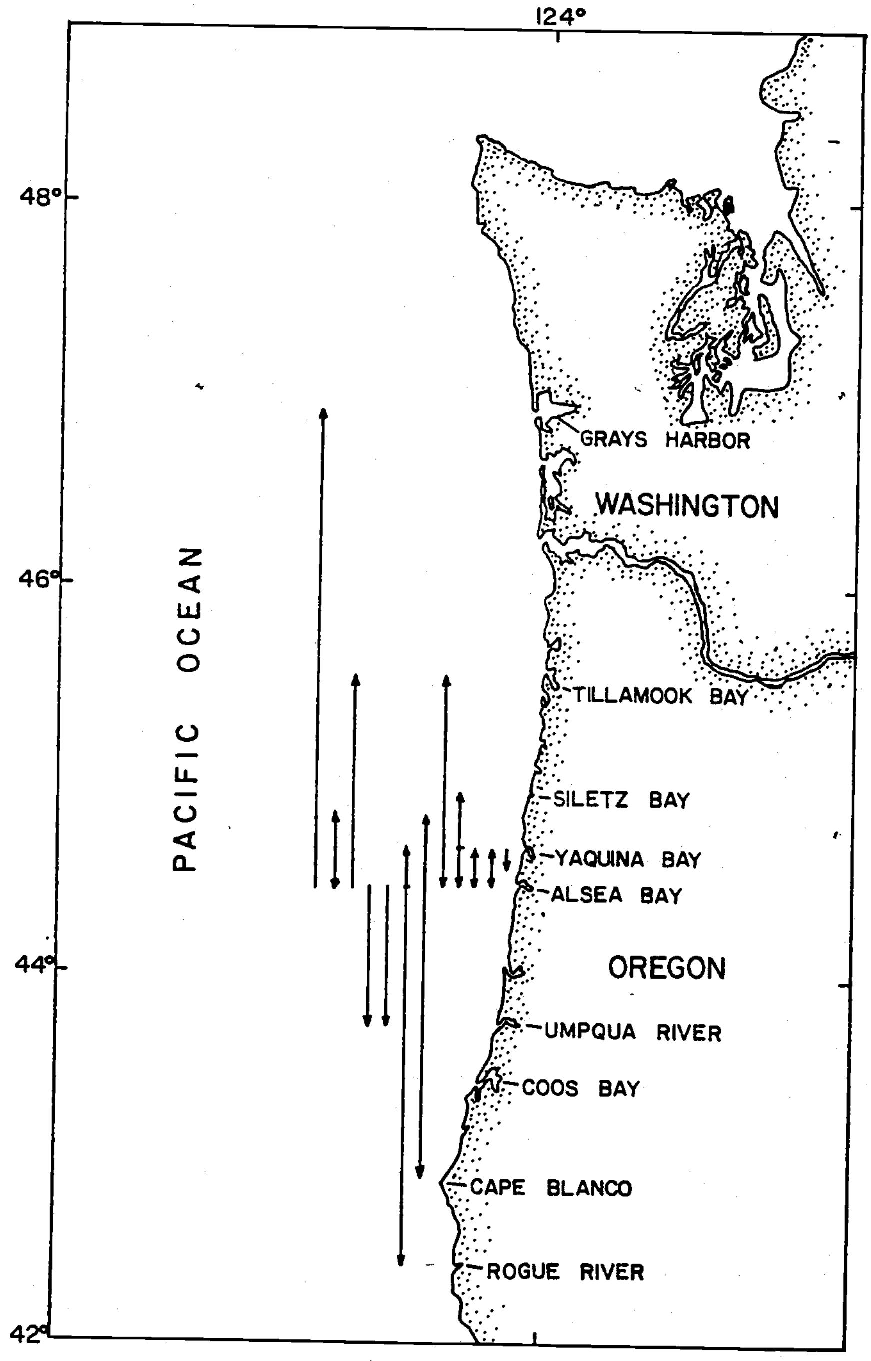

Fig. 12.--Movements of 12 radio-tagged harbor seals in Oregon and Washington. Harbor seals were tagged in Yaquina and Alsea Bays, and moved in 1 direction (one-ended arrow) or in 2 directions (two-ended arrow).

however, so depth may not be responsible for duration of harbor seal dives. Depth and duration of dives during feeding is probably related to the behavior and location of prey. Harbor seals in Oregon consume primarily benthic fishes and small schooling fishes (Brown and Mate, 1983; Graybill 1981). Harbor seals, generally found within 5 km of shore (Wahl, 1977), would be in water no deeper than 60 - 80 m. Harbor seals probably do not dive to great depths; therefore, the duration of their dives is generally less than 11 min.

Tagged harbor seals rarely rested on land during the time their activities were monitored. This is in contrast to the findings of Sullivan (1979) who reported harbor seals along the open California coast spent 44% of time on land. Sullivan (1979), however, visually located harbor seals, and did not follow their movements away from the haul-out site or at night.

Long-distance movements of tagged harbor seals have been reported by Bonner and Witthames (1974) who found juvenile harbor seals as far as 250 km from the tagging site in the Wash, East Anglia, England. Boulva and McLaren (1979) reported movements of three pups from Sable Island onto Nova Scotia, a minimum distance of 190 km. Harbor seals have been reported to move 194 km along the coast of Kodiak Island, Alaska (Pitcher and McAllister, 1981). Seals tagged in Netarts and Tillamook Bays, were located as far as 220 km south of where they were tagged (Brown and Mate, 1983). Seventy-five percent of the resightings of radio-tagged harbor seals were outside the release site in the Columbia River, and one was 300 km to the south (Beach et al., 1985). These reports are of harbor seals tagged such that the animal had to be visually inspected or on land to be identified, which may overemphasize long-distance movements. Radio-tagged individuals, in the present study, may have been located primarily near the capture site because they could be located in water. Other studies may have also reported only long-distance movements because they were most noteworthy.

Harbor seals using the nearshore environment in Oregon make dives of short duration compared to many other pinnipeds. Because they feed in relatively shallow water on relatively slow-moving prey, and because they are relatively small pinnipeds this species probably has not evolved the capacity for extended apnea.

Three types of harbor-seal movements were indicated by relocating tagged harbor seals in Oregon. A few individuals moved some distance (>8 km) from the tagging site, and appeared to become residents in that area. Other harbor seals moved in and out of the estuary in which they were tagged, but remained within 8 km of this location. Many (46%) individuals were never located outside the estuary where they were tagged. Possibly individual harbor seals have different home ranges, but a larger sample size of males and females, and year-long tracking is required to answer this question.

CHAPTER 6

ANNUAL FISH CONSUMPTION BY HARBOR SEALS IN OREGON.

Harbor seals, Phoca vitulina, are somewhat controversial because they feed on fish and squid species eaten by human beings. They become entangled in nets and cause damage to fishermen's gear and catch, and feed upon returning hatchery salmon (Beach et al., 1985; Brown and Mate, 1983; Contos, 1982; Fiscus, 1980; Hirose, 1977; Mate, 1980; Puustinen, 1975). The focus of many recent studies was to assess damage to catch and gear, and impact of harbor seals predation on salmon stocks. Both dollar value and numbers of salmon caught, however, has decreased in recent years in Oregon (Lukas and Carter, 1985). Commercial fishermen now catch species of fishes and squid (Loligo opalescens) that were not commercially valuable before. Many of these fishes and cephalopods also are prey of harbor seals. As a result, harbor seals may compete with man for the same fish and squid species, and the effects may reduce fishery catches and affect harbor-seal populations.

The objectives of this study were to: (1) determine size, number, and biomass of individual prey of each species eaten by harbor seals in Oregon, (2) determine if there are seasonal or regional differences in prey selection, and (3) compare estimates of annual consumption of prey biomass with commercial catches and estimates of natural mortality.

Harbor seals are considered to be opportunistic predators, feeding principally on benthic and schooling fishes. They eat primarily fishes in the families Clupeidae, Embiotocidae, Gadidae, Pleuronectidae, Bothidae, Scorpaenidae, Osmeridae, Salmonidae, cephalopods (*Octopus* sp. and *L. opalescens*), and crustaceans (Imler and Sarber, 1947; Jones, 1981; Kenyon, 1965; Morejohn et al., 1978; Pitcher, 1980a; Scheffer and Sperry, 1931; Spalding, 1964; Wilke, 1957).

In four studies of food habits of harbor seals in Oregon (Beach et al., 1985; Brown and Mate, 1983; Graybill, 1981; Roffe and Mate, 1984), investigators used fish otoliths and cephalopod beaks from fecal samples to identify and enumerate prey taxa. Roffe and Mate (1984) also reported stomach contents from collected individuals. In addition, Brown and Mate (1983) used measurements of otoliths to estimate lengths of some fish species eaten by harbor seals. These studies contributed to our understanding of types of marine organisms eaten by harbor seals. Until now, there has been no attempt to quantify effects of harbor seal feeding on fish populations in Oregon. In this study I used otoliths collected in previous studies, recent information on digestion of otoliths from this dissertation, and energetic requirements of harbor seals to estimate annual consumption of number and biomass of fish in Oregon. A portion of natural mortality of some fish species may determined directly, using estimates of harbor seals predation. Effects of a possibly increasing numbers of seals on fisheries resources, and alternately, effects of increased fishing effort on harbor-seal populations may be predicted based on calculations such as these. A model of the effects of harbor-seal predation on nektonic prey also is needed for evaluating the deficiencies of available data.

METHODS

The estimated annual biomass of prey species consumed by harbor seals in Oregon during 1980 was determined using the following generalized equation:

EBC = ABUNDANCE X SIZE X ENERGETICS X PREY SELECTION,

where EBC is the estimated biomass of a prey species consumed by harbor seals annually, ABUNDANCE is the number of harbor seals in Oregon, SIZE is the size distribution of harbor seals in the state, ENERGETICS is the daily food requirement for a seal of a specific size, and PREY SELECTION is the proportion and size of a particular prey species eaten by harbor seals in Oregon.

Food consumption was estimated for 1980 because most dietary information was collected within two years of this time, a count of harbor seals was made for the entire state during this year, and there were data on landings and population size for some species of fishes in this year.

Abundance.--Harbor seal abundance in Oregon was estimated from an aerial count of harbor seals on land during July, 1980. The number of harbor seals was determined for four regions: Columbia River (Columbia River), north coast (Tillamook Head to Strawberry Hill), south coast (Siuslaw River to Island Rock), and the Rogue River area (Hubbard Mound Reef to Hunter's Island; Fig. 1). These regions were chosen because studies of harbor-seal diets were conducted in the center of each region, and food habits of harbor seals were different among regions.

Counts of harbor seals on land underestimate the actual abundance by 2 - 14 times, based on population studies with radio-tagged harbor seals presented in Chapter 3. I used two times the 1980 statewide count of 2,517 individuals, or 5,034 harbor seals, as a conservative estimate of numbers.

Size of harbor seals.--The size distribution and sex of harbor seals in Oregon were estimated from collections of individuals captured during tagging studies along the

Oregon coast. Weight, to the nearest 0.5 kg, was determined by suspending the seal in a bag of netting from a scale attached to a tripod. The weight of the netting was subtracted from the total. Standard length and girth were determined to the nearest 1 cm (Committee on Marine Mammals, 1967).

Length/weight relationships were based on a linear regression of logarithm of standard length versus weight. Male and female length/weight relationships were compared using a *t*-test of slope and intercept of the linear regression. The proportion of seals within a 5 kg weight class ($PROPWT_i$) was calculated as:

$$PROPWT_i = NWT_i \ / \ TOTNWT, \qquad (1)$$

where NWT is the number of seals in the ith weight class, and TOTNWT is the total number of seals weighed.

The weight distribution of captured seals was assumed to be representative of the statewide population. Total weight of harbor seals in a region ($TOTWT_r$), was estimated as sum of weight distribution multiplied by regional abundance as follows:

$$TOTWT_r = \sum (N_r)(PROPWT_i). \qquad (2)$$

where N_r is number of harbor seals in rth region.

These figures were used with estimates of energetic requirements to calculate biomass of fishes consumed.

Food requirements of harbor seals.--Equations used to calculate food consumption were those reported by Innes et al. (1987) for phocid seals. Food consumption was estimated for phocis seals maintained at basal levels of metabolic rate. These equations are based on data collected Because Innes et al. (1987) reported a significant difference in biomass consumed between juveniles and adults, and between growing and non-growing adults, food consumption was calculated separately for each group. In the following calculations, juvenile, male harbor seals are those <70 kg; growing, adult males are 70 - 90 kg; and non-growing, adult males are >90 kg. Juvenile, females are assumed to be <55 kg, growing, adult females 55 - 90 kg, and non-growing, adult females are >90 kg. These classifications are based on growth data from Pitcher and Calkins (1979) and Boulva and McLaren (1979). A 50:50 ratio of males to females was assumed for harbor seals in Oregon, and was consistent with the sex ratio of captured seals.

The biomass of food consumed (kg) was estimated using the following set of equations from Innes et al. (1987):

$$IB=0.068M^{0.78} \text{ (juveniles)}, \quad (3)$$

$$IB=0.0547M^{0.84} \text{ (growing adults)}, \quad (4)$$

$$IB=0.068M^{0.78} \text{ (non-growing adults)}, \quad (5)$$

where IB is daily ingested biomass and M is mass of seal in kg. The ingested biomass was calculated using the average mass of seal in a weight class (5 kg intervals). For example, the biomass ingested a harbor seal in the weight class 40 - 45 kg would be: $0.068 \times 42.5^{0.78} = 1.27$ kg/day.

Innes et al. (1987) proposed that average daily metabolic rate for pinnipeds was 1.5 to 3.0 times the basic metabolic rate. Sullivan (1979) reported adult harbor seals in northern California spent 56% of time in water, whereas subadult spent 60%, and pups 70%. In Oregon, tagged harbor seals, monitored for 24-h periods, were in water 80-90% of the time. As a conservative estimate, I assumed that harbor seals were in the water or active for 50% of the day. The estimates of ingested biomass therefore were multiplied by 1.5, which provided for a doubling of food requirements for 50% of the diel period.

The total biomass consumed within a region (BC_r) was calculated as:

$$BC_r = \sum (NWT_i)(IB_i)(1.5). \qquad (6)$$

Number and size of prey consumed by harbor seals.--Species and relative abundance of prey eaten by harbor seals in Oregon were obtained from studies by Roffe and Mate (1984), Graybill (1981), Brown and Mate (1983), and Beach et al. (1985). Between 1976 and 1982, fecal samples were collected on harbor-seal haul-out sites in the Columbia River (Beach et al., 1985), Tillamook and Netarts Bays (Brown and Mate, 1983), Coos Bay (Graybill, 1981), and Rogue River (Roffe and Mate, 1984). Otoliths were removed from the feces, and identified to the lowest taxa by the late J. Fitch (California Dept. Fish Game).

For each region, number of each prey species eaten was estimated using a correction factor based on the mean rate of recovery of otoliths from experiments with captive harbor seals. There was a significant difference in rates of recovery of otoliths from different species of fishes, and number of fish consumed was corrected as follows:

$$CF_i = 100 / \%REC_i, \qquad (7)$$

where CF is the correction factor for the ith species, and %REC is the mean percent of otoliths of the ith fish species recovered in experiments with captive harbor seals. For example, an average of 32.5% of _C. harengus_ otoliths were recovered in feces of captive harbor seals. The correction factor for this fish species therefore is 3.08 (i.e. 100/32.5). An estimate of number of fish consumed of a certain species (ENSP) is determined as:

$$ENSP_i = (NSP_i)(CF_i), \qquad (8)$$

where NSP is the greatest number of left or right otoliths of the ith species of fish in one of four regions of Oregon. If a regional sample of feces contained 35 otoliths of _C. harengus_ (25 left and 10 right), then the estimated number eaten would be 77 (i.e. 25 X 3.08).

The length of fish was determined by measuring fish otoliths collected in the aforementioned studies and entering otolith measurements into a linear regression of otolith length or weight to fish length. Otolith lengths, to the nearest 0.1 mm, were measured from the rostrum to the posterior edge, parallel to the sulcus, using a caliper and viewing under a dissecting microscope. Otoliths were weighed to the nearest 1 mg on a Mettler balance. Otolith length and weight/fish length relationships were determined by measuring otoliths from fresh fish. Fish standard length to the nearest 0.1 cm and mass to the nearest 0.01 g were determined. The length and mass of otolith were entered into a regression model, with standard length as the dependent variable. The significance of the relationship was determined using a _t_-test of slope (Snedecor and Cochran, 1980).

To compensate for digestion of otoliths recovered from feces, estimated length of each otolith was increased using a correction factor of 27.5%, as determined from experiments with captive harbor seals. Estimates of otolith length (EOL) were obtained using the following equation:

$$EOL = 1.275 \times (OL) \quad (9)$$

where OL is otolith length in mm. For example, a 3.0 mm otolith from _C. harengus_ collected in feces was estimated to have been 3.82 mm (1.275 X 3.0 mm) when eaten by harbor seals. Estimates of otolith length were used in the regression equations of otolith length/fish length, and standard length of each fish consumed was estimated.

The weight of each prey species was estimated from a length/weight relationship reported in the literature or developed in this study. Standard length of fresh fishes were measured to the nearest 1 mm, and weighed on a Mettler balance to the nearest 0.1 g. A weight/length relationship (i.e. $WT = aSL^b$) was calculated based on a linear regression of the logarithm of length and weight, where WT is weight of fish, SL is standard length of fish, a = intercept and b = slope (Ricker, 1975). The mass of fish species was estimated if no otolith length/fish length relationship was obtained from collections or fish measurements by Bayer (1981), Beardsley (1969), Hart (1973), and Miller and Lea (1972).

In each region, the proportional weight of each prey species (PROPWTSP) was determined as:

$$PROPWTSP_i = (ENSP_i)(WTSP_i) \ / \sum([ENSP_i][WTSP_i]), \quad (10)$$

where $WTSP_i$ is weight of ith species. Regional estimates of the annual biomass (EBC_i) and number (ENC_i) consumed by harbor seals for each fish species were calculated as:

$$EBC_i = (BC_r)(PROPWTSP_i)(365), \text{ and} \quad (11)$$

$$ENC_i = (EBC_i)/WTSP_i. \quad (12)$$

<u>Assumptions for calculations of harbor seal fish consumption</u>.--Number of seals within a region was assumed

constant throughout the year. This may be valid for some regions (e.g. north and south coast) but invalid for others. Many harbor seals, especially pregnant females, are known to move from the Columbia River into adjacent estuaries along the Oregon and Washington coasts in the spring (Beach et al., 1985). Brown (1986) reported approximately 250 harbor seals in the Columbia River during spring 1984, and as many as 2,100 seals in the river during the winter of 1985. Because summer counts were used to estimate the proportion of seals in the area, the estimates of fish consumed by harbor seals in the Columbia River area are considered minimal. During winter, harbor seals in the Columbia River feed predominantly on *T. pacificus* (Beach et al., 1985). Estimates of the amount of fish consumed by harbor seals in the Columbia River region, especially with regards to *T. pacificus*, probably were underestimated.

The size distribution of harbor seals was derived from individuals captured in bays, and was assumed to be representative of harbor seals throughout Oregon. The sample of harbor seals weighed was 8.1% of the number of harbor seals counted in Oregon during 1980. Seals were captured throughout the year, although there was greater effort in summer and fall. If harbor seals of different sizes differentially use bay and offshore haul-out sites or larger individuals avoid capture, the size distribution used in the present study may not be representative. Individuals, marked with transmitters and visual tags, moved frequently and rapidly among bay and offshore haul-out sites (Chapter 5). The movement of some harbor seals tagged in estuaries to offshore haul-out sites indicates that individuals captured in bays are at least a sub-sample of the size distribution of harbor seals in Oregon. This does not rule out the possibility that some harbor seals remain offshore, and the size distribution of harbor seals caught in estuaries does not represent all harbor seals in Oregon.

The food habits of harbor seals were assumed to be similar from year to year. This may not be the case, as evident by the significant difference in the rankings of prey species among years in Coos Bay. Although the relative ranks, based on number of fish consumed, changed through the 4 years tested, the 15 most numerous prey species were always the same over this period. The total collection of all 4 years, therefore represents an average for that period, and is the best approximation of the species composition of prey for that region. These types of data were not available for other regions, and it was assumed that the fish species in the fecal samples were representative of the fishes consumed by seals over all years. Ichthyofaunal composition appears to have remained stable over time in Coos Bay (D. Varoujean, pers.comm.), and if this is true for other areas, prey composition of harbor seals has likely also remained constant.

Food habits of harbor seals, throughout the year, were assumed to be well represented by the collections of otoliths from feces. Most fecal samples used in this analysis, however, were collected during the summer. Prey species may change dramatically throughout the year, and size of prey may change significantly. Seasonal influxes of fish species into or through estuaries to spawn, such as C. harengus, A. hexapterus, T. pacificus, L. tridentatus, and salmonids, may provide sporadic food supplies, but sampling was inadequate to document this possibility. Harbor seals use offshore haul-out sites more frequently during winter, when fecal samples are more difficult to collect, therefore evidence of nearshore feeding was emphasized. Predation on estuarine fishes also may have been overemphasized if harbor seals that use estuarine haul-out sites are more inclined to eat in these areas than other individuals.

Additionally, fecal samples may not provide a true representation of harbor seal diet. The identification of prey, based on collected otoliths from feces, is dependent on harbor seals eating at least the heads of fish, otoliths passing through their digestive tracts, and otoliths being retained by the sieve. Consumption of some fish species may be underestimated if heads of fish are not eaten, otoliths are completely digested, or otoliths are too small and not retained by sieves. I compensated for the later two biases using correction factors derived from experiments with captive harbor seals, however the former bias was not assessed.

Given the number of assumptions required to estimate the biomass and number of fishes consumed by harbor seals in Oregon, these estimates should be regarded as minimum values. The harbor-seal population is probably larger than estimated. A correction factor of two used to correct aerial counts of harbor seals in 1980 was the lowest in a range of 2 - 14, based on behaviors of tagged individuals. Estimates of ingested biomass per day were based on the lowest level approximated for phocid seals (Innes et al., 1987). All three factors would minimize estimates of food consumption, although predation on specific species of fish may be overestimated because of the seasonal nature and biases associated with collecting harbor-seal feces.

RESULTS

Size of harbor seals.--Harbor seals captured in Oregon (n=214) averaged 126 cm (SD = 20.6, range = 77-177 cm) in length, 55.7 kg (SD = 26.3, range= 9.1-126.0 kg) in mass, and 96.0 cm (SD = 17.0, range = 61-141 cm) in girth. Males were slightly longer ($\bar{X}$ = 126.9 cm, SD = 22.9) than females ($\bar{X}$ = 125.4 cm, SD = 18.8), but females had an average mass ($\bar{X}$ = 56.5 kg, SD = 24.6) and girth ($\bar{X}$ = 98.3 cm, SD = 17.1) greater than males (Fig. 13). There was, however, no significant difference between the mass/length relationship of males and females (t = 0.05, P > 0.05); therefore, the following mass/length relationship was calculated for all harbor seals:

$$\text{mass} = 0.0000137\text{length}^{2.67} \quad (r^2 = 0.80).$$

Number and size of prey consumed by harbor seals.--Otolith length and weight/fish length relationships were determined for 34 species, and eight relationships were obtained from the literature (Table 10). These relationships were used to determine the length of 67.7% of the species and 96.3% of the individual fish represented by otoliths collected in feces.

There was a significant linear relationship between otolith length and mass, and fish length for most (91.2%) species (exceptions: *E. bison*, *P. simillimus*, and *T. symmetricus*; t-test of slope; P < 0.01). The coefficient of determination was greater than 0.80 for 58.8% of the species (Table 10). Otolith length was a better predictor of fish length for 23 (67.6%) of the species, and otolith mass provided a more reliable estimate of fish length for 22.4% of the species. All fish weight/length relationships were significant (P < 0.01), although for some species the sample size was small.

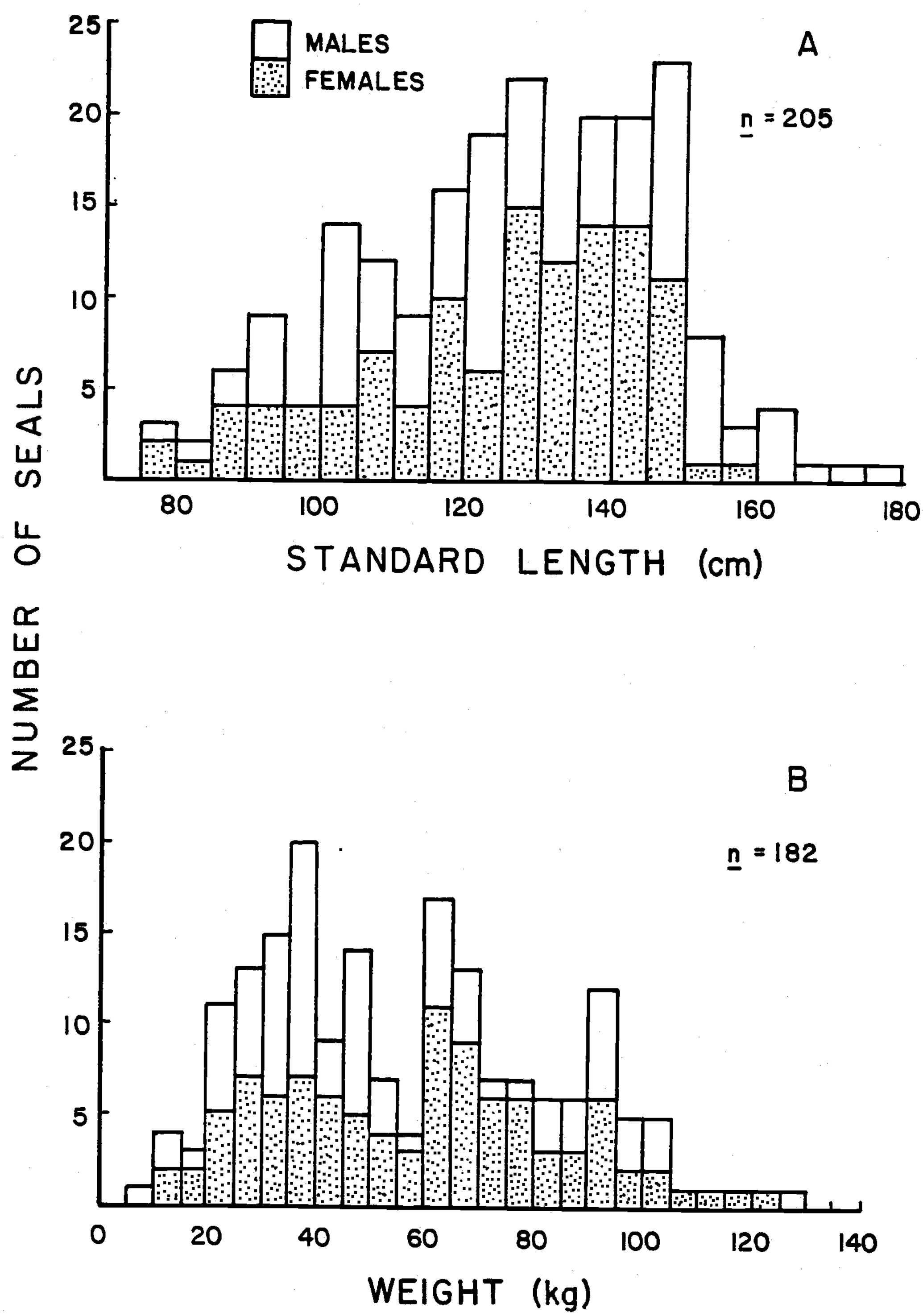

Fig. 13.--Frequency histograms of (A) standard length, and (B) weight of harbor seals in Oregon.

Table 10. Fish weight (g)/length (cm) relationship and linear relationship between otolith length (mm), both left (LOL) and right (ROL), or otolith weight (mg), both left (LOW) and right (ROW), and standard length (SL) for fish species found in harbor seal feces in Oregon. Fish species are listed in alphabetical order, and the scientific and common names are according to Robins et al. (1980). The coefficient of determination (r^2) and number of otoliths (n) used in the regressions are presented. Estimated mean weights of fish are given if an otolith regression was not used to estimate fish length and weight.

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
Allosmerus elongatus (whitebait smelt)	$WT=0.00627SL^{3.07}$	SL= 2.3(LOL)+ 2.6	23	0.82
		SL= 2.0(ROL)+ 3.2	23	0.80
	($\underline{n}$=25, $\underline{r}^2$=0.89)	SL= 9.5(LOW)+ 6.8	23	0.73
		SL= 8.2(ROW)+ 7.0	23	0.74
Alosa sapidissima (American shad)	$WT=0.00918SL^{3.16}$	SL=11.4(LOL)-11.2	8	0.88
		SL=10.3(ROL)- 7.4	7	0.85
	($\underline{n}$=6, $\underline{r}^2$=0.99)	SL=46.5(LOW)+15.3	7	0.81
		SL=49.3(ROW)+14.4	6	0.82
Ammodytes hexapterus (Pacific sand lance)	$WT=0.00625SL^{2.75}$	SL= 2.5(OL)+ 5.22[A]	8	0.98
	($\underline{n}$=10, $\underline{r}^2$=0.90)			
Amphistiichus rhodoterus (redtail surfperch)	$\overline{X}$ = 120.0g			
Anoplopoma fimbria (sablefish)	$WT=0.01626SL^{2.90}$	SL= 5.3(LOL)+ 1.3	79	0.96
		SL= 5.3(ROL)+ 1.3	79	0.96
	($\underline{n}$=74, $\underline{r}^2$=0.99)	SL=15.9(LOW)+14.1	78	0.93
		SL=16.0(ROW)+13.8	78	0.93

Table 10.-- (Cont.,p.2)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
Atheresthes stomias (arrowtooth flounder)	$WT=0.22490SL^{2.21}$ (n=4, r^2=0.90)	SL= 2.7(LOL)+11.2	4	0.92
		SL= 2.4(ROL)+14.2	4	0.70
		SL= 2.4(LOW)+24.3	4	0.96
		SL= 1.8(ROW)+22.9	4	0.93
Brachyistius frenatus (kelp surfperch)	$\bar{X}$ = 110.0g			
Brosmophycis marginata (red brotula)	$\bar{X}$ = 300.0g			
Chilara taylori (spotted cusk-eel)	$\bar{X}$ = 47.0g			
Chitonotus pugetensis (roughback sculpin)	$\bar{X}$ = 176.0g			
Citharichthys sordidus (Pacific sanddab)	$WT=0.00973SL^{3.12}$ (n=39, r^2=0.92)	SL= 3.4(LOL)+ 1.0	40	0.72
		SL= 3.5(ROL)- 0.2	43	0.76
		SL= 1.9(LOW)+11.6	40	0.76
		SL= 2.0(ROW)+11.7	43	0.73
Citharichthys stigmaeus (speckled sanddab)	$WT=8.12800SL^{0.26}$ (n=2, r^2=1.0)	SL= 3.2(LOL)- 0.3	5	0.96
		SL= 3.2(ROL)- 0.3	5	0.96
		SL= 8.6(LOW)+ 4.1	5	0.97
		SL= 9.3(ROW)+ 1.0	5	0.91

Table 10.--(Cont.,p.3)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
Clevelandia ios (arrow goby)	$\underline{X}$ = 2.0g			
Clupea harengus pallasi (Pacific herring)	$WT=0.02259SL^{2.81}$	SL= 5.3(LOL)- 1.8	30	0.78
		SL= 5.3(ROL)- 1.8	34	0.74
	(n=35, r^2=0.90)	SL=24.8(LOW)+ 9.8	27	0.81
		SL=22.8(ROW)+10.8	31	0.74
Coryphopterus nicholsi (blackeye goby)	$\underline{X}$ = 18.8g			
Cymatogaster aggregata (shiner perch)	$WT=0.01343SL^{3.39}$ (N=69, r^2=0.98)	SL= 1.7(LOL)- 0.5	69	0.96
		SL= 1.7(ROL)- 0.5	68	0.96
		SL= 2.2(LOW)+ 4.4	69	0.95
		SL= 2.2(ROW)+ 4.4	68	0.94
Damalichthys vacca (pile perch)	$WT=0.01524SL^{3.27}$ (N=19, r^2=0.99)	SL= 3.6(LOL)-10.6	18	0.90
		SL= 3.5(ROL)- 9.8	18	0.87
		SL= 1.4(LOW)+12.3	18	0.89
		SL= 1.4(ROW)+12.3	18	0.89
Embiotica lateralis (striped seaperch)	$WT=0.01675SL^{3.25}$ (N=9, r^2=1.0)	SL= 2.8(LOL)- 4.3	9	0.97
		SL= 2.8(ROL)- 4.2	9	0.97
		SL= 1.9(LOW)+ 7.0	9	0.88
		SL= 1.9(ROW)+ 7.1	9	0.88

Table 10.-- (Cont.,p.4)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
Engraulis mordax (northern anchovy)	$WT=0.00009SL^{3.00}$[B] (N=2,300)	SL= 3.3(OL)- 0.85[C]	121	0.88
Enophrys bison (buffalo sculpin)	$WT=0.014852SL^{3.36}$ (N=9, r^2=0.89)	SL= 0.7(LOL)+13.9	9	0.09
		SL= 0.6(ROL)+15.1	7	0.00
		SL= 1.9(LOW)+15.0	9	0.35
		SL= 1.2(ROW)+16.4	7	0.10
Eopsetta jordani (petrale sole)	$WT=0.01178SL^{3.14}$ (N=15, r^2=0.87)	SL= 4.1(LOL)+ 0.4	15	0.75
		SL= 4.1(ROL)+ 1.2	18	0.64
		SL= 2.4(LOW)+20.4	15	0.58
		SL= 2.7(ROW)+19.1	18	0.62
Gadus macrocephalus (Pacific cod)	$WT=0.00788SL^{3.10}$[D]	SL=13.5(OW)- 15.1[E]	23	0.93
Genyonemus lineatus (white croaker)	Mean=200.0g			
Glyptocephalus zachirus (rex sole)	$WT=0.00306SL^{3.34}$ (N=49, r^2=0.91)	SL= 4.4(LOL)- 0.3	49	0.68
		SL= 4.3(ROL)+ 0.5	46	0.66
		SL= 2.4(LOW)+13.1	49	0.77
		SL= 2.5(ROW)+12.9	46	0.74
Hemilepidotus sp. (Irish lord)	Mean=920.0g			

Table 10.--(Cont.,p.5)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
Hexagrammos decagrammus (kelp greenling)	$WT=0.02075SL^{3.00}$ ($N=8$, $r^2=0.98$)	SL= 7.4(LOL)- 8.4	8	0.66
		SL= 7.2(ROL)- 7.6	8	0.72
		SL=33.8(LOW)+ 7.7	8	0.77
		SL=34.1(ROW)+ 7.4	8	0.67
Hippoglossoides elassodon (flathead sole)	Mean=280.0g			
Hyperprosopon ellipticum (silver surfperch)	$WT=0.46240SL^{1.86}$ ($N=2$, $r^2=1.00$)	SL= 4.5(LOL)-12.7	2	1.00
		SL= 3.0(ROL)- 4.9	2	1.00
		SL= 7.5(LOL)- 3.4	2	1.00
		SL=-18.(ROW)+45.4	2	1.00
Hypomesus pretiosus (surf smelt)	$WT=0.00447SL^{3.34}$ ($N=41$, $r^2=0.99$)	SL= 3.8(LOL)- 1.4	21	0.96
		SL= 3.7(ROL)- 1.2	19	0.97
		SL=13.3(LOW)+ 6.3	21	0.87
		SL=13.7(ROW)+ 6.2	19	0.97
Icelus sp. (sculpin)	Mean=19.0g			
Isopsetta isolepis (butter sole)	Mean=111.2g	SL= 3.3(OL)- 0.53[A]	44	0.96
Lampetra tridentatus (Pacific lamprey)	Mean=270.0g			

Table 10.--(Cont.,p.6)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
Lepidogobius lepidus (bay goby)	Mean=18.0g			
Lepidopsetta bilineata (rock sole)	Mean=288.0g			
Leptocottus armatus (staghorn sculpin)	$WT=0.01107SL^{3.23}$ (N=30, r^2=0.99)	SL= 2.6(LOL)- 2.2	45	0.94
		SL= 2.6(ROL)- 2.4	43	0.95
		SL= 4.3(LOW)+ 5.4	44	0.95
		SL= 3.6(ROW)+ 6.3	42	0.90
Lumpenus sagitta (snake prickleback)	Mean=10.0g			
Lyopsetta exilis (slender sole)	$WT=0.00306SL^{3.55}$ (N=7, r^2=0.98)	SL= 5.0(OL)- 1.50[A]	47	0.96
Merluccius productus (Pacific hake)	$WT=0.00845SL^{2.96}$ (N=75, r^2=0.93)	SL= 2.0(LOL)+ 1.6	83	0.90
		SL= 1.9(ROL)+ 3.7	84	0.86
		SL= 0.8(LOW)+24.8	83	0.84
		SL= 0.7(ROW)+25.2	84	0.84
Microgadus proximus (Pacific tomcod)	$WT=0.00764SL^{3.13}$ (N=46, r^2=0.97)	SL= 1.7(LOL)- 2.9	45	0.95
		SL= 1.7(ROL)- 2.7	44	0.95
		SL= 0.8(LOW)+ 8.2	45	0.91
		SL= 0.8(ROW)+ 8.1	44	0.91

Table 10.--(Cont.,p.7)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
Microstomus pacificus (dover sole)	$WT=0.00800SL^{3.12}$ (N=51, r^2=0.90)	SL= 4.2(LOL)+ 3.8	63	0.69
		SL= 4.5(ROL)+ 2.8	67	0.65
		SL= 3.6(LOW)+18.1	63	0.75
		SL= 3.9(ROW)+17.6	67	0.77
Oncorhynchus kisutch (coho salmon)	$WT=0.01033SL^{3.09}$ (N=43, r^2=0.99)	SL=17.9(LOL)-47.2	39	0.52
		SL=16.9(ROL)-43.3	39	0.44
		SL=44.9(LOW)- 4.8	39	0.66
		SL=43.0(ROW)- 4.1	39	0.55
Oncorhynchus nerka (sockeye salmon)	WT= 4.1(OL)- 1.95[F]		86	0.95
Oncorhynchus tshawytscha (chinook salmon)	WT= 4.2(OL)- 1.39[F]		53	0.99
Ophiodon elongatus (lingcod)	$WT=0.00339SL^{3.35}$ (N=8, r^2=0.96)	SL= 8.1(LOL)- 5.1	8	0.95
		SL= 8.2(ROL)- 5.5	8	0.97
		SL=14.9(LOW)+10.1	8	0.93
		SL=16.0(ROW)+ 9.5	8	0.96
Parophrys vetulus (English sole)	$WT=0.01854SL^{2.88}$ (N=81, r^2=1.00)	SL= 3.6(LOL)- 1.8	112	0.96
		SL= 3.7(ROL)- 2.4	110	0.95
		SL= 4.2(LOW)+ 7.0	105	0.91
		SL= 4.2(ROW)+ 7.1	104	0.91

Table 10.--(Cont.,p.8)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
<u>Peprilus</u> <u>simillimus</u> (Pacific pompano)	Mean=240.g	SL= 0.1(LOL)+11.2	3	0.00
		SL= 1.1(ROL)+ 6.7	3	0.00
<u>Phanerodon</u> <u>furcatus</u> (white seaperch)	$WT=0.01959SL^{3.14}$ (N=10, r^2=1.00)	SL= 2.4(LOL)- 1.6	15	0.95
		SL= 2.4(ROL)- 1.6	15	0.95
		SL= 2.1(LOW)+ 4.8	10	0.94
		SL= 2.0(ROW)+ 4.8	10	0.95
<u>Pholis</u> sp. (gunnel)	$WT=0.00371SL^{3.11}$ (N=8, r^2=0.99)	SL= 6.7(LOL)+ 2.0	6	0.78
		SL= 6.9(ROL)+ 2.0	6	0.79
		SL=80.8(LOW)+ 7.2	6	0.68
		SL=59.5(ROW)+ 7.9	6	0.84
<u>Platichthys</u> <u>stellatus</u> (starry flounder)	$WT=0.01035SL^{3.28}$ (N=20, r^2=0.99)	SL= 3.8(LOL)- 2.6	19	0.90
		SL= 3.9(ROL)- 3.1	19	0.93
		SL= 5.0(LOW)+ 7.9	20	0.91
		SL= 5.1(ROW)+ 7.7	19	0.93
<u>Plectobranchus</u> <u>evides</u> (bluebarred prickleback)	Mean=5.0g			
<u>Pleuronichthys</u> sp. (curlfin sole)	Mean=195.0g			
<u>Porichthys</u> <u>notatus</u> (plainfin midshipman)	Mean=41.0g			

Table 10.--(Cont.,p.9)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
<u>Poroclinus</u> <u>rothrocki</u> (whitebarred prickleback)	Mean=30.0g			
<u>Psettichthys</u> <u>melanostictus</u> (sand sole)	Mean=184.6g	$SL= 5.0(OL)- 4.45^{A}$	14	0.94
<u>Radulinus</u> <u>asprellus</u> (slim sculpin)	Mean=120.0g			
<u>Salmo</u> <u>gairdneri</u> (rainbow trout)	$WT=0.02748SL^{2.90}$ ($N=18$, $r^2=0.90$)	SL= 6.1(LOL)- 3.2	28	0.88
		SL= 6.6(ROL)- 4.7	25	0.92
		SL=17.6(LOW)+10.2	28	0.91
		SL=20.2(ROW)+ 9.2	25	0.91
<u>Scorpaenichthys</u> <u>marmoratus</u> (cabezon)	$WT=0.02985SL^{3.04}$ ($N=2$, $r^2=1.00$)	SL=10.5(LOL)-14.3	4	0.93
		SL=10.6(ROL)-11.2	2	1.00
		SL=27.6(LOW)+ 7.4	4	0.78
		SL=42.2(ROW)+ 3.7	2	1.00
<u>Sebastes</u> sp. (rockfish)	Mean=280.2g	SL= 1.7(LOL)+ 6.6	8	0.78
		SL= 1.8(ROL)+ 5.8	8	0.84
		SL= 0.3(LOW)+26.7	8	0.81
		SL= 0.3(ROW)+26.4	8	0.85
<u>Spirinchus</u> <u>starksi</u> (night smelt)	$WT=0.02094SL^{2.68}$ ($N=49$, $r^2=0.87$)	SL= 2.5(LOL)- 0.2	3	0.41
		SL= 2.0(ROL)+ 1.5	3	0.00

Table 10.--(Cont.,p.10)

Species (common name)	Weight/length relationship	Otolith/fish regression Equation	n	r^2
Spirinchus thaleichthys (longfin smelt	$WT=0.02094SL^{2.68}$ ($N=49$, $r^2=0.87$)	SL= 2.5(LOL)+ 0.1	48	0.87
		SL= 2.5(ROL)+ 0.3	49	0.90
		SL= 5.4(LOW)+ 6.5	48	0.87
		SL= 5.7(ROW)+ 6.3	48	0.89
Thaleichthys pacificus (eulachon)	$WT=0.00667SL^{3.12}$ ($N=100$, $r^2=0.88$)	SL= 4.5(LOL)- 1.9	91	0.72
		SL= 4.3(ROL)- 1.0	89	0.70
		SL=13.1(LOW)+ 9.5	91	0.54
		SL=13.9(ROW)+ 9.2	90	0.55
Trachurus symmetricus (Jack mackerel)	$WT=0.06353SL^{2.56}$ ($N=18$, $r^2=0.75$)	SL= 1.5(LOL)+17.9	12	0.00
		SL=-0.7(ROL)+35.9	14	0.00
		SL= 4.2(LOW)+21.7	12	0.13
		SL= 2.6(ROW)+25.0	14	0.00
Trichodon trichodon (Pacific sandfish)	Mean=180.0g			

[A] Equation from Brown and Mate (1983).
[B] Equation from Messersmith (1969)
[C] Equation from Spratt (1975).
[D] Equation from Ketchen (1967).
[E] Equation from Mina (1967).
[F] Equation from Casteel (1974).

Estimated average length of fish eaten by harbor seals in the Columbia River region was 13.3 cm (SD = 5.5, range = 0.9-47.5 cm), based on measurements of 2,034 otoliths. Approximately 62% of fish were estimated to be between 8 and 15 cm in SL (Fig. 14). C. stigmaeus generally were the smallest fish eaten ($\bar{X}$ = 7.9 cm, SD = 2.5), whereas G. macrocephalus were the largest ($\bar{X}$ = 86.6 cm, SD = 40.7; Table 11). Four species, E. mordax, L. armatus, M. proximus, and P. vetulus, were sufficiently abundant in samples throughout most of the year to allow comparisons of seasonal changes in length of fish eaten. There was no significant difference in estimated standard length of L. armatus among the seasons (F = 2.6, P > 0.05). The estimated standard length was significantly greater during autumn and winter months compared with spring and summer for E. mordax, M. proximus, and P. vetulus (F = 14.0, 9.3, and 12.1, respectively; P < 0.01). This trend, of larger fish being eaten in autumn and winter, was evident for other species for which there were insufficient data to compare statistically.

Estimated mean length of fish eaten by harbor seals in the Netarts Bay area was 15.2 cm (SD = 8.0, range = 1.7-49.0 cm). P. vetulus was the smallest fish eaten ($\bar{X}$ = 6.7, SD = 2.8), while M. productus was the largest ($\bar{X}$ = 49.0, n = 1; Table 11). Size distribution of fishes eaten by harbor seals in Netarts Bay was more even than for the

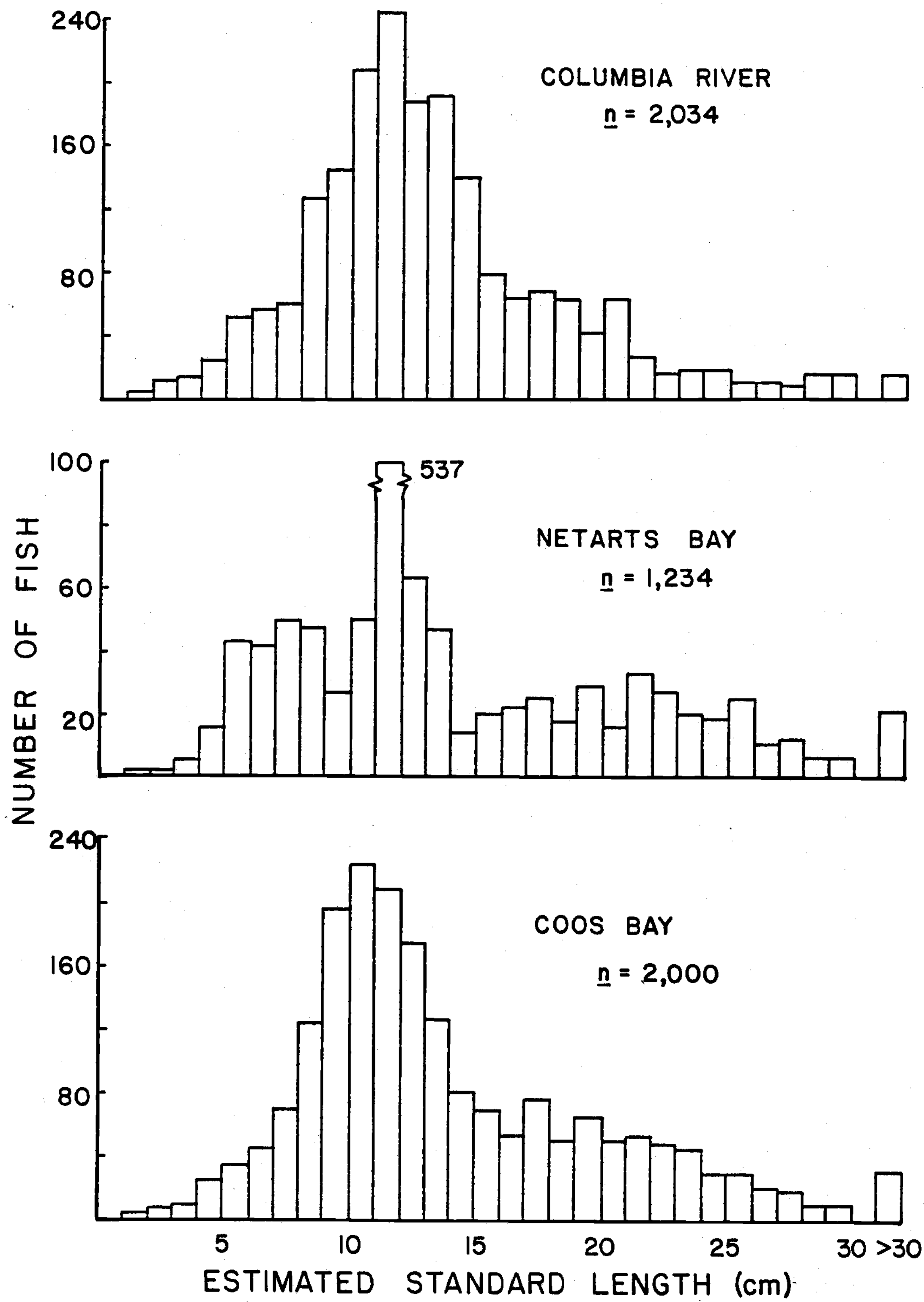

Fig. 14.--Length frequency histogram of fishes consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

Table 11.--Estimated mean, standard deviation (SD), and range of standard lengths (SL; cm) of fish consumed by harbor seals. The number of otoliths measured is given for each species. Fish length is based on measurements of otoliths recovered from feces collected in the Columbia River, Netarts Bay, and Coos Bay.

	COLUMBIA RIVER			NETARTS BAY			COOS BAY		
SPECIES	#	MEAN SL (SD)	RANGE	#	MEAN SL (SD)	RANGE	#	MEAN SL (SD)	RANGE
A. *elongatus*	28	9.4 (1.9)	1.9- 6.2	13	10.5 (1.4)	8.6-13.1	49	10.6 (1.1)	8.4-13.1
A. *sapidissima*	1	45.3 (0.0)	45.3-45.3	0			0		
A. *hexapterus*	49	12.5 (1.3)	11.2-31.5	621	11.7 (0.1)	9.8-15.1	22	12.6 (1.2)	10.2-15.6
A. *rhodopterus*	2			0			0		
A. *fimbria*	10	30.5 (2.1)	28.0-34.8	16	33.6 (3.9)	24.5-39.5	3	46.5 (6.2)	40.0-52.4
A. *stomias*	0			0			1	36.0 (0.0)	36.0-36.0
B. *frenatus*	4			0			0		
B. *marginata*	0			0			1		
C. *taylori*	1			0			0		
C. *pugetensis*	0			0			4		
C. *sordidius*	25	23.4 (2.2)	18.0-27.8	54	10.9 (5.3)	5.4-28.0	16	18.1 (2.5)	15.4-21.9
C. *stigmaeus*	11	7.7 (1.9)	4.3-10.7	28	8.0 (1.1)	6.3-11.1	115	7.9 (2.5)	2.7-14.6
C. *ios*	0			0			3		
C. *harengus*	64	18.7 (3.8)	13.6-28.0	32	18.8 (3.6)	12.8-25.9	139	17.4 (2.2)	13.1-23.6
C. *nicholsi*	11	31.5 (5.7)	21.9-40.7	0			4	21.9 (2.4)	19.7-24.8
C. *aggregata*	65	10.3 (2.3)	4.8-14.3	31	9.9 (1.7)	5.2-12.8	526	10.5 (1.8)	4.3-15.0
D. *vacca*	0			0			8	22.5 (3.7)	15.3-27.0
E. *lateralis*	0			0			1	25.6 (0.0)	25.6-25.6
E. *mordax*	821	11.5 (2.5)	3.9-18.0	6	13.3 (2.4)	9.9-17.3	2	13.1 (0.9)	12.4-13.7
E. *bison*	0			0			2	22.1 (0.9)	21.4-22.7
E. *jordani*	11	31.5 (5.7)	21.9-40.7	0			4	21.9 (2.4)	19.7-24.8
G. *macrocephalus*	0			0			6	86.6(40.7)	51.0-
G. *zachirus*	38	23.2 (5.8)	13.5-36.3	113	22.0 (4.2)	10.7-33.2	135	22.3 (3.4)	17.2-34.8
Hemilepidotus	2			0			0		
H. *decagrammus*	0			6	33.5 (6.3)	27.9-42.1	0		
H. *elassodon*	2			0			2		
H. *ellipticum*	0			0			2	13.4 (0.1)	13.4-13.5
H. *pretiosus*	2	10.2 (0.1)	10.2-10.2	7	16.2 (4.2)	10.4-20.4	68	14.9 (3.1)	9.5-28.7
Icelus sp	1			0			0		
I. *isolepis*	12	16.7 (5.0)	9.1-25.6	10	18.7 (6.8)	7.5-27.0	52	20.5 (4.9)	8.3-28.3
L. *lepidus*	0			0			1		

Table 11.--(Cont.,p.2)

SPECIES	COLUMBIA RIVER #	COLUMBIA RIVER MEAN SL (SD)	COLUMBIA RIVER RANGE	NETARTS BAY #	NETARTS BAY MEAN SL (SD)	NETARTS BAY RANGE	COOS BAY #	COOS BAY MEAN SL (SD)	COOS BAY RANGE
L. bilineata	1			0			0		
L. armatus	251	13.5 (3.2)	3.5-20.7	84	13.4 (4.7)	4.4-23.6	368	12.9 (4.1)	7.9-29.4
L. sagitta	158			0			0		
L. exilis	2	26.8 (5.2)	23.1-30.5	21	21.2 (4.3)	13.5-30.8	15	27.2 (3.0)	22.5-31.3
M. productus	4	36.5(14.6)	16.0-47.5	1	49.0 (0.0)	49.0-49.0	0		
M. proximus	111	9.2 (6.0)	1.2-21.7	8	15.4 (8.9)	1.7-26.2	53	16.0 (4.9)	1.5-23.8
M. pacificus	18	25.2 (5.0)	16.4-33.2	62	22.1 (3.2)	16.1-28.0	14	29.6 (4.4)	25.4-40.5
O. kisutch	0			0			1	71.5 (0.0)	71.5-71.5
O. nerka	1			0			0		
O. tshawytscha	1			0			0		
O. elongatus	17	19.4 (4.0)	12.9-29.6	0			5	17.8 (4.7)	13.2-23.5
P. vetulus	101	12.3 (8.6)	2.4-30.7	124	6.7 (2.8)	3.4-27.6	270	13.3 (7.7)	1.9-33.5
P. simillimus	2	7.7 (9.6)	0.9-14.5	0			0		
P. furcatus	10	14.5 (4.9)	5.6-19.1	0			13	13.8 (5.5)	7.8-23.7
Pholis sp.	1	16.5 (0.1)	16.5-16.5	0			1	11.3 (0.0)	11.3-11.3
P. stellatus	82	14.3 (3.5)	10.5-28.8	2	16.8(11.7)	8.5-25	19	23.8 (10.4)	5.1-40.4
P. evides	2			0			0		
P. notatus	2			0			0		
P. rothrocki	1			0			0		
P. melanostictus	12	23.9 (6.1)	11.2-31.5	1	17.3 (0.0)	17.3-17.3	26	21.7 (7.0)	9.8-37.2
R. asprellus	1			0			0		
S. gairdneri	22	19.5 (2.1)	16.2-23.3	0			24	13.0 (4.4)	6.8-22.2
S. marmoratus	0			0			1	11.5 (0.0)	11.5-11.5
Sebastes sp.	0			23	18.8 (2.6)	14.0-25.8	0		
S. starksi	0			1	11.2 (0.0)	11.2-11.2	0		
S. thaleichthys	118	9.5 (1.8)	4.4-13.3	0			0		
T. pacificus	171	17.2 (3.6)	7.4-23.8	15	10.7 (3.8)	6.0-17.3	22	14.7 (3.5)	6.9-19.5
T. symmetricus	0			0			1	33.6 (0.0)	33.6-33.6
T. trichodon	2			0			2		

other areas (Fig. 14), except for a large peak between 11 and 12 cm standard length composed primarily of 519 A. hexapterus. Approximately 63% of all fish were between 8 and 15 cm standard length, and only 1.7% were greater than 30 cm SL.

Estimated mean length of fish eaten by harbor seals in Coos Bay area was 14.1 cm (SD = 7.6, range = 1.5-165.6 cm). Approximately 57% of the fishes were estimated to be between 8 and 15 cm standard length (Fig. 14). Few (1.8%) fish were estimated to be larger than 30 cm, although the frequency distribution appeared bimodal, with a second peak near 20 cm (Fig. 14). C. stigmaeus was the smallest fish eaten by harbor seals ($\bar{X}$ = 7.9, SD = 2.5), while G. macrocephalus was the largest fish ($\bar{X}$ = 86.6 cm, SD = 40.7; Table 11).

Six species of fish (C. aggregata, L. armatus, P. vetulus, C. harengus, C. stigmaeus, and M. proximus) were sufficiently numerous in Coos Bay samples of 1978, 1979, and 1980 to compare lengths of fish among years. Length was significantly different among years for only one species, P. vetulus; fish were smaller in 1980 (F = 11.7, P < 0.01).

The 10 most numerous and frequently occurring species of fish in the three collections were L. armatus, P. vetulus, C. aggregata, C. harengus, A. hexapterus, G. zachirus, M. proximus, C. sordidus, A. elongatus, and T.

pacificus. The distributions of standard length for each species were compared among regions to determine if there were differences in size of fish eaten by harbor seals. The Rogue River region is not included in this discussion because few otoliths were collected there; the dominant food item, L. tridentatus, has minute otoliths that were not retained by the sieves.

Leptocottus armatus was the second most numerous fish in harbor-seal feces collected in the Columbia River and Coos Bay, and fifth in Netarts Bay. Harbor seals ate L. armatus that were estimated to be 3.5 - 29.4 cm standard length ($\bar{X}$ = 13.2, SD = 4.0). There was no significant difference in estimated mean length among the three collection areas ($P > 0.05$). Length-frequency distributions for this species were similar among collection areas, although a few larger fish were eaten in Coos Bay (Fig. 15). The variation in standard length was least for fish eaten by harbor seals in the Columbia River area (CV = 23.7%), compared with Netarts Bay (CV = 35.1%) and Coos Bay (CV = 31.8%).

Parophrys vetulus was the third most numerous species of fish in fecal samples of harbor seals in the Netarts Bay and Coos Bay areas, and seventh in the Columbia River area. Harbor seals ate P. vetulus 1.9 - 33.5 cm ($\bar{X}$ = 11.4 cm, SD = 6.6) in standard length. Length distributions were bimodal for this species in the Columbia River and

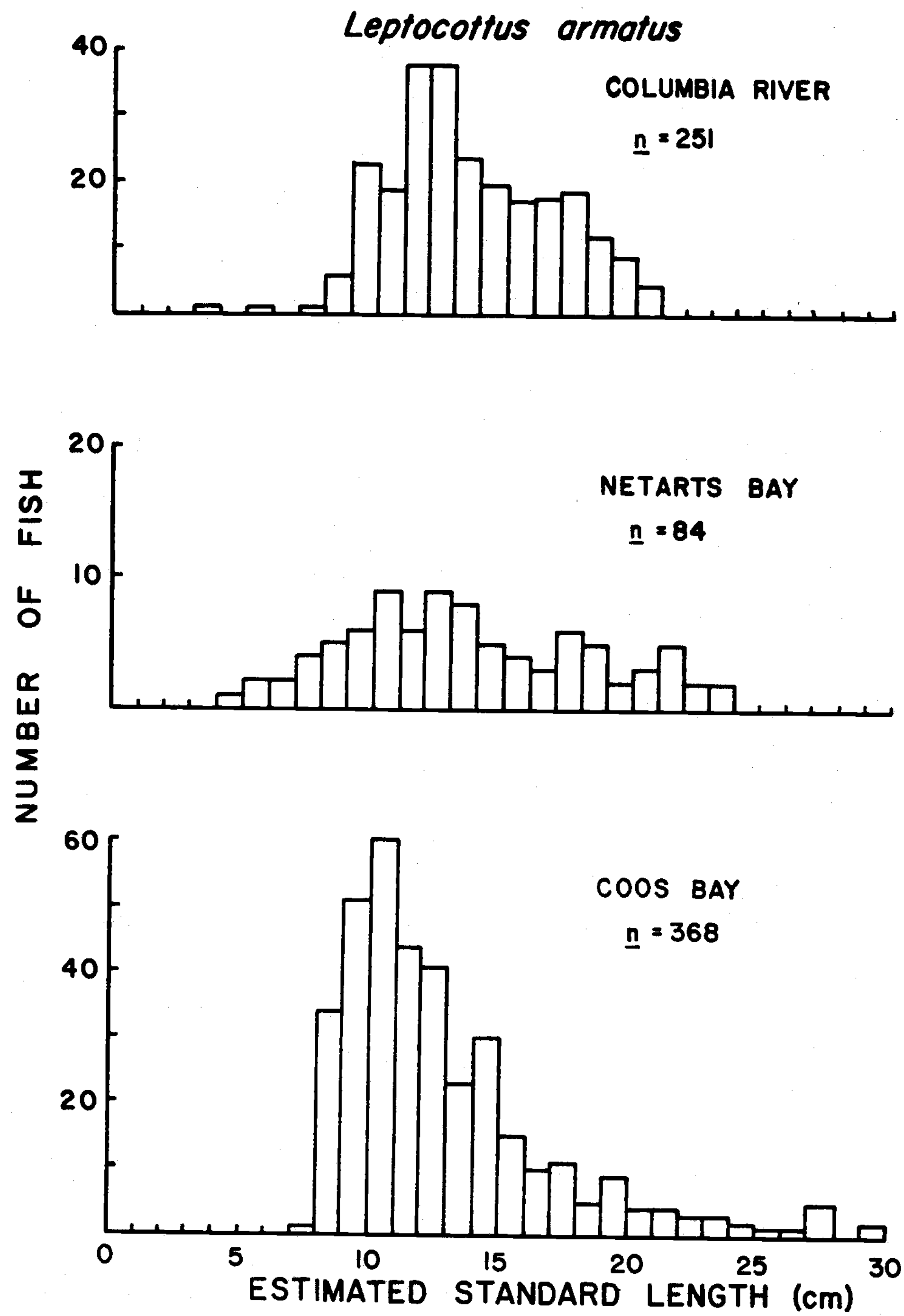

Fig. 15.--Length frequency histogram of <u>Leptocottus armatus</u> consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

Coos Bay regions. Harbor seals in Netarts Bay region, in comparison, ate *P. vetulus* of a limited size range, and predominantly *P. vetulus* 3 - 10 cm in standard length (Fig. 16). There was a significant difference between the mean standard length of P. *vetulus* eaten by harbor seals in Netarts Bay ($\bar{X}$ = 6.7 cm, *SD* = 2.8) and those in Coos Bay ($\bar{X}$ = 13.3 cm, *SD* = 7.7; *t* = 14.2, *P* < 0.01).

Cymatogaster aggregata was the predominant prey item of harbor seals in Coos Bay, and this species was the 9th and 13th most numerous fish species in fecal samples from Netarts Bay and the Columbia River, respectively. Harbor seals preyed upon *C. aggregata* that were 1.7 - 15.0 cm ($\bar{X}$ = 10.4 cm, *SD* = 1.8) in length. Although the standard length of this species eaten by harbor seals in Netarts Bay ($\bar{X}$ = 9.9 cm, *SD* = 1.7) was less than the other two regions ($\bar{X}$ = 10.3 cm and 10.5 cm), there was no significant difference (*P* > 0.05; Fig. 17). Harbor seals in Netarts Bay also ate smaller *C. aggregata* than in the other two areas.

Clupea harengus, consumed by harbor seals in Oregon, was an average length of 17.9 cm (*SD* = 2.4, range = 12.8-28.0 cm). Fish of this species, eaten by harbor seals in Coos Bay, were smaller than in the Columbia River and Netarts Bay, although the difference was not significant (*P* > 0.05; Fig. 18). Most (71.1%) of these fish eaten by seals were between 15 and 20 cm standard length. The

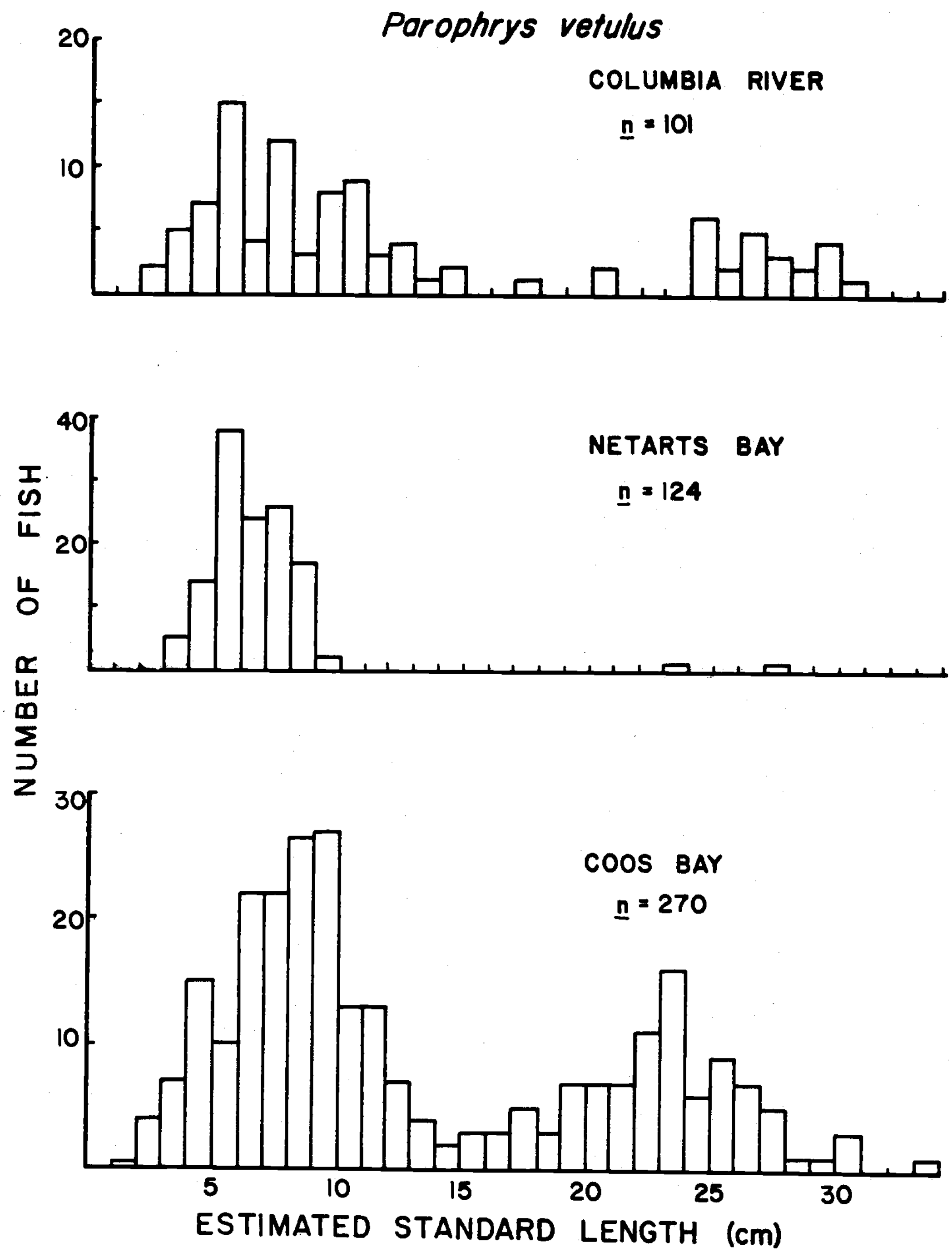

Fig. 16.--Length frequency histogram of Parophrys vetulus consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

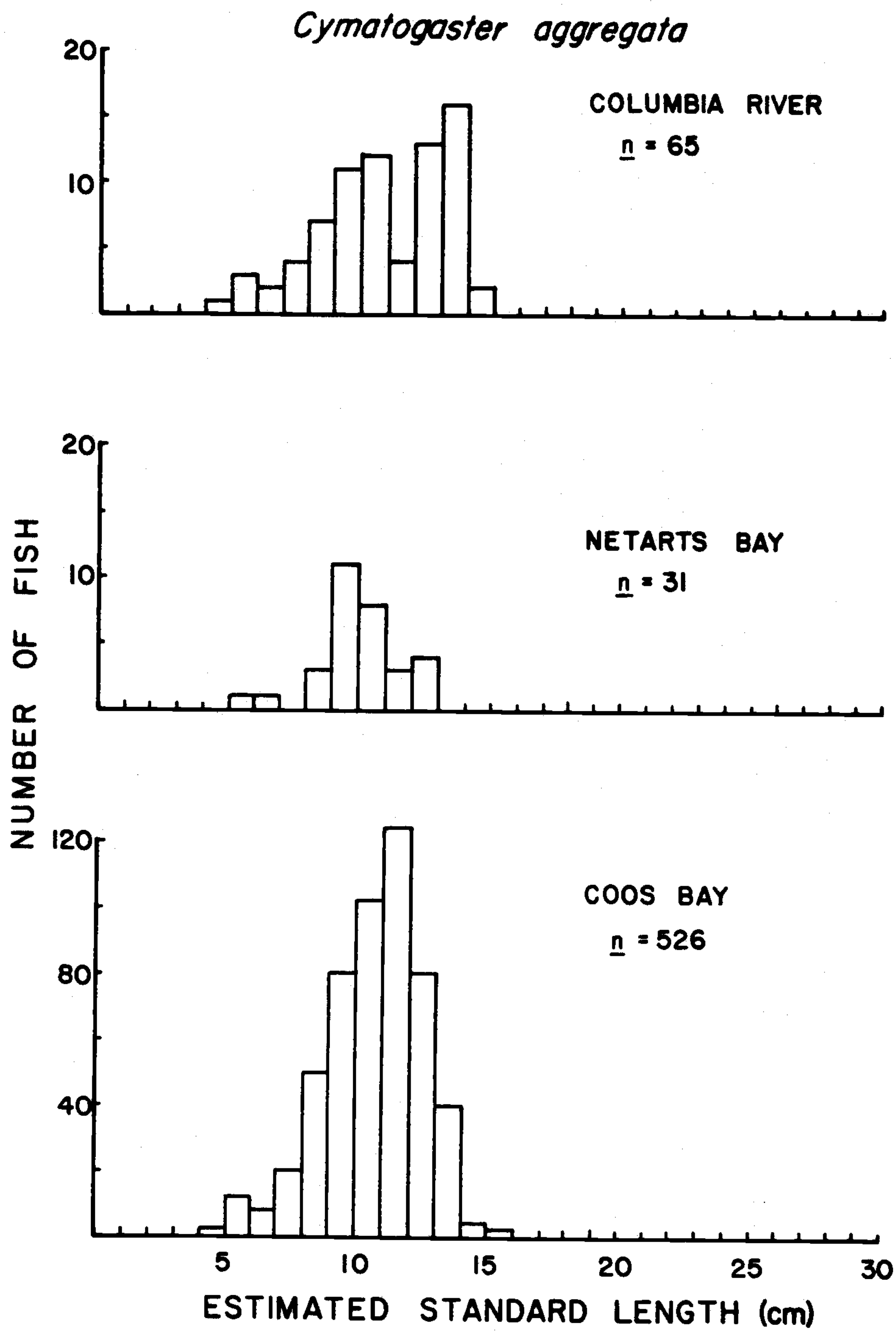

Fig. 17.--Length frequency histogram of Cymatogaster aggregata consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

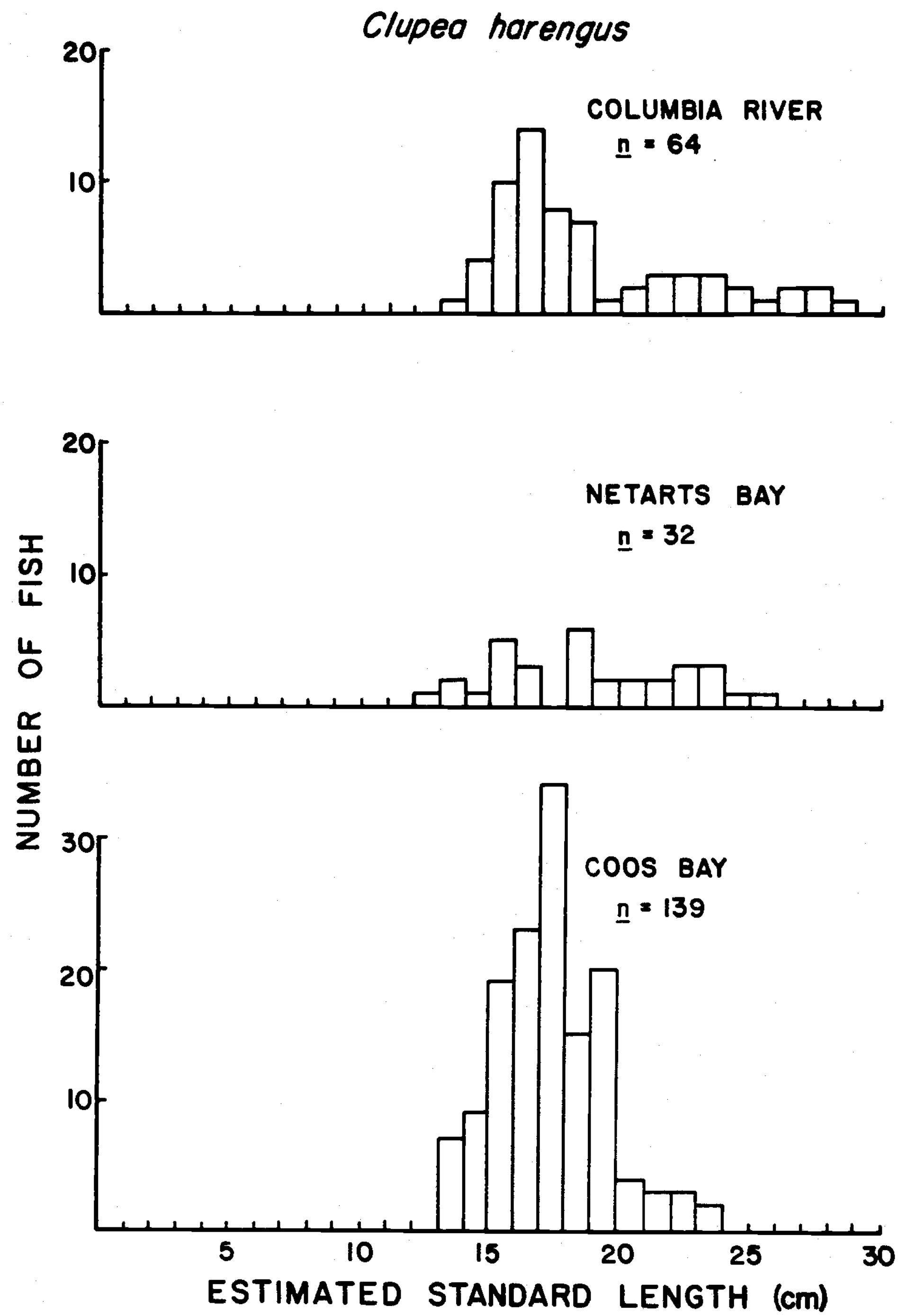

Fig. 18.--Length frequency histogram of Clupea harengus consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

largest fish of this species were taken by harbor seals in the Columbia River (Fig. 18).

Ammodytes hexapterus, eaten by harbor seals in Oregon was an average 11.8 cm standard length (*SD* = 0.2, range = 9.7-15.1 cm). Although the average length of this species was slightly less in the Netarts Bay collection, there was no significant difference in length of this species among the three regions ($P > 0.05$, Fig. 19). There was very little variability in estimated standard length of *A. hexapterus* consumed in the three areas (*CV* = 6.9%).

Glyptocephalus zachirus was generally larger than other species of fishes eaten by harbor seals in Oregon. The average standard length of *G. zachirus* for all collections was 22.3 cm (*SD* = 4.0, range = 10.7-36.3 cm). There were no significant differences in estimated mean length among the three collections ($P > 0.05$), and all three frequency distributions were similar (Fig. 20).

Microgadus proximus, eaten by harbor seals in Oregon, was an average 11.6 cm (*SD* = 2.7, range = 1.2-26.2 cm) in length. There was a significant difference in mean estimated length for this species between the Columbia River ($\bar{X}$ = 9.2 cm, *SD*=6.0) and Coos Bay ($\bar{X}$ = 16.0 cm, *SD* = 4.9) collections ($t = 5.6$, $P < 0.01$; Fig. 21). Harbor seals in Netarts Bay appeared to feed on *M. proximus* of similar length to those eaten in Coos Bay, however the sample size was small.

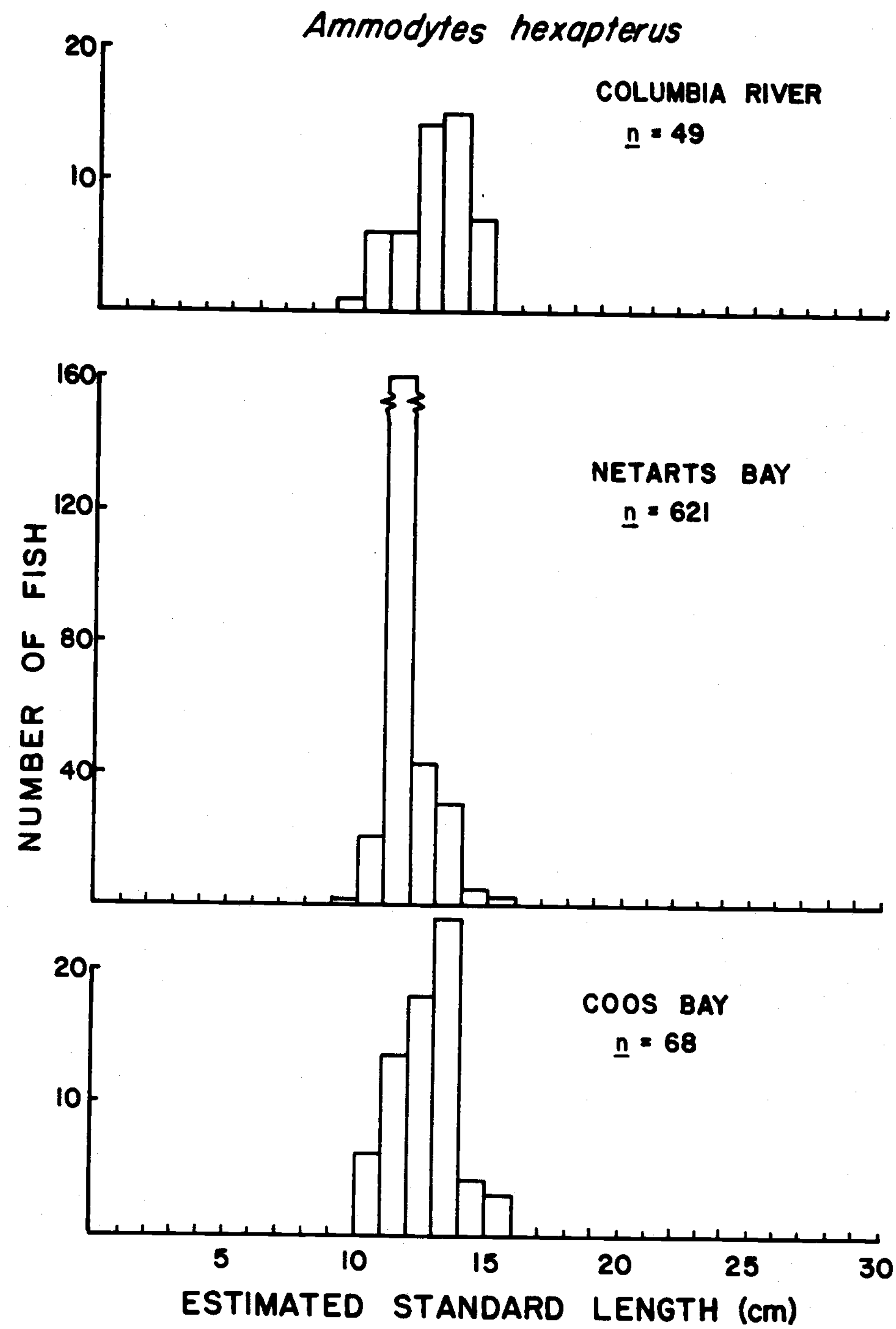

Fig. 19.--Length frequency histogram of Ammodytes hexapterus consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

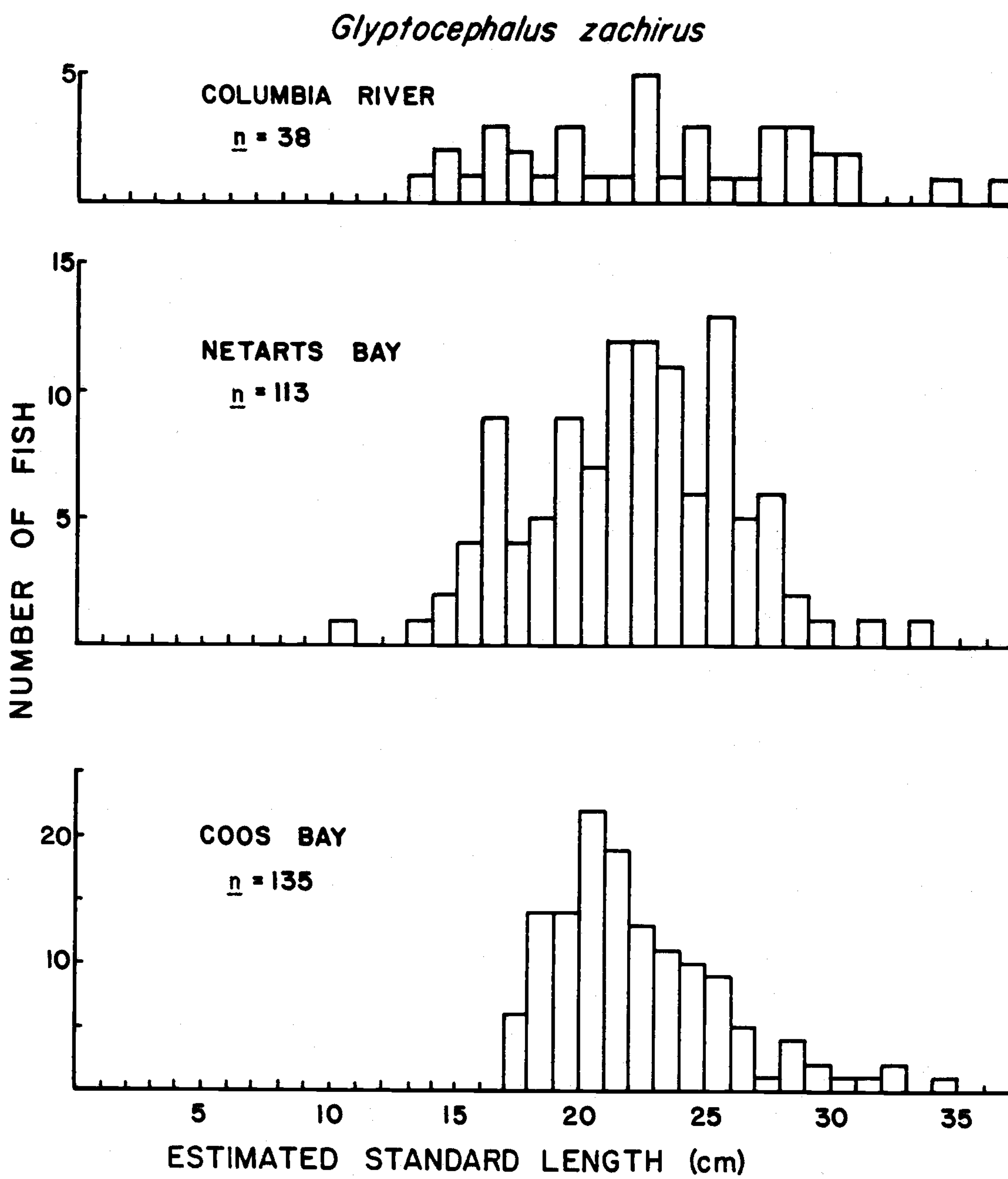

Fig. 20.--Length frequency histogram of Glyptocephalus zachirus consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

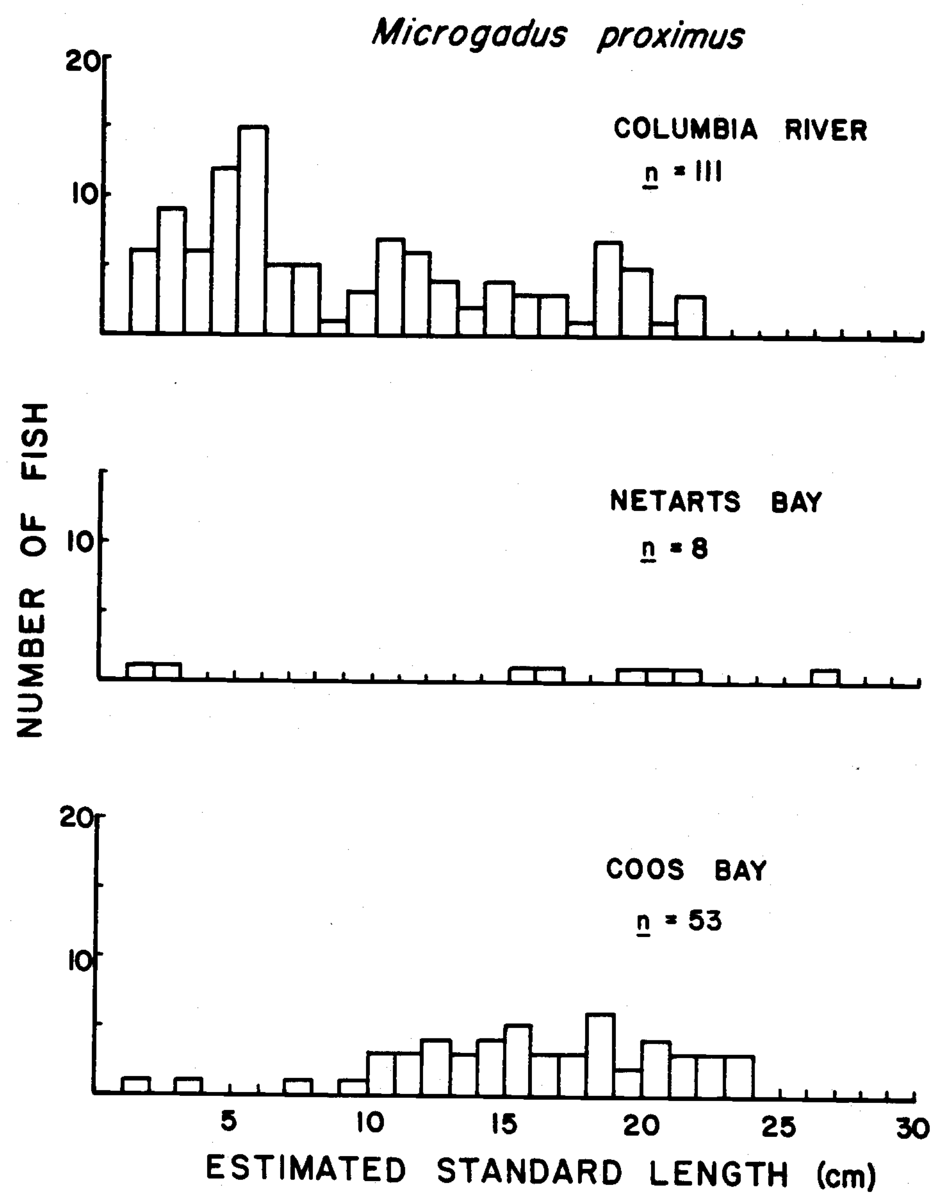

Fig. 21.--Length frequency histogram of <u>Microgadus proximus</u> consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

Citharichthys sordidus, eaten by harbor seals in Oregon, was variable in length among regions, and averaged 15.4 cm (*SD* = 4.0, range = 5.4-28.0 cm) for all areas combined. Harbor seals in the Columbia River ate primarily larger individuals of this species ($\bar{X}$ =23.4 cm, *SD* = 2.2), and in Netarts Bay the average length was significantly less ($\bar{X}$ =10.9 cm, *SD* = 5.3; $P < 0.05$). Fewer fish of this species were eaten by harbor seals in Coos Bay, and they were intermediate in length to those eaten in other regions (Fig 22).

Allosmerus elongatus, eaten by harbor seals in the three regions, averaged 10.2 cm (*SD* = 1.4, range = 6.2-13.1 cm) standard length. The length distribution of fish consumed did not vary significantly among the three regions ($P > 0.05$, Fig. 23), although slightly smaller fish were eaten in the Columbia River area. Harbor seals did not eat a wide range of lengths of this species (*CV* = 14.6%).

Thaleichthys pacificus averaged 16.4 cm standard length (*SD* = 3.6, range = 6.0-23.6) for all regions. The average length of this species was greater in the Columbia River collection ($\bar{X}$ = 17.2 cm, *SD*=3.6) than for Netarts Bay ($\bar{X}$ = 10.7 cm, *SD*=3.8) and Coos Bay ($\bar{X}$ = 14.7 cm, *SD* = 3.5), although this was not significant ($P > 0.05$, Fig. 24). This species was the third most numerous species in the diet of harbor seals in the Columbia River.

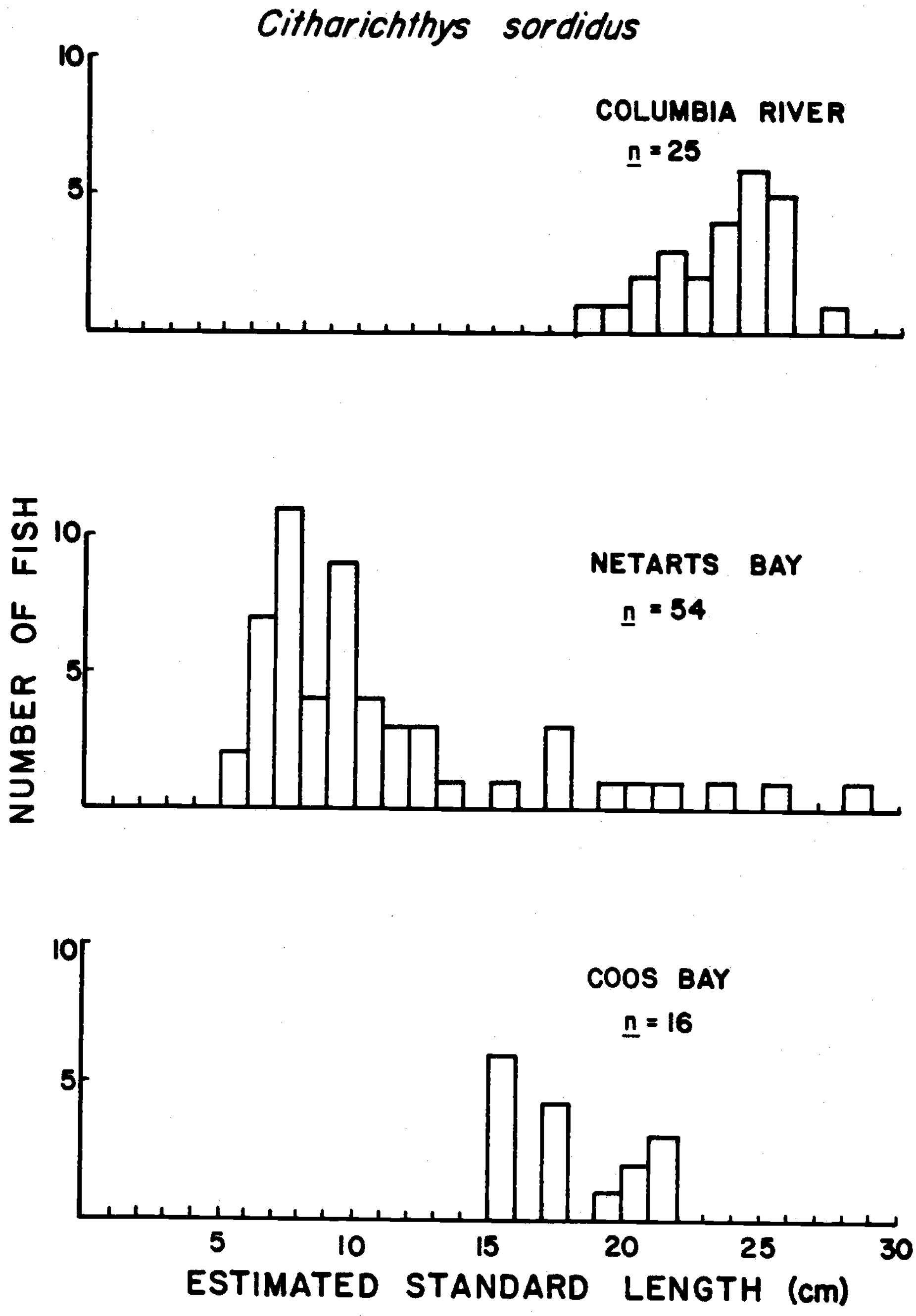

Fig. 22.--Length frequency histogram of <u>Citharichthys</u> <u>sordidus</u> consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

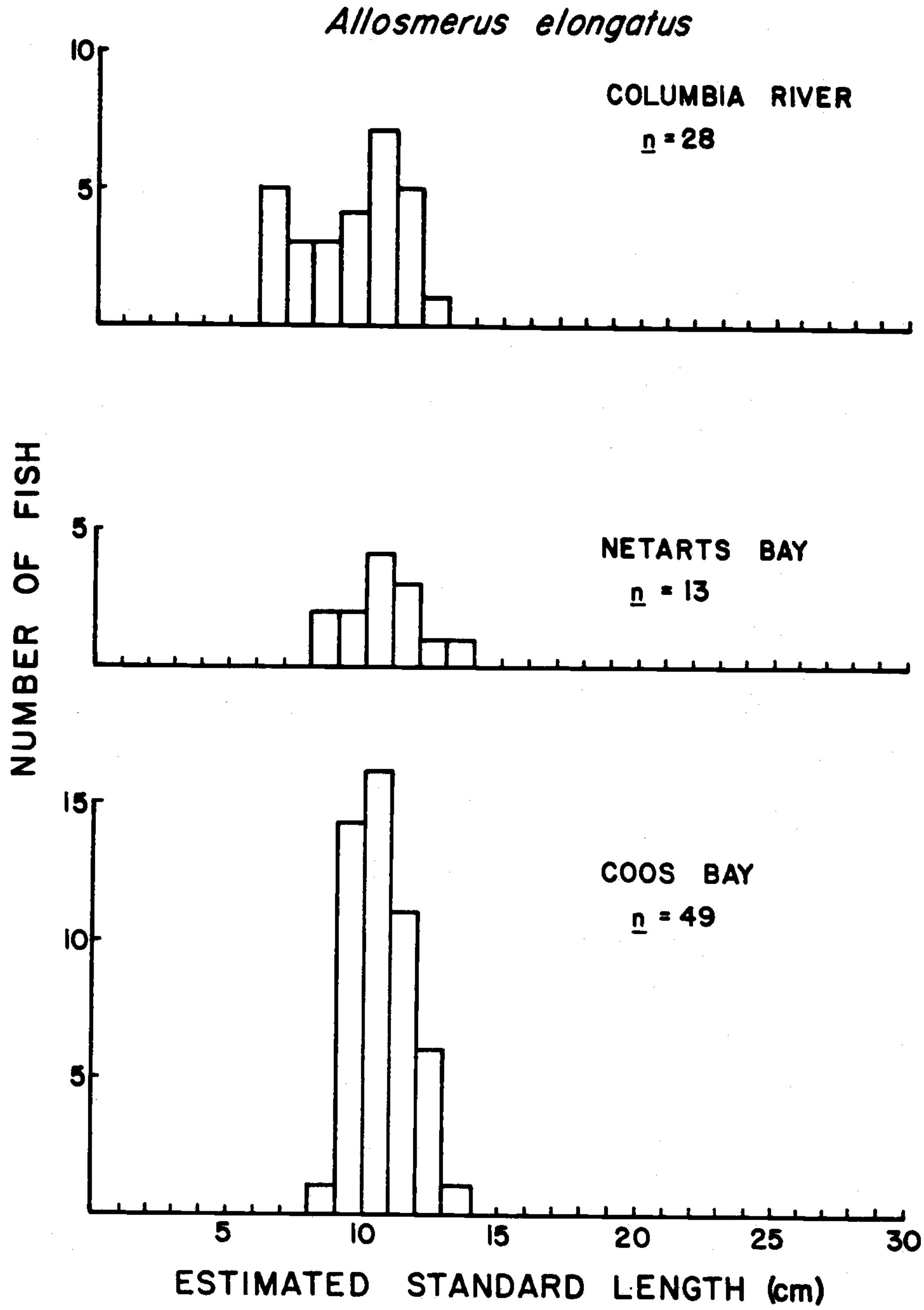

Fig. 23.--Length frequency histogram of Allosmerus elongatus consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

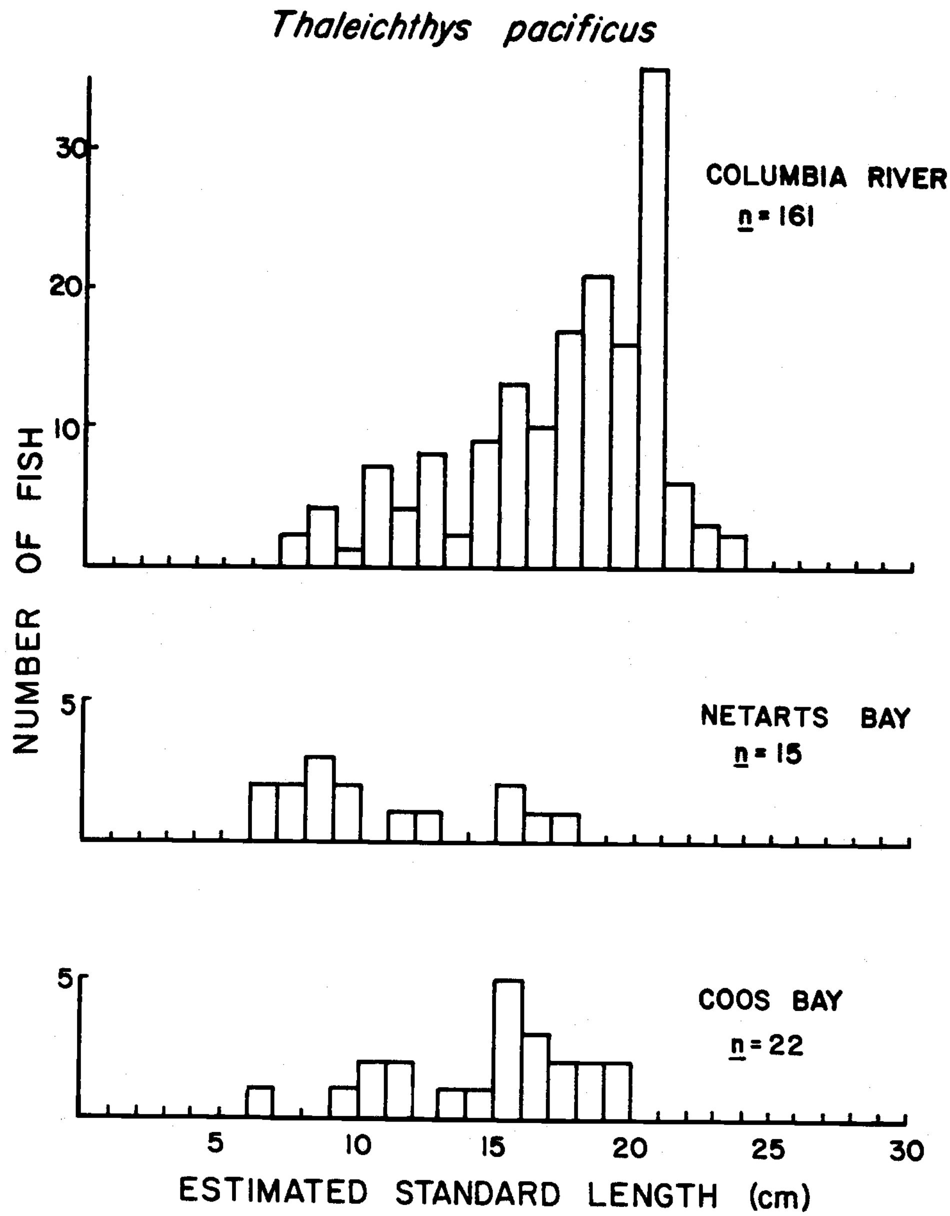

Fig. 24.--Length frequency histogram of Thaleichthys pacificus consumed by harbor seals in the Columbia River, Netarts Bay, and Coos Bay, Oregon.

Biomass and number of fishes consumed.--Estimated annual biomass of fish consumed by harbor seals in Oregon during 1980 was 5.69 metric tons. The five most important fish species for harbor seals in Oregon, ranked according to greatest estimated biomass consumed, were *L. armatus* (721.4 metric tons), *C. harengus* (451.6 metric tons), *C. aggregata* (440.8 metric tons), *P. vetulus* (427.8 metric tons), and *G. zachirus* (332.6 metric tons). These five species constituted 42.5% of the total estimated biomass consumed by harbor seals in 1980, whereas the top ten species accounted for 65.6% of the total (Table 12). Because fecal samples were collected primarily in estuaries and during summer, consumption estimates for these species of fish may be overestimated.

The biomass of flatfishes (1,626.1 metric tons) consumed by harbor seals was over twice the biomass of other groups of fishes. In 1980, harbor seals ate an estimated 763.8 metric tons of Cottidae, 712.5 metric tons of Clupeiformes, 604.5 metric tons of Salmonidae, 486.6 metric tons of Embiotocidae, and 226.9 metric tons of Osmeridae fishes. Together these fishes represented 79.1% of the total biomass eaten by harbor seals in the state during 1980. An estimated 604.5 metric tons (10.8% of total biomass consumed) of salmonids (principally *O. tshawytscha* and *O. kisutch*) were eaten by seals in the state.

Table 12.--Estimates of biomass (BIO) and number (NUM) of fish species consumed by harbor seals in four regions in Oregon during 1980. Estimates are based on a population size of 5,034.

SPECIES	Estimated biomass ($X10^3$ kg) and number ($X10^3$) consumed									
	COLUMBIA RIVER		NORTH COAST		SOUTH COAST		ROGUE RIVER		TOTAL	
	BIO	NUM	BIO	NUM	BIO	NUM	BIO	NUM	BIO	NUM
L. armatus	77.3	1302.0	125.1	1760.1	529.6	8667.6	---	---	732.0	11729.7
C. harengus	44.2	467.3	103.4	1097.9	310.6	4343.8	---	---	458.2	5909.0
C. aggregata	12.3	281.3	22.4	627.4	412.6	9572.6	---	---	447.3	10481.3
P. vetulus	35.0	535.3	23.4	3049.7	372.7	5832.0	3.0	46.6	434.1	9463.6
G. zachirus	17.7	127.0	133.0	1254.7	185.0	1729.5	1.8	16.7	337.5	3127.9
O. tshawytscha	106.9	9.1	---	---	---	---	202.1	39.6	309.0	48.7
A. fimbria	15.1	45.4	172.4	383.4	92.8	80.4	---	---	280.3	509.2
A. hexapterus	2.6	344.8	235.9	39314.8	15.8	2111.6	---	---	254.3	41771.1
E. mordax	231.8	7476.6	9.3	209.1	3.1	80.4	---	---	244.2	7766.1
O. kisutch	---	---	---	---	223.1	40.2	---	---	223.1	40.2
P. stellatus	23.2	290.4	1.9	17.4	167.0	281.5	---	---	222.1	589.3
L. tridentatus	---	---	---	---	---	---	214.0	792.6	214.0	792.6
M. pacificus	12.5	59.0	93.5	697.1	74.0	221.2	1.9	5.6	181.9	982.9
T. pacificus	68.2	1265.8	6.4	418.2	23.0	663.6	58.1	1678.6	155.7	4026.2
H. decagrammos	---	---	148.1	174.3	---	---	---	---	148.1	174.3
L. exilis	1.8	4.5	41.9	226.5	80.2	201.1	---	---	123.9	432.1
C. sordidus	22.0	118.0	35.0	1045.6	28.0	321.8	3.2	37.3	88.2	1522.7
Sebastes sp.	---	---	87.9	313.7	---	---	---	---	87.9	313.7
I. isolepis	2.0	31.7	12.6	122.0	71.6	643.5	---	---	86.2	797.2
P. melanost.	11.3	45.4	3.1	17.4	63.1	341.9	---	---	77.5	404.7
S. gairdneri	13.4	86.2	---	---	27.4	442.4	31.7	31.7	72.5	560.3
M. proximus	7.7	376.5	9.1	122.0	48.7	844.6	3.4	58.7	68.9	1401.8
D. vacca	---	---	---	---	61.6	140.8	---	---	61.6	140.8
H. pretiosus	0.1	4.5	7.2	122.0	42.3	965.3	---	---	49.6	1091.8
C. stigmaeus	0.3	54.4	4.0	627.4	43.8	2533.9	---	---	48.1	3215.7
E. jordani	20.7	31.8	---	---	7.8	40.2	---	---	28.5	72.0
P. furcatus	4.1	36.3	---	---	22.8	201.1	---	---	26.9	237.4
A. sapidissima	21.4	13.6	---	---	---	---	---	---	21.4	13.6
M. productus	6.4	13.6	14.9	17.4	---	---	---	---	21.3	31.0
A. elongatus	1.6	231.4	3.1	348.5	15.7	1749.6	---	---	20.4	2329.5
Hemilepidotus	16.7	18.1	---	---	---	---	---	---	16.7	18.1
O. elongatus	7.5	90.7	---	---	7.8	120.7	---	---	15.3	211.4
C. pugetensis	---	---	---	---	14.2	80.4	---	---	14.2	80.4

Table 12.--(Cont.,p.2)

SPECIES	COLUMBIA RIVER		NORTH COAST		SOUTH COAST		ROGUE RIVER		TOTAL	
	Estimated biomass ($X10^3$ kg) and number ($X10^3$) consumed									
	BIO	NUM	BIO	NUM	BIO	NUM	BIO	NUM	BIO	NUM
E. lateralis	---	---	---	---	12.7	20.1	---	---	12.7	20.1
H. elassodon	1.3	4.5	---	---	11.2	40.2	---	---	12.5	44.7
A. stomias	---	---	---	---	12.4	20.1	---	---	12.4	20.1
B. marginata	---	---	---	---	12.1	40.2	---	---	12.1	40.2
T. symmetricus	---	---	---	---	10.3	20.1	---	---	10.3	20.1
E. bison	---	---	---	---	9.8	20.1	---	---	9.8	20.1
T. trichodon	1.6	9.1	---	---	7.2	40.2	---	---	8.8	49.3
O. nerka	8.8	9.1	---	---	---	---	---	---	8.8	9.1
L. sagitta	7.5	9.1	---	---	---	---	---	---	7.5	9.1
S. thaleichthys	4.0	830.2	---	---	---	---	---	---	4.0	830.2
P. simillimus	3.3	13.6	---	---	---	---	---	---	3.3	13.6
B. frenatus	3.0	27.2	---	---	---	---	---	---	3.0	27.2
G. macrocephalus	---	---	---	---	2.3	120.7	---	---	2.3	120.7
C. nicholsi	---	---	---	---	2.3	120.7	---	---	2.3	120.7
H. ellipticum	---	---	---	---	2.3	40.2	---	---	2.3	40.2
Pleuronichthys	---	---	---	---	---	---	2.2	11.2	2.2	11.2
S. marmoratus	---	---	---	---	2.0	40.2	---	---	2.0	40.2
A. rhodopterus	1.6	13.6	---	---	---	---	---	---	1.6	13.6
L. bilineata	1.3	4.5	---	---	---	---	---	---	1.3	4.5
G. lineatus	---	---	---	---	---	---	1.0	5.1	1.0	5.1
Pholis sp.	0.3	13.6	---	---	0.4	60.3	---	---	0.7	73.9
L. lepidus	---	---	---	---	0.7	40.2	---	---	0.7	40.2
S. starksii	---	---	0.5	34.8	---	---	---	---	0.5	34.8
C. taylori	0.4	9.1	---	---	---	---	---	---	0.4	9.1
P. rothrocki	0.3	9.1	---	---	---	---	---	---	0.3	9.1
C. ios	---	---	---	---	0.2	120.7	---	---	0.2	120.7
R. asprellus	0.2	9.1	---	---	---	---	---	---	0.2	9.1
Icelus sp.	0.2	9.1	---	---	---	---	---	---	0.2	9.1
P. notatus	0.2	4.5	---	---	---	---	---	---	0.2	4.5
P. evides	0.1	9.1	---	---	---	---	---	---	0.1	9.1
TOTALS:	821.7	15089.3	1292.8	52001.6	3030.6	42996.2	522.4	2723.9	5667.5	112811

The most numerous fish species in harbor seal diets in 1980 was _A. hexapterus_ (41.8 million individuals eaten), ranked 8th based on biomass. Ninety-four percent of this species was consumed in the north coast region. _A. hexapterus_, together with _L. armatus_ (11.7 million individuals) and _C. aggregata_ (10.4 million individuals), composed 56.7% of the total estimated number of fish consumed by harbor seals (Table 12). It was estimated that 112.8 million individual fish were consumed in Oregon during 1980. Only an estimated 658,300 individual Salmonidae (0.6% of total number of fish) were consumed by harbor seals.

DISCUSSION

Size of harbor seals.--There have been few studies on the west coast of North America, and none in Oregon, that quantified size distribution of harbor seals. In Alaska, adult male harbor seals were significantly longer than females, although females were of greater mass (Pitcher and Calkins, 1979). Female harbor seals collected in Grays Harbor, Washington averaged greater in mass and length than males (Johnson and Jeffries, 1983). Adult males, however, were not collected. The maximum weights and lengths of harbor seals in these studies were similar to those of seals caught in the present study. Males are probably longer than females but weigh less because pregnant females gain weight during pregnancy.

An estimated 46.5% of female harbor seals, and only 19.8% of the males, caught in Oregon were sexually mature. Male harbor seals become sexually mature at 6 years of age, approximately 150 cm in standard length (Bigg, 1969a; Pitcher and Calkins, 1979). Females become sexually mature at 3 - 4 years of age (Bigg, 1969a; Boulva and McLaren, 1979), or 5 years of age (Pitcher and Calkins, 1979). If females are assumed to reach sexual maturity at 4 years of age, this corresponds to a standard length of approximately 130 cm (Pitcher and Calkins, 1979; Johnson and Jeffries, 1983). If harbor seals reach sexual maturity at lengths of 130 - 150 cm, then the population in Oregon appears to be relatively young.

If mature harbor seals use offshore haul-out sites more frequently than immature individuals, then less would be caught in bays. Movements of radio-tagged harbor seals (Chapter 5), however, have indicated that individuals commonly move between bay and offshore haul-out sites within 1 day. Harbor seals were caught only in bays; it is possible that seals using offshore haul-out sites may behave differently.

A great proportion of young individuals is indicative of a growing population. This is supported by estimates that the population is increasing at a rate of approximately 6%/year (Chapter 2). Collections of harbor seals in Grays Harbor also indicated that few adult individuals were present (Johnson and Jeffries, 1983). It still remains to be determined whether most adult males in Oregon are using offshore haul-out sites, and remain unsampled.

Size of prey consumed.--Only Brown and Mate (1983) reported the size of some fishes eaten by harbor seals in Oregon. They estimated an average length of 6.0 - 18.0 cm for 12 species of fishes based on measurements of otoliths collected in harbor-seal feces. Brown and Mate (1983), however, probably underestimated lengths of fish by approximately 27%, as reported in this dissertation. They assumed most of the flatfish species, excluding *P. vetulus*, were consumed outside Netarts Bay, although feces were collected within the bay.

Harbor seals, in this study, consumed *L. armatus* that averaged 2.5 cm greater in standard length than those caught in beach seines in Coos Bay (D. Varoujean, pers. comm.). Harbor seals eat few *L. armatus* less than 8.0 cm in length, a size that appears frequently in seine catches. *L. armatus* grow to 11 -14 cm in length within a year, and individuals 5 -25 cm in length are common in Yaquina Bay from June - November (Bayer 1985a). Larger individuals of this species may move seasonally from the ocean, becoming more abundant in estuaries during summer (Burreson, 1973).

Cymatogaster aggregata caught in Coos Bay averaged 8.4 cm standard length (D. Varoujean, pers. comm.), whereas harbor seals ate individuals averaging 10.5 cm in this bay. C. aggregata, 8 - 16 cm in length, are common in Yaquina Bay from June - October, but smaller individuals are in the estuary during autumn and winter (Bayer, 1985). Generally, harbor seals consumed C. aggregata greater than 9 cm in length, which are older than 1 year and sexually mature (Hart, 1973).

Clupea harengus accounted for 8.1% of the estimated biomass of fishes consumed by harbor seals in 1980, and was primarily adult fish (17 - 24 cm) eaten in southern Oregon. This species averages 16.3 cm in length at spawning (Misitano, 1977). This species spawns in shallow waters of bays and estuaries usually during winter (Spratt, 1981), although in the Columbia River they may spawn in April - July (Misitano, 1977). C. harengus caught in Coos Bay averaged 8.1 cm in standard length (D. Varoujean, pers. comm.); harbor seals consumed fish that averaged 17.4 cm in this bay. In Yaquina Bay, Myers (1980) reported C. harengus, 7 -12 cm in length, were abundant from May - November. Although young of the year are plentiful in many estuaries, harbor seals do not consume them.

Thaleichthys pacificus, the third most commonly consumed fish species in the Columbia River, was an average 17.2 cm (SD = 3.6) in length based on fecal samples, whereas in the fishery it averaged 16.0 (SD = 1.9) in length. Harbor seals in the Columbia River ate larger T. pacificus than elsewhere in the state, probably because more adult fish were available there. This species was the second most abundant fish, comprising 19% of all fishes, found in the Columbia River in 1973 (Misitano, 1977). A large spawning population of T. pacificus enters the river in December, and remains in the river until March (Oregon Dept. Fish and Wildlife, 1986). Adult fish of this species therefore are available in abundance for harbor seals, and numbers of harbor seals increase concurrently with this run of fish (Beach et al., 1985).

Harbor seals consumed predominantly large H. pretiosus ($\bar{X}$ = 14.9 cm), but the 0-age class of this species ($\bar{X}$ = 7.8 cm) was most abundant in seine catches in Coos Bay (D. Varoujean, pers. comm.), and individuals 5 -12 cm in length are most abundant throughout the year in Yaquina Bay (Myers, 1980).

All salmon eaten by seals were adults; no otoliths of juvenile salmon were collected. Although only eight salmon were known to be ingested, they were the largest fishes eaten ($\bar{X}$ = 75.2 cm), comprising a significant portion of the biomass consumed. Otoliths of O. tshawytscha were collected only in harbor-seal feces in the two large river systems, Columbia and Rogue rivers, where large runs of this species occur. The estimated number of salmon consumed by harbor seals, however, is small compared to the numbers of some other fish species consumed by harbor seals. The estimated biomass of salmon eaten by harbor seals was relatively great considering how few individuals were consumed because these fish are large. Biomass eaten may be overestimated if the entire salmon was not consumed. It is likely, however, that biomass of salmon consumed was underestimated, because heads of these fish are frequently not eaten. S. gairdneri were all juveniles, estimated to be less than 24 cm standard length, and were probably consumed by harbor seals in or near estuaries as they migrated into the ocean.

Predation on flatfishes.--Parophrys vetulus was ranked fourth based on estimated biomass of this species consumed by harbor seals. Two distinct size classes (2.0 - 14.0 cm and 15.0 - 30.0 cm standard length) of this species were consumed by harbor seals in Oregon (Fig. 15b). The smaller size class (2 - 14 cm in length) represents 0-age fish, many of which use estuaries as nursery areas during summer (Westerheim, 1955). P. vetulus of 0-age class also may be found offshore in shallow-water (10 - 30 m depth) nursery grounds (Hogue and Carey, 1978; Krygier and Pearcy, 1986). P. vetulus occurs as deep as 220 m (Day and Pearcy, 1968), and larger individuals are usually farther from shore (Demory, 1971). In offshore bottom trawls, P. vetulus is mostly 22 - 28 cm in length (Demory et al., 1976). Most of the 0-age fish, found in diets of harbor seals in Oregon, probably were consumed in estuaries, and larger individuals, averaging approximately 24 cm standard length and 1 - 4 years-of-age (Smith and Nitsos, 1969), were eaten offshore. Harbor seals seem to switch from eating 0-age P. vetulus during the summer in estuaries, to consuming larger individuals offshore during the winter. Greater than 90% of P. vetulus consumed by harbor seals were less than three years old, the age at which these fish enter the commercial fishery.

In 1980, G. zachirus ranked fifth in estimated biomass and ninth in number of fish consumed by harbor seals in Oregon. This species is found as deep as 600 m (Day and Pearcy, 1968), although most of the population occurs between 60 and 180 m depth (Demory, 1971). Harbor seals mainly consumed G. zachirus of 15 - 28 cm standard length, that corresponds to ages of 4 - 10 years (Hosie and Horton, 1977). This species does not enter estuaries, therefore harbor seals must catch these fish offshore. Pearcy (1978) reported a peak in abundance of larger individuals of this species at 190 m depth; therefore harbor seals may be diving in water this deep to catch this species.

Citharichthys stigmaeus commonly occur in estuaries in Oregon (Hostick, 1975), generally as juveniles (6.0 - 11.0 cm standard length); most larger individuals of this species are found in offshore water of less than 100 m depth (Demory, 1971; Pearcy, 1978). Lengths of C. stigmaeus in the diet of harbor seals correspond to lengths of fish found in the estuaries (Howe, 1980). Harbor seals ate mostly 0-age C. sordidus in Netarts Bay, 2 - 3-year-old fish near Coos Bay, and older individuals near the Columbia River.

Platichthys stellatus and P. melanostictus also occur in estuaries and in the diet of harbor seals. Harbor seals fed primarily on juvenile P. stellatus, 10 - 16 cm standard length, whereas many individuals in estuaries are 16 - 50 cm in length and 1 - 6 years old (Beardsley, 1969). Although this species is distributed throughout the estuary, larger individuals usually are located in the lower bay (Cummings and Berry, 1974), where harbor seals are most commonly observed. Harbor seals consumed P. melanostictus larger than 17 cm SL and found in offshore areas.

The remaining species of flatfishes (L. exilis, M. pacificus, I. isolepis, A. stomias, E. jordani, L. bilineata, and Pleuronichthys sp.) were relatively large individuals and undoubtedly consumed by harbor seals offshore, because few individuals are found in estuaries (Myers, 1980; Bayer, 1981; Bottom et al., 1984).

Harbor seals seem to consume a limited size range of fishes, but most of the most abundant species found in Oregon estuaries and nearshore environment. Most of these fishes are benthic or small schooling species. Some species that were not commonly eaten by harbor seals but were commonly reported in Oregon estuaries were: *Atherinops affinis*, *Lumpenus sagitta*, and many of the Embiotocidae (Mullen, 1977; Myers, 1980; Bottom et al., 1984). These data seem to indicate harbor seals feed opportunistically on the most abundant, available fish species. Because the biomass and number of fish is greatest in estuaries during spring and summer (Myers, 1980; Bayer, 1981; Bottom et al., 1984), harbor seals feed in estuaries during this period, then feed in the ocean during winter. Harbor seals consume many juveniles and smaller species of fish in estuaries, and larger individuals offshore. Estimates of annual fish consumption for individual species were therefore influenced by the bias towards smaller fish represented in the fecal samples collected in estuaries.

Annual fish consumption.--In 1980, commercial fisherman in Oregon landed 12,448.7 metric tons of fishes of the same species eaten by harbor seals (Lukas and Carter, 1985). During that year, harbor seals consumed an estimated 3,067.9 metric tons (24.6%) of the same species of fishes landed commercially. Harbor seals consumed amounts equivalent to 60.3%, 113.9%, and 63.1% of commercial landings of P. vetulus, P. stellatus, and G. zachirus, respectively. Harbor seals consumed an estimated 1,321.5 metric tons of flatfishes, and 533.0 metric tons of salmon, 22.3% and 16.5% of the commercial catch of these groups, respectively.

These estimates of fish consumed by harbor seals in Oregon are much less than reported for harbor seal populations in the Bering Sea. The number of harbor seals in the North Pacific Ocean, however, is approximately 50 times that in Oregon, and most of the calculations have assumed a feeding rate for harbor seals twice that used in this study. Laevastu and Favorite (1978) estimated that harbor seals consumed 66,900 tons of herring, 6,700 tons of salmon, 89,200 tons of pollock, 8,900 tons of flatfishes, 13,400 tons of other gadids, and 31,200 tons of other pelagic fish. In the eastern Bering Sea, an estimated population of 42,000 harbor seals annually consumed 102,600 metric tons of food (64% fishes) (McAlister and Perez, in litt.). Harbor seals ate 16.8% of the total biomass of fish consumed by pinnipeds in the eastern Bering Sea. In these calculations, they assumed that harbor seals were consuming 5% of their body mass per day in food. Laevastu and Favorite (1978) reported that the biomass of fishes removed from the Bering Sea by marine mammals was in excess of that taken by human fisheries. McAlister and Perez (in litt.) used feeding rates of captive pinnipeds to estimate daily energy intake. Harbor seals consumed 4.3% of food eaten by pinnipeds in the eastern Bering Sea, and 0.2% of standing biomass of all fish species in this region. In the eastern Bering Sea, walleye pollock (Theragra chalcogramma) is the most abundant fish species caught in fisheries and by marine mammals.

Effects of harbor-seal predation on nearshore fish community.--Natural mortality was calculated for only one fish species, Parophrys vetulus, because there were insufficient data on other species. Total natural mortality of P. vetulus was estimated using data from a population analysis provided by Golden et al. (1986), and extrapolated to cover the Oregon coast. Harbor seals in Oregon fed primarily on P. vetulus less than 30 cm length, which corresponds to an age of less than 5 years old (Smith and Nitsos, 1969). Therefore, I estimated natural mortality for P. vetulus of that age group. Golden et al. (1986) provided estimates of abundance for P. vetulus 3 years and older, and I back-calculated abundance of newly metamorphosed to two-year-old individuals using natural mortality figures given by Peterman et al. (1987). I applied natural mortality figures (Golden et al., 1986;

Peterman et al., 1987) to each age class from newly metamorphosed to 4 years old, and estimated 931.7 million _P. vetulus_ died of natural causes during 1980, of which harbor seals consumed 9.5 million. Therefore, an estimated 1.02% of _P. vetulus_ natural mortality was attributed to harbor seals in 1980. Although harbor seals seemed to consume a large quantity of 0-age _P. vetulus_ (74.3% of _P. vetulus_ consumed), the proportion of natural mortality attributed to harbor seal predation was minimal because natural mortality was at its highest during the first year. I estimated harbor seals were responsible for 5.5% of the natural mortality of _P. vetulus_ 1 - 4 years-of-age. Harbor-seal predation on juvenile _P. vetulus_ was probably underestimated, because fecal samples were collected mostly during the summer when juvenile _P. vetulus_ occupy the estuaries.

The effects of harbor seal predation on a fishery resource are difficult to assess because fish recruitment and harbor seal predation change dramatically from year to year. Because harbor seals are consuming mostly juvenile _P. vetulus_, their impact is two fold: reducing abundance of fish before recruitment to the fishery, and before sexual maturity which might affect future production. Harbor-seal abundance seems to be increasing, therefore predation on _P. vetulus_ will probably increase also. Recruitment of 3 year old _P. vetulus_ into the fishery has steadily declined since 1977 (Golden et al., 1986), possibly because of long-term changes in the environment, overfishing, and increased harbor-seal predation.

Estuaries serve as a nursery grounds for many fish species, including: C. harengus, P. vetulus, P. stellatus, C. stigmaeus, H. pretiosus, and C. aggregata (Pearcy and Myers, 1974). These areas may be suitable for juvenile fishes because they are more protected, have a greater abundance of prey, warmer water, and contain less large predators than in the ocean (Pearcy and Myers, 1974; Rosenberg, 1982). Harbor seals may be one of a few large predators that prey on juvenile and small adult fish in estuaries. Brandts cormorants (Phalacrocorax penicillatus) and great blue herons (Ardea herodias) consume flatfishes, sculpins, and anchovies (Ainley et al., 1981; R. Bayer, pers. comm.). Few fish, however, are known to feed on other fishes in Oregon estuaries. L. armatus consumes mainly invertebrates, although occasionally it eats E. mordax, C. harengus, and C. aggregata (Jones, 1962). Some species of flatfish are consumed by P. melanostictus and P. stellatus (Orcutt, 1950; Miller, 1967). Harbor seals, therefore, seem to have few competitors for fish prey in estuaries, and this also may be true in offshore areas.

Most seabird predators, feeding in the nearshore environment in Oregon, consume small schooling fishes (Engraulidae, Osmeridae, and Clupeidae), Sebastes sp., Cottidae, flatfishes, and cephalopods (Scott, 1973; Ainley, et al., 1981; Matthews, 1983). Harbor seals generally consumed larger fish of those species also eaten by seabirds. For instance, Scott (1973) reported E. mordax eaten by pelagic cormorants (Phalacrocorax pelagicus) in Oregon were an average 10.5 cm in length, whereas harbor seals, in the present study, ate individuals an average 12.9 cm in length.

Harbor seals in Oregon probably do not compete extensively for fish prey with other pinniped species, such as Zalophus californianus and Eumetopias jubatus. These pinnipeds feed primarily on fishes, such as M. productus, Sebastes sp., M. productus, and T. symmetricus (Morejohn et al., 1978; Fiscus, 1979; Heath and Francis, 1983; Antonelis et al., 1984) that are found in deeper water and farther offshore. Additionally, Oregon harbor seals consume fishes an average 13 - 15 cm standard length, whereas many of the fish eaten by Z. californianus and E. jubatus are an average 15 - 17 cm in length (Antonelis et al., 1984). It seems that nearshore vertebrate predators exploit different habitats and size classes of fishes. Harbor seals are generally prey on benthic and schooling fishes in water less than 200 m depth.

The potential impact of harbor-seal predation on some populations of fishes may be substantial, and deserves additional consideration. Harbor seal abundance seems to be increasing, but more studies are needed to quantify variability in counts and percent of individuals not counted during surveys. Otoliths can be used, once correction factors have been established, to determine number and size of fish consumed by harbor seals. Better estimates of annual fish consumption than those provided in this study, however, require systematic collections of feces throughout the year and at a more representative sample of haul-out sites. Once these additional studies are completed, estimates of annual food consumption by harbor seals may be improved. Considering the potential for increased predation by harbor seals on some commercial species of fishes, especially some juvenile flatfishes, these studies are important and should be of great value to fishery management.

BIBLIOGRAPHY

Ainley, D. G., D. W. Anderson, and P. R. Kelly. 1981. Feeding ecology of marine cormorants in southwestern North America. Condor, 83:120-131.

Allen, S. G. 1985. Mating behavior in the harbor seal. Mar. Mamm. Sci., 1:84-87.

Allen, S. G., and H. R. Huber. 1984. Pinniped assessment in Point Reyes, California 1983-1984. Point Reyes Bird Observatory, Stinson Beach, California, Final Rept., 71 pp.

Allen, S. G., D. G. Ainley, G. W. Page, and C. A. Ribic. 1984. The effect of disturbance on harbor seal haul out patterns at Bolinas Lagoon, California. Fish. Bull., 82:493-500.

Antonelis, G. A., Jr. and M. A. Perez. 1984. Estimated annual food consumption by northern fur seals in the California current. California Coop. Oceanic Fish. Invest. Rept., 25:135-145.

Antonelis, G. A., Jr., C. H. Fiscus, and R. L. DeLong. 1984. Spring and summer prey of California sea lions, Zalophus californianus, at San Miguel Island, California, 1978-79. Fish. Bull., 82:67-76.

Antonelis, G. A., Jr., M. S. Lowry, D. P. DeMaster, and C. H. Fiscus. 1987. Assessing northern elephant seal feeding habits by stomach lavage. Mar. Mamm. Sci., 3:308-322.

Appelbaum, S. and T. Hecht. 1978. Otolith length/fish length relationship of leptocephali elvers and sub-adult (reared) eels, Anquella anquilla. Environ. Biol. Fishes, 3:245-247.

Bayer, R. D. 1981. Shallow-water intertidal ichthyofauna of the Yaquina estuary, Oregon. Northwest Sci., 55:182-193.

------. 1985a. Shiner perch and Pacific staghorn sculpin in Yaquina estuary, Oregon. Northwest Sci., 59:230-240.

------. 1985b. Six years of harbor seal censusing at Yaquina estuary, Oregon. Murrelet, 66:44-49.

Beach, R. J., A. C. Geiger, S. J. Jeffries, S. D. Treacy, and B. L. Troutman. 1985. Marine mammals and their interactions with fisheries of the Columbia River and adjacent waters, 1980-1982. Natl. Mar. Fish. Serv., Northwest Alaska Fish. Center, Seattle, Washington, Processed Rept., 85-04:1-316.

Beardsley, A. J. 1969. Movement and angler use of four foodfishes in Yaquina Bay, Oregon. Unpubl. Ph.D. dissert., Oregon State Univ., Corvallis, 173 pp.

Beddington, J. R., R. J. H. Beverton, and D. M. Lavigne (eds.). 1985. Marine mammals and fisheries. Geo. Allen and Unwin, London, 544 pp.

Bigg, M. A. 1969a. The harbour seal in British Columbia. Fish. Res. Board Canada, Bull., 172:1-33.

------. 1969b. Clines in the pupping season of the harbour seal, Phoca vitulina. J. Fish. Res. Board Canada, 26:449-455.

------. 1981. Harbour seal, Phoca vitulina Linnaeus, 1758 and Phoca largha Pallas, 1811. Pp. 1-27, in Handbook of marine mammals, Vol. 2: Seals (S. H. Ridgway and R. J. Harrison, F. R. S., eds.). Academic Press, London, 359 pp.

Bishop, R. H. 1967. Reproduction, age determination, and behavior of the harbor seal, Phoca vitulina L. in the Gulf of Alaska. Unpubl. M.S. thesis, Univ. Alaska, Anchorage, 121 pp.

Bonner, W. N., and S. R. Witthames. 1974. Dispersal of common seals (Phoca vitulina), tagged in the Wash, East Anglia. J. Zool., 174:528-531.

Bottom, D. L., K. K. Jones, and M. J. Herring. 1984. Fishes of the Columbia River estuary. Final Report of Columbia River Data Development Program by Oregon Dept. Fish Wildl., 506 Mill St., P. O. Box 3503, Portland, Oregon 97208, 113 pp.

Boulva, J., and I. A. McLaren. 1979. Biology of the harbor seal, _Phoca vitulina_, in eastern Canada. Fish. Res. Board Canada, Bull., 200:1- 24.

Briggs, K. T., and C. W. Davis. 1972. A study of predation by sea lions on salmon in Monterey Bay. California Fish Game, 58:37-43.

Brown, R. F. 1986. Assessment of pinniped populations in Oregon. Natl. Mar. Fish. Serv., Northwest Alaska Fish. Center, Seattle, Washington, Final Rept., 44 pp.

Brown, R. F., and J. T. Harvey. 1981. Movements and dive behavior of radio-tagged harbor seals. Fourth Biennial Conf. Biol. Mar. Mamm., 14-18 December 1981, San Francisco, California, Abstr., Pp. 14.

Brown, R. F., and B. R. Mate. 1983. Abundance, movements, and feeding habits of harbor seals, _Phoca vitulina_, at Netarts and Tillamook Bays, Oregon. Fish. Bull., 81:291-301.

Burreson, E. M. 1973. Host-parasite relationships of the staghorn sculpin, _Leptocottus armatus_ Girard, in Oregon. Unpubl. M.S. thesis, Oregon State Univ., Corvallis, Oregon, 68 pp.

Calambokidis, J., et al. 1978. Chlorinated hydrocarbon concentrations and the ecology and behavior of harbor seals in Washington state waters. Natl. Sci. Found., Evergreen State College, Olympia, Washington, Final Rept., 121 pp.

Casteel, R. 1974. Use of Pacific salmon otoliths for estimating fish size, with a note on the size of late Pleistocene and Pliocene salmonids. Northwest Sci., 48:175-179.

Clarke, M. R. 1962. The identification of cephalopod beaks and the relationship between beak size and total body weight. Bull. British Mus. Nat. Hist., 8:419-480.

------. 1980. Cephalopods in the diet of sperm whales of the southern hemisphere and their bearing on sperm whale biology. Discovery Rept., 37:1-324.

Committee on Marine Mammals. 1967. Standard measurements of seals. J. Mamm., 48:459-462.

Condy, P. R. 1981. Annual food consumption, and seasonal fluctuations in biomass of seals at Marion Island. Mammalia, 45:21-30.

Contos, E. 1982. Marine mammal fisheries interactions coordination workshop, 26 October 1981. Research Summaries, Vancouver, Washington, 64 pp.

Costa, D. 1978. The sea otter: it's interaction with man. Oceanus, 21:24-30.

Cummings, T. E., and R. L. Berry. 1974. Some observations on fish distribution in Tillamook Bay, Oregon, with notes on shelfish, temperature, and physical characteristics. Fish Commission Oregon, Coastal Rivers Invest., Inf. Rept., 74-1:1-29.

da Silva, J., and J. D. Neilson. 1985. Limitations of using otoliths recovered in scats to estimate prey consumption in seals. Canadian J. Fish. Aquatic Sci., 42:1439-1442.

Day, D. S., and W. G. Pearcy. 1968. Species associations of benthic fishes on the continental shelf and slope off Oregon. J. Fish. Res. Board Canada, 25:2665-2675.

Dayton, P. K. 1975. Experimental studies of algal canopy interactions in a sea otter dominated kelp community at Amchitka Island, Alaska. Fish. Bull., 73:230-237.

DeMaster, D. P., D. J. Miller, D. Goodman, R. L. DeLong, and B. S. Stewart. 1982. Assessment of California sea lion fishery interactions. Trans. 47th North Amer. Wildl. Natural Resource Conf., Pp. 253-264.

Demory, R. L. 1971. Depth distribution of some small flatfishes off the northern Oregon-southern Washington coast. Fish Commission Oregon, Res. Rept., 3:44-48.

Demory, R. L., M. J. Hosie, N. T. Eyck, and B. O. Forsberg. 1976. Marine resource surveys on the continental shelf off Oregon, 1971-74. Oregon Dept. Fish Wildl., Completion Rept., 49 pp.

Eberhardt, L. L., and D. B. Siniff. 1977. Population dynamics and marine mammal policies. J. Fish. Res. Board Canada, 34:183-190.

Eberhardt, L. L., D. G. Chapman, and J. R. Gilbert. 1979. A review of marine mammal census methods. Wildl. Monogr., 63:1-46.

Estes, J. 1976. The reliability of aerial surveys to estimate population abundance of marine mammals: Considerations from a survey of Pacific walruses. Advisory Com. Mar. Resources Res., 31 August - 9 September 1976, Bergen, Norway, Food and Agric. Org. United Nations, ACMRR/MM/SC/80:1-13.

Estes, J. A., and J. F. Palmisano. 1975. Sea otters: their role in structuring nearshore communities. Science, 185:1058-1060.

Everitt, R. D., and H. W. Braham. 1980. Aerial survey of Pacific harbor seals in the southeastern Bering Sea. Northwest Sci., 54:281-288.

Everitt, R. D., and S. J. Jeffries. 1979. Marine mammal investigations in Washington, 1975-1979. Third Biennial Conf. Biol. Mar. Mamm., 7-11 October 1979, Seattle, Washington, Abstr., Pp. 18.

Everitt, R. D., C. H. Fiscus, and R. L. Delong. 1980. Northern Puget Sound marine mammals. Office Energy, Minerals, Industry, Office Res. and Develop., U. S. Environ. Protect. Agency, Washington, D. C., 132 pp.

Everitt, R. D., R. J. Beach, A. C. Geiger, S. J. Jeffries, and S. D. Treacy. 1981. Marine mammal-fisheries interactions on the Columbia River and adjacent waters, 1980. Washington Dept. Game, Olympia, Annual Rept. March 1, 1980 to October 31, 1980, 109 pp.

Fancher, L. E., and D.J. Alcorn. 1982. Harbor seal census in south San Francisco Bay (1972-1977 and 1979-1980). California Fish Game, 68:118-124.

Fedak, M. A., S. S. Anderson, and M. G. Curry. 1982. Attachment of a radio tag to the fur of seals. Notes Mamm. Soc., 49:298-300.

Fiscus, C. H. 1979. Interactions of marine mammals and Pacific hake. U. S. Natl. Mar. Fish. Serv., Mar. Fish. Rev., 41:1-9.

______. 1980. Marine mammal - salmonid interactions: a review. Pp. 121-132, in Salmonid ecosystems of the North Pacific (J. McNeil and D. C. Himsworth, eds.). Oregon State Univ. Press, Corvallis,

Floyd, T. J., L. D. Mech, and M. E. Nelson. 1979. An improved method of censusing deer in deciduous-coniferous forests. J. Wildl. Mgmt., 43:258-261.

Frost, K. J., and L. F. Lowry. 1980. Feeding of ribbon seals (Phoca fasciata) in the bering Sea in spring. Canadian J. Zool., 58:1601-1607.

------. 1981. Trophic importance of some marine gadids in northern Alaska and their body-otolith size relationships. Fish. Bull., 79:187-192.

Gearin, P., B. Pfeifer, S. Jeffries. 1986. Control of California sea lion predation on winter-run steelhead at the Hiram M. Chittenden Locks, Seattle, December 1985-April 1986 with observations on sea lion abundance and distribution in Puget Sound. Washington Dept. Game, Fish. Mgmt. Rept., 86-20:1-108.

Golden, J. T., R. L. Demory, E. K. Pikitch, and W. H. Barss. 1986. Results of virtual population analysis of English sole in the INPFC Columbia River - Vancouver areas. Final Rept. to National Marine Fisheries Service by Oregon Dept. Fish Wildl., Hatfield Marine Science Center, Newport, Oregon 97365, 89 pp.

Goodman, L. A. 1960. On the exact variance of products. J. Amer. Stat. Assoc., 55:708-713.

Graybill, M. R. 1981. Haul out patterns and diet of harbor seals, Phoca vitulina, in Coos County, Oregon. Unpubl. M.S. thesis, Univ. Oregon, Eugene, 55 pp.

Grunewald, K. K., and T. J. Tucker. 1985. Gastric emptying in exercised mice. Comp. Biochem. Physiol., 80A:173-175.

Guyton, A. C. 1981. Textbook of medical physiology. Sixth ed. W. B. Saunders Co., Philadelphia, 1074 pp.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Canada, Bull., 180:1-740.

Havinga, B. 1933. Der seehund (Phoca vitulina L.) in den hollaendischen gewaessern. Ned. Dierkd. Ver., Tijdschr., 3:79-111.

Hawes, S. D. 1983. An evaluation of California sea lion scat samples as indicators of prey importance. Unpubl. M.S. thesis, San Francisco State Univ., California, 50 pp.

Heath, C. B., and J. M. Francis. 1983. Population dynamics and feeding ecology of the California sea lion with applications for management: results of 1981-1982 research on Santa Barbara and San Nicolas Islands. Natl. Mar. Fish. Serv., Southwest Fish. Center, La Jolla, California, Admin. Rept., LJ-83-04C:1-48.

Hellebrandt, F. A., and R. H. Tepper. 1934. Studies on the influence of exercise on the digestive work of the stomach. II. Its effects on emptying time. Amer. J. Physiol., 107:355-363.

Helm, R. C. 1983. Intestinal length of three California pinniped species. J. Zool., 199:297-304.

Helm, R. C. 1984. Rate of digestion in three species of pinnipeds. Canadian J. Zool., 62:1751-1756.

Herder, M. J. 1986. Seasonal movements and hauling site fidelity of harbor seals, Phoca vitulina richardsi, tagged at the Klamath River, California. Unpubl. M.S. thesis, Humboldt State Univ., Arcata, California, 52 pp.

Hirose, P. 1977. Incidence of seal-damaged salmonids sampled from the lower Columbia River gillnet fishery, 1972-1976. Oregon Dept. Fish Wildl., Inf. Rept., 77-4:1-6.

Hochachka, P. W. 1981. Brain, lung, and heart functions during diving and recovery. Science, 212:509-514.

Hogue, E. W., and A. G. Carey. 1978. Feeding ecology of 0-age flatfishes at a nursery ground on the Oregon coast. Fish. Bull., 80:555-565.

Hosie, M. J., and H. F. Horton. 1977. Biology of rex sole, Glyptocephalus zachirus, in waters off Oregon. Fish. Bull., 75:51-60.

Hostick, G. A. 1975. Numbers of fish captured in beach seine hauls in Coos River estuary, Oregon, June through September 1970. Fish Commission Oregon, Coastal Rivers Invest., Inf. Rept., 74-11:1-22.

Howe, K. M. 1980. Habitats, distribution, and abundance of the summer ichthyofauna of Netarts Bay, Oregon. Oregon State Univ. Agric. Exp. Stn., Tech. Paper, 5416:1-38.

Imler, R. H., and H. R. Sarber. 1947. Harbor seals and sea lions in Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rept., 28:1-22.

Innes, S., D. M. Lavigne, W. M. Earle, and R. M. Korvacs. 1987. Feeding rates of seals and whales. J. Anim. Ecol., 56:115-130.

Jobling, M., and A. Breiby. 1986. The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. Sarsia, 71:265-274.

Johnson, M. L., and S. J. Jeffries. 1983. Population biology of the harbor seal (Phoca vitulina richardsi) in the waters of the state of Washington: 1976-1977. U.S. Dept. Commerce, Natl. Tech. Inf. Serv., PB83-159715:1-53.

Jones, A. C. 1962. The biology of the euryhaline fish, Leptocottus armatus armatus Girard. Univ. California Publ. Zool., 67:321-368.

Jones, R. E. 1981. Food habits of smaller marine mammals from northern California. Proc. California Acad. Sci., 42:409-433.

Kenyon, K. W. 1965. Food of harbor seals at Amchitka Island, Alaska. J. Mamm., 46:103-104.

Ketchen, K. S. 1967. Length composition of Pacific cod (Gadus macrocephalus) in landings by Canadian trawlers, 1951-66. Fish. Res. Board Canada, Tech. Rept., 23:1-27.

Knudsen, P. M. 1974. Birth of a harbor seal. Nat. Hist., 83:30-37.

Krygier, E. E., and W. G. Pearcy. 1986. The role of estuarine and offshore nursery areas for young English sole, Parophrys vetulus Girard, of Oregon. Fish. Bull., 84:119-132.

Laevastu, T., and F. Favorite. 1978. Dynamical numerical marine ecosystem model (DYNUMES II) for eastern Bering Sea. Natl. Mar. Fish. Serv. Ecosystem Model Workshop, 7-9 February 1978, Northwest Alaska Fish. Center, Seattle, Washington, Rept., 81 pp.

Laevastu, T., P. Livingston, and K. Niggol. 1980. Marine mammals in fisheries ecosystem in the eastern Bering Sea and in the northeastern Pacific Ocean. Part 2. Consumption of fish and other marine biota by mammals in the eastern Bering Sea and Aleutian region. Natl. Mar. Fish. Serv., Northwest Alaska Fish. Center, Seattle, Washington, Processed Rept., 80-10:1-13.

Lavigne, D. M., S. Innes, R. E. A. Stewart, and G. A. J. Worthy. 1985. An energy budget for Northwest harp seals. Pp. 319-336, in Marine mammals and fisheries (J. E. Beddington, R. J. H. Beverton, and D. M. Lavigne, eds.). George Allen and Unwin Publ., London, 354 pp.

Lavigne, D. M., et al. 1986. Metabolic rates of seals and whales. Canadian J. Zool., 64:279-284.

Ling, J. K., C. E. Button, and B. A. Ebsary. 1974. A preliminary account of gray seals and harbor seals at Saint-Pierre and Miquelon. Canadian Field-Nat., 88:461-468.

Loughlin, T. R. 1978. Harbor seals in and adjacent to Humboldt Bay, California. California Fish Game, 64:127-132.

Loughlin, T. R., and R. Nelson. 1986. Incidental mortality of northern sea lions in Shelikof Strait, Alaska. Mar. Mamm. Sci., 2:14-33.

Lukas, J., and C. Carter. 1985. Pounds and value of commercially caught fish and shellfish landed in Oregon 1984. Oregon Dept. Fish Wildl., Portland, 69 pp.

Mate, B. R. 1977. Aerial censusing of pinnipeds in the eastern Pacific for assessment of the population numbers, migratory distributions, rookery stability, breeding effort, and recruitment. Mar. Mamm. Commission, Natl. Tech. Inf. Serv., PB-265859:1-67.

------. 1980. Workshop report on marine mammal-fisheries interactions in the eastern Pacific. Natl. Tech. Inf. Serv., PB80-175144:1-48.

Matthews, D. R. 1983. Feeding ecology of the common murre, Uria aalge, off the Oregon coast. M.S. Thesis, Univ. Oregon, Eugene, 108 pp.

McAlister, W. B., and M. A. Perez. 1976. Ecosystem dynamics birds and marine mammals. Part 1. Preliminary estimates of pinniped-finfish relationships in the Bering Sea. Environ. Assessment Alaskan Continental Shelf, Bur. Land Mgmt., RU-77:1-29.

McMahon, T. E., and J. C. Tash. 1979. Effects of formalin (buffered and unbuffered) and hydrochloric acid on fish otoliths. Copeia, 1975:155-156.

Messersmith, J. D. 1969. The northern anchovy (Engraulis mordax) and its fishery 1965-1968. California Fish Game, Fish Bull., 147:1-102.

Miller, B. S. 1967. Stomach contents of adult starry flounder and sand sole in East Sound, Orcas Island, Washington. J. Fish. Res. Board Canada, 24:2515-2526.

Miller, D. J., and R.N. Lea. 1972. Guide to the coastal marine fishes of California. California Fish Game, Fish. Bull., 157:1-249.

Miller, D. J., M. J. Herder, and J. P. Scholl. 1983. California marine mammal-fishery interactions study, 1979-1981. Natl. Mar. Fish. Serv., Southwest Fish. Center, La Jolla, California, Admin. Rept., LJ-83-13C:1-233.

Mina, M. V. 1967. Study of the relation between weight of an otolith (sagitta) and the length of an individual in the cod population of the Barents and White Seas. Fish. Res. Board Canada, Trans. Ser., 990:1968.

Misitano, D. A. 1977. Species composition and relative abundance of larval and post-larval fishes in the Columbia River estuary, 1973. Fish. Bull., 75:218-222.

Morejohn, G. V., J. T. Harvey, and L. K. Krasnow. 1978. The importance of Loligo opalescens in the food web of marine vertebrate in Monterey Bay, California. California Fish Game, Fish. Bull., 169:67-98.

Mullen, R. E. 1977. The occurrence and distribution of fish in the Umpqua River estuary, June through October, 1972. Oregon Dept. Fish Wildl., Info. Res.Ser., Fish., 77-3:1-39.

Murie, D. J., and D. M. Lavigne. 1985. A technique for the recovery of otoliths from stomach contents of piscivorous pinnipeds. J. Wildl. Mgmt., 49:910-912.

------. 1986. Interpretation of otoliths in stomach content analyses of phocid seals: quantifying fish consumption. Canadian J. Zool., 64:1152-1157.

Myers, K. W. W. 1980. An investigation of the utilization of four study areas in Yaquina Bay, Oregon by hatchery and wild juvenile salmonids. Unpubl. M.S. thesis, Oregon State Univ., Corvallis, 234 pp.

Neter, J., and W. Wasserman. 1974. Applied linear statistical models. Richard D. Irwin, Inc., Homewood, Illinois, 842 pp.

Newby, T. C. 1973. Changes in the Washington state harbor seal population. Murrelet, 54:4-6.

North, A. W., J. P. Croxall, and D. W. Doidge. 1983. Fish prey of the Antarctic fur seal <u>Arctocephalus gazella</u> at South Georgia. British Antarctic Survey, Bull., 61:27-37.

Norton-Griffiths, M. 1974. Reducing counting bias in aerial censuses by photography. J. East African Wildl., 12:245-248.

Orcutt, H. G. 1950. The life history of the starry flounder, Platichthys stellatus (Pallus). California Fish Game, Fish. Bull., 78:1-64.

Oregon Department of Fish and Wildlife. 1986. Columbia River fish runs fisheries, 1960-85. Oregon Dept. Fish Wildl. and Wash. Dept. Fish., Rept., 77pp.

Packard, J. M., R. C. Summers, and L. B. Barnes. 1985. Variation of visibility bias during aerial surveys of manatees. J. Wildl. Mgmt., 49:347-351.

Payne, P. M., and D. C. Schneider. 1984. Yearly changes in abundance of harbor seals, Phoca vitulina, at a winter site in Massachusetts. Fish. Bull., 82:440-442.

Pearcy, W. G. 1978. Distribution and abundance of small flatfishes and other demersal fishes in a region of diverse sediments and bathymetry off Oregon. Fish. Bull., 76:629-640.

Pearcy, W. G. and S. S. Myers. 1974. Larval fishes of Yaquina Bay, Oregon: A nursery ground for marine fishes?. Fish Bull., 72:201-213.

Pearson, J. P. 1969. The abundance and distribution of harbor seals and Steller sea lions in Oregon. Unpubl. M.S. thesis, Oregon State Univ., Corvallis, 23 pp.

Pearson, J. P., and B. J. Verts. 1970. Abundance and distribution of harbor seals and northern sea lions in Oregon. Murrelet, 51:1-5.

Perez, M. A., and E. E. Mooney. 1986. Increased food and energy consumption of lactating northern fur seals, Callorhinus ursinus. Fish. Bull., 84:371-381.

Peterman, R. M., M. J. Bradford, and G. H. Kruse. 1988. Simulation model of English sole (Parophrys vetulus) population dynamics in Washington and Oregon coastal waters. Can. J. Fish. Aquat. Sci., in press.

Pitcher, K. W. 1980a. Food of the harbor seal, Phoca vitulina richardsi, in the Gulf of Alaska. Fish. Bull., 78: 544-549.

------. 1980b. Stomach contents and feces as indicators of harbor seal, Phoca vitulina, foods in the Gulf of Alaska. Fish. Bull., 78:797-798.

Pitcher, K. W., and D. G. Calkins. 1979. Biology of harbor seal, Phoca vitulina richardsi, in the Gulf of Alaska. Outer Continental Shelf Environ. Assessment Prog., Final Rept., 79 pp.

Pitcher, K. W., and D. C. McAllister. 1981. Movements and haulout behavior of radio-tagged harbor seals, _Phoca_ _vitulina_. Canadian Field-Nat., 95:292-297.

Power, G., and J. Gregoire. 1978. Predation of freshwater seals on the fish community of Lower Seal Lake, Quebec. J. Fish. Res. Board Canada, 35:844-850.

Puustinen, W. W. 1975. Seals and sea lions cause loss to fishery. Columbia River Gillnetter, 6:7-8.

Renouf, D., L. Gaborko, G. Galway, and R. Finlayson. 1981. The effect of disturbance on the daily movements of harbour and grey seals between the sea and their hauling grounds at Miquelon. Appl. Anim. Ethol., 7:292-297.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Canada, Bull., 191:1-382.

Robins, C. R., et al. 1980. A list of common and scientific names of fishes from the United States and Canada. Amer. Fish. Soc. Spec. Publ. No. 12, 175pp.

Roffe, T. J. 1980. Population, food habits, and behavior of pinnipeds in the Rogue River and their relation to salmonid runs. Unpubl. Ph.D. dissert., Oregon State Univ., Corvallis, 155 pp.

Roffe, T. J., and B. R. Mate. 1984. Abundances and feeding habits of pinnipeds in the Rogue River, Oregon. J. Wildl. Mgmt., 48:1262-1274.

Rosenberg, A. A. 1982. Growth of juvenile English sole, Parophrys vetulus, in estuarine and open coastal nursery grounds. Fish. Bull., 80:245-258.

Scheffer, T. H. 1928. Precarious status of the seal and sea-lion on our northwest coast. J. Mamm., 9:10-16.

Scheffer, V. B., and J. W. Slipp. 1944. The harbor seal in Washington state. Amer. Midland Nat., 32:372-416.

Scheffer, T. H., and C. C. Sperry. 1931. Food habits of the pacific harbor seal, Phoca richardsi. J. Mamm., 12:214-226.

Schneider, D. C., and P. M. Payne. 1983. Factors affecting haul-out of harbor seals at a site in southeastern Massachusetts. J. Mamm., 64:518-520.

Scholander, P. F. 1940. Experimental investigations on the respiratory function in diving mammals and birds. Hvalrad Skr., 221-131.

Scott, J. M. 1973. Resource allocation in four synpatric species of marine diving birds. Ph.D. thesis, Oregon State University, Corvallis, 97 pp.

Seber, G. A. F. 1982. The estimation of animal abundance. MacMillan Publ. Co., Inc., N. Y., 654 pp.

Smith, J. G. and R. J. Nitsos. 1969. Age and growth studies of English sole, Parophrys vetulus, in Monterey Bay, California. Pacific Mar. Fish. Comm. Bull., 7:73-79.

Smith, T. G. 1973. Censusing and estimating the size of ringed seal populations. Fish. Res. Bd. Canada, Tech. Rept., 427:1-23.

Snedecor, G. W., and W. G. Cochran. 1980. Statistical methods. Seventh ed. Iowa State Univ. Press, Ames, 507 pp.

Southward, G. M. 1962. A method of calculating body lengths from otolith measurements for Pacific halibut and its application to portlock-albatross grounds data between 1935 and 1957. J. Fish. Res. Board Canada, 19:339-362.

Spalding, D. J. 1964. Comparative feeding habits of the fur seal, sea lion, and harbour seal on the British Columbia coast. Fish. Res. Board Canada, Bull., 146:1-52.

Spratt, J. D. 1975. Growth rate of the northern anchovy, Engraulis mordax, in southern California waters, calculated from otoliths. California Fish Game, 61:116-126.

------. 1981. The status of the Pacific herring, Clupea harengus pallasii, resource in California 1972-1980. California Fish Game, Fish Bull., 171:1-107.

Stewart, B. S. 1981. Seasonal abundance, distribution, and ecology of the harbor seal, _Phoca vitulina richardsi_, on San Miguel Island, California. Unpubl. M.S. thesis, San Diego State Univ., California, 66 pp.

------. 1984. Diurnal hauling patterns of harbor seals at San Miguel Island, California. J. Wildl. Mgmt., 48:1459-1461.

Stewart, B. S., and P. K. Yochem. 1983. Radiotelemetry studies of hauling patterns, movements, and site fidelity of harbor seals (_Phoca vitulina richardsi_) at San Nicolas and San Miguel Islands, California, 1982. Hubbs-Sea World Research Inst., Tech. Rept., 83-152:1-56.

Sullivan, R. M. 1979. Behavior and ecology of harbor seals, _Phoca vitulina_, along the open coast of northern California. Unpubl. M.S. thesis, Humboldt State Univ., Arcata, California, 115 pp.

------. 1980. Seasonal occurrence and haul-out use in pinnipeds along Humboldt County, California. J. Mamm., 61:754-760.

Templemann, W., and H. J. Squires. 1956. Relationship of otolith lengths and weights in the haddock, _Melanogrammus aeglefinas_ (L.) to the rate of growth of the fish. J. Fish. Res. Board Canada, 13:467-487.

Terhune, J. M. 1985. Scanning behavior of harbor seals on haul-out sites. J. Mamm., 66:392-395.

Terhune, J. M., and M. Almon. 1983. Variability of harbor seal numbers on haul-out sites. Aquatic Mamm., 10:71-78.

Treacy, S. D., and T. H. Crawford. 1981. Retrieval of otoliths and statoliths from gastrointestinal contents and scats of marine mammals. J. Wildl. Mgmt., 45:990-993.

United States Department of Commerce. 1986. Marine mammal protection act. United State Dept. Comm., Washington D.C., 82 pp.

Wade, L. S. 1981. Census of harbor seals, <u>Phoca vitulina</u>, in San Luis Obispo County, California, 1972-1973. California Fish Game, 67:126-129.

Wahl, T. R. 1977. Sight records of some marine mammals offshore from Westport, Washington. Murrelet, 58:21-23.

Westerheim, S. J. 1955. Size composition, growth, and seasonal abundance of juvenile English sole (<u>Parophrys vetulus</u>) in Yaquina Bay. Fish Commission Oregon, Res. Briefs, 6:4-9.

Wilke, F. 1957. Food of sea otters and harbor seals at Amchitka Island. J. Wildl. Mgmt., 21:241-242.

Wolff, G. A. 1982. A beak key for eight eastern tropical Pacific cephalopod species with relationships between their beak dimensions and size. Fish. Bull., 80:357-370.

Yochem, P. K., B. S. Stewart, R. L. Delong, and D. P. DeMaster. 1987. Diel haul-out patterns and site fidelity of harbor seals (Phoca vitulina richardsi) on San Miguel Island, California in Autumn. Mar. Mamm. Sci., 3:323-332.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, N.J., 718 pp.

Zopf, D. O., H. C. Creech, and W. H. Quinn. 1976. The wavemeter: A land-based system for measuring nearshore ocean waves. Mar. Tech. Soc. J., 10:19-25.