Trends and Potential Interactions Between Pinnipeds and Fisheries of New England and the U.S. West Coast

LISA S. BARAFF and THOMAS R. LOUGHLIN

ABSTRACT—Long-term trends in the abundance and distribution of several pinniped species and commercially important fisheries of New England and the contiguous U.S. west coast are reviewed, and their actual and potential interactions discussed. Emphasis is on biological interactions or competition. The pinnipeds include the western North Atlantic stock of harbor seals, Phoca vitulina concolor*; western North Atlantic gray seals,* Halochoerus grypus*; the U.S. stock of California sea lions,* Zalophus californianus californianus*; the eastern stock of Steller sea lions,* Eumetopias jubatus*; and Pacific harbor seals,* Phoca vitulina richardii. *Fisheries included are those for Atlantic cod,* Gadus morhua*; silver hake,* Merluccius bilinearis*; Atlantic herring,* Clupea harengus*; the coastal stock of Pacific whiting,* Merluccius productus*; market squid,* Loligo opalescens*; northern anchovy,* Engraulis mordax*; Pacific herring,* Clupea pallasi*; and Pacific sardine,* Sardinops sagax. *Most of these pinniped populations have grown exponentially since passage of the U.S. Marine Mammal Protection Act in 1972. They exploit a broad prey assemblage that includes several commercially valuable species. Direct competition with fisheries is therefore possible, as is competition for the prey of commercially valuable fish. The expanding pinniped populations, fluctuations in commercial fish biomass, and level of exploitation by the fisheries may affect this potential for competition. Concerns over pinnipeds impacting fisheries (especially those with localized spawning stocks or at low biomass levels) are more prevalent than concerns over fisheries' impacts on pinnipeds. This review provides a framework to further evaluate potential biological interactions between these pinniped populations and the commercial fisheries with which they occur.*

Introduction

Most U.S. pinniped populations have increased dramatically since passage of the Marine Mammal Protection Act (MMPA) in 1972, precipitating concern over the potential for competition with humans for resources. Pinniped and fisheries interactions have subsequently gained attention in recent years (Beddington et al., 1985; NMFS, 1997a; Stone et al., 1997). These interactions are characterized as being either operational (direct) or biological (indirect) (Lowry, 1982).

Operational interactions include entanglement in fishing gear or debris, incidental take, and shooting by fishermen. Biological interactions are typically more widespread (may include entire ecosystems) or long-term, and include prey competition, changes in prey size structure, changes in prey distribution, or changes in community composition resulting from fishery harvests (Lowry, 1982; Beverton, 1985; Harwood, 1987; NMFS[1]). Two types of biological interactions are exploitative competition and interactive competition. The former involves direct competition for a particular prey, while the latter involves abandonment of a foraging area because of disturbance by a fishery, disruption of foraging patterns by fishing activities, or diminished foraging effectiveness because of disrupted prey aggregations (NMFS[1]).

Operational interactions are well documented (Beddington et al., 1985; Perez and Loughlin, 1991; Wickens, 1995; Woodley and Lavigne[2]) and comparatively straight forward and quantifiable (Lowry, 1982). Fishery caused mortality and serious injury are presented in National Marine Fisheries Service (NMFS) marine mammal stock assessment reports (Barlow et al., 1997; Barlow et al., 1998; Hill and DeMaster, 1998; Waring et al., 1999a).

Biological interactions are more difficult to quantify, yet they are of growing concern. Much emphasis has been on the competitive effects of pinnipeds on commercial fisheries, rather than the

[1] NMFS. 1998. Endangered Species Act Section 7 Consultation—Biological Opinion considering authorization of an Atka mackerel fishery under the BSAI groundfish Fishery Management Plan between 1999 and 2002; authorization of a walleye pollock fishery under the Bering Sea-Aleutian Island groundfish Fishery Management Plan between 1999 and 2002, and authorization of a walleye pollock fishery under the Gulf of Alaska groundfish Fishery Management Plan between 1999 and 2002. Consultation by Alaska Region, Natl. Mar. Fish. Serv., NOAA, on file at Natl. Mar. Mammal Lab., Alaska Fish. Sci. Cent., NOAA 7600 Sand Point Way, N.E., Seattle, WA 98115, 160 p.

[2] Woodley, T. H., and D. M. Lavigne. 1991. Incidental capture of pinnipeds in commercial fishing gear. Manuscr. prep. for pinniped meeting held in conjunction with the IWC Symposium and Workshop on Mortality of Cetaceans in Passive Fishing Nets and Traps, SWFSC, La Jolla, CA, 20–25 October 1990. On file at Natl. Mar. Mammal Lab. Library, Alaska Fish. Sci. Cent., NOAA 7600 Sand Point Way, N.E., Seattle, WA 98115.

The authors are with the National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA,7600 Sand Point Way, N.E., Seattle, WA 98115. Lisa Baraff's current address is the School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 245 O'Neill, P.O. Box 757220, Fairbanks, AK 99775-7220 (email: fslsb1@uaf.edu).

reverse (Gulland, 1987; DeMaster and Sisson, 1992; Harwood, 1992; Haug and Nilssen, 1995; Mohn and Bowen, 1996; NMFS, 1997a). This emphasis is largely a result of increasing pinniped populations in regions of overexploited fish stocks and the potential economic impacts of resource competition.

The primary biological mechanism by which a fishery can adversely impact a marine mammal population is by altering its prey availability (Beverton, 1985), the effects of which are complex and difficult to establish conclusively (Lowry and Frost, 1985). The potential for exploitative competition depends on the spatial and temporal distribution of the fishery, the size-class targeted by the fishery, population size of the "competing" pinnipeds, their prey preferences, and the availability of alternative prey (NRC, 1996).

There are few documented cases of commercial fisheries impacting pinniped populations, partly because of the difficulty inherent in establishing such cause and effect relationships. Large reductions in the Barents Sea stocks of herring in the 1960's, polar cod in the early 1970's, and capelin in the mid 1980's produced observed changes in the Barents Sea harp seal population (Haug and Nilssen, 1995; Timoshenko, 1995). (Please refer to Tables 1 and 2 for a list of the common and scientific names for all marine mammals, fish, and invertebrates mentioned in this review). Food limitations precipitated by the collapse of the capelin stock led to increased harp seal juvenile mortality and a mass movement of harp seals into Norwegian coastal waters during the late 1980's (Haug and Nilssen, 1995; Timoshenko, 1995). A subsequent resurgence of Norwegian spring spawning herring helped mitigate these effects by the early 1990's (Haug and Nilssen, 1995).

The large-scale walleye pollock and Atka mackerel fisheries of the Gulf of Alaska and the Bering Sea and Aleutian Islands area have been implicated by some as causal agents in the continued decline of the western stock of Steller sea lions (Alverson, 1992; NMFS[1]). The western stock has declined by 80% since the 1970's, prompting a listing as threatened under the Endangered Species Act (ESA) in 1990 (NMFS, 1990) and then as endangered in 1997 (NMFS, 1997b). Walleye pollock and Atka mackerel have been the principal prey items of Steller sea lions in that region since at least the 1970's; the prevalence of walleye pollock in the diet decreases east to west where it is replaced by Atka mackerel (Merrick and Calkins, 1996; Merrick et al., 1997). Because these commercially exploited species constitute a large percentage of the Steller sea lion diet, prey overlap and the potential for biological interactions may be substantial.

Table 1.—Common and scientific names of pinniped species mentioned in the text.

Common Name	Scientific Name
California sea lion	*Zalophus californianus californianus*
Gray seal	*Halichoerus grypus*
Guadalupe fur seal	*Arctocephalus townsendi*
Harbor seal (North Atlantic)	*Phoca vitulina concolor*
Harbor seal (Pacific)	*Phoca vitulina richardii*
Harp seal	*Pagophilus groenlandicus*
Hooded seal	*Cystophora cristata*
Northern elephant seal	*Mirounga angustirostris*
Northern fur seal	*Callorhinus ursinus*
Steller sea lion	*Eumetopias jubatus*

The continued decline of Steller sea lions and the concern over fisheries impacts has led to many fisheries management actions since 1991. The December 1998 ESA Section 7 Consultation-Biological Opinion concluded that both the Bering Sea–Aleutian Islands and Gulf of Alaska walleye pollock fisheries were likely to jeopardize the continued existence of the western stock of Steller sea lions and adversely modify its critical habitat (NMFS[1]).

The possibility that the continued Steller sea lion decline may be, at least partly, caused by biological interactions with important commercial fisheries has inspired this review of trends in abundance and distribution of pinnipeds and their potential interactions with several fisheries of New England and the contiguous United States west coast. Greater emphasis is on biological interactions; operational interactions are only briefly noted. Biological interactions, however, are difficult to prove unequivocally and making such determinations is beyond the scope of this review.

Table 2.—Common and scientific names of fish and invertebrates mentioned in the text.

Common Name	Scientific Name
Alewife	*Alosa pseudoharengus*
American plaice	*Hippoglossoides platessoides*
Atka mackerel	*Pleurogrammus monopterygius*
Atlantic cod	*Gadhus morhua*
Atlantic herring	*Clupea harengus*
Atlantic mackerel	*Scomber scombrus*
American shad	*Alosa sapidissima*
Capelin	*Mallotus villosus*
Eulachon	*Thaleichthys pacificus*
Flatfish	Pleuronectidae/Bothidae
Haddock	*Melanogrammus aeglefinus*
Hake (red or white)	*Urophycis* spp.
Jack mackerel	*Trachurus symmetricus*
Market squid	*Loligo opalescens*
Northern anchovy	*Engraulis mordax*
Octopus	*Octopus* spp.
Pacific herring	*Clupea pallasi*
Pacific lamprey	*Lampetra tridentata*
Pacific (chub) mackerel	*Scomber japonicus*
Pacific sanddab	*Citharichthys sordidus*
Pacific sand lance	*Ammodytes hexapterus*
Pacific sardine	*Sardinops sagax*
Pacific tomcod	*Microgadus proximus*
Pacific whiting	*Merluccius productus*
Plainfin midshipman	*Porichthys notatus*
Polar cod	*Boreogadus saida*
Pollock	*Pollachius virens*
Redfish	*Sebastes* spp.
Red hake	*Urophycis chuss*
Rex sole	*Errex zachirus*
Sand lance	*Ammodytes* spp.
Shiner perch	*Cymatogaster aggregata*
Shortbelly rockfish	*Sebastes jordani*
Short-finned squid	*Ilex illecebrosus*
Silver hake	*Merluccius bilinearis*
Skates	Rajidae
Smelts	Osmeridae
Spiny dogfish	*Squalus acanthias*
Spotted cusk eel	*Chilara taylori*
Squid/Octopus	Cephalopoda
Staghorn sculpin	*Leptocottus armatus*
Starry flounder	*Platichthys stellatus*
Walleye pollock	*Theragra chalcogramma*
White croaker	*Genyonemus lineatus*
Windowpane flounder	*Scophthalmus aquosus*
Yellowfin goby	*Acanthogobius flavimanus*
Yellowtail flounder	*Pleuronectes ferrugineus*

Materials and Methods

We have reviewed several pinniped species and commercial fisheries of New England, including the Gulf of Maine and Georges Bank (Fig. 1), and the contiguous U.S. west coast and California Current ecosystem (Fig. 2) for the period 1970–98. Most of the species described are transboundary species, so Canadian data are occasionally included for either additive or comparative purposes.

The pinnipeds discussed are the western North Atlantic stocks of harbor seals and gray seals for New England waters, and the U.S. stock of California sea lions, the eastern stock of Steller sea

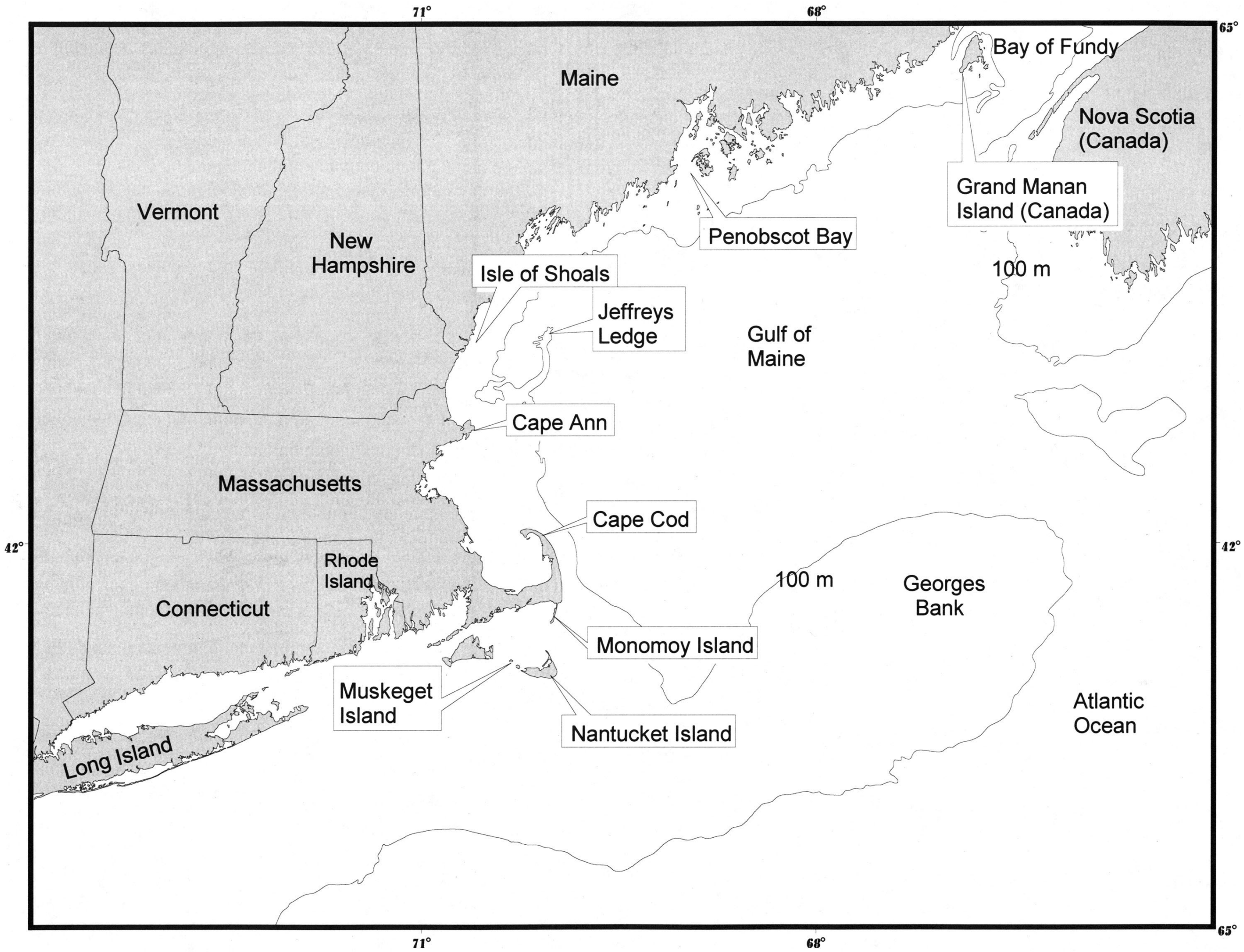

Figure 1.—The Gulf of Maine and New England regions of the northeastern United States with place names mentioned in the text.

lions as defined by Loughlin (1997), and Pacific harbor seals for the U.S. west coast (Table 3). Information on stock definition and distribution, seasonal movements and migrations, population counts and growth trends, stock status, and food habits is summarized for each species. Population data are based on counts, rather than corrected population estimates, and as such, represent minimum population estimates.

Fisheries were selected based on two criteria: 1) they were of relatively large scale and economic significance, either historically or presently, and 2) the target species was a dominant prey of the selected pinnipeds. The New England fisheries chosen were Atlantic cod, silver hake, and Atlantic herring. West coast fisheries selected were Pacific whiting, market squid, northern anchovy, Pacific herring, and Pacific sardine. Information included basic life history and distribution, description and history of the fishery, stock status including biomass (spawning stock biomass or total biomass) and exploitation rate, and pertinent management measures. Landings and biomass estimates are in metric tons (t); data originally listed as either pounds or short tons were converted to metric tons. The fisheries are summarized in Table 4.

New England Pinnipeds

Four pinniped species occur in New England: harbor seals, gray seals, harp seals, and, occasionally, hooded seals. The former two are year-round residents; occurrence of the latter two is recent, seasonal, and extralimital. The incidence of harp seal and hooded seal strandings in New England and incidental take in the New England sink gillnet fishery during the winter and spring increased since the 1980's (Kraus and Early, 1995; Waring et al., 1999a). Sightings in the northern Gulf of Maine increased 92-fold since 1990 (McAlpine et al., 1999). Reasons for this are uncertain (Kraus and Early, 1995), but collapsing fish stocks in regions where these seals commonly feed has been suggested (McAlpine et al., 1999). Harp and hooded seals are considered vagrants in New England waters and will not be discussed further.

Harbor Seals

Distribution, Abundance, and Population Trends

The western North Atlantic stock of harbor seals ranges from Labrador to southern New England, with occasional sightings as far south as the Carolinas (Richardson[3]); they constitute a single population (Temte et al., 1991; Waring et al., 1999a). They occur year-round along the coasts of Maine and eastern Canada, and from late September through May from southern New England (south of Maine) to Long Island Sound (Payne and Selzer, 1989; Katona et al., 1993). There is a general southward movement during fall (Rosenfeld et al., 1988), and a northward migration in spring prior to pupping along the Maine coast (Whitman and Payne, 1990; Kenney, 1994). Pupping occurs in late May to early June, primarily on rocky ledges and islands in protected inlets and bays; coastal Maine harbor seals tend to move offshore to more isolated ledges for molting in August (Kenney, 1994; Richardson[4]).

Massachusetts paid a bounty on harbor seals from 1888 until 1962 in response to an assumed competition with fisheries (Payne and Selzer, 1989). Maine had a similar bounty that, despite being rescinded in 1905, resulted in near extirpation of some localized populations. A bounty also existed in eastern Canada until 1976 (Katona et al., 1993). The intense hunting pressure in Massachusetts apparently eliminated breeding activities there. Breeding and pupping are currently limited to coastal Maine (Payne and Selzer, 1989; Temte et al., 1991).

Population estimates for the U.S. portion of this stock are derived from periodic aerial surveys of the Maine coast during the peak haulout period of pupping. These surveys have been conducted systematically since 1981 (Kenney, 1994; Kenney and Gilbert[5]; Gilbert and Guldager[6]). Richardson conducted coastwide surveys in 1972–73 and partial surveys in 1974–77 (Richardson[3]; Richardson[4]; Richardson[7]), but differences in coverage, timing, and methods preclude direct comparison with later censuses (Kenney, 1994). To illustrate general trends, however, these earlier counts are included in Figure 3. Population growth rates are based on the sys-

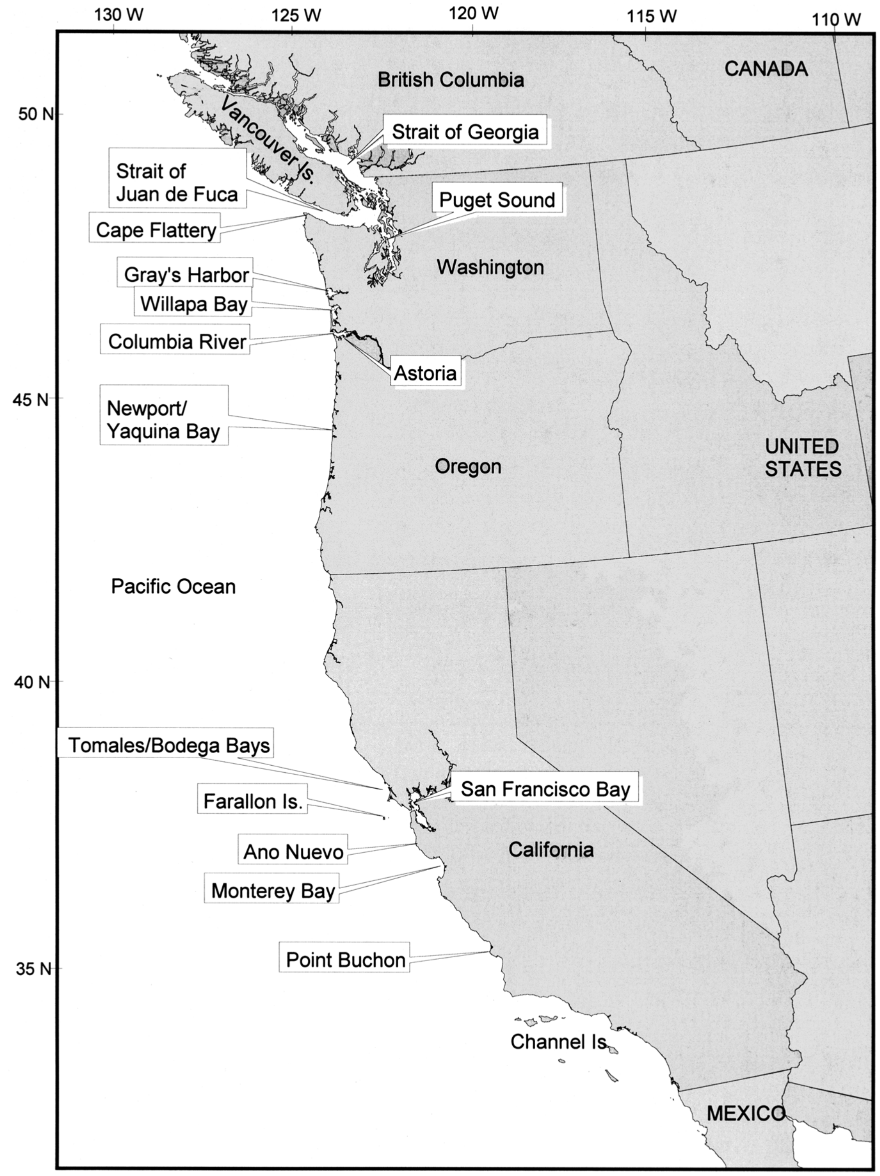

Figure 2.—The contiguous west coast of the United States with several place names mentioned in the text.

[3] Richardson, D. T. 1976. Assessment of harbor seal and gray seal populations in Maine, 1974–1975. Final rep. to Mar. Mammal Comm., Contr. MM4AC009, 33 p.

[4] Richardson, D. T. 1978. Six-year assessment of abundance and distribution of harbor seals and gray seals in the Acadia National Park area. Order No. PX 1700 7 0301, 13 p.

[5] Kenney, M. K., and J. R. Gilbert. 1994. Increase in harbor and gray seal populations in Maine. Final rep. to Natl. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Woods Hole, Mass., Contract 50-EANF-2-00064,19 p.

[6] Gilbert, J. R., and N. Guldager. 1998. Status of harbor and gray seal populations in northern New England. Final rep. to Nat. Mar. Fish. Serv., Northeast Fish. Sci. Cent., Woods Hole, Mass., NMFS/NER Coop. Agreement 14-16-009-1557, 13 p.

[7] Richardson, D. T. 1974. Feeding habits and population studies of Maine's harbor and gray seals. Contract between Nat. Geo. Soc. and Maine Dep. Sea and Shore Fish., 33 p.

tematic surveys (Kenney, 1994; Gilbert and Guldager[6]).

The New England harbor seal population has nearly quintupled in size since passage of the MMPA (Waring et al., 1999a). Harbor seal counts in Maine grew from 10,540 at 334 haulout sites in 1981 to 30,990 at 584 haulout sites in 1997 (Gilbert and Guldager[6]) (Fig. 3). The average annual rate of increase was 4.2% from 1981 to 1997, 8.7% from 1981 to 1993 (Kenney, 1994), and 1.8% from 1993 to 1997 (Gilbert and Guldager[6]). The number of pups counted increased from 676 in 1981 to 5,359 in 1997. The 1997 pup count was 26% higher than the 1993 count (Gilbert and Guldager[6]). The average annual increase in pups since 1981 was 12.9% (Gilbert and Guldager[6]). Although the population is increasing, its status relative to Optimum Sustainable Population (OSP) is unknown (Waring et al., 1999b).

General trends at winter haulouts in southern New England show a twofold increase in seal numbers since the 1970's (Payne and Selzer, 1989; Kraus and Early, 1995; Rough[8]). The three largest concentrations in southern New England are around Cape Cod (Jeremy Point, Monomoy National Wildlife Refuge, Nantucket Island), followed by the Isle of Shoals near the New Hampshire/ Maine border (Payne and Selzer, 1989). Monomoy supports the single largest concentration of harbor seals in eastern U.S. waters. Over 3,000 harbor seals were there in early May 1994 (Payne and Selzer, 1989; Rough[8]).

Fishery-related Mortality

The New England multispecies sink gillnet fishery is responsible for the majority of the harbor seal incidental take in New England waters, with a mean average annual mortality of 934 seals from 1993 to 1997 (Waring et al., 1999b). Take occurs year-round, with its temporal and spatial distribution related to the seasonal distribution of both seals and the fishery. Incidental

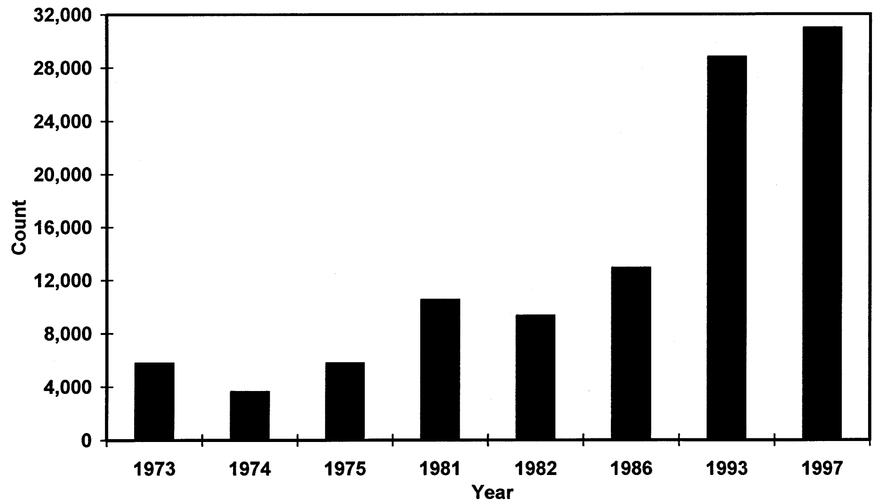

Figure 3.—Maine coast harbor seal counts. The 1973 count includes data from 1972 and 1973 and censuses from outside the pupping season. The 1974 and 1975 counts are estimates based on stratified random samples. The 1982 survey was incomplete. Data from Richardson (text footnote 4), Gilbert and Guldager (text footnote 6), and Richardson (text footnote 7).

Table 3.—Summary of the current status of the pinniped stocks reviewed.

Species	Stock area	N_{MIN}[1]	Total annual mortality	Average annual fishing mortality	ESA status
Harbor seal[2]	Western North Atlantic	30,990	934	934	Not listed
Gray seal[2]	Western North Atlantic	N.d.[3]	70	70	Not listed
Harbor seal[4]	California	27,962	243	234	Not listed
Harbor seal[5]	Oregon and Washington coasts	24,733	19	17	Not listed
Harbor seal[5]	Washington inland waters	16,104	41	36	Not listed
California sea lion[4]	U.S.	111,339	974	915	Not listed
Steller sea lion[6]	Eastern U.S. (Pacific)	30,403[7] 6,555[8]	17	15	Threatened

[1] N_{MIN} = minimum population estimate; based on counts, unless otherwise noted.
[2] Waring et al., 1999b.
[3] Insufficient data for U.S. waters.
[4] Barlow et al., 1997 (N_{MIN} for harbor seals includes correction factor; N_{MIN} for California sea lions based on counts of all age and sex classes ashore at major rookeries and haulouts during July 1995).
[5] Barlow et al., 1998 (N_{MIN} calculated using correction factor).
[6] Hill and DeMaster, 1999.
[7] N_{MIN} for entire eastern U.S. stock, 1996 (southeast Alaska, British Columbia, Washington, Oregon, and California).
[8] Total 1996 count for Washington, Oregon, and California components of the stock. Data from Gearin (text footnote 22); Brown (text footnote 28); Sydeman (text footnote 31); Perryman (text footnote 32).

takes of harbor seals by the groundfish gillnet, herring purse seine, halibut tub trawl, and lobster fisheries are negligible (Waring et al., 1999a).

Food Habits and Prey

Food habits data for New England harbor seals are limited in range and scope, and no prey studies have been done at Maine coast rookeries and haulout sites. The 24 species identified in stomach remains of the predominantly juvenile harbor seals incidentally caught in the New England sink gillnet fishery indicate a broad prey base that varies seasonally and regionally (Williams, 1999). Silver hake was the predominant year-round prey at 71% frequency of occurrence (FO). Atlantic cod, Atlantic herring, red or white hake, redfish, pollock, alewife, and squids (mostly *Illex illecebrosus*) were also consumed (>10% FO for each species), but these species varied more seasonally and regionally.

Prey remains from stomachs of seals stranded in southern New England included squid, haddock, silver hake, pol-

[8] Rough, V. 1995. Gray seals in Nantucket Sound, Massachusetts, winter and spring, 1994. Final rep. to Mar. Mammal Comm., Contract T10155615. NTIS publication PB95-191391, 28 p.

Table 4.—Summary of fisheries reviewed.[1, 2, 3]

Fishery	Stocks	Location	Management	Fishery type	Fishery dates
Atlantic cod	Gulf of Maine	Gulf of Maine	NEFMC multispecies FMP	Otter trawls, gillnets	Year-round
Atlantic cod	Georges Bank and Southward	Georges Bank to Nantucket Shoals	NEFMC multispecies FMP	Otter trawls, gillnets	Year-round
Silver hake	Gulf of Maine–northern Georges Bank	Gulf of Maine and north-western Georges Bank	NEFMC multispecies FMP	Otter trawl	Varies with time/area closures and experimental fisheries
Silver hake	Southern Georges Bank – Middle Atlantic	Southern New England to Mid Atlantic	NEFMC multispecies FMP	Otter trawl	Seasonal depending on abundance in southern area
Atlantic herring	Coastal stock complex (Gulf of Maine and Georges Bank-Nantucket Shoals stocks)	North Carolina to Gulf of Maine and Georges Bank	ASFMC, states, NEFMC Atlantic herring FMP	Weirs, stop seines, purse seines, midwater pair trawls	Year-round (south of New England in winter, GOM area June–November)
Pacific whiting	Coastal	Southern CA to Queen Charlotte Sound	PFMC groundfish FMP	Midwater pelagic trawls (At-sea processors, catcher-processors, shore-based)	April – November (varies by fishery sector)
Market squid	Unknown	Central Baja to SE Alaska (concentrated in central and southern CA)	Largely unregulated; PFMC's CPS FMP; CDFG since 1998	Primarily purse seine	Southern CA: fall/winter; central CA: spring/summer OR to AK: late summer
Northern anchovy	Central subpopulation	San Francisco to Baja California (mostly Southern CA Bight)	PFMC Northern Anchovy FMP & CPS FMP	Primarily round haul	Year-round (July 1–June 30)
Northern anchovy	Northern subpopulation	Monterey, CA to British Columbia	WDFW (in WA), but not actively managed	Mostly purse seines & lampara nets	Primarily late spring through fall
Pacific herring	Washington (19 stocks)	Puget Sound, Strait of Juan de Fuca, Willapa Bay	WDFW forage fish FMP	Spawn on kelp, sac roe, sport bait: gillnets, lampara nets, purse seines, beach seines, dip nets	Bait: spring–fall; Roe: spring
Pacific herring	Oregon	Yaquina Bay	ODFW	Roe fishery	Late winter
Pacific herring	California (4 primary stocks)	San Francisco Bay, Tomales Bay, Humboldt Bay, Cresecent City	CDFG	Roe fishery and roe-on-kelp: gill nets, purse seines, and lampara nets	November to March
Pacific sardine	Northeastern Pacific northern subpopulation	Northern Baja to Alaska	CDFG and PFMC's proposed CPS FMP	Mostly purse seines, lampara nets, drum seines	Year-round

[1] Acronyms used: ABC = Acceptable Biological Catch, CDFG = California Department of Fish and Game, CPS = Coastal Pelagic Species, FMP = Fishery Management Plan, GOM = Gulf of Maine, MSY = Maximum Sustainable Yield, NEFMC = New England Fishery Management Council, ODFW = Oregon Department of Fish and Game, PFMC = Pacific Fishery Management Council, SNE = Southern New England, SSB = Spawning Stock Biomass, TAC = Total Allowable Catch, WDFW = Washington Department of Fish and Wildlife.

[2] Literature cited: Bargmann, 1998; Barlow et al., 1997; CDFG, 1998; Dorn et al., 1999; Friedland, 1998; Helser et al., 1995; Lemberg et al., 1997; Mayo, 1998; Mayo and O'Brien, 1998; Methot and Dorn, 1995; NMFS, 1996, 1999b; NEFMC, 1998a, 1999a, 1999b, 1999c; PFMC, 1997, 1998a, 1998b; Wildermuth, 1995.

[3] Text footnotes cited: NEFSC[11]; NEFSC[12]; NEFSC[13]; Brown[18]; Beeson and Hanan[23]; PacFIN[42]; Jacobson et al.[43]; Jacobson et al.[44]; Bodenmiller[45]; Watters[48]; and Hill et al.[50]

lock, red hake, sand lance, and flatfish (Selzer et al., 1986). Since many of these seals died during an influenza epidemic in 1980, they may not represent normal prey habits.

Scats collected in southern New England during the winter showed area and substrate prey differences. Sand lance dominated the diet (up to 99% FO) in the sandy Cape Cod area, whereas the more diverse diet at the rocky Isle of Shoals included rockfish, gadids, Atlantic herring, American plaice, and yellowtail flounder. Herring consumption near Cape Cod increased when sand lance availability decreased. Overall, sand lance constituted at least 55% FO of the winter diet in both New Hampshire and Massachusetts (Payne and Selzer, 1989).

Of the 23 taxa identified in stomachs collected at Grand Manan Island and eastern Nova Scotia, Can., Atlantic herring, Atlantic cod, short-finned squid, and pollock constituted 72% of identified prey and 84% of estimated biomass consumed (Bowen and Harrison, 1996). Herring accounted for about 30% of biomass consumed. Frequency of occurrence varied seasonally, annually, and by age-group. Pups ate more herring and squid, seals older than 1 year ate more gadids and flatfish, and yearlings were intermediate between the two. Prey similarities between Grand Manan Island and eastern Maine are plausible based on their relative geographic proximity.

Gray Seals

Distribution, Abundance, and Population Trends

The western North Atlantic stock of gray seals ranges from Labrador, Can., to Long Island, N.Y., with occasional strandings as far south as Virginia. The

Size/age class targeted	Current biomass	Quota	Landings	Level of exploitation
Minimum 19″	1998 total: 11,825 t; 1998 SSB: 8,275 t	1999 TAC: 1,340 t	1998: 4,183 t	Overexploited and in a state of collapse
Minimum 19″	1998 total: 36,317 t; 1998 SSB: 28,656 t	1999 TAC: 5,354 t	1998 U.S.: 6,923 t	Overexploited
Mostly age 3+; juvenile fishery: ages 1–2	No current estimates	Trip limits based on mesh size	1997: 3,270 t (northern stock: 1,713 t; Cultivator Shoal: 1,552 t)	Overexploited
Mostly age 3+; juvenile fishery: ages 1–2	No current estimates		1997: 12,026 t	Overexploited
Mix of ages 2, 3, and 4+	1997 total: 2.9 million t; 1997 SSB: 1.8 million t	1999 total TAC: 224,000 t	1997 total: 118,400 t (Georges Bank: 6,262 t; GOM: 70,115 t; SNE: 20,914 t)	Coastal stock complex: under exploited; GOM stock: fully exploited
Generally ages 3–6	1998 total: 1.67 million t	1998 U.S.: 232,000 t (80% of total ABC)	1998 U.S.: 232,509 t	Fully exploited
Spawning adults	Unknown	ABC = 25% of MSY catch (MSY catch unknown)	1997 CA: 70,246 t; 1998 CA: 3,016 t (El Niño effect)	Unknown
Primarily ages 0–1	1995 total: 392,000 t; 1995 SSB: 388,000 t	Total stock: 31,000 t; U.S only: 25,000 t	1997: 5,719 t; 1998: 1,438 t (U.S. only)	1995: fully exploited; 1999: underutilized
	Current abundance unknown	ABC = 25% MSY catch; MSY catch unknown, so ABC unknown	1998 WA: 103 t; 1998 OR: .01 t	Unknown, but current harvest levels well below assumed biomass
Bait: juveniles; Roe: adults	1996 Puget Sound total: 11,799 t; coastal stock: unknown	5–20% of biomass (roe: 6%; bait: 10%)	1996: 540 t (no directed fisheries on coastal stock)	Status of stocks: 8 healthy, 1 moderately healthy, 3 depressed, 1 critical, 6 unknown
Roe: adults	No good indices of abundance	20% of spawning biomass	1998: 148 t	
Roe: adults	San Francisco and Tomales combined: 1996–97: 82,845 t; 1997–98: 18,733 t (El Niño)	Generally 15% of estimated biomass	1997: 9,215 t; 1998: 2,014 t (El Niño) (does not include roe-on-kelp fishery)	Fully exploited
< age 5 (primarily age 2)	1998 total: 1.07 million t	1998 CA total: 44,906 t (directed, dead bait, and live bait)	1998 U.S.: 42,580 t; 1998 Mexico: 60,426 t	Fully exploited

population center is in eastern Canada on Sable Island, Nova Scotia, which accounts for over one-half of the population, and in the southern Gulf of St. Lawrence. Smaller populations occur in the United States around Nantucket Sound and central Maine (Katona et al., 1993; Rough[8]). The southernmost breeding sites are those of Nantucket Sound, where Muskeget Island was the only known U.S. breeding site until 1990 (Rough[8]). In 1990, pups were discovered on Monomoy Island (Rough[8]) and in 1994, a new breeding colony was discovered in Penobscot Bay, Maine (Gilbert, 1995).

Pupping occurs from late December to early February, after which gray seals typically disperse (Stobo and Zwanenburg, 1990; Rough[8]). They haulout again during molt beginning in early April in Nantucket Sound and May and June in eastern Canada. Spring and summer sightings off Maine are primarily on offshore ledges of the central coast (Kenney, 1994; Richardson[3]; Gilbert et al.[9]) and are thought to be from the Canadian population (Gilbert and Guldager[6]). Gray seals generally disperse again during late summer and fall (Stobo et al., 1990).

Gray seals were considered extinct in the United States prior to 1958, although about 40 were killed during the bounty hunt in Massachusetts in the 1940's and 1950's (Andrews and Mott, 1967; Rough[8]). Some were also likely taken during Maine's bounty hunt (Reeves et al., 1992; Rough[8]). Massachusetts passed legislation protecting gray seals in 1965 (Andrews and Mott, 1967) and they received federal protection with the MMPA in 1972.

Gray seals around Nantucket Sound were periodically monitored during the late 1960's and 1970's and regularly monitored since the 1980's (Richardson[3]; Rough[8]; Gilbert et al.[9]). Fewer than 17 gray seals were observed in any one year from 1965 to 1977. Counts

[9] Gilbert, J. R., V. R. Schurman, and D. T. Richardson. 1979. Grey seals of New England: present status and management alternatives. Final rep. to U.S. Mar. Mammal Comm., Contract MM7AC002. NTIS publication PB-295 599, 45 p.

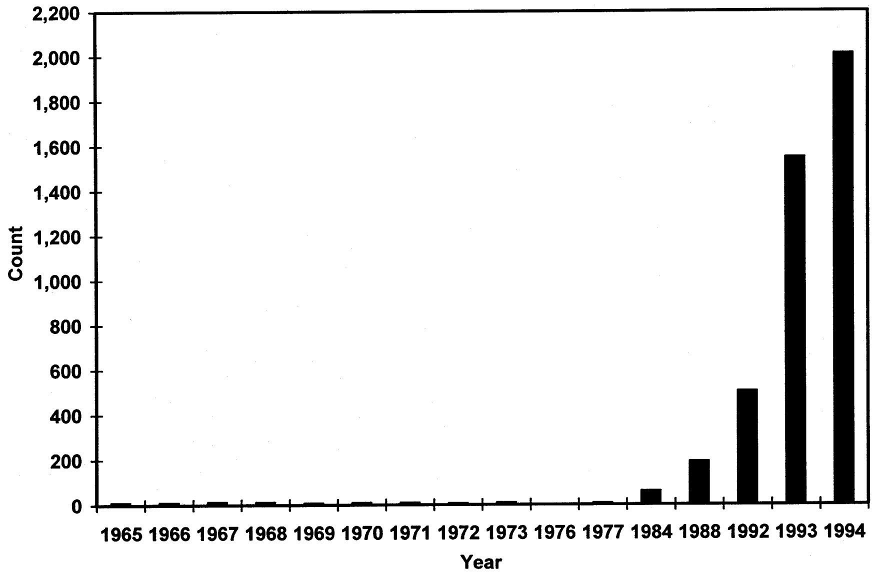

Figure 4.—Nantucket Sound gray seal counts. Data from Waring et al. (1999a), Rough (text footnote 8), and Gilbert et al. (text footnote 9).

grew to 61 in 1984 and to 2,010 in 1994 (Richardson[3]; Rough[8]; Gilbert et al.[9]) (Fig. 4). From 1971 thru 1987, only 6 pups were reported, 3 of which were strandings. Pupping has since increased, from 12 born on Muskeget Island in 1992 to 59 in 1994 (Rough[8]). The nonpup population rise is likely due to immigration from Canada (Rough[8]).

Gray seals in Maine also increased. Richardson[3] estimated approximately 80 in summer from 1965 to 1975. A minimum of 600 gray seals were counted in 1993 (Kenney, 1994; Gilbert, 1995; Kenney and Gilbert[5]). Between 25 and 50 pups per year have been seen in Penobscot Bay since 1994 (Gilbert[10]).

Estimates of gray seal numbers for the entire western North Atlantic are not available, so U.S. and Canadian components are estimated separately. Waring et al. (1999a) used 2,010 as the minimum abundance estimate for U.S. waters. In 1998, the Atlantic Regional Scientific Review Group recommended against using that number because it failed to account for seals from Sable Island that winter around Nantucket (Waring et al., 1999b). Thus, there is currently no estimate for the number of gray seals in the United States and their status relative to optimum sustainable population (OSP) is unknown. Gray seal numbers appear to be increasing, but at an unknown rate (Waring et al., 1999b). In Canada, there is a minimum of 143,000 gray seals for Sable Island and the Gulf of St. Lawrence combined (Waring et al., 1999a), and numbers have been increasing. Sable Island pup production averaged roughly 13% per year from 1977 through 1993 (Zwanenburg and Bowen, 1990; Mohn and Bowen, 1996).

Fishery-related Mortality

Known fishery-related mortality is low in U.S. waters and primarily involves the New England multispecies sink gillnet fishery. The average annual mortality for that fishery was 70 during 1993–97 (Waring et al., 1999b) and occurred primarily in winter.

Food Habits and Prey

The only prey information for gray seals in U.S. waters was based on 42 scat samples from Muskeget Island (Rough[8]). Prey consumed included windowpane flounder, silver hake, sand lance, skates, and gadids.

Gray seal prey habits in eastern Canada have been well assessed. Over 24 species, including sand lance, silver hake, Atlantic cod, capelin, and flatfish, were identified from scats collected on Sable Island (Bowen and Harrison, 1994). Atlantic herring, Atlantic cod, pollock, Atlantic mackerel, silver hake, and squid dominated the Grand Manan Island and eastern Nova Scotia diets (Bowen et al., 1993). Prey habits in eastern Maine may be comparable to Grand Manan, given their geographic proximity.

New England Fisheries

Significant changes have occurred in New England fisheries resources over the last 30 years. During the 1960's and early 1970's, fishing effort by foreign vessels off the U.S. northeast coast was high, with takes more than triple the average annual catch of U.S. fishermen (Anthony, 1990). Enactment of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977 led to the demise of large-scale foreign fisheries; in response, the northeast domestic fishing fleet grew rapidly in numbers and vessel size (Kitts et al., 1998). Domestic fishing effort doubled in New England between 1976 and 1983, and stocks that had not been targeted by the foreign fleet quickly went from being underutilized to overexploited (Anthony, 1990; Murawski et al., 1999). While the number of vessels participating in the groundfish fishery gradually declined after 1980, it remains nearly twice the pre MFCMA size. Competition for resources escalated with the increase in vessels harvesting the rapidly filled quotas, resulting in many management problems and rapidly declining stocks.

Groundfish abundance began declining in the early 1980's and reached record lows by the early 1990's (Murawski and Almeida, 1998). Along with this declining trend came an increasing reliance on cod (Murawski et al., 1999). But there have also been increased landings of nontraditional species like spiny dogfish and skates (Murawski and Almeida, 1998). Meanwhile, abundance of principal pelagics (Atlantic herring, Atlantic mackerel) has recently been increasing.

Over half of the 51 stocks reviewed in Murawski and Almeida (1998) are at low abundance levels, one-third are

[10] Gilbert, J. 1999. Dep. Wildl. Ecology, Univ. Maine, Orono, ME 04469. Personal commun.

at medium levels, and only one-tenth are considered at high abundance. Two-thirds of the stocks are overexploited, one-fourth are fully exploited, and one-tenth are underexploited. Nearly three-fourths of New England's principal groundfish stocks are overexploited, as are all those of the mid Atlantic (New York–Virginia) region (Murawski and Almeida, 1998). Further details regarding fish, fisheries, stock status, and management for select commercially important stocks in the northeast follow.

Atlantic Cod

Atlantic cod range from North Carolina to Greenland in the northwest Atlantic. In U.S. waters, cod are assessed and managed as the Gulf of Maine stock and the Georges Bank and Southward stock (Mayo and O'Brien, 1998). The continental slope is the offshore boundary for cod along the coast of North America (Bigelow and Schroeder, 1953). Although cod are found at most depths throughout the year and are essentially nonmigratory, they form some coastal concentrations during the summer months (Bigelow and Schroeder, 1953; NEFSC[11]). Spring distribution extends from Cape Cod across Georges Bank and up into the Bay of Fundy, with localized concentrations; densities decrease and cod are more geographically isolated during fall (Hunt et al., 1999).

Cod attain sexual maturity between ages 2 and 4, with ages 2–5 dominating catches. They can grow to 130 cm long and 25–35 kg and may live >20 years. Spawning time varies somewhat by area, but it is generally between February and June (Bigelow and Schroeder, 1953; Mayo and O'Brien, 1998; NEFMC, 1998a) and in water depths <50 fathoms (≈100 m) (Bigelow and Schroeder, 1953).

The Fishery

Cod has been an important component of New England commercial fisheries for about 400 years. Originally a hook and line fishery, it ranged from Massachusetts inshore waters out to Georges Bank (Bigelow and Schroeder, 1953). Gillnets came into use in the 1880's. The mechanized fishery, dominated by otter trawls, began in the early 1900's and led to increased landings (Bigelow and Schroeder, 1953). Today, commercial cod fisheries are conducted year-round principally with large-mesh otter trawls and sink gillnets. The Georges Bank fishery is dominated by otter trawls, while the Gulf of Maine fishery is more diversified. A large recreational cod fishery occurs during late summer in the lower Gulf of Maine and from late fall to early spring from Massachusetts southward (Mayo and O'Brien, 1998).

Gulf of Maine commercial landings averaged 5,500 t between 1960 and 1975, averaged more than twice that from 1976 to 1985, declined from 1986 to 1988, then reached a record high of 17,800 t in 1991. Landings decreased since then to 4,183 t in 1998 (NEFMC, 1996; 1999c; 1999d; NEFSC[11]) (Fig. 5). The Gulf of Maine recreational fishery decreased from about 2,800 t in 1990 to 300 t in 1997 (NEFSC[11]). Georges Bank landings quadrupled between 1960 and 1980 (NEFMC, 1996), peaked at 57,000 t in 1982, declined during the mid 1980's, then increased through 1990 to 42,500 t (U.S. and Canada). Landings dropped precipitously by 1995, with a slight increase in 1997 (NEFSC[11]) (Fig. 6). The U.S. accounted for 72% and Canada for 28% of the landings (Mayo and O'Brien, 1998). U.S. landings for 1998 were 6,923 t (NEFMC, 1999d). Recreational catches averaged 3,700 t between 1979 and 1986 (Mayo and O'Brien, 1998; NEFSC[12]).

Discards of cod in the Gulf of Maine fishery reached 3,600 t in 1990. Since 1993, discards have decreased to 200–400 t/year (Mayo and O'Brien, 1998; NEFSC[11]). Discards occur in the Georges Bank fishery, but reliable estimates are unavailable (NEFSC[11]).

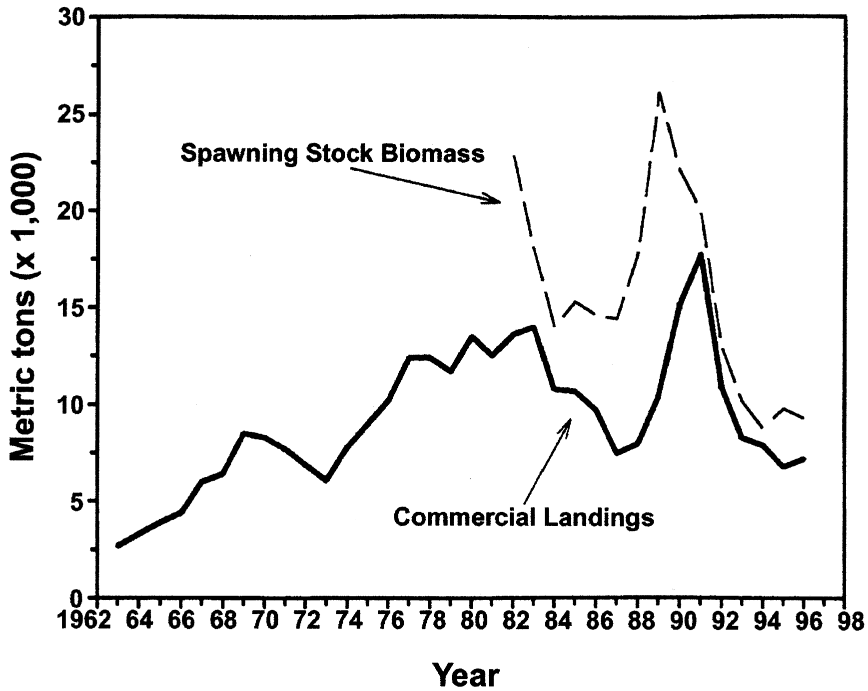

Figure 5.—Annual landings and biomass for the Gulf of Maine stock of Atlantic cod. Adapted from Mayo and O'Brien (1998).

[11] NEFSC. 1998a. Report of the 27th Northeast Regional Stock Assessment Workshop (27th SAW): Public Review Workshop. NOAA/NMFS, Northeast Fish. Sci. Cent. Ref. Doc. 98-14, 78 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

[12] NEFSC. 1998b. Report of the 27th Northeast Regional Stock Assessment Workshop (27th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. NOAA/NMFS, Northeast Fish. Sci. Cent. Ref. Doc. 98-15, 350 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

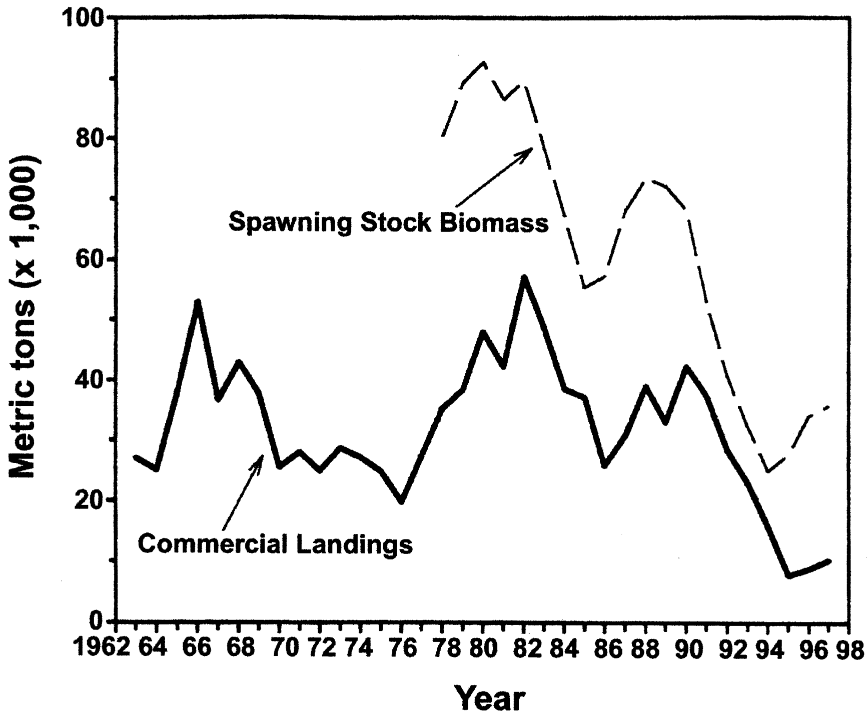

Figure 6.—Annual landings and biomass for the Georges Bank stock of Atlantic cod. Adapted from Mayo and O'Brien (1998).

Stock Status

Cod stock biomass in the Gulf of Maine is extremely low and in a state of collapse (NEFMC, 1998a). Spawning stock biomass is low, fishing mortality is high, recruitment is poor, and the pre-recruit survival rate is low (NEFSC[11]). Overall, spawning stock biomass declined by 80% since the early 1960's and was expected to continue declining (NEFSC[11]) (Fig. 5). Recruitment has been poor since 1992, with each succeeding year class roughly half the strength of the preceding year class (NEFSC[11]). Exploitation rates have remained high and, since 1983, have been 2–3 times above the level needed to attain maximum spawning potential (Mayo and O'Brien, 1998). The mean exploitation rate from 1989 to 1997 was 59% (NEFSC[11]). Biomass surveys indicate a contracting cod distribution, with areas of high cod catches more narrowly distributed during 1994–98 than during 1979–83 (NEFMC, 1998b).

The Georges Bank spawning stock biomass averaged 61,500 t for 1978–97, from a high of 92,800 t in 1980 to a record low of 25,100 t in 1994 (Fig. 6). The exploitation rate for this stock averaged 40% from 1978 to 1997. It peaked at 64% in 1994, but dropped to 21% in 1997 (NEFSC[12]).

Management

The U.S. Atlantic cod fisheries are managed under the New England Fishery Management Council's (NEFMC) Northeast Multispecies Fishery Management Plan (FMP), which includes a complex of ten groundfish species. The FMP was established in 1986 and has been modified many times since. Its principal goal is to reduce fishing mortality sufficiently to allow stocks to rebuild. Management measures include time/area closures, gear restrictions, minimum size limits (19 inches for cod), a permit moratorium, days-at-sea restrictions, trip limits for the Gulf of Maine fishery, and a vessel buyout program (Mayo and O'Brien, 1998; NMFS, 1999a). Several of these measures are summarized in NEFMC (1996), (1998a), (1999c), (1999d), and (2000).

Due to the critical state of the Gulf of Maine stock, a Stock Assessment Review Committee, comprised of U.S. and Canadian experts, recommended immediate reduction of fishing mortality by ending all directed fishing and minimizing bycatch (NEFSC[11]). They also recommended a substantial reduction in effort including 56% reduction of fishing mortality rates for Gulf of Maine cod stocks and 36% reduction for Georges Bank cod stocks (NEFMC, 2000). Total Allowable Catch (TAC) for Georges Bank (4,700 t) and the Gulf of Maine (1,783 t) were both grossly exceeded in 1998 (NEFMC, 1999c). Thus, proposed low trip limits, reduced TAC's, and closed area extensions are being used to essentially create a bycatch-only fishery in the Gulf of Maine (NEFMC, 1999c).

Time/area closures for the sink gillnet fishery were initiated in the mid 1990's to protect harbor porpoise in New England coastal waters from Rhode Island to the Canadian border and in an offshore region adjacent to, and including, Cashes Ledge. The Northeast (Penobscot Bay to the Canadian border) and Massachusetts Bay Closure Areas were later closed to all gear for groundfish conservation beginning in 1996 and 1997, respectively (NEFMC, 1998a). Other area closures were implemented to protect right whales between 1 January and 15 May in Cape Cod Bay Federal waters and 1 April–30 June in the Great South Channel (NEFMC,1998a).

Silver Hake

Silver hake, or whiting, range from Newfoundland to South Carolina, but are most abundant from Nova Scotia to New York (Helser et al., 1995; Mayo, 1998), and are typically in depths of less than 200 m (Helser et al., 1995). Their distribution shifts seasonally, as most adults move offshore into deeper, outer-shelf and slope waters in the winter and spring, then into shallower coastal waters and banks during the summer and fall (Helser et al., 1995; Mayo, 1998). The greatest concentrations of adults during the winter and spring are in the deep basins of the Scotian Shelf and Gulf of Maine and along the continental slope from Sable Island to Cape

Hatteras (Helser et al., 1995; Mayo, 1998). Adults are more widespread in the summer and early fall, with concentrations over the shallower waters of northern Georges Bank and the inshore waters of the Gulf of Maine. Juveniles exhibit similar movement patterns, but generally in shallower waters (Helser et al., 1995).

Within U.S. waters are the Gulf of Maine–Northern Georges Bank (northern) stock and the Southern Georges Bank–Middle Atlantic (southern) stock (Helser et al., 1995; Mayo, 1998; Bolles and Begg, 2000). A separate stock ranges over the Scotian Shelf in Canadian waters (Helser et al., 1995).

Spawning runs from May through November, starting earliest in the south and progressing northward (Helser et al., 1995). It occurs throughout the range, with heaviest concentrations in the mid-Atlantic region between Cape Cod, Mass. and Montauk Point, N.Y., on the southeastern slope of Georges Bank, and between Cape Cod and Grand Manan Island in the Gulf of Maine. Most silver hake mature between ages 2 (20–30 cm) and 3 (25–35 cm) (Helser et al.,1995; Mayo, 1998).

Silver hake become increasingly piscivorous, even cannibalistic, with age and may exert some regulatory influence on other fish populations of the northeast continental shelf ecosystem. When hake is abundant, Atlantic mackerel and Atlantic herring stocks are low, both of which are prey of silver hake (Helser et al., 1995).

The Fishery

U.S. fishing efforts for groundfish increased in the Gulf of Maine, Georges Bank, and southern New England between 1976 and 1986 coinciding with a 72% decrease in silver hake biomass and a decline in U.S. landings (Helser et al., 1995; NEFMC, 1999b) (Fig. 7). Distant water fleets (DWF) entered the fishery in 1962 and began a period of intense exploitation of groundfish stocks on Georges Bank and the Scotian Shelf; silver hake was a principal target species. In just 3 years, the total take of hake reached 351,000 t, most of which was from the Gulf of Maine, northern Georges Bank, and mid-Atlantic areas.

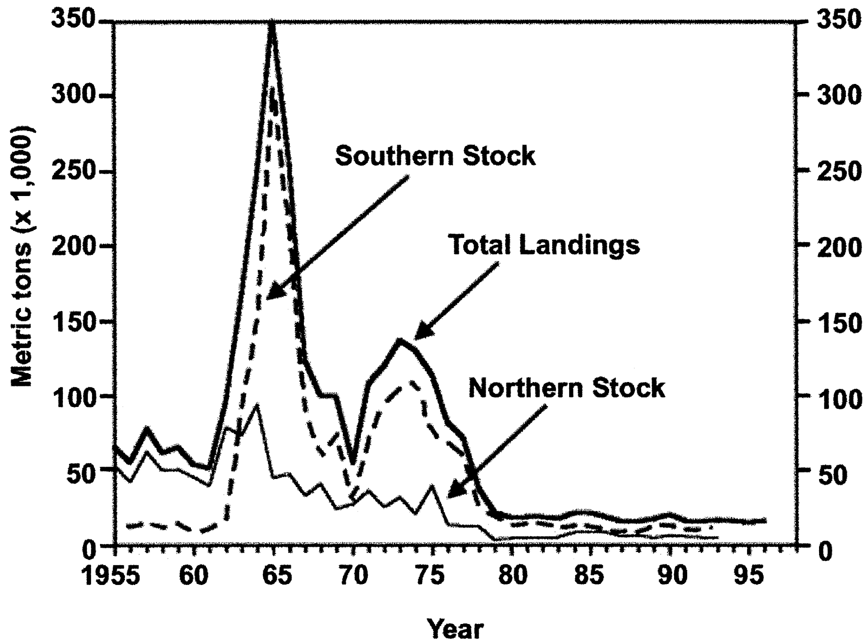

Figure 7.—Silver hake annual landings, northern and southern stocks. Adapted from Mayo (1998).

Exploitation levels caused a decline in silver hake abundance and landings plummeted to 55,000 t by 1970 (Helser et al., 1995; Mayo, 1998). With declining U.S. stocks, DWF efforts on the Scotian Shelf intensified (NEFMC, 1999b). DWF take in U.S. waters after 1970 focused primarily on the southern stock, where landings averaged 70,000 t/year from 1970 to 1977 and reached 137,000 t in 1973 (Helser et al., 1995; Mayo, 1998) (Fig. 7).

Regulations imposed by the International Commission for the Northwest Atlantic Fisheries in 1973 restricted the DWF fishery both temporally and spatially (Helser et al., 1995; NEFMC, 1999b). Implementation of the MFCMA further curtailed efforts (Mayo, 1998). The DWF fishery on the northern stock ended after 1977, but not until 1987 for the southern stock where silver hake was primarily caught incidental to the squid fishery (Mayo, 1998).

Stock status

Silver hake stocks were last assessed in 1990; there are no current estimates of stock size or spawning stock biomass (NEFSC[13]; NEFMC, 1999b). Previous estimates show a downward trend for the southern stock and a generally downward, but fluctuating, trend for the northern stock. Spawning stock biomass for the southern stock was 650,000 t in 1965, but the intensified DWF fishery caused a rapid decline to 150,000 t in 1970. Recruitment dropped from 4.4 billion age 1 fish in 1965 to less than 500 million by 1968 (Helser et al., 1995). Survey biomass indices decreased by over 50% since 1985 and have been at record lows since the mid 1990's. The DWF fishery similarly impacted the northern stock. Fishing mortality rates tripled between 1961 and 1964. Spawning stock biomass decreased from 300,000 t in 1962 to very low levels in the 1970's, and has been between 9,000 and 33,000 t since 1978. Despite increases in biomass indices since 1980, there has been no corresponding increase in the adult (spawning stock) biomass (Helser et al., 1995; Mayo, 1998; NEFSC[13]).

[13] NEFSC. 1994. Report of the 17th Northeast Regional Stock Assessment Workshop: the plenary. NOAA/NMFS, Northeast Fish. Sci. Cent. Ref. Doc. 94-07, 59 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

The age structure of the stocks has become severely truncated and year classes are disappearing before becoming adults (NEFMC, 1999b). A substantial juvenile mortality caused by consistently high discard rates in the otter trawl and northern shrimp fisheries may be impacting the adult populations, long-term yield, and spawning stock biomass (Mayo, 1998; NEFMC, 1999b). Most of the juveniles lost through discards are 15–25 cm long and ages 1–2 (NEFSC[13]). Discard estimates for 1989–92 represented sizeable portions of each stock's total landings (NEFSC[13]).

Fishing mortality rates increased substantially over the last 20 years (NEFMC, 1999b). Since 1992, the northern stock's exploitation rate grew from 42% to about 65% (Mayo, 1998; NEFMC, 1999b). The exploitation rate for the southern stock was 33% from 1978 to 1980, 54% from 1983 to 1987, and was recently estimated at 60% (Mayo, 1998). Both stocks are considered overexploited (Mayo, 1998; NEFMC, 1999b).

Management

Direct management of the U.S. silver hake fishery began with its addition to the Northeast Multispecies FMP in 1991 (Helser et al., 1995; NEFMC, 1999b). Amendment 12 to the FMP was submitted in February 1999 with the primary goal of decreasing silver hake exploitation by roughly 63%, to a target rate of 25% (NEFMC, 1999b). The proposed action includes trip possession limits and mesh regulations, limiting access to the fishery through a permit moratorium, and shortening the Cultivator Shoal season by one month (NEFMC, 1999b). Trip possession limits based on mesh size (the larger the mesh, the higher the limit) were developed as an incentive to use larger mesh sizes and reduce juvenile take. Also recommended is treating the northern and southern stocks as a single management unit, while continuing to manage the Cultivator Shoal fishery separately (NEFMC, 1999b).

Atlantic Herring

Atlantic herring range from North Carolina to the Canadian Maritime Provinces. Adults occur along the southern New England and mid-Atlantic coasts from the inshore waters out to the continental shelf break during late winter to early spring, migrate north into the Gulf of Maine to feed in the spring, segregate into spawning aggregations in late summer and fall, then migrate south again after spawning to overwinter in warmer waters (Friedland, 1998; NEFMC, 1999a).

Maximum length is about 43 cm and maximum weight 680 g. Most fish mature by age 5, some by age 3 (Friedland, 1998; NEFMC, 1999a). Recruitment into the exploitable population is at about age 2, the target age-group of the juvenile herring fishery (NEFMC, 1999a).

Three major geographically distinct spawning stocks of Atlantic herring are on Georges Bank and Nantucket Shoals, in the coastal waters of the Gulf of Maine, and in the waters off southwest Nova Scotia (Grosslein, 1987; Stevenson, 1998). Each is further divided into smaller spawning areas that support discrete spawning aggregations (Iles and Sinclair, 1982; Friedland, 1998). Spawning occurs at depths of 10–100 m from late summer to fall, following a counter-clockwise progression from the northeastern Gulf of Maine around to Georges Bank (Friedland, 1998; NEFMC, 1999a).

In 1991, the two U.S. spawning stocks (Georges Bank/Nantucket Shoals and Gulf of Maine) were combined to form the coastal stock complex. This encompasses North Carolina to the Gulf of Maine, Georges Bank (U.S. and Canadian portions), and the western Bay of Fundy in New Brunswick. U.S. management is limited to U.S. jurisdictional waters (NEFMC, 1999a; NEFSC[12]).

The Fishery

The Maine herring fishery developed in the 19th century along with the sardine canning industry in northeastern Maine and the growth of the lobster fishery, for which herring were used as bait. Weirs were the most commonly used fixed gear until the 1940's in eastern Maine and are still routinely used in New Brunswick. Stop seines became the dominant gear in the 1950's as herring became more abundant along the coast of central Maine. Juvenile (age 2, ≈17 cm) herring were the primary target of this fishery and remained so through the 1970's. Purse seines gained importance after 1960 and continue to harvest an increasing percentage of the catch today. The majority of herring are either canned or used as lobster bait (NEFMC, 1999a).

An adult herring fishery developed in the Jeffreys Ledge area in 1967 (Anthony and Waring, 1980) and was supported by filleting and freezing plants that shipped the fish to West Germany. Southern New England and mid-Atlantic landings were relatively insignificant (less than 5,000 t/year) until recently (NEFMC, 1999a); 1996 landings were 20,200 t, roughly 20% of the U.S. total (Stevenson, 1998).

The offshore foreign fishery began in 1961 with 100 Soviet vessels fishing Georges Bank. Between 1965 and 1972, the number of foreign vessels fishing from Georges Bank to Cape Hatteras increased from 450 to over 1,000. Most targeted herring. The foreign fleet consisted primarily of stern trawlers and side trawlers rigged for purse seining (Anthony and Waring, 1980; NEFMC, 1999a).

This intense fishing pressure led to the collapse of the Georges Bank/Nantucket Shoals stock and fishery by the mid 1970's (Anthony and Waring, 1980; Friedland, 1998). Estimated age 3+ biomass dropped from 1.2–1.35 million t in the late 1960's to 400,000 t by the mid 1970's (NEFMC, 1999a). Landings steadily declined from 373,600 t in 1968 to less than 1,000 t in 1981 (Friedland, 1998; NEFSC[12]). Directed foreign fishing ended in 1982. Mid-water trawlers recently returned to Georges Bank, with catches of less than 3,000 t in 1996 and over 6,000 t in 1997 (NEFMC, 1999a; NEFSC[12]).

Unlike Georges Bank, landings from the Gulf of Maine stock have been relatively stable, averaging about 73,000 t since 1995 (NEFSC[12]). The total stock complex catch averaged 116,000 t since 1995 (NEFSC[12]) (Fig. 8).

Declines in fixed gear use since 1982 changed the Maine coastal fishery. Purse seines and, increasingly, mid-water otter trawls now dominate the fishery.

Pair trawls are also starting to be used (NEFMC, 1999a; NEFSC[12]). Mobile gear use increased from less than 50% in the 1970's to greater than 90% during the mid 1990's (Friedland, 1998).

With this shift in gear usage, the proportion of juveniles harvested declined and the fishery is now more a mix of ages 2, 3, and 4+ fish. Since 1986, the catch has been about 75% age 3+ fish (NEFMC, 1999a).

The seasonal pattern of the fishery basically follows the seasonal distribution of the herring. The fishery is active south of New England during winter; there has been no winter fishing north of Cape Cod since 1993 (NEFMC, 1999a). In spring, fishing shifts north into the offshore Gulf of Maine, then into the coastal Gulf of Maine in late summer/early fall when herring move into these areas prior to spawning. Highest landings in the Gulf of Maine are from July through October, although herring are caught in Maine coastal waters from June to November. This coincides with spawning aggregations and the peak lobster season. Landings in Maine usually diminish by November and the fishery shifts south again (NEFMC, 1999a). Recent Georges Bank catches have been made during summer to early fall (NEFMC, 1999a). Most herring are caught off and landed in Maine, followed by Massachusetts and, recently, Rhode Island (NEFMC, 1999a).

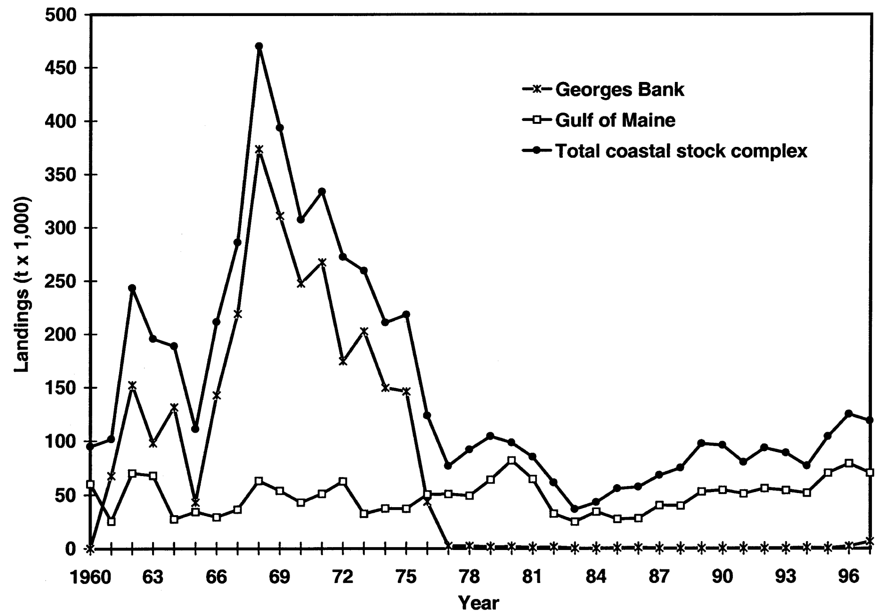

Figure 8.—Atlantic herring annual landings. Coastal stock complex total includes landings from Georges Bank, Gulf of Maine, New Brunswick fixed gear, and southern New England fisheries. Data from NEFSC (text footnote 11).

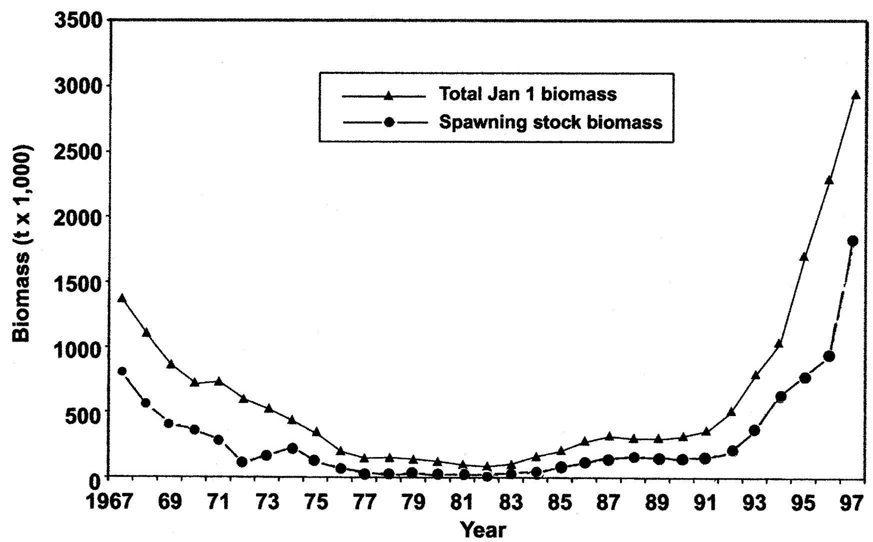

Figure 9.—Atlantic herring coastal stock complex biomass. Adapted from NEFMC (1999a).

Stock Status

The coastal stock complex has grown since the mid 1980's and markedly so since the early 1990's (NEFSC[12]) (Fig. 9), a likely result of the recent recovery of the Georges Bank/Nantucket Shoals components of the stock complex (NEFMC, 1999a). Total stock biomass increased from 500,000 t in 1992 to 2.9 million t in 1997 (NEFMC, 1999a; NEFSC[12]). Spawning stock biomass increased from 143,000 t in 1990 to 1.8 million t in 1997 (NEFMC, 1999a; NEFSC[11]).

Coincident to the rising biomass, the relative exploitation rate for the entire coastal stock complex declined from 67% in 1968 to 30% in 1990 to 4% in 1997 (NEFSC[11]). In contrast, annual harvest rates were 25–40% for the inshore waters of the Gulf of Maine where the herring fishery concentrated over the last 20 years (NEFMC, 1999a). As a result, the Gulf of Maine component of the stock is fully exploited, if not overfished. The total coastal stock complex, however, is considered underexploited (NEFMC, 1999a; NEFSC[12]).

Management

Herring fishing is managed by NMFS, NEFMC, Atlantic States Marine Fisheries Commission (ASMFC), and by state governments. The ASMFC coordinates management of interjurisdictional fisheries and resources within state waters

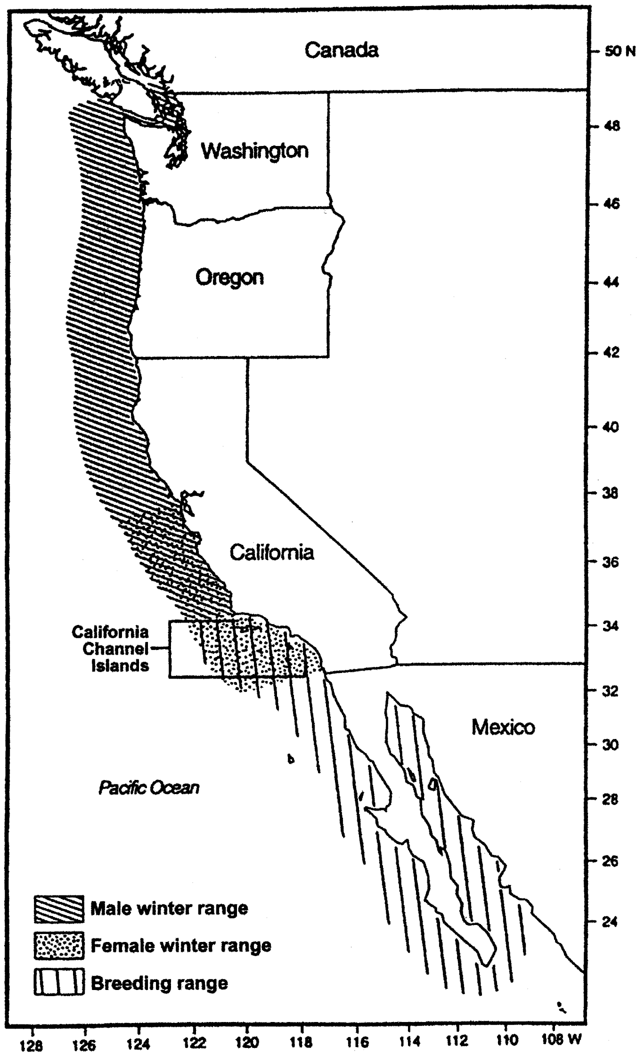

Figure 10.—Breeding and migratory ranges of California sea lions (Melin et al., text footnote 17).

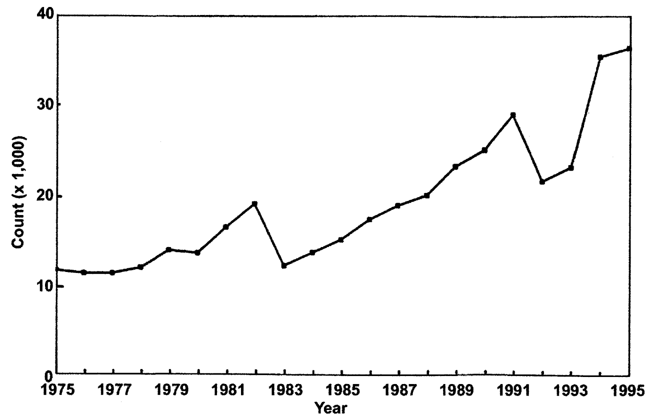

Figure 11.—California sea lion pup counts in southern California. Adapted from NMFS (1997a).

and is working with NEFMC to develop complimentary management measures for state and Federal waters. The Final Rule for the Atlantic Herring FMP was published by NMFS in December 2000 (NMFS, 2000). Maine, New Hampshire, Massachusetts, and Rhode Island all have state specific regulations.

The NEFMC is taking a conservative approach under the new management plan by attempting to account for natural population fluctuations, ecosystem level considerations, such as predator-prey interactions, and the potential impacts of overfishing. In developing maximum sustainable yield (MSY) and target fishing mortality rates, there was an effort to include nonfishery sources of mortality, such as predation, including that by marine mammals. Because of potential overestimation of biomass, a precautionary approach was taken, allowing for slower development of the fishery and reducing the possibility for overfishing (NEFMC, 1999a).

West Coast Pinnipeds

U.S. west coast pinnipeds are the California sea lion, Steller sea lion, harbor seal, northern elephant seal, northern fur seal, and Guadalupe fur seal. Guadalupe fur seals are occasionally sighted in southern and central California offshore waters, and a female and pup were recently observed on San Miguel Island (Melin and DeLong, 1999). However, their only known breeding rookery is on Guadalupe Island, Mexico (Barlow et al., 1997), so they will not be discussed further.

Northern elephant seals and northern fur seals are also excluded from this report. They both breed and pup on some California islands (fur seals only on San Miguel Island in the Channel Islands), but their distribution is generally more offshore, and both species widely disperse after the breeding season (Barlow et al., 1997). California sea lions, Steller sea lions, and harbor seals are essentially year-round residents and are described in further detail below.

California Sea Lion

Distribution, Abundance, and Population Trends

California sea lions range from southern Mexico to Vancouver Island, B.C. (Barlow et al., 1997; Lowry et al.[14]). Three geographically distinct breeding stocks occur within this range, but only the U.S. stock (from the U.S./Mexico border north into Canada) is considered here (Fig. 10). The southern California Channel Islands (Santa Barbara, San

[14] Lowry, M. S., P. Boveng, R. J. DeLong, C. W. Oliver, B. S. Stewart, H. DeAnda, and J. Barlow. 1992. Status of the California sea lion (*Zalophus californianus californianus*) population in 1992. Admin. Rep. LJ-92-32, Southwest Fish. Sci. Cent., La Jolla, Calif., 34 p.

Nicolas, San Miguel, and San Clemente) are principal breeding and pupping sites for this stock (Lowry et al.[14]). California sea lions occasionally pup on the South Farallon Islands, where they are year-round residents, but fewer than 20 pups have been recorded there in the last 20 years (Sydeman and Allen[15]). Pupping takes place from late May to July, and peaks in mid-June. Breeding occurs in late June through July.

After the breeding season, adult and subadult males migrate north to the coasts of central and northern California, Oregon, Washington, and British Columbia and return to the rookeries in spring (Lowry et al.[14]). Some immature sea lions undertake shorter migrations (Huber, 1991). The nonbreeding season range of adult females from the Channel Islands extends from southern California to the Farallon Islands (Melin, 1995), although most remain near the rookeries year-round. Animals that stay year-round in southern California are primarily adult females, pups, and juveniles (NMFS, 1997a; Heath and Francis[16]). Año Nuevo Island in central California commonly supports a large nonbreeding sea lion population (NMFS, 1997a; Melin et al.[17]). The largest concentrations in central/northern California waters are usually found on the Farallon Islands in the fall and spring during migration before and after the breeding season (Huber, 1991). Only males haulout north of the Farallones (Melin et al.[17]) (Fig. 10).

California sea lions are found in Oregon waters from mid-August through mid-June, absent only during the peak breeding season (Brown, 1997a). The peak northward migration is during September and October (Mate, 1973; NMFS, 1997a). Numbers decrease during the winter, but increase again with a smaller peak in April/May during the southward migration (Brown, 1997a; Brown[18]). Sea lions are not restricted to coastal areas and have been seen as far up the Columbia River and its tributaries as 128 miles at Willamette Falls on the Willamette River (Brown, 1997a).

In Washington the peak northward migration occurs in December, and the peak southward migration is in March/April (NMFS, 1997a). Large aggregations occur in Puget Sound from September to May, but decline during January–March. Increased numbers around Vancouver Island, B.C., in January corresponds with the decrease in Puget Sound and may be related to herring abundance. California sea lions are most abundant along the outer coast from March to May and from October to December and are absent, or in low numbers, from June to August (Gearin et al.[19]).

California sea lion abundance increased dramatically during the latter half of the 1900's after a period of extensive exploitation that began in the 1800's (Cass, 1985; Stewart et al., 1993). They were taken for pet food, hides, "trimmings," display, sport, bounty, fishery protection, and even target practice (Lowry et al.[14]). Commercial fishermen could lethally remove sea lions that interfered with fishing operations until prohibited to do so under the 1994 amendments to the MMPA (Cass, 1985; 16 U.S.C. §1387(a)(5)). Sea lion numbers began increasing after curtailment of the commercial hunt in the 1940's and markedly so after passage of the MMPA in 1972.

The 1995 population estimate for the U.S. stock was 167,000–188,000 (Barlow et al., 1997), higher than the previous estimates of 111,016 in 1990 (Lowry et al.[14]) and 87,000 in 1988 (Boveng[20]).

Pup counts increased 8.8% per year between 1976 and 1982, 10.2% per year from 1983 to 1991, and at 8.3% per year for 1983–95 (Barlow et al., 1997) (Fig. 11). El Niño events profoundly impact growth rates and survivorship through decreased prey availability for pregnant and lactating females (DeLong et al., 1991); major declines in pup counts occurred during the strong El Niño years of 1983, 1992 (see Fig. 11), and 1998 (DeLong et al.,1991; Barlow et al.,1997; DeLong[21]). Because of these pup declines, the average annual rate of increase in pup counts was 5.4% between 1975 and 1995 (Barlow et al., 1997).

Peak Oregon counts grew from 1,000–2,000 in the late 1970's to 5,000–7,000 in the early 1990's (NMFS, 1997a). An estimated 7,000–10,000 California sea lions likely pass through Oregon coastal waters during northward and southward migrations (Brown, 1997a). Counts in the inland waters of Washington averaged 300–500 from 1986 to 1994, then increased to over 1,100 in 1995. Approximately 200–500 California sea lions were present along Washington's outer coast during most of the 1990's (NMFS, 1997a). Numbers have increased substantially since 1997, with high counts of approximately 980, 1,200, and over 2,700 in 1997, 1998, and 1999, respectively (Gearin[22]).

Fishery-related Mortality

California sea lion incidental mortality is highest in the California driftnet fishery for sharks and swordfish and the California set gillnet fishery for halibut

[15] Sydeman, W. J., and S. G. Allen. 1997. Trends and oceanographic correlates of pinniped populations in the Gulf of the Farallones, California. Final rep. to Nat. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Contract 40JGNF500431. Admin. Rep. LJ-97-2C, Southwest Fish. Sci. Cent., La Jolla, Calif., 19 p.

[16] 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. Admin. Rep. LJ-83-04C, Southwest Fish. Sci. Cent., La Jolla, Calif.

[17] Melin, S. R., R. L. DeLong, and J. L. Laake. 1997. Evaluation of the life history parameters and breeding season distribution of California sea lions (*Zalophus californianus*) from a branding study at San Miguel Island, California. *In* P. S. Hill and D. P. DeMaster (Editors), Marine Mammal Protection Act and Endangered Species Act implementation program 1996, p. 25–42 . U.S. Dep. Commer., NMFS, AFSC Proc. Rep. 97-10.

[18] Brown, R. F. 1986. Assessment of pinniped populations in Oregon. First ann. rep. Nat. Mar. Mammal Lab. NOAA, NMFS Coop. Agreement 84-ABH-00028, 44 p.

[19] Gearin, P. J., S. J. Jeffries, M. E. Gosho, J. R.Thomason, R. L. DeLong, M. Wilson, D. Lambourn, B. Hanson, S. Osmek, and S. Melin. 1996. Capture and marking California sea lions in Puget Sound, Washington during 1994–95: distribution, abundance and movement patterns. Nat. Mar. Mammal Lab., NMFS, AFSC, Seattle, Wash., 33 p.

[20] Boveng, P. 1988a. Status of the California sea lion population on the U.S. west coast. Admin. Rep. LJ-88-07, Southwest Fish. Sci. Cent., La Jolla, Calif., 26 p.

[21] DeLong, R. L. 1999. National Marine Mammal Laboratory, Seattle, Wash. 98115. Personal commun.

[22] Gearin, P. J. 1999. National Marine Mammal Laboratory, Seattle, Wash. 98115. Personal commun.

and angel shark, with mean annual takes of 49 and 815, respectively, for 1991–95. Other commercial fisheries with known incidental mortalities are the California, Oregon, and Washington Pacific salmon troll fishery, Oregon and Washington nonsalmon troll fisheries, California herring purse seine fishery, California anchovy, mackerel, and tuna purse seine fisheries, California squid purse seine fishery, Washington, Oregon, California, and British Columbia salmon net pen fishery and the Washington, Oregon, and California groundfish trawl fishery (Barlow et al., 1997; Beeson and Hanan[23]). Information on the mean annual takes is unavailable for many of these fisheries and is relatively low for the others. The total estimated minimum annual take for all fisheries combined was 915 for 1991–95 (Barlow et al., 1997).

Food Habits and Prey

Diet varies by location, year, and season. The most commonly consumed prey at the Channel Islands were market squid, northern anchovy, Pacific whiting, shortbelly rockfish, jack mackerel, Pacific (chub) mackerel, and Pacific sardine (NMFS,1997a; Lowry and Caretta, 1999).

Market squid, present in 35–44% of scats from three Channel Islands rookeries (1981–95), is one of the most important prey items for sea lions in that area (Lowry and Carretta, 1999). Its prevalence in the diet increases in fall and winter, except during El Niño years when squid abundance declines (Lowry et al., 1991; Lowry and Caretta, 1999). Most Pacific whiting consumed were 1–2 years old (Antonelis, 1996). The abundance of northern anchovy, which was available year-round and at a high frequency of occurrence in the diet, was inversely related to the consumption of other prey at San Nicolas and San Clemente Islands (1981–86) (Lowry et al., 1990; Lowry et al., 1991).

In central California offshore waters, Pacific whiting, rockfish, market squid, and herring dominate the diet. At the Farrallon Islands, Pacific whiting was most prevalent from April to August and less so from September to March. Sea lions primarily consumed 2–3 year old whiting, the availability of which was inversely related to diet diversity. Rockfish were a major component of the winter diet (Ainley et al., 1982; Bailey and Ainley, 1982). Principal prey at Año Nuevo Island were Pacific whiting, shortbelly rockfish, and market squid (NMFS, 1997a). Market squid dominate the California sea lion summer diet in Monterey Bay (Harvey and Weise, 1997). In San Francisco Bay, Pacific herring was most common in fall and winter (NMFS, 1997a), and peak sea lion numbers around Tomales Bay coincided with winter herring spawning (Huber, 1991).

In coastal Oregon, the most common prey were Pacific mackerel, Pacific whiting, Pacific herring, cephalopods, Pacific sardines, salmonids, smelts (Osmeridae), spiny dogfish, lamprey, rockfish, jack mackerel, skates, and sand lance (NMFS, 1997a; Riemer and Brown[24]). Pacific mackerel was most abundant in February and Pacific whiting most abundant in October (Riemer and Brown[24]).

In Puget Sound, Wash., important prey included Pacific whiting, Pacific herring, squid, salmonids, spiny dogfish, and gadids (Schmitt et al., 1995; NMFS, 1997a). Diet data are not currently available for the Washington outer coast.

Steller Sea Lion

Distribution, Abundance, and Population Trends

Steller sea lions of the contiguous U.S. west coast are part of the eastern stock which ranges from east of Cape Suckling, Alaska, through southeast Alaska, British Columbia, and along the west coast to California (Loughlin, 1997). Only the California, Oregon, and Washington components will be discussed. The southern extent of the breeding range is currently in central California on Año Nuevo Island (Stewart et al., 1993; LeBeouf et al.[25]). Other rookeries include the Farallon Islands, Sugarloaf/Cape Mendocino, and St. George Reef (off Crescent City) in California and Rogue Reef, Orford Reef, and Three Arch Rocks in Oregon (Loughlin et al., 1984; Loughlin et al., 1992) (Fig. 12).

There are 10 regular haulout sites in Oregon, including the above-mentioned rookeries, from the south jetty at the Columbia River south to Rogue Reef (Brown[18]; Brown and Riemer[26]). Principal haulout sites in Washington range along the outer coast, and include Tatoosh Island, Cape Alava, Carroll Island, and Split/Willoughby Rocks (NMFS[27]). Steller sea lions are not commonly found in coastal bays or rivers, except the lower Rogue River and, occasionally, the lower Columbia River in Oregon; they tend to remain within 5 miles of shore on offshore islands, reefs, and ledges (Brown, 1997a; Brown[28]).

Since the early 1900's the southern extent of the breeding range has shifted northward. In the late 1930's there were over 2,000 Steller sea lions on the Channel Islands. By 1958, there were less than 100 on San Miguel Island, the historical southernmost breeding site (Bartholomew, 1967). No pups have been born there since 1981, and no adults have been seen there since 1983 (NMFS[27]). On Año Nuevo, the current southernmost rookery, Steller sea lions were no longer present year-round beginning in the 1980's (LeBeouf et al.[25]). There has been no pupping at Point

[23] Beeson, M. J., and D. A. Hanan. 1996. An evaluation of pinniped-fishery interactions in California. Rep. to Pac. States Mar. Fish. Comm., Portland, Oreg., 22 p.

[24] Riemer, S. D., and R. F. Brown. 1997. Prey of pinnipeds at selected sites in Oregon identified by scat (fecal) analysis, 1983–1996. Wildl. Diversity Prog., Mar. Reg., Oregon Dep. Fish Wildl., Newport, Oreg. Tech. Rep. 97-6-02, 34 p.

[25] Le Boeuf, B. J., K. Ono, and J. Reiter. 1991. History of the Steller sea lion population at Año Nuevo Island, 1961–1991. NMFS, SWFSC Admin. Rep. LJ-91-45C, 24 p.

[26] Brown, R. F., and S. D Riemer. 1992. Steller sea lion counts in Oregon during June and July, 1975–1991. Oregon Dep. Fish Wildl., Mar. Reg., Marine Science Drive, Newport, OR 97365. Unpubl. rep., 12 p.

[27] NMFS. 1995. Status review of the United States Steller sea lion (*Eumetopias jubatus*) population. Prep. by Nat. Mar. Mammal Lab., Alaska Fish. Sci. Cent., Nat. Mar. Fish. Serv., Seattle, Wash., 61 p.

[28] Brown, R. 2000. Oregon Department of Fish and Wildlife, 7118 N.E. Vandenberg Ave., Corvallis, OR 97330. Personal commun.

Reyes Peninsula since the mid 1970's (Sydeman and Allen, 1999) and little pupping at the Farallones since the early 1970's (Hastings and Sydeman[29]).

The breeding season is from late May to early July; peak pupping is in June (Gentry, 1970). Males generally disperse northward after breeding (Mate, 1973; Hastings and Sydeman[29]); Mate (1973) found no adult males south of Oregon after August. Peak abundance in California and Oregon is during the breeding season. Because there are no rookeries in Washington, abundance there is lowest during the breeding season and highest from late-summer through winter (NMFS, 1997a; Gearin[22]).

Steller sea lions were reportedly abundant along the California coast and outer islands prior to being hunted during the late 1800's and into the 1900's. Although California and Steller sea lions were not distinguished, a portion of the sea lions taken by hunting were undoubtedly Steller sea lions (Cass, 1985). Large numbers were killed for bounties along the Oregon, Washington, and British Columbia coasts (Stewart et al., 1993). Prior to 1971, most subadult and adult mortality was from gunshot wounds. Rookeries in Oregon were dynamited and sea lions shot because of assumed fisheries interactions (Brown[18]). The frequency of such events declined after being declared a nongame species in 1971 and gaining protection through the MMPA in 1972 (Mate, 1973).

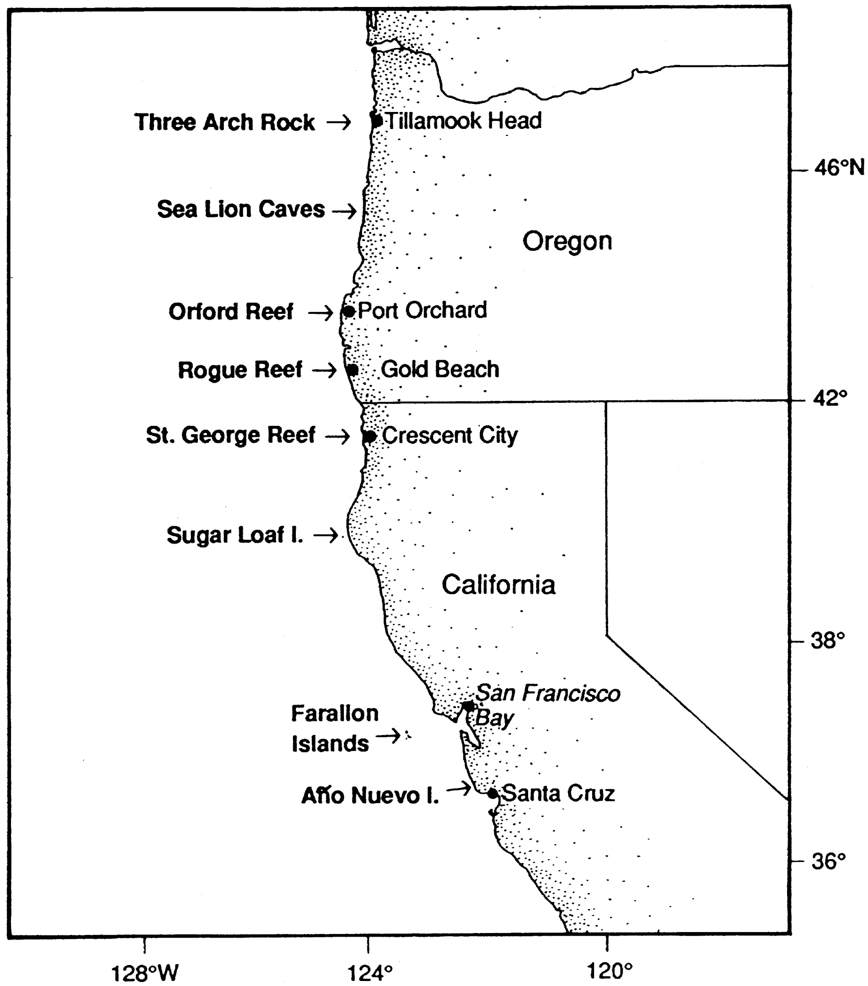

Figure 12.—Steller sea lion rookeries and major haulouts in Oregon and California (Loughlin et al., 1992).

Steller sea lion populations did not escalate after passage of the MMPA. While counts in northern California and Oregon have been relatively stable to increasing, those in southern and central California have been declining (Westlake et al., 1997; Sydeman and Allen, 1999; LeBeouf et al.[25]; NMFS[27]; Hastings and Sydeman[29]). Counts of nonpups in California diminished from 5,000–7,000 between 1927 and 1947 to 1,500–2,000 since 1980 (NMFS[27]). Pup counts are also decreasing (Hastings and Sydeman[29]; NMFS[30]), and on Año Nuevo, the largest central California rookery, they decreased nearly 10% per year from 1990 to 1993 (Westlake et al., 1997). The Oregon population averaged about 2,000–3,000 since the 1970's, and nonpup counts increased from roughly 1,500 in 1976 to over 3,000 20 years later (Brown and Riemer[26]; Brown[28]; NMFS[30]). This may reflect both improved and expanded surveys and an actual increase (Brown and Riemer[26]). An estimated 550–600 pups are born annually in Oregon, mostly at Rogue and Orford Reefs and a few at Three Arch Rocks (Loughlin et al., 1992; NMFS, 1997a).

Range-wide surveys of the eastern and western stocks were conducted during the summer breeding seasons of 1989 and 1994 (Loughlin et al., 1992; NMFS[30]) and a coast-wide census was made in summer 1996. The 1994 nonpup counts included 1,046 in California, 3,070 in Oregon, and 447 in Washington (NMFS[30]). Several California sites surveyed in 1989 were excluded in 1994, and Washington was not surveyed in 1989 (Loughlin et al., 1992; NMFS[30]), precluding a comprehensive assessment of trends. The total count for the 1996 census was 6,555 (5,464 non-pups, 1,091 pups) and included California (2,042), Oregon (3,990), and Washington (523)

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[29] Hastings, K. K., and W. J. Sydeman. 1998. Status, seasonal variation and long-term trends in numbers of Steller sea lions, *Eumetopias jubatus*, at the Farallon Islands, California: 1927–1996. Final rep. to Nat. Mar. Fish. Serv., Southwest Fish. Sci. Cent., La Jolla, Calif., Contract 40JGNF600336, 41 p.

[30] NMFS unpublished data, National Marine Mammal Laboratory, 7600 Sand Point Way, N.E. Seattle, WA 98115.

(Gearin[22]; Brown[28]; Sydeman[31]; Perryman[32]). Figure 13 shows combined nonpup counts for California and Oregon trend sites only. The 1996 Washington coast summer count was comparable to counts during 1956–60 (Loughlin et al., 1984), 1958–70 (Mate[33]), and 1994 (NMFS[30]). Nonbreeding season counts in Washington are substantially higher at 1,000–1,300 Steller sea lions (Gearin[22]).

The eastern stock of Steller sea lions is listed as threatened under the ESA and depleted under the MMPA. Stock status relative to OSP is unknown (Hill and DeMaster, 1999).

Fishery-related Mortality

Mortality incidental to west coast commercial fisheries was very low during 1990–97. Mean annual mortality in the California–Oregon thresher shark fishery was less than two Steller sea lions per year, and less than one in the swordfish gillnet fishery, the Pacific whiting component of the Washington–Oregon–California groundfish trawl fishery, and the northern Washington marine set gillnet fishery, respectively (Hill and DeMaster, 1999).

Food Habits and Prey

Preliminary analysis of Steller sea lion prey in Oregon (1986–96) included 27 families and 36 species (Riemer and Brown[24]; Gearin and Brown[34]). Prey identified in ≥10% of scat samples for all years combined included, by percent frequency of occurrence, Pacific whiting (83%), Pacific lamprey (39%), salmonids (23%), Pacific herring (19%), squid/octopus (18%), skates (16%), and smelts (10%) (Riemer and Brown[24]).

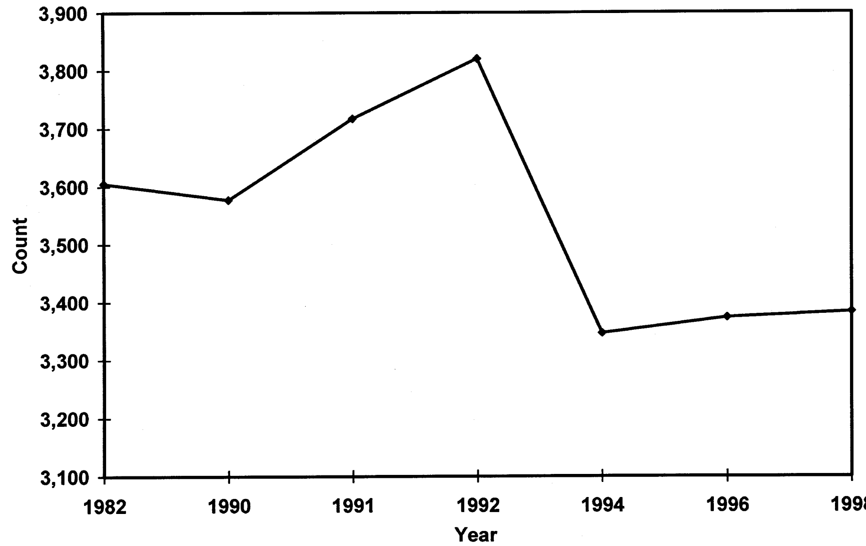

Figure 13.—Combined adult and juvenile Steller sea lion counts from trend sites in California and Oregon. Trend sites include Año Nuevo, Farallon Island, St. George Reef, Rogue Reef and Orford Reef. Based on unpublished data from Oregon Department of Fish and Wildlife (Brown, text footnote 28), Point Reyes Bird Observatory (Sydeman, text footnote 31) and Southwest Fisheries Science Center (Perryman, text footnote 32).

Pacific whiting ranked highest for all years, except 1986 and 1987, when it was second to Pacific lamprey (Riemer and Brown[24]). Prey consumed at the Columbia and Rogue Rivers included Pacific whiting, rockfish, eulachon, anchovy, Pacific herring, staghorn sculpin, and Pacific lamprey (NMFS, 1997a).

Scats collected in Washington during June–September 1993–97 included prey remains from 22 families and 25 species (Gearin and Brown[34]). Frequencies of occurrence for the seven major prey items, all sites combined, were Pacific whiting (94%), Pacific herring (23%), spiny dogfish (19%), skates (12%), Pacific sand lance (10%), Salmonidae (10%), and Pacific mackerel (4%) (Gearin[22]).

Harbor Seals

Eastern North Pacific harbor seals range from Baja California to the Aleutian Islands and from the Bering Sea to Cape Newenham and the Pribilof Islands (Barlow et al., 1998). There are several stocks within this range. The three along the contiguous U.S. west coast have been designated by NMFS, using combined biological and management considerations, as the California stock, the Oregon and Washington coast stock, and the Washington inland waters stock (Boveng[35]).

Harbor seals frequent coastal and estuarine waters and haulout on a variety of substrates, including rocks, reefs, and beaches (Hanan, 1996; Barlow et al., 1998). They are essentially nonmigratory and exhibit strong site fidelity (Herder, 1986; Barlow et al., 1998). Movements are usually within 25–50 km, but may be up to 550 km (Brown and Mate, 1983; Herder, 1986), and occur primarily outside of the pupping season (Huber, 1995). Harbor seals are year-round residents of Washington, Oregon, and California and pup in all three states (NMFS, 1997a). There is a cline in the timing of pupping, occurring earlier in the south and later in the north. Pupping in Washington exhibits addi-

[31] Sydeman, W. 2000. Point Reyes Bird Observatory, unpublished data, 4990 Shoreline Hwy., Stinson Beach, CA 94970. Personal commun.

[32] Perryman, W. 2000. Southwest Fisheries Science Center, Box 271, La Jolla, CA 92038. Personal commun.

[33] Mate, B. R. 1976. History and present status of the northern (Steller) sea lion, *Eumetopias jubatus*. FAO Advisory Comm. on Mar. Resou. Res., Sci. Consult. on Mar. Mammals, Bergen, Norway. ACMRR/MM/SC/66.

[34] Gearin, P. J., and R. F. Brown. 1999. Diets and food habits of Steller sea lions in Washington and Oregon. Steller Sea Lion Res. Peer Rev. Feed. Ecol. Workshop, 11–12 Feb. 1999, Nat. Mar. Mammal Lab., NOAA/NMFS/AFSC, Seattle, Wash.

[35] Boveng, P. 1988b. Status of the Pacific harbor seal population on the U.S. west coast. Admin. Rep. LJ-88-06, Southwest Fish. Sci. Cent., La Jolla, Calif., 43 p.

tional area-specific variability (Temte et al., 1991; Jeffries et al.[36]).

California Stock: Distribution, Abundance, and Population Trends

The California harbor seal population has been steadily increasing, and its distribution has expanded since the 1960's. The number of occupied haulout sites in California increased from 427 in 1982 to 877 in 1995 (Hanan, 1996; NMFS, 1997a). Harbor seals range along the mainland coast, the Channel Islands, Año Nuevo Island, and the Farallon Islands (Hanan, 1996). They were uncommon on the Channel Islands during the 1950's, but now breed on all eight islands (Stewart et al., 1993; NMFS, 1997a). Mean pupping dates are from late March to mid-May (Temte et al., 1991).

Harbor seals were hunted for bounty in California during the early 1900's, received state protection from hunting in 1938, and Federal protection under the MMPA in 1972 (Hanan, 1996). Surveys occurred as early as 1927, but they were infrequent until the 1960's and not systematic until the late 1970's (Hanan, 1996). Statewide counts are currently derived from aerial surveys during the premolt period from late June to early July (Hanan, 1996) or from May to June (Barlow et al., 1997). The most recent statewide count was 23,302 in 1995 (Hanan, 1996) (Fig. 14).

The overall population growth rate slowed from 1984 to 1995 (Hanan, 1996). The average annual statewide growth rate was 3.5% from 1982 to 1995, but was 1.9%, 5.8%, and 3.1% for the southern, central, and northern parts of the state, respectively (Hanan, 1996). The rate of increase on the South Farrallon Islands was 15.9% per year from 1973 to 1985, then averaged 9% per year from 1985 to 1997. This high rate of increase was attributed to immigration rather increased pupping (Sydeman and Allen, 1999). The status of the California stock of harbor seals relative to OSP is uncertain, although the population is increasing and fishing mortality is decreasing (Barlow et al., 1997).

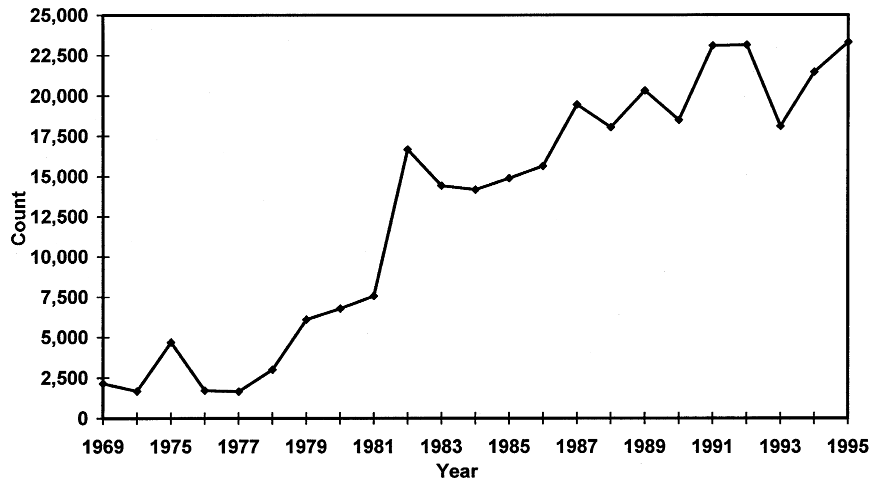

Figure 14.—California harbor seal counts. Counts include the mainland and southern California islands, except 1980 and 1981 are mainland only. Data from Hanan (1996).

Fishery-related Mortality

The set gillnet fisheries for angel shark, halibut, and other large mesh fisheries accounted for nearly all incidental mortality of harbor seals in California. The mean annual take during 1994–95 was 228 seals. Implementation of gillnet area closures in southern California in 1994 reduced fishing effort and incidental mortality from a previous high of nearly 5–10% per year (Hanan, 1996; Barlow et al., 1997). The California Department of Fish and Game (CDFG) implemented similar restrictions along the central and north coasts (Hanan, 1996; Barlow et al., 1997).

Oregon and Washington Coast Stock: Distribution, Abundance, and Population Trends

Most harbor seal data describe the populations by state rather than by stock. The following is differentiated by stock, when possible, and by state, when necessary. General Oregon and Washington information precedes the more specific regional and stock information.

In Washington harbor seals are found on the outer Olympic coast, in the coastal estuaries of Grays Harbor and Willapa Bay, the Strait of Juan de Fuca, San Juan Islands, south Puget Sound, and Hood Canal (Huber, 1995; Jeffries and Johnson[37]). In Oregon, they occur in most coastal estuaries, embayments, along isolated shorelines, offshore rocks and ledges, and at least 150 miles up the Columbia River (Brown, 1997a; Jeffries et al.[36]). There are 319 known haulout sites in Washington and 101 in Oregon (Huber, 1995; NMFS, 1997a). Pupping and breeding occur at all of these sites. Peak pupping in Oregon is from mid-May to mid-June (Brown[38]). Pupping in Washington occurs in early June in the coastal estuaries, around mid-June along the outer coast, from August to September in the inland waters, and from August to January, usually with a peak in mid-September, in the Hood Canal area (Jeffries and Johnson[37]; Huber, 1995).

Prior to the 1940's, about 5,000–6,000 harbor seals were estimated to be in Washington waters (Newby, 1973). An estimated 17,133 seals were killed

[36] Jeffries, S. J., R. F. Brown, H. R. Huber, and R. L. DeLong. 1997. Assessment of harbor seals in Washington and Oregon, 1996. *In* P. S. Hill and D. P. DeMaster (Editors), Marine Mammal Protection Act and Endangered Species Act implementation program 1996, p. 83–94. U.S. Dep. Commer., NMFS, AFSC Proc. Rep. 97-10, 255 p.

[37] Jeffries, S. J., and M. L. Johnson. 1990. Population status and condition of the harbor seal, *Phoca vitulina richardsi,* in the waters of the state of Washington: 1975–1980. Final rep to U.S. Mar. Mammal Comm., Contract MM7AC030, 77 p.

[38] Brown, R. F. 1997b. Abundance of Pacific harbor seals (*Phoca vitulina richardsi*) in Oregon: 1977–1996. Wildl. Diversity Prog., Oregon Dep. Fish Wildl., Tech. Rep. 97-6-04, 12 p.

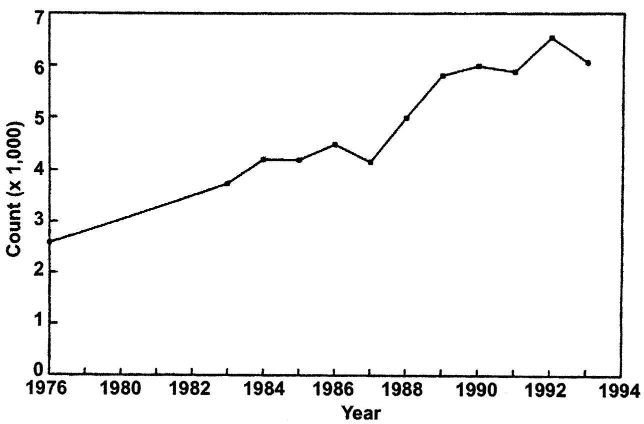

Figure 15.—Oregon harbor seal counts. Adapted from NMFS (1997a).

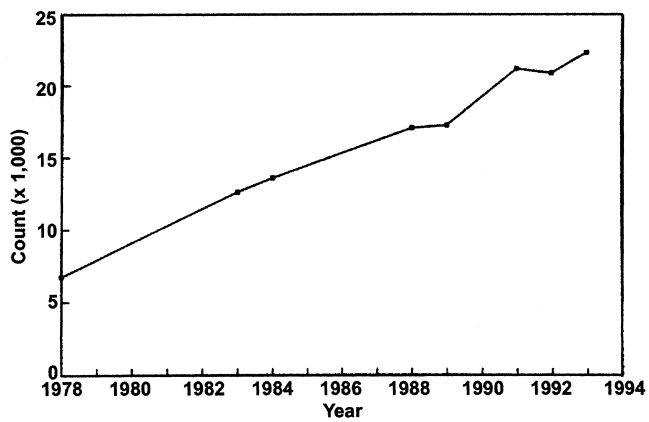

Figure 16.—Washington state harbor seal counts. Adapted from NMFS (1997a).

in Washington between 1943 and 1960 through a bounty hunt to control apparent competition with commercial fisheries (Newby, 1973; Johnson and Jeffries[39]). About 3,800 seals were similarly killed in Oregon between 1925 and 1972 (Barlow et al., 1998).

The Oregon and Washington coast stock increased nearly three-fold between 1977 and 1996 (Fig. 15, 16), with a peak count in 1992, but the annual rate of increase slowed substantially during the latter part of this period (Barlow et al., 1998). The average annual rate of increase in Oregon was only 0.3% during 1988–96 (Brown[38]). The combined annual rate of increase for the Washington coast and inland waters was 7.7% for 1978–93 but was less than 3% for 1991–93 (Huber, 1995) (Fig. 16). The Oregon and Washington coast stock of harbor seals may be nearing OSP (Barlow et al., 1998).

Fishery-related Mortality

Incidental mortality has been reported in the northern Washington marine set gillnet fishery (5.6/year), the Washington–Oregon–California Pacific whiting groundfish trawl fishery (0.2/year), Grays Harbor salmon drift gillnet fishery (6.7/year), the Willapa Bay drift gillnet fishery (≥3.5/year), and the Washington–Oregon salmon net pen fishery (≥0.5/year). The Washington–Oregon lower Columbia River drift gillnet fishery averaged 213 harbor seals per year for 1991–92, but was only open 3 days in 1994 and closed in 1995 (Barlow et al., 1998).

Washington Inland Waters Stock: Distribution, Abundance, and Population Trends

The Washington inland waters stock includes Hood Canal, Puget Sound, the San Juan Islands, and the Strait of Juan de Fuca. General distribution, pupping, and historical trends are noted above. The 1996 count was nearly double the 1984 count of 6,062 (Boveng[35]; Barlow et al., 1998). Unlike the coastal stock, this population is continuing to increase (Huber, 1995; Barlow et al., 1998), perhaps due to emigration from British Columbia (Huber, 1995). Tagging data indicate that harbor seals readily move between the San Juan Islands and the Gulf Islands and Boundary Bay in British Columbia, but not between the coast and the inland waters (Huber, 1995). The stock status relative to OSP is presently unknown (Barlow et al., 1998).

Fishery-related Mortality

The minimum total estimated fishery-related mortality is 36 seals per year based on observer data and strandings. Fisheries with reported takes include the northern Washington marine set gillnet fishery (9.2/year), Puget Sound nontreaty chum salmon gillnet fishery (10/year), and the Puget Sound treaty and nontreaty sockeye salmon gillnet fisheries (15/year) (Barlow et al., 1998).

Food Habits and Prey

At the Channel Islands and coastal waters of southern California, prey included octopus, plainfin midshipman, market squid, rockfishes, flatfish, Pacific whiting, and spotted cusk-eel (NMFS, 1997a). In Monterey Bay, prey included octopus, market squid, Pacific whiting, spotted cusk-eel, rockfish, plainfin midshipman, white croaker, Pacific sanddab, and staghorn sculpin (Harvey and Weise 1997; NMFS, 1997a). Yellowfin goby dominated in San Francisco Bay, followed by plainfin midshipman, northern anchovy, and staghorn sculpin (Torok, 1994; NMFS, 1997a). The anchovies were primarily juveniles consumed during the pupping season (Torok, 1994).

Prey consumed in Oregon was equally diverse. In the Columbia River, the diet consisted primarily of 15 taxa (Browne et al.[40]), including eulachon, staghorn sculpin, Pacific herring, starry flounder, and other flatfish, smelts, lamprey, juvenile salmonids, Pacific tomcod, American

[39] Johnson, M. L., and S. J. Jeffries. 1977. Population evaluation of the harbor seal (*Phoca vitulina richardi*) in the waters of the state of Washington. Final rep. to U.S. Mar. Mammal Comm., Contract MM5AC019. Rep. No. MMC-75/05, 27 p.

[40] Browne, P., J. L. Laake, and R. L. DeLong. 1998. Diet of harbor seals (*Phoca vitulina*) on the Columbia River, 1995–1997. *In* P. S. Hill, B. Jones, and D. P. DeMaster (Editors), Marine Mammal Protection Act and Endangered Species Act implementation program 1997, p. 183–203. U.S. Dep. Commer., NOAA, NMFS, AFSC Proc. Rep. 98-10.

shad, surfperch (Embiotocidae), northern anchovy, and Pacific whiting (Riemer and Brown[24]; Browne et al.[40]; NMFS, 1997a).

Highest seal counts in the river coincided with winter spawning aggregations of eulachon, which was present in 85–100% of winter scats (NMFS, 1997a). Coastal prey included sand lance, several species of sole, staghorn sculpin, Pacific whiting, smelts, lamprey, cephalopods, Pacific herring, surfperch, sanddab, rockfish, flatfish, eulachon, and salmonids (NMFS, 1997a; Riemer and Brown[24]). Pacific lamprey, cephalopods, rex sole, Pacific herring, rockfishes, Pacific tomcod, and salmonids made up less than 10% frequency of occurrence for all sites in Oregon combined, 1983–96 (Riemer and Brown[24]).

Prey consumed in Grays Harbor and Willapa Bay, Washington included northern anchovy, smelts, Pacific whiting, flatfish, sculpins, salmonids, Pacific herring, gadids, lamprey, and crustaceans (NMFS, 1997a). Prey in the inland waters included Pacific whiting (Puget Sound stock), Pacific tomcod, plainfin midshipman, Pacific herring, market squid, shiner perch, sculpins, walleye pollock, sole, and sand lance (NMFS, 1997a). In the nearby Strait of Georgia, Pacific whiting (Strait of Georgia stock) and Pacific herring constituted 75% of biomass consumed by harbor seals (Olesiuk, 1993).

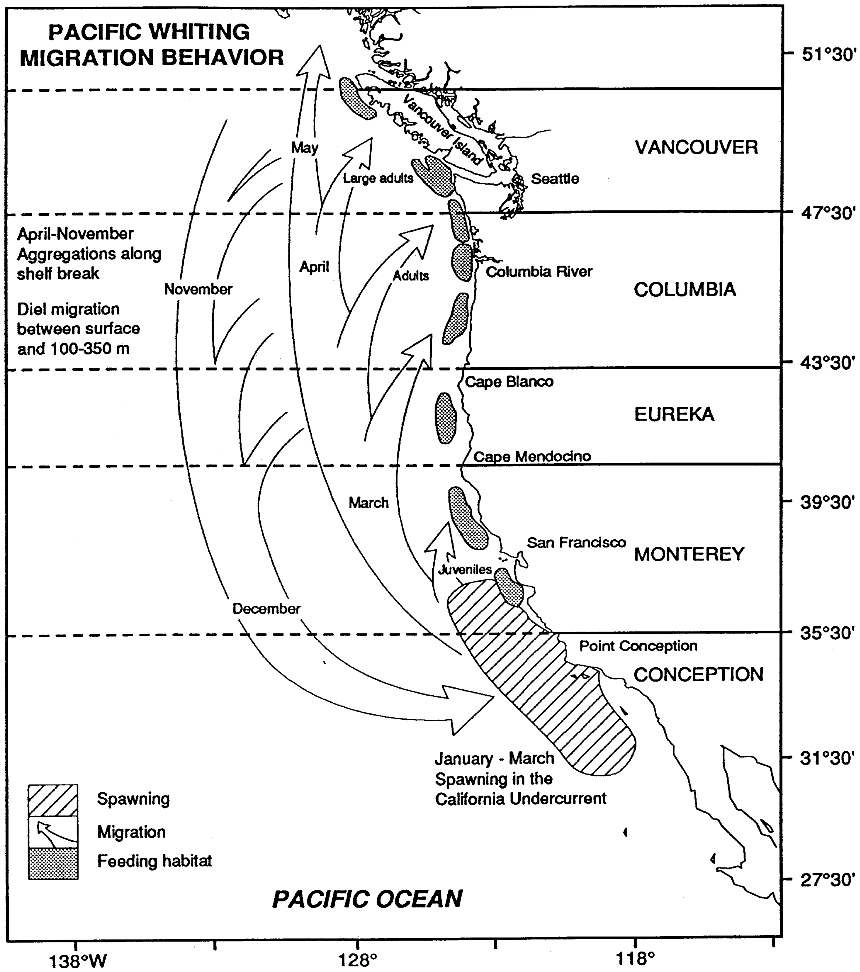

Figure 17.—Coastal Pacific whiting migration behavior (Dorn, 1995). Regional delineations are International North Pacific Fishery Commission management areas.

West Coast Fisheries

Pacific Whiting

The four major spawning stocks of Pacific whiting (also known as Pacific hake) are the coastal stock, the Puget Sound stock, the Strait of Georgia stock, and a stock off the west coast of southern Baja California (Dorn et al., 1999). The coastal stock is the most abundant and widely distributed, is genetically distinct, and characterized by a larger body size and extensive seasonal migrations (Stauffer, 1985; Dorn et al., 1999). It is also the most abundant groundfish resource of the California Current (Dorn et al., 1999) and is important as both predator and prey (Fiscus, 1979; Livingston and Bailey, 1985). Only the coastal stock is discussed here.

The coastal stock is highly migratory and typically ranges from southern California to Queen Charlotte Sound, B.C. (Dorn et al., 1999). It is a transboundary stock with biomass and landings in both U.S. and Canadian waters. From April to October, Pacific whiting migrate onshore and north along the continental shelf and slope from northern California to northern Vancouver Island, B.C. (Dorn, 1995; Dorn et al., 1999). The densest summer feeding aggregations occur over depths of 200–300 m, and diurnal vertical migrations bring them near to the surface at night (Alverson and Larkins, 1969; Dorn et al., 1994). The peak southward migration to the spawning areas is generally during November and December and spawning occurs from January to March (Dorn, 1995). Spawning concentrations are difficult to locate, but they range from central California to Baja California, over the continental slope, and out to 400 km offshore (Stauffer, 1985; Dorn et al., 1999; Bailey et al.[41]) (Fig. 17). Pacific whiting remain between 200–500 m deep when spawning and do not migrate diurnally (Alverson and Larkins, 1969; Bailey and Ainley, 1982; Ainley et al., 1982).

[41] Bailey, K. M., R. C. Francis, and P. R. Stevens. 1982. The life history and fishery of Pacific whiting, *Merluccius productus*. NWAFC Proc. Rep. 82-03, 81 p.

Migratory behavior is age-dependent, resulting in age stratification along the coast in summer. The mean migration distance increases with age; older fish are more widely distributed than younger fish (Dorn, 1995), and there is a higher mean size-at-age farther north (Methot and Dorn, 1995). Juveniles (1–3 years old) usually remain off central and southern California from spring through fall (Ainley et al., 1982; Bailey et al.[41]). Larger, older whiting typically arrive off Oregon and Washington by late April and off Vancouver Island by late May; smaller fish arrive later (Methot and Dorn, 1995). A preponderance of older (age 5+), larger, and female whiting migrate into Canadian waters (Stauffer, 1985; Methot and Dorn, 1995; Dorn et al., 1999). In general, whiting smaller than 40 cm are in the southern areas and those larger than 40 cm are in the northern areas (Wilson and Guttormsen, 1997). However, range and biomass shift northward during El Niño events (Dorn et al., 1999).

The coastal stock is characterized by extreme recruitment variability. Strong year classes can be two orders of magnitude greater than weak year classes (Dorn, 1995) and dominate the population for 5–7 years (Bailey and Francis, 1985). This affects the mean age and spatial distribution of the population (Dorn, 1995). Recruitment to the exploitable stock is generally between ages 3–6 (Stauffer, 1985), with a significant contribution by age 3 (Methot and Dorn, 1995). Average weight and length of mature whiting are 1 kg and 52 cm, respectively (Alverson and Larkins, 1969).

The Fishery

Large-scale harvests of Pacific whiting in U.S. waters began in 1966 with newly arrived foreign fleets, and they expanded through the 1970's (Dorn, 1995; Dorn et al., 1999). A U.S.–foreign joint venture (JV) fishery began in 1978. Suspension of Soviet and Polish fishing privileges in 1980 and 1982, respectively, resulted in a diminished foreign non JV fishery in 1982 and no directed foreign fishery in 1983 (Nelson, 1985). Non JV foreign fishing ended in 1989. The fishery became fully domestic in 1991 with the end of the JV fishery (Methot and Dorn, 1995).

The domestic Pacific whiting fishery is a midwater trawl fishery comprised of at-sea processors (motherships), catcher-processors (factory trawlers), and a shore-based fishery (Dorn et al., 1999). Seasons and quotas vary by sector.

The primary fishery occurs between April and November from northern California to British Columbia. Subject to spatial and temporal regulations, it essentially follows the whiting migration. Foreign and JV fisheries began off central Oregon in April, then worked northward through the summer and fall (PFMC, 1997). Most catch from 1966–72 was off Washington, Oregon, and British Columbia (Ainley et al., 1982). During 1972–76, fishing effort shifted south to central California; more juveniles were targeted as a result (Ainley et al., 1982). Beginning in 1977, the MFMCA prohibited fishing south of lat. 39°N and within 12 nautical miles (n.mi.) of shore (Ainley et al., 1982; PFMC, 1997) because of chinook salmon by-catch, national security, and a high juvenile whiting catch (Methot and Dorn, 1995). U.S. catches are currently taken from Oregon to Cape Flattery, Wash., over depths of 100–500 m (Dorn et al., 1999). The Makah Indian Tribe, which entered the fishery in 1997, fishes off Cape Flattery. The Canadian fishery is primarily south of lat. 49°N, off of southwest Vancouver Island, B.C. (Methot and Dorn, 1995; Dorn et al., 1999).

The at-sea fishery generally fills its quota in 2–3 weeks (PFMC, 1997). Season closures in 1997 were in June for motherships and factory trawlers, and in August for most of the shore-based sector (northern California closed in June) (PFMC, 1998a; Dorn et al., 1999). The season closures differed in 1998 because of the shift in distribution associated with El Niño. The mothership fishery ended in May, factory trawling and the northern California shore-based fishing sector fishery closed in August, and Washington and Oregon shore-based fisheries closed in mid-October (PFMC, 1998a, Dorn et al., 1999).

The U.S. catch averaged 152,053 t from 1966 to 1998. Canadian landings averaged 51,044 t for the same time period. The combined catch averaged 203,097 t, from a low of 89,936 t (1980) to a high of 358,901 t (1994) (Dorn et al., 1999) (Fig. 18).

Most of the Canadian catch (1985–95) was age 7 and greater, whereas the U.S. catch had a higher frequency of age 3 and 4 fish. The mean size of fish landed in Newport, Oreg., (1991–98) ranged from 40.6 cm to 44.7 cm. The smaller mean size in 1998 (40.6 cm) may have been due to the El Niño induced northward shift of age 2 and 3 year classes that year (Dorn et al., 1999).

Stock Status

Biomass increased substantially in the early 1980's, peaking at 5.7 million t in 1987, then decreased as the 1980 and 1984 year classes were replaced (Dorn et al., 1999)(Table 5). Average biomass from 1972 to 1998 was 2.8 million t, and was 1.67 million t in 1998 (Dorn et al., 1999) (Fig. 18). A continued decline in biomass is expected over the next 3 years (Dorn et al., 1999).

The coastal stock is fully exploited relative to the acceptable biological catch (ABC), harvest guidelines (HG), and quotas (Low, 1993; Methot and Dorn, 1995; Dorn et al., 1999). U.S. catches were below HG prior to 1989, but the entire HG has been taken since then. Canada harvested below their quota prior to 1987 but have fully utilized it since (Dorn et al., 1999). The combined U.S. and Canadian quotas have exceeded the annual ABC since domestication of the fisheries, averaging 128% of ABC from 1991 to 1992 and 112% from 1993 to 1998 (Dorn et al., 1999).

The exploitation rate also increased recently. United States exploitation averaged 6.5% from 1972 to 1998, with a high of 13.9% in 1998. The 1972–98 Canadian average was 2.0% and was also highest in 1998 at 5.2%. The combined exploitation rate was generally below 10% through 1993 but has averaged roughly 17% since 1994 (Dorn et al., 1999) (Fig. 18).

Management

Stock assessment and management are conducted jointly by the U.S. and Canada. Joint assessment, however, is recent (1997) and management is not

Table 5.—Coastal Pacific whiting biomass, Acceptable Biological Catch (ABC), quotas, catch, and harvest rates for U.S. and Canada. Modified from Dorn et al., 1999: Tables 2 and 12.

Year	Total estimated biomass (coastwide) (t)	Acceptable Biological Catch (coastwide) (t)	U.S. Harvest Guideline (quota) (t)	U.S. catch (t)	%U.S. Harvest Guideline utilized	U.S. harvest rate (% biomass utilized)	Canadian quota (t)	Canadian catch (t)	% Canadian quota utilized	Canadian harvest rate (% biomass utilized)	Total catch (combined U.S. and Canadian) (mt)	% of ABC harvested	Total harvest rate (% biomass utilized)
1978	1,716,000		130,000	98,372	75.7	5.7	N/A	5,267	N/A	0.3	103,639		6.0
1979	1,674,000		198,000	124,681	62.7	7.4	35,000	12,435	35.5	0.7	137,116		8.2
1980	2,382,000		175,000	72,353	41.3	3.0	35,000	17,584	50.2	0.7	89,937		3.8
1981	2,226,000		175,000	114,762	65.6	5.2	35,000	24,361	69.6	1.1	139,123		6.2
1982	1,717,000		175,500	75,578	43.1	4.4	35,000	32,157	91.9	1.9	107,735		6.3
1983	4,412,000		175,500	73,151	41.7	1.7	45,000	40,774	90.6	0.9	113,925		2.6
1984	4,703,000	270,000	175,500	96,381	54.9	2.0	45,000	42,109	93.6	0.9	138,490	51.3	2.9
1985	4,110,000	212,000	175,000	85,440	48.8	2.1	50,000	24,962	49.9	0.6	110,402	52.1	2.7
1986	3,449,000	405,000	295,800	154,963	52.4	4.5	75,000	55,653	74.2	1.6	210,616	52.0	6.1
1987	5,737,000	264,000	195,000	160,449	82.3	2.8	75,000	73,699	98.3	1.3	234,148	88.7	4.1
1988	4,815,000	327,000	232,000	160,690	69.3	3.3	98,000	90,490	92.3	1.9	251,180	76.8	5.2
1989	4,056,000	323,000	225,000	210,992	93.8	5.2	98,000	99,532	101.6	2.5	310,524	96.1	7.7
1990	3,953,000	245,000	196,000	183,800	93.8	4.6	73,500	76,680	104.3	1.9	260,480	106.3	6.6
1991	3,779,000	253,000	228,000	217,505	95.4	5.8	98,000	104,522	106.7	2.8	322,027	127.3	8.5
1992	2,904,000	232,000	208,800	208,576	99.9	7.2	90,000	86,370	96.0	3.0	294,946	127.1	10.2
1993	2,722,000	178,000	142,000	141,222	99.5	5.2	61,000	58,783	96.4	2.2	200,005	112.4	7.3
1994	2,271,000	325,000	260,000	252,729	97.2	11.1	110,000	106,172	96.5	4.7	358,901	110.4	15.8
1995	1,656,000	223,000	178,400	176,107	98.7	10.7	76,500	70,418	92.0	4.3	246,525	110.5	15.0
1996	1,761,000	265,000	212,000	212,900	100.4	12.1	91,000	88,240	97.0	5.0	301,140	113.6	17.1
1997	1,844,000	290,000	232,000	233,423	100.6	12.7	99,400	90,630	91.2	4.9	324,053	111.7	17.6
1998	1,673,000	290,000	232,000	232,509	100.2	13.9	80,000	86,738	108.4	5.2	319,247	110.1	19.1

always smooth. The Pacific whiting fishery is managed by the Pacific Fishery Management Council (PFMC) and the Canadian Department of Fisheries and Oceans (DFO) (Dorn et al., 1999).

A long–standing disagreement exists over Canadian and U.S. allocations of the annual ABC (Dorn et al., 1999). The respective quotas, relative to ABC, were basically compatible from 1985 to 1990. The United States accounted for 58–80% and Canada 28–37% of the total (Methot and Dorn, 1995). In 1991 and 1992, the U.S. and Canadian quotas were 90% and 30% of ABC, respectively. The U.S. quota has been 80% since 1993 (Methot and Dorn, 1995; PFMC, 1998a; Dorn et al., 1999). The ABC has been set at 290,000 t since 1997 and allotted as described above, for U.S. and Canadian quotas of 232,000 t and 80,000 t, respectively. The 25,000 t quota given to the Makah tribe in 1997 and 1998 was part of the total U.S. quota (Dorn et al., 1999).

Prior to 1997, 60% of the U.S. quota was available on a competitive basis to all vessels, with the remaining 40% set as a reserve for the shore-based sector (PFMC, 1997). Since 1997, 34% is allocated to factory trawlers, 24% to motherships, and 42% to the shore-based plants (PMFC, 1997; PFMC, 1998a). The Pacific Whiting Conservation Cooperative (PWCC), established in 1997, further allocates shares of the factory trawler quota among member catcher-processor companies (PFMC, 1998a; Dorn et al., 1999).

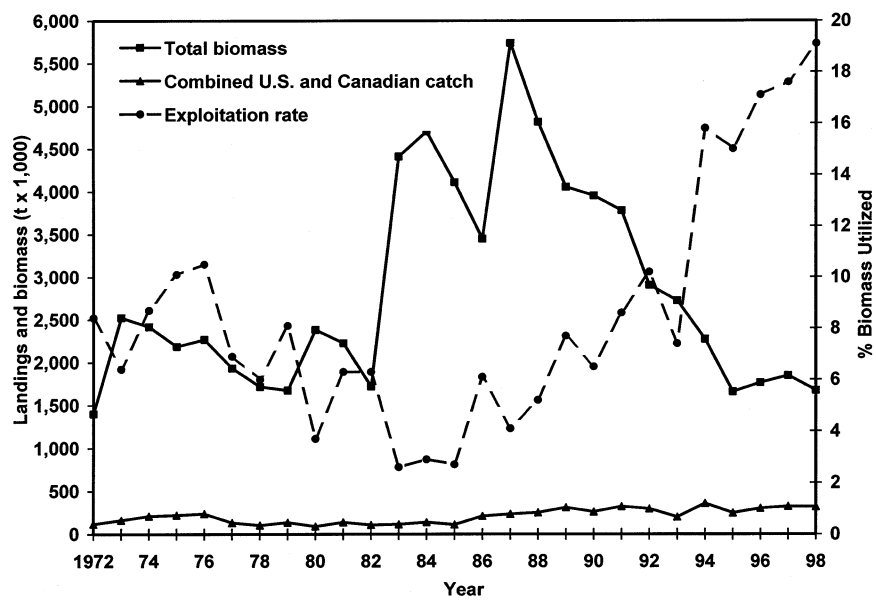

Figure 18.—Annual landings, biomass, and exploitation rate of the coastal stock of Pacific whiting. Data from Dorn et al. (1999).

Market Squid

Market squid is an important prey resource throughout its range. Nineteen species of fish, 13 avian species, and 7 marine mammal species reportedly consume market squid in Monterey Bay (Morejohn et al., 1978). Market squid range from central Baja California, Mexico to southeast Alaska, but are most abundant between Punta Eugenio, Baja Calif., Mex., and Monterey Bay, Calif. (Dickerson and Leos, 1992;

PFMC, 1998b; Vojkovich, 1998). They are considered pelagic and are primarily found over the continental shelf, from the surface down to 800 m (PFMC, 1998b). The number of stocks, or subpopulations, along the Pacific coast is unknown, as is the portion of the stock residing in U.S. waters (PFMC, 1998b).

This is a small squid, with adults reaching 305 mm and 56–84 g (Vojkovich, 1998). The maximum age is 2 years and most spawn when 1 year old (Spratt, 1979; Jackson, 1998), but maturity and longevity may occur at earlier ages (Butler et al., 1999). The natural mortality rate is nearly 100% per year after spawning (Spratt, 1979; Jackson, 1998). Basic life history and fisheries biology information, such as productivity, growth, and maturity are largely unknown (PFMC, 1998b).

Market squid form dense aggregations when spawning and prefer shallow, protected nearshore waters (Fields, 1965; Vojkovich, 1998). Total spawning area is unknown, but the greatest spawning concentrations are off central and southern California (Fields, 1965; Vojkovich, 1998). Spawning occurs year-round, with peaks in southern California from November to April, and from April to November or December in central California (primarily Monterey Bay) (Fields, 1965; Spratt, 1979; Vojkovich, 1998). Spawning may peak biannually (Spratt, 1979; Leos, 1998; Butler et al., 1999). Spawning has been observed off Oregon and Washington from May to July and off British Columbia in late summer (PFMC, 1998b).

The Fishery

Fishing occurs on the spawning grounds during the spawning season. Therefore, peak catches are in the fall and winter (October to March) in southern California, during the late spring and summer (April to November) in central California, and during the late summer from Oregon to Alaska (CDFG, 1998; PFMC, 1998b; Butler et al., 1999). The California fishery lands most of the catch; landings elsewhere are quite small (Fig. 19, 20). Landings in Washington increase during or just after warm water El Niño events (Schoener and Fluharty, 1985).

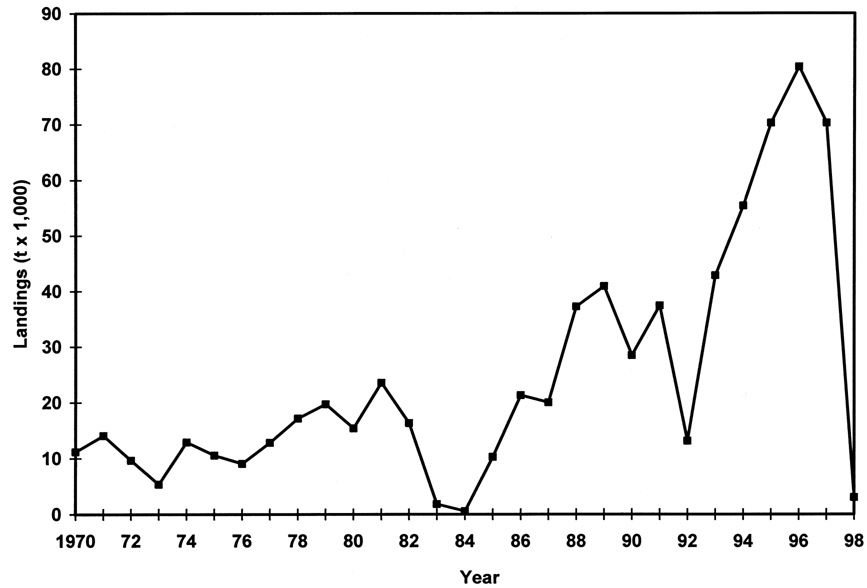

Figure 19.—Annual landings of market squid in California. Note declines associated with strong El Niño events of 1983, 1992, and 1997–98. Data from CDFG (1993), CDFG (1998), and PacFIN (text footnote 42).

Chinese immigrants started fishing for market squid in Monterey Bay over 130 years ago. Domestic markets for canned and frozen squid were developed in the 1920's, and the fishery steadily increased during WW II and the 1950's, as it expanded into southern California (PFMC, 1998b; Vojkovich, 1998). Most of the catch was from central California, especially Monterey Bay, until the early 1950's. From the 1960's to the 1980's, landings were split between central and southern California. The southern California fishery, which concentrates around the Channel Islands (PFMC, 1998b), increased since the late 1980's and currently accounts for 90% of the landings (CDFG, 1998; Vojkovich, 1998).

The market squid fishery was relatively minor until the 1980's, yet recently became California's largest fishery in tons landed and value. The central California take averaged about 6,000 t since 1950. The southern California landings increased from an average of 9,000 t in the 1970's and early 1980's to over 41,000 t during the 1990's (Vojkovich, 1998). From 1995 to 1997, the total California landings exceeded 70,000 t per year (PacFIN[42]) (Fig. 19).

Landings plummeted during the 1997–98 El Niño (Fig. 19), as the squid were either unavailable or harder to catch (PFMC, 1998b; CDFG, 1999). The 1997 fishery was not as heavily impacted as the 1998 fishery (PacFIN[42]).

The growing importance of the fishery in California resulted in an expansion in area fished (Dickerson and Leos, 1992) and in the number of participating vessels. The number of vessels fishing for market squid increased from 85 in the 1970's and 1980's to 149 in 1997 (CDFG, 1998; Vojkovich, 1998). Fishing effort is expanding into previously underutilized spawning habitat off southern California (Vojkovich, 1998). The commercial squid fishery predominantly uses round-haul (purse seine) nets, although some scoop nets are used off southern California (PFMC, 1998b).

Stock Status

No information is available on the stock size of market squid. Because of the high rate of natural mortality, the status of the stock may be dependent

[42] PacFIN (Pacific Fisheries Information Network). 1999. Database managed by Pac. States Mar. Fish. Comm., Portland, OR.

on spawning success and survival of recruits (Spratt, 1979; PFMC, 1998b). The resource was considered underutilized for several decades, although that may be changing as the fishery expands (Vojkovich, 1998).

Management

The California market squid fishery has essentially been an unregulated, open fishery, with a few small area closures in California off Santa Catalina Island and weekend closures in Monterey Bay. All vessel operators have needed to fish for squid were a commercial fishing license and boat registration (CDFG, 1998; Vojkovich, 1998). In 1997, the California Senate passed a bill that included an expansion of the Monterey Bay weekend closure, a requirement for a squid permit for squid vessels and all light vessels (those that use lights in catching squid), and a moratorium on new permits. Funds generated by the permit fees were to be used by CDFG to conduct squid research. The Squid Research Scientific Committee and Squid Fishery Advisory Committee were established and CDFG was given management authority over the squid fishery (CDFG, 1998; PFMC, 1998b).

Market squid is included in the PFMC's new Coastal Pelagic Species Fisheries Management Plan (CPS FMP). Because of the paucity of basic information on market squid, the current preferred option is monitored management. The ABC recommended for the stock was 25% of the Maximum Sustainable Yield (MSY) catch, but MSY catch is unknown. The California Senate bill, noted above, required that CDFG develop management options based on the findings of the funded research by the year 2001 (PFMC, 1998b).

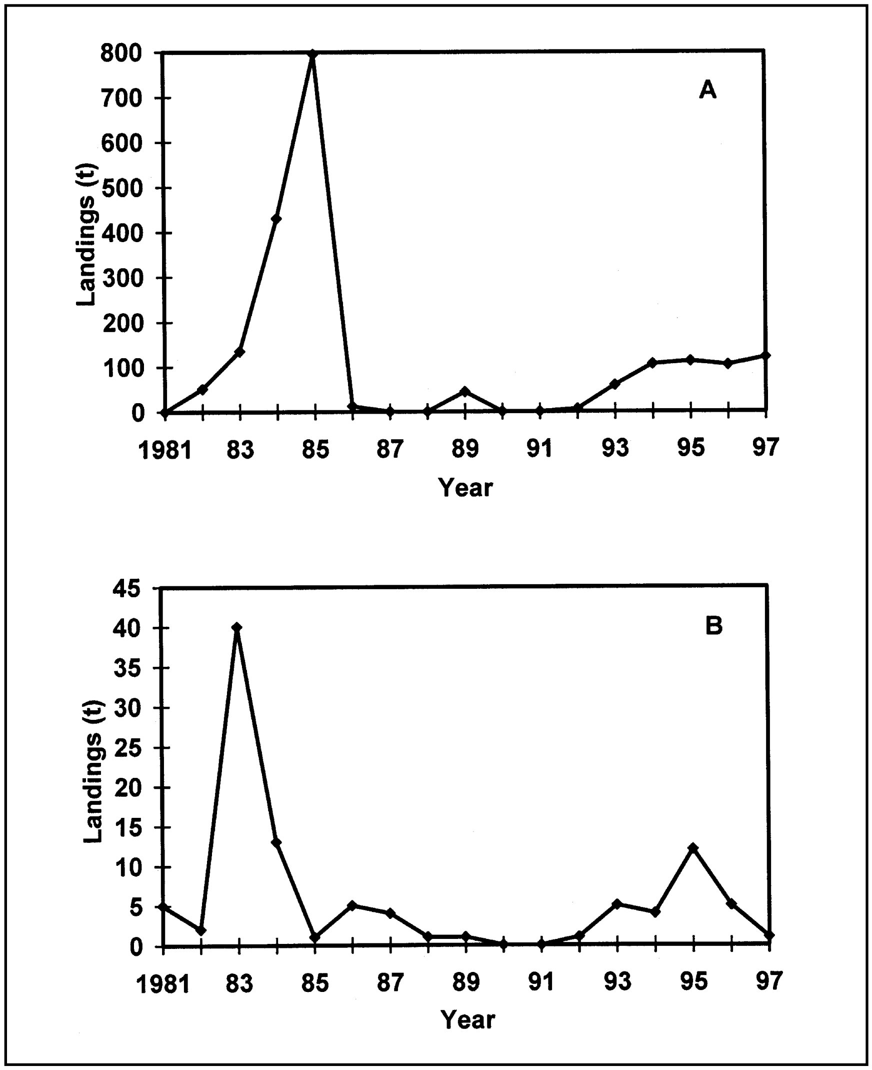

Figure 20.—Annual landings of market squid in A) Oregon and B) Washington. Data from PFMC (1998b).

Northern Anchovy

Northern anchovy are preyed upon during all life stages. Juveniles and adults are important forage for a variety of fish, bird, and marine mammal species (PFMC, 1998b). They range from Magdalena Bay, Baja Calif., to the Queen Charlotte Islands, B.C. (Frey, 1971). The population is divided into northern (Monterey Bay, Calif., to B.C.), central (San Francisco to Punta Baja, Baja Calif.) and southern (entirely within Mexican waters) subpopulations, or stocks (PFMC, 1998b). Most of the central subpopulation is within the Southern California Bight (between Point Conception, Calif., and Point Descanso, Mex.) (PFMC, 1998b). It supported a significant commercial fishery and has been the most extensively studied. The southern subpopulation will not be discussed.

Northern anchovy are small and short-lived, rarely surpassing 18 cm and 4 years of age (Frey, 1971; PFMC, 1998b). Age composition and size vary regionally, with older and larger fish farther north and offshore (Parrish et al., 1989). This distribution pattern is exaggerated during warmwater periods, such as El Niños, and at high abundance levels (Methot, 1989; PFMC, 1998b). Anchovies commonly school in near surface (<50 m) and nearshore waters; juvenile anchovy densities are about ten times higher nearshore than elsewhere (PFMC, 1998b). Although spawning occurs year-round, it increases in late winter and early spring and peaks from February to April for the central subpopulation. The central subpopulation attains sexual maturity by age 2; spawning at an earlier age depends on water temperature (Frey, 1971; Methot, 1989).

Most of the northern subpopulation is offshore. Anchovies are only common along the Washington coast and coastal estuaries of Grays Harbor, Willapa Bay, and in the mouth of the Columbia River from May to October (Lemberg et al., 1997). They also occur in Puget Sound, where they were once reportedly abundant (Bargmann, 1998). Spawning occurs from mid-June to mid-August, but specific spawning locations are not well known. A major spawning center off Washington and Oregon is associated with the Columbia River plume and anchovy eggs have been found in Puget Sound (Richardson, 1981; Bargmann, 1998).

The Fishery

The anchovy fishery on the central subpopulation was small-scale until the mid 1940's when the decline of Pacific sardines shifted focus to anchovies (Frey, 1971). Anchovies were initially landed for canning, and fluctuations in landings reflected changing consumer demand for canned anchovies. The reduction fishery for conversion to fish meal, oil, and livestock and pet food began in 1965. Landings for reduction hit record high levels in the mid 1970's, declined in the late 1970's and early 1980's, and have remained low since 1983 (Thomson, 1990; Jacobson and Thomson, 1993).

Anchovy harvests for live bait began just prior to WW II, and those landings have ranged from 3,500 t to 7,000 t per year (PFMC, 1998b). Landings for use as dead bait, canned, fresh, or frozen products, and anchovy paste ranged from 250 t to 5,800 t from 1965 to 1997 (PFMC, 1998b). Total landings in California grew from less than 5,000 t in the early 1960's to over 140,000 t in 1975, decreased to around 50,000 t per year in the late 1970's, and to only a few thousand metric tons per year since 1983. Landings in 1998 were 1,438 t (PFMC, 1998b; PacFIN[42]) (Fig. 21). This fluctuation is partly a response to market demand and the decline in the reduction fishery (NMFS, 1996).

The fishery operates year-round, from 1 July to 30 June of the following year (Jacobson et al.[43]). Round haul purse seines are primarily used. The age group targeted depends on the fishery. The live bait fishery probably targets younger fish than the reduction fishery, although both fisheries take large numbers of age 0–1 fish (PFMC, 1998b).

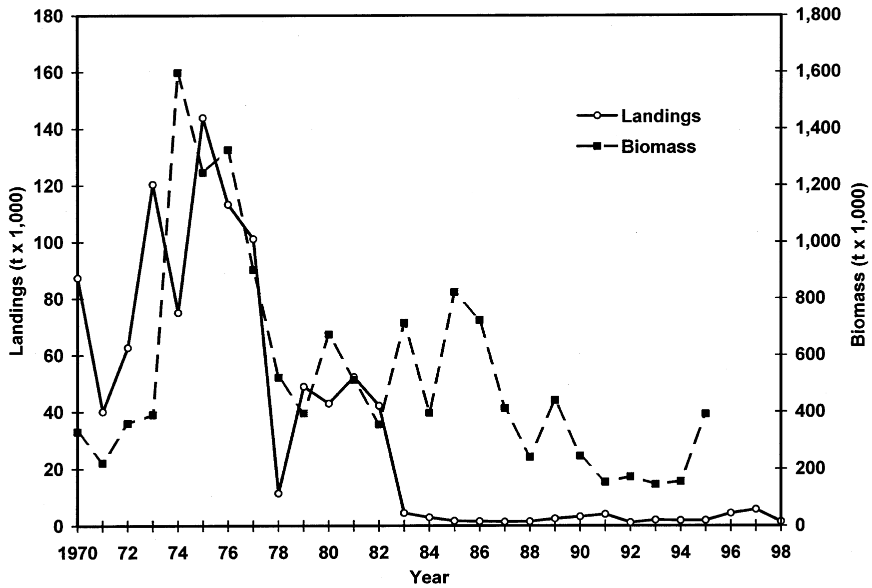

Figure 21.—Annual landings and biomass of northern anchovy, central subpopulation. Data from PFMC (1998b) and PacFIN (text footnote 42).

The anchovy fishery is the most active coastal forage fish fishery in Washington. Landings fluctuate, but are generally relatively low; 103 t were landed in 1998 (Fig. 22). Fluctuations are related more to demand than to biomass availability (Lemberg et al., 1997; Bargmann, 1998). Landings in Oregon are negligible.

Stock Status

Total biomass for age 1+ fish for the central subpopulation averaged 326,000 t until the early 1970's, increased to nearly 1.6 million t in 1974, then declined to about 500,000 t in 1978. Levels fluctuated through the 1980's, declined during the early 1990's, then increased again in 1995 (PFMC, 1998b) (Fig. 21). Spawning stock biomass (SSB) increased to an estimated 388,000 t in 1995, apparently because of high recruitment in 1993 (Jacobson et al.[43]). The stock was last assessed in 1995, but 1997 biomass levels were assumed to be similar (Jacobson et al.[44]). The decline in total biomass was blamed on low recruitment, rather than on harvesting; fishing mortality rates rarely surpassed 17% (Jacobson et al.[43]). Environmental fluctuations appear to influence variability in anchovy abundance (Lluch-Belda et al., 1989). The central subpopulation was considered fully exploited during the early 1990's (Low, 1993; NMFS, 1996), but is presently underutilized (NMFS, 1999a).

The status of the northern subpopulation is unknown for there have been no recent estimates. This stock apparently has declined since the 1980's (Bargmann, 1998). Stock assessments are not currently conducted for Washington coastal anchovies (Lemberg et al., 1997), however, landings have been

[43] Jacobson, L. D., N. C. H. Lo, S. F. Herrick Jr., and T. Bishop. 1995. Spawning biomass of the northern anchovy in 1995 and status of the coastal pelagic fishery during 1994. NMFS, SWFC Admin. Rep. LJ-95-11, 49 p.

[44] Jacobson, L. D., N. C. H. Lo, and M. Yaremko. 1997. Status of the northern anchovy (*Engraulis mordax*) stock (central subpopulation) during the 1996–1997 season. NMFS, SWFSC Admin. Rep. LJ-97-08, 11 p.

small relative to the assumed biomass available.

Management

Prior to 1977, the northern anchovy (central subpopulation) fishery was managed by the CDFG. In 1978, the PFMC assumed management with the adoption of the Northern Anchovy FMP (PFMC, 1998b). Between 1966 and 1989, reduction fishery quotas ranged from 68,000 t to over 370,000 t (1981); most years averaged closer to 100,000 t. From 1991 to 1994, that quota was zero (Jacobson et al.[43]). There is no quota for the live bait fishery and a 7,000 t quota for other nonreduction uses (PFMC ,1998b).

California state waters are divided at Point Buchon into southern and northern permit areas for regulating anchovy fishing. The northern permit area is open to fishing from 1 August to 30 June and the southern permit area is open from 15 September to 30 June; each includes small area closures. The allowable take is 5,000 t if there is no biomass estimate.

Management of the northern subpopulation in Washington is achieved primarily by compiling and monitoring fish ticket landings data; there is little active management of the fishery (Lemberg et al., 1997). In Oregon, anchovy fishing permits and gear restrictions are determined annually (PFMC, 1998b).

Pacific Herring

The range of Pacific herring extends from California to Alaska, and includes many spawning stocks (Frey, 1971). Herring is managed by individual states, usually on a stock-by-stock basis, and stock delineation is frequently spawning-ground specific.

Herring are relatively small and extremely important forage fish for marine mammals, sea birds, and other fishes throughout their range. They attain sexual maturity and enter the spawning population between ages 2 and 4 (Spratt, 1981). Adults are capable of spawning for several years and tend to return annually to their natal spawning areas. Herring spawn in shallow subtidal zones, with most egg deposition from 0 to minus 10 feet in tidal range (Bargmann, 1998).

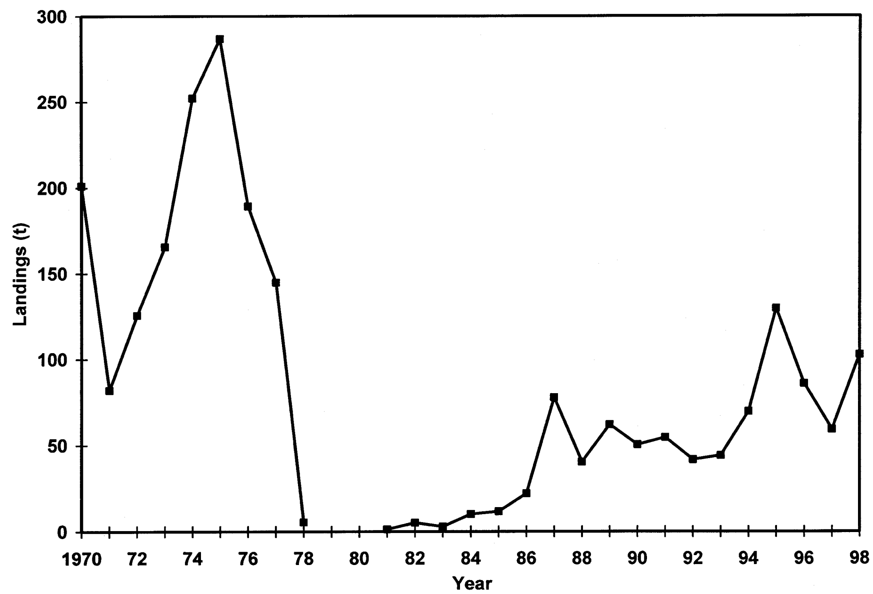

Figure 22.—Annual landings and biomass of northern anchovy, northern subpopulation, in Washington. Data from Bargmann (1998) and PacFIN (text footnote 42).

Nineteen spawning areas, or stocks, are located in Washington, 18 of which are east of Cape Flattery and 1 is coastal. Stocks that spend their entire lives within Puget Sound are considered resident, while those that summer off the coasts of Washington and British Columbia are considered migratory (Bargmann, 1998). Spawning in Washington is from late January to early June and lasts two months. Spawning dates rarely vary by more than 7 days from year to year (Lemberg et al., 1997; Bargmann, 1998). Yaquina Bay is the primary spawning area in Oregon (Bodenmiller[45]). Spawning aggregations occur there from mid-January to late April, with peaks in February and March (Brown[18]).

The four largest spawning areas in California are in San Francisco Bay, the Tomales–Bodega Bay area, Humboldt Bay, and Crescent City Harbor. San Francisco Bay supports the largest spawning population, from which 90% of the state's catch originates (NMFS, 1999a). The spawning season in California extends from November to March (Beeson and Hanan[23]).

The Fishery

Herring has been an important fishery resource in Washington for over a century. Several fisheries have existed in Puget Sound, including commercial sport bait, general purpose, sac-roe, spawn-on-kelp, and recreational (Bargmann, 1998). Landings peaked at about 3,300 t in 1970, then declined rapidly thereafter (Bargmann, 1998). Commercial sport bait and roe fisheries are currently the two principal fisheries in Washington; there are no commercial herring harvests along Washington's outer coast (Lemberg et al., 1997; Bargmann, 1998).

The commercial sport bait fishery targets juvenile (ages 1–2) herring, mostly in south/central Puget Sound, during the spring through early fall when sport fishing is greatest (Lemberg et al., 1997; Bargmann, 1998). Landings were highest in the mid 1970's at around 900 t/ year (Bargmann, 1998). Average landings from 1992 to 1996 were 464 t. Most take is with small (<200 feet) lampara seines (Lemberg et al., 1997).

Adult herring fisheries target roe and are limited to north Puget Sound.

[45] Bodenmiller, D. 1999. Oregon Department of Fish and Wildlife, Newport, OR 97365. Personal commun.

For the sac-roe fishery, spawning herring are caught and killed in gillnets or seines and the roe harvested and processed. Landings reached over 3,600 t in 1974, then declined with diminished stock size.

In Oregon, only Yaquina Bay has a large enough spawning stock to support a roe fishery, and takes are comparatively small. Average annual landings from 1981 to 1998 were 119 t (PacFIN[42]; Bodenmiller[45]) (Fig. 23). The fishery generally opens in early February and takes are with lampara seines (Brown[18]).

The California herring fisheries, which peaked at over 10,000 t in 1982 (NMFS, 1996), are the largest on the west coast. Herring was initially harvested for reduction, bait, and canning, but the fishery for human consumption ended in 1954. Since 1973, California herring have been harvested primarily for roe for export to Japan (NMFS, 1999a). The roe fishery season is November to March. California herring landings fell from 9,215 t in 1997 to little over 2,000 t in 1998 during the 1997–98 El Niño (CDFG, 1999; PacFIN[42]) (Fig. 24).

The California roe-on-kelp (spawn-on-kelp) fishery began in San Francisco and Tomales Bays in 1965, but it is currently limited to San Francisco Bay (NMFS, 1996; CDFG, 1998). The season is similar to that for roe, running from December through March for the 1998–99 season (Ryan et al.[46]). Landings in Figure 25 do not include this fishery.

There is also a very small dead-bait-and-animal-food fishery in Monterey Bay during the summer (Spratt, 1981). Only 45 pounds were landed in 1997 (CDFG, 1998).

Stock Status

Spawn deposition and hydroacoustic surveys are used to assess herring biomass in both Washington and California (O'Toole ,1995; NMFS, 1996; Lemberg et al., 1997). Stocks in Washington are assessed individually but will not be individually described. Cumulative spawning stock biomass (SSB) in south/central Puget Sound was fairly stable from 1977 to 1996, averaging 5,514 t. The north sound SSB usually exceeded 9,100 t during 1977–80, fluctuated through 1994, then declined to roughly

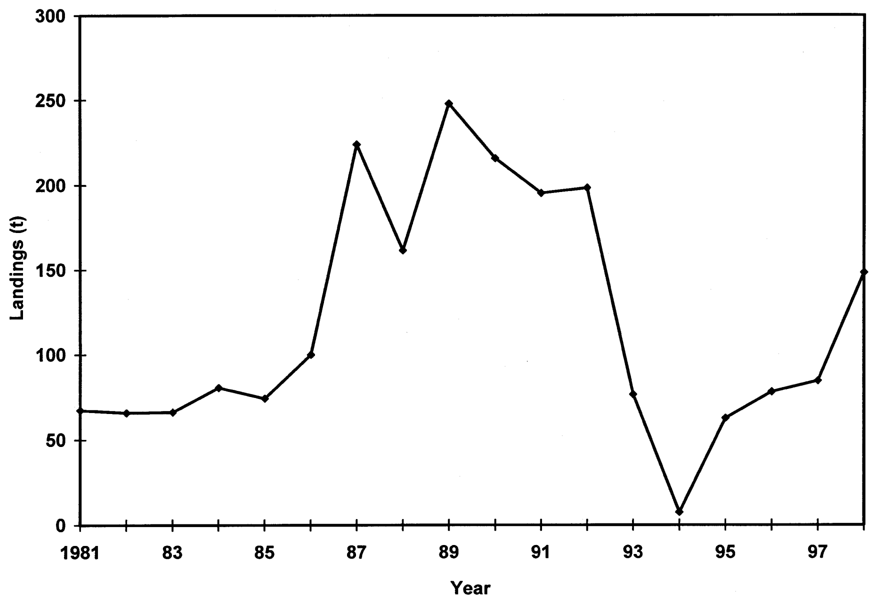

Figure 23.—Annual landings of Pacific herring in Oregon. Data from PacFIN (text footnote 42).

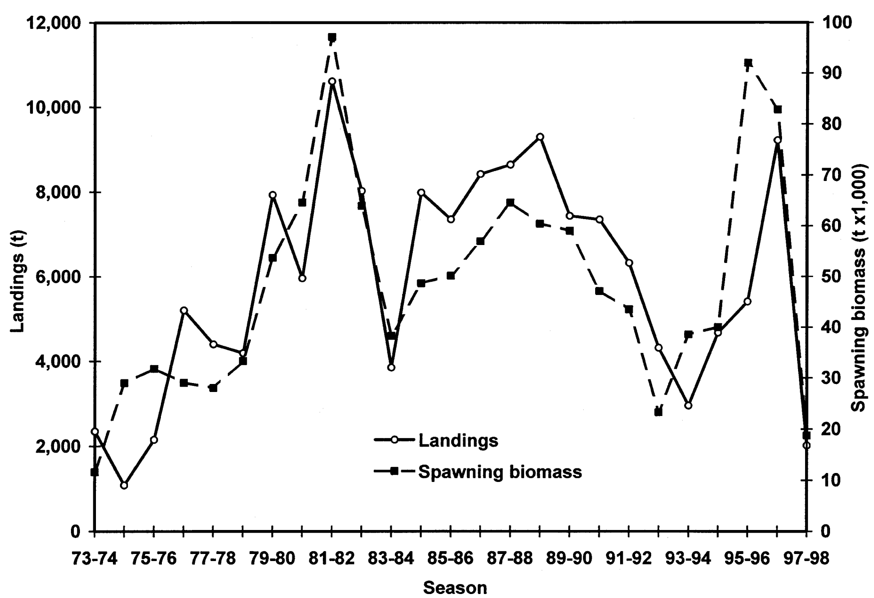

Figure 24.—Annual landings and spawning stock biomass of Pacific herring in California. Landings do not include spawn-on-kelp. Biomass includes combined estimates for San Francisco and Tomales Bays; there are no estimates for Humboldt Bay or Crescent City. Note declines associated with strong El Niño events of 1983, 1992, 1997–98. Data from CDFG (1993), CDFG (1998), PacFIN (text footnote 42), and Watters (text footnote 48).

[46] Ryan, C., S. E. Ashcraft, and S. Peterson. 1999. Summary of herring fisheries in San Francisco Bay, 1998–99 season. Prep. for Herring Public Meeting, 7 April 1999, San Rafael, CA. Calif. Dep. Fish Game, Mar. Reg., Menlo Park, CA 94025.

5,500–6,500 t in 1995–96. The Strait of Juan de Fuca, with the smallest stocks, gradually declined from the mid 1980's to 1995, then increased slightly in 1996. Cumulative annual Puget Sound SSB for 1977 to 1999 averaged 14,069 t and has been below average since 1996, despite a slight increase in 1999 (Lemberg et al., 1997; Bargmann[47]) (Fig. 25).

As of 1996, nine Puget Sound stocks were classified as healthy/moderately healthy, four were in a depressed or critical state, and information was insufficient for five. The Cherry Point stock, historically the largest in Washington, went from moderately healthy in 1994 to depressed by 1996 (Lemberg et al., 1997). In June 1999, NMFS received a petition to list several Puget Sound herring stocks as endangered, warranting initiation of a status review and inclusion on the list of candidate species for the List of Endangered and Threatened Species (NMFS, 1999c). Status of the coastal stock is unknown, but sporadic survey coverage suggests an overall decline in SSB (Lemberg et al., 1997).

In California, SSB is estimated annually for San Francisco and Tomales Bays; there are no estimates for Humboldt Bay or Crescent City (NMFS, 1996; CDFG, 1998; Watters[48]). The vast majority of the biomass is in San Francisco Bay, where 1978–98 SSB estimates ranged from 18,200 t (1997–98) to 90,636 t (1981–82). The SSB estimates for the 1995–96 and 1996–97 seasons were among the highest ever due to large 1992–94 year classes (CDFG, 1998). The smaller Tomales Bay stock ranged from 314 t (1989–90) to 10,046 t (1982–83) (Watters[48]). Combined SSB estimates for Tomales and San Francisco Bays ranged from 11,613 t (1973–74) to 97,142 t (1981–82) (Fig. 24). The precipitous decline in SSB in 1997–98 was likely a result of pronounced El Niño conditions. Preliminary 1998–99 spawning biomass estimates for San Francisco Bay were 35,945 t, primarily due to an influx of 2-year old fish from the large 1997 year class (Oda and Watters[49]).

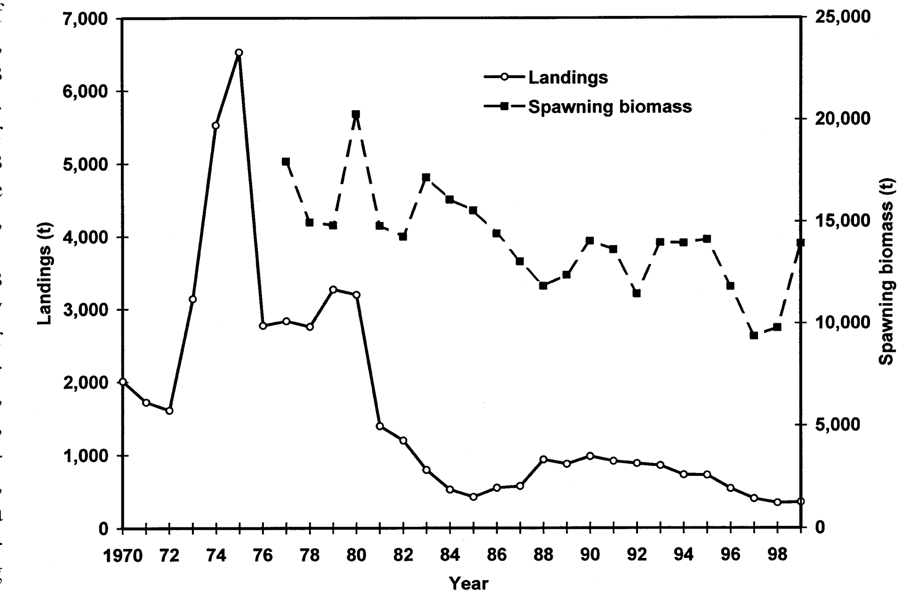

Figure 25.—Annual commercial landings and spawning biomass estimates of Pacific herring in Washington. Landings include estimates of adult take equivalents for the spawn-on-kelp fishery. Spawning biomass is cumulative for Puget Sound stocks. Data from Lemberg et al. (1997), Bargmann (1998), and Bargmann (text footnote 47).

Management

Washington State herring are managed by the Washington Department of Fish and Wildlife (WDFW) and the Puget Sound Treaty Tribes. Harvest guidelines are based on stock biomass estimates (Lemberg et al., 1997) and are used to minimize adult takes in the juvenile fishery area (south Puget Sound) and juvenile takes in the adult fishery area (north Puget Sound) (Wildermuth, 1995). Quotas for north Puget Sound fisheries are determined preseason and divided 50:50, treaty and nontreaty. The harvest rate is a sliding scale of 5–20%, depending on stock size (O'Toole, 1995). Harvest guidelines for north Puget Sound Cherry Point stock roe fishery and the spawn-on-kelp fishery have been around 6% since 1992 (Bargmann, 1998). The target harvest rate for the commercial sport bait fishery is 10% of the average estimated adult biomass in south Puget Sound, and has recently averaged about 7% (Bargmann, 1998).

Market demand for bait and some gear restrictions help maintain a take level below the calculated average yield of 819 t per year for Puget Sound (Wildermuth, 1995). Also, legislation passed in 1977 placed nontreaty herring fisheries under limited entry (O'Toole, 1995).

Quotas for the Yaquina Bay fishery in Oregon are based on 20% of SSB. Abundance is predicted from one year to the next, although there are no good indices of abundance. There are no ocean harvest regulations (Bodenmiller[45]).

The CDFG manages each of the four major California spawning stocks separately (NMFS, 1996). Prior season estimates are used to determine catch quotas for the subsequent season. Allocation is usually 15% of estimated biomass, has been as low as 10%, but never above 20% (Watters[48]). Quotas for the 1996–97 roe fishery season included 11,181 t for San Francisco Bay, 215 t for Tomales

[47] Bargmann, G. 2000. Marine Fish Manager, Fish Program, Wash. Dep. Fish Wildl., Olympia, WA 98501-1091. Personal commun.

[48] Watters, D. 1999. Pacific Herring Research Project, Calif. Dep. Fish Game, Menlo Park, CA 94025. Personal commun.

[49] Oda, K., and D. Watters. 1999. 1998–99 Pacific herring spawning season in San Fransisco Bay. Prep. for Herring Public Meeting, 7 April 1999, San Rafael, CA. Calif. Dep. Fish Game, Mar. Reg., Menlo Park, CA 94025.

Bay, 32 t for Humboldt Bay, and 25 t for Crescent City (CDFG, 1998).

Pacific Sardine

Three subpopulations of Pacific sardine exist off the west coast of North America: the northern subpopulation (northern Baja California to Alaska), southern subpopulation (off Baja California), and a Gulf of California subpopulation (Vrooman, 1964). Only the northern stock is included here.

Pacific sardines have, periodically, been the most abundant fish of the California Current. When abundance is high, the range extends from the tip of Baja California to southeastern Alaska (Parrish et al., 1989). When it is low, commercial quantities do not exist north of Point Conception, California. Occurrence in the northern part of the range is seasonal (PFMC, 1998b). Increased biomass and warmer surface waters in recent years prompted the reoccupation of more northerly grounds off northern California, Oregon, Washington, and British Columbia (Parrish et al., 1989; Hargreaves et al., 1994).

Sardines are common in both nearshore and offshore areas and move seasonally along the coast. Older adults may migrate from southern California and Baja California spawning grounds to feeding grounds in the Pacific Northwest. Younger adults (age 2–4) feed along central and northern California. Juveniles are primarily in the nearshore waters of northern Baja and southern California (PFMC, 1998b).

Sardines are small pelagic schooling fish, rarely exceeding 30 cm. Age at maturity changes with biomass levels. Maturity is common at age 1 at low biomass and at age 2+ at high biomass (PFMC, 1998b). Spawning occurs in the upper 50 m of the water column and is influenced by water temperature. It peaks April through August between Point Conception, California and Magdalena Bay, Mexico. Spawning shifts northward and spans a longer time period during periods of warm water (Lluch-Belda et al., 1989).

The Fishery

The Pacific sardine fishery was the largest fishery in the Western Hemisphere during the 1930's and 1940's, with peak landings of over 700,000 t. Fish were harvested from Mexico to British Columbia, with 83–99% of the harvest taken in California (PFMC, 1998b). The fishery began declining in the 1940's. The range shifted southward with reduced abundance, and the fishery ended first in the Pacific Northwest (1947–48), then northern California (1952–53), but continued in southern California through the 1950's (Frey, 1971; Wolf,1992; PFMC, 1998b). California imposed a 2-year moratorium on directed fishing in 1967 and allowed for a 15% take by weight in mixed loads for use as dead bait. Dead bait usage was limited to 227 t in 1969. In 1974, California enacted a complete moratorium on directed fishing but maintained incidental catch allowances for canning or reduction (Wolf, 1992; PFMC, 1998b).

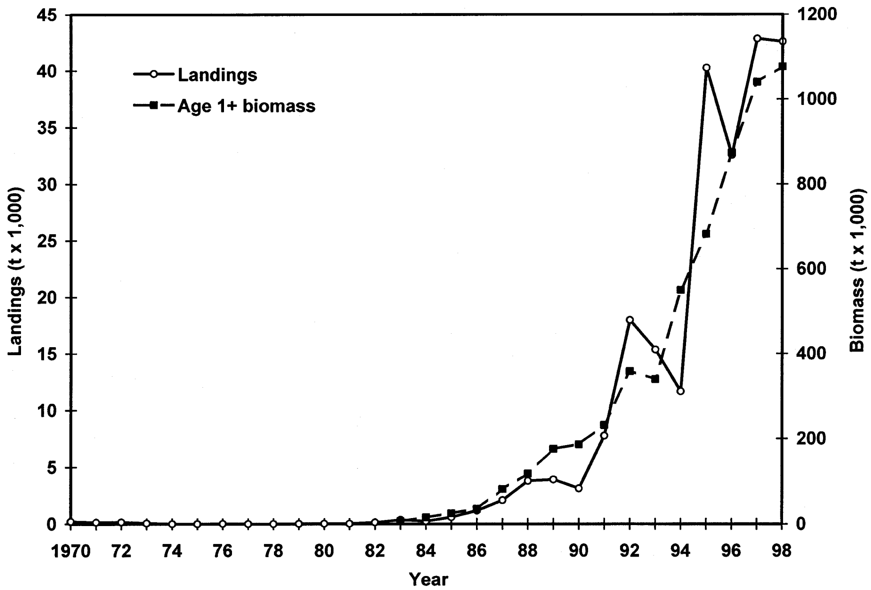

Figure 26.—Annual landings and estimated biomass for Pacific sardine in California. Data from PFMC (1998b), PacFIN (text footnote 42), and Hill et al. (text footnote 50).

Rising levels of sardine bycatch in the southern California mackerel and live bait fisheries, and increased sardines in juvenile fish surveys in the 1980's indicated increasing abundance (Wolf, 1992). The harvest moratorium was lifted in 1986, reestablishing a directed purse seine fishery. There are currently 30 active purse seine vessels, known as the "wetfish fleet," participating in the California sardine fishery (Hill et al.[50]). Sardines are canned for overseas use, sold fresh, or used for live or dead bait (PFMC 1998b).

Since the resumption of the California purse seine fishery in 1986, landings have increased dramatically from 1,164 t to 42,580 t in 1998 (Fig. 26). The fishery opens 1 January and operates year-round; landings vary monthly due to fluctuations in availability, demand, and fleet participation. In 1997, much of the catch was during the last quarter of the year when market squid was less available because of El Niño conditions (CDFG, 1998).

Landings in Ensenada, Mexico are also significant and increasing. Between 1983 and 1997, Ensenada fishermen landed 63,700 t of sardines, 34% more than all California ports combined. Ensenada landings totaled 68,652 t in 1997 and 60,426 t in 1998, compared to 42,839 t and 42,580 t in California (PacFIN[42]; Hill et al.[50]). This resulted in total landings from this stock in excess

[50] Hill, K. T., L. D. Jacobson, N. C. H. Lo, M. Yaremko, and M. Dege. 1999. Stock assessment of Pacific sardine (*Sardinops sagax*) for 1998 with management recommendations for 1999. Calif. Dep. Fish Game Mar. Region Admin. Rep. 99-4.

of 100,000 t. Landings in Oregon were 3.9 t in 1992, but have been under or near 1 t since then (PacFIN[42]). There are currently no sardine fisheries in Washington (Bargmann, 1998).

Stock status

Sardine biomass typically varies over periods of about 60 years, with declines generally averaging 36 years and recovery periods 30 years. Even in the absence of fishing, sardines are prone to fluctuations in biomass levels because of sensitivity to environmental variability (Lluch-Belda et al., 1989; PFMC, 1998b). Spawning stock biomass averaged 3.5 million t from 1932 to 1934, was between 1.2 million t and 2.8 million t until the mid 1940's, then sharply declined through 1965. It was estimated as less than 5,000–10,000 t during the 1960's and 1970's. By the mid 1980's, biomass began increasing at about 27% per year (Barnes et al., 1992; PFMC, 1998b). Age 1+ biomass escalated since 1983 and recently surpassed the 1 million metric ton criteria that defines population recovery. The estimated biomass for inside the range of fishery and survey data was 1.07 million t in 1998 (Hill et al.[50]) (Fig. 26). Biomass estimates include data from Mexico and the U.S. (Barnes et al., 1997).

The stock's range has been expanding along with the increasing biomass. The stock was mostly south of Point Conception between 1983 and 1992, but has since extended northward (Hill et al.[50]). The stock is reoccupying its historic geographic range (Baja California to British Columbia) and historic age groups are also currently represented (Hargreaves et al., 1994; Bentley et al., 1996; Bargmann, 1998; Hill et al.[50]). Recent increases in the Mexican harvest may be sufficient to hinder sardine recovery even without a U.S. fishery (PFMC, 1998b). With the combined harvests, the resource may well be fully utilized.

Management

The CDFG currently manages sardines, with assistance and data from NMFS. Sardines are also included in PFMC's Coastal Pelagic Species FMP as an actively managed species. Current regulations permit a fishery when spawning stock biomass exceeds 18,200 t (PFMC, 1998b). Recent allocations include a 20% target harvest rate for the entire stock. In the absence of a cooperative management plan with Mexico, allocations are prorated by the percent biomass in U.S. and Mexican waters. As a result, 59% is allotted to the California fishery (PFMC, 1998b).

The annual directed quota was 997 t from 1986 to 1990, grew to 10,886 t in 1991, and continued increasing thereafter to 43,545 t in 1998 and 120,848 t in 1999 (PFMC, 1998b; Hill et al.[50]). A dead bait quota of 227 t was established in 1988 and raised to 454 t in 1990. The live bait quota was 68 t in 1984 and steadily increased to 907 t since 1988 (PFMC, 1998b). The Coastal Pelagic Species (CPS) FMP includes a limited entry zone south of 39°N within which vessels possessing limited entry permits may land no more than 125 t of CPS finfish per trip. Those lacking a permit may possess no more than 5 t (NMFS, 1999b). The Coastal Pelagic Species FMP includes management options, such as harvest formulas and overfishing definitions, that incorporate forage needs and consider maintaining a forage reserve (PFMC, 1998b).

Discussion

New England

Pinniped populations in New England are healthy and expanding. Resident species are increasing, and the extralimital ranges of higher latitude species are extending into the Gulf of Maine and southern New England. Food availability is apparently not a limiting factor. Prey studies, scanty for New England, suggest that harbor seals and gray seals consume a broad assortment of fish and squid, the selection of which is related to local abundance and availability and influenced by season, year, sex, and age class. Some prey species, such as Atlantic cod, silver hake, and Atlantic herring, are commercially valuable. There may be greater concern over the potential impact of expanding pinniped populations on commercial fisheries, rather than the reverse. The precarious state of New England groundfish resources could fuel this concern and exacerbate the issue. Incidences of operational interactions are well documented, especially in the New England sink gillnet fishery. The potential for prey overlap and resource competition may exist, but a detailed evaluation is not possible because of the complexity of these trophic interactions and a paucity of necessary prey data.

On average, only 3% of the New England sink gillnet hauls had to discard fish because of seal damage (Williams, 1999). Both harbor seals and gray seals were observed feeding on herring inside and outside of purse seines off the coast of Maine. The seals were released unharmed, so no seal mortality was associated with the depredation (Stevenson and Scully[51]).

Williams (1999) found little overlap between the size of the target species in the New England sink gillnet fishery and the prey consumed by harbor seals caught in that fishery. They were principally feeding on prerecruits to the fisheries, so were not considered in direct competition for the targeted fish. This seemed particularly true for the Atlantic cod fishery. Most of the cod consumed by harbor seals were between 25–30 cm in length and those kept by the fishery were in the 60–70 cm range. However, these data were primarily derived from juvenile harbor seals, whose prey size selection may differ from that of adults.

Cod consumption by gray seals in the Gulf of Maine is unknown, but has been a critical issue in eastern Canada where cod stocks are also collapsing. Hammill et al. (1995) estimated cod consumption by gray seals to be as high as 40,000 t in Atlantic Canada, a number derived by using estimates for the entire gray seal population. Over half of the cod consumed were less than 45 cm in length, or prerecruits to the commercial fishery. Similarly, Bowen et al. (1993) found that only 17% of cod consumed by gray seals in New Brunswick and Nova Scotia were of commercial size.

[51] Stevenson, D. K., and B. Scully. 1999. Using observers to monitor the status of Atlantic herring spawning stocks and groundfish by-catch in the Gulf of Maine. Contract completion rep. to U.S. Dep. Commer./NOAA/NMFS, Northeast Region State, Federal and Constituent Programs.

Gray seal predation of Atlantic cod on the Scotian Shelf was estimated to equal only 10–20% of fishing mortality and not considered an important factor in the cod stock collapse (Mohn and Bowen, 1996). The population of gray seals in the Gulf of Maine is comparatively small and localized in distribution. Any impacts on cod stocks are likely to be minimal.

Cod consistently appears in the diets of harbor seals in the Gulf of Maine and gray seals in eastern Canada, but its frequency of occurrence was never more than 26% (Bowen et al., 1993; Bowen and Harrison, 1994; Bowen and Harrison, 1996; Williams, 1999) and the size consumed was smaller than commercially valuable size. Although not directly competing with the fishery, the seals' removal of prerecruits could lead to a potential loss to the adult spawning population (Beverton, 1985; Harwood, 1987; Hammill et al., 1995).

Silver hake consumed by pinnipeds and that targeted by the fishery were more similarly sized. Juvenile harbor seals consumed silver hake that ranged in size from 5–50 cm, with a mean length of 21.9 cm (Williams, 1999). The fishery primarily targets 25–35+ cm fish; the new juvenile fishery targets fish that are generally less than 20 cm. A portion of the silver hake taken by harbor seals is also of the size class that is typically discarded (15–25 cm). Although this does not directly overlap with the primary fishery, it does with the juvenile fishery; it could perpetuate the truncated age structure of the silver hake stocks. About 80% of the silver hake consumed by gray seals in eastern Canada were of commercial size (Bowen et al., 1993).

The potential for biological interaction may differ by stock of silver hake. Most information available regarding hake consumption comes from the smaller northern stock. Given the distribution of seals in the Gulf of Maine, this is probably the stock with which they would most frequently interact. Overholtz et al. (1991) estimated that harbor seals annually consumed an average of 449 t of silver hake from the northern stock and none from the southern stock between 1988 and 1992. This was only a fraction (7.7%) of the average annual fishery removal was 5,829 t in 1988–92 (Helser et al, 1995), so may have had little impact on stock status. Proposed management measures that include coastal closure zones and take restrictions may minimize the likelihood for direct competition despite the current high level of fishery exploitation and the overexploited status of the northern stock of silver hake. Most landings are from the southern stock during the winter months and could overlap with harbor seals and gray seals wintering in southern New England. Silver hake was consumed year-round by juvenile harbor seals caught in the New England sink gillnet fishery and was present in gray seal scats collected near Nantucket Island. The sample size for the latter was quite small (present in 3 out of 42 scats (Rough[8])) and the overall importance of silver hake in the diet was indiscernible. Also, the feeding rate of gray seals declines during the breeding and molting periods (Reeves et al., 1992; Bowen et al., 1993; Rough[8]), which would further reduce overlap. The impact of the expanding population of seals on the recovery of silver hake cannot be ascertained.

Of the New England fisheries reviewed here, the Atlantic herring fishery has the greatest potential for biological interactions with pinnipeds. Assessing the extent of real or potential interactions is limited by the absence of prey information from the coast of Maine, where large numbers of harbor seals and a large herring fishery coexist. Most of the herring are landed off Maine between June and November when seals are abundant along the coast. The seasonal movement of the fishery is also similar to the seasonal movement of harbor seals in the Gulf of Maine. Herring is an important component of the summer diet in eastern Canada, where most of the herring consumed by both gray seals and harbor seals is of commercial size (Bowen et al., 1993; Bowen and Harrison, 1996). The mean size of herring consumed by harbor seals caught in the New England sink gillnet fishery was 25.3 cm (Williams, 1999), also within the commercial size range. Overholtz et al. (1991) estimated that harbor seals in the northeastern United States annually consumed an average of 1,433 t of herring during 1988–92. This was roughly 1.6% of the average annual landings for the total stock complex and 2.8% of the average annual Gulf of Maine landings. This consumption estimate was for years during which herring biomass was just beginning to escalate; the current high levels of available biomass could alter that figure.

Herring is an important forage species for a number of predators, including seals and several commercially valuable fish, such as cod and silver hake (NEFMC, 1999a). The increase in the seal population in the northeast coincided with increasing herring biomass. This may minimize direct competition for declining groundfish resources, but could lead to indirect competition with groundfish through the common pursuit of herring as prey (NEFMC, 1996; Williams, 1999).

The NEFMC, concerned that a high rate of juvenile herring predation could affect recruitment to the fishery at age-2, is taking a cautious approach to herring management and attempting to account for predator-prey interactions in the newly developed Atlantic Herring FMP. In developing the MSY and the target fishing mortality rates, there was an effort to account for non-fishery sources of mortality, including marine mammal predation (NEFMC, 1999a).

The precautionary management approach and current high biomass levels may minimize the potential for biological interactions. However, the recent resurgence of the fishery, change in gear types used, shifting target size and location of fishing may result in as yet unforseen impacts and interactions.

Sand lances are important prey for pinnipeds in the Gulf of Maine and eastern Canada, but they were not detailed in this review because they are not commercially harvested in either the U.S. or Canada. Since there is no fishery for this resource, there is little possibility for direct biological interactions, an important consideration when evaluating pinniped prey availability. However, fluctuations in abundance of commercially exploited species that either prey upon or compete with sand lance could indirectly affect sand lance populations. Such was the case with herring. Herring and sand lance apparently exploit similar prey and fill similar niches trophically. When herring abundance declined in the 1970's, the sand lance population increased significantly in shelf waters from the Gulf of Maine to Cape Hatteras (Sherman et al., 1981; Kenney et al., 1996). When the sand lance population around Cape Cod declined in the mid to late 1980's, herring abundance increased and became a more important part of the harbor seal diet around Cape Cod (Payne and Selzer, 1989).

West Coast

The potential for pinniped-fisheries interactions appears greater and more complex along the U.S. west coast than in New England. This is related to the size of the region, the number of pinniped species, the extensive seasonal migrations undertaken by different sex and age classes of pinnipeds, tremendous variation in prey preferences, and numerous state and federally managed fisheries. Periodic El Niño events may further complicate matters by altering the abundance and distribution of prey and fisheries resources.

Pacific harbor seal and California sea lion populations have grown substantially since passage of the MMPA in 1972, and some of the harbor seal stocks appear to be approaching carrying capacity. As opportunistic feeders, these pinnipeds exploit a large assemblage of prey, based on local abundance and availability, season, year, age or sex, and location. Fully 136 species or genera of fish, cephalopods, and crustaceans were identified as pinniped prey items in Washington, Oregon, and California (NMFS, 1997a). Several, including Pacific whiting, market squid, northern anchovy, Pacific herring, and Pacific sardine, support commercially valuable fisheries with the potential for biological and operational interactions with pinnipeds.

Pinniped impacts on fisheries and gear damage on the U.S. west coast have been well documented (NMFS, 1997a; Beeson and Hanan[23]); only those involving the commercial fisheries included in this review will be noted. California sea lions and harbor seals prey on the California herring gillnet fishery, with the frequency of depredation inversely related to fishing frequency. Both species also interact with the herring round haul (purse seine and lampara net) fishery and with the squid, sardine, and mackerel purse seine fisheries in California by foraging inside of the nets (Barlow et al., 1997).

California sea lions usually escape from the herring nets before closure, so mortality is low (Barlow et al., 1997). Depredation of the Yaquina Bay, Oreg., herring fishery by California sea lions was considered problematic in the mid 1970's. By the mid 1980's, it was limited by a February opening date and was no longer considered a problem (Brown[18]).

The high abundance and extensive migrations of the coastal stock of Pacific whiting make it available as pinniped prey coastwide. Pacific whiting is consumed by pinnipeds from the southern California rookeries to Cape Flattery, Wash. Availability is seasonal, size class differs regionally, and its abundance locally can strongly influence the predator's diet (Bailey and Ainley, 1982). Smaller juvenile fish are generally consumed in southern California and larger, adult fish farther north. Availability of Pacific whiting is usually highest from spring through fall in California, and from summer through late fall in northern coastal regions. Its frequency of occurrence in the pinniped diet reflects seasonal changes in availability.

Pacific whiting is also the most commercially valuable and abundant groundfish resource of the California Current. As a result, it is one of the more thoroughly and regularly assessed of the U.S. west coast fisheries and has also been evaluated relative to its importance as pinniped forage. Bailey and Ainley (1982) and Livingston and Bailey (1985) estimated the total annual coastwide pinniped consumption of coastal Pacific whiting to be 200,000–300,000 t, comparable to the commercial fishery's annual landings. California sea lions were considered the largest pinniped consumer of whiting, with estimated consumption highest south of 35°N, based on population distribution (Bailey and Ainley, 1982).

Whiting is clearly an important component of the west coast pinniped diet, and seems particularly so for Steller sea lions in Oregon and Washington (Gearin and Brown[34]; Riemer and Brown[52]). Timing and location of the whiting fishery overlap with both Steller sea lion and California sea lion distribution along the northwest coast, and fishery closures south of 42°N concentrate fishing efforts in this area. Lactating female Steller sea lions on the rookeries in Oregon focus foraging efforts on the dense offshore concentrations of Pacific whiting (Riemer and Brown[52]). Steller sea lions along the Washington coast, including several age and sex classes from rookeries to the north and to the south, consume a preponderance of Pacific whiting during the months it is available. There are currently no indications of resource competition for Pacific whiting along the Oregon and Washington outer coasts, but with fishing effort increasing near Cape Flattery, localized interactions could result. More detailed and year-round prey and foraging studies, or more detailed analyses of existing data are needed to better assess the likelihood of this occurring.

Since the coastal Pacific whiting fishery is, for the most part, closed south of lat. 42°N, there are no apparent direct fishery impacts on California sea lions in southern and central California, including the Channel Islands rookeries, Steller sea lions in central California, and central and southern California harbor seals. In the few years preceding the fishery's closure south of 39°N in 1977, intense whiting fishing in the continental slope waters off central California may have sufficiently depleted the resource near the Farallon Islands to cause California sea lions to feed inshore on other prey during late summer and fall. Sea lion distribution around the Farallones changed subsequent to the closure. The number of adults foraging offshore in the fall increased, as did the number of adults remaining at the Farallones during the summer, and juveniles moved farther north and farther offshore. This was attributed to whiting

[52] Riemer, S. D., and R. F. Brown. 1996. Marine mammal (pinniped) food habits in Oregon. Rep. to Pac. States Mar. Fish. Comm., Portland, Oreg., Contract 95-97, 26 p.

availability increasing offshore in the absence of fishing (Ainley et al., 1982).

Other fish are more localized in either their distribution, importance as prey, or fishery. Market squid is distributed coastwide, but is in greatest concentrations in southern and central California where it is a significant fishery resource and prey item. Its availability may be essential for female and juvenile California sea lions on the Channel Islands during the winter months, the primary spawning season for market squid in southern California. Both the fishery and pinnipeds exploit the dense schools of spawning adults around the Channel Islands during the winter, where its occurrence in sea lion scats mirrors the commercial harvest rate (Lowry et al., 1990). Both also suffer the effects of market squid declines during El Niño years, resulting in the need to "prey switch." The fishery may have greater short-term resilience and suffer fewer repercussions compared to the reproductive failures and high pup mortality experienced by California sea lions during strong El Niño events. Other prey consumed along with, or in place of, market squid need to be considered when evaluating the importance of market squid in the diet and, in particular, the impact of its decline during El Niño events. The recent expansion of the fishery and relative lack of management heighten the potential for resource competition, but evaluating this is hindered by a dearth of information on market squid's basic biological parameters, including stock size and status. Market squid are also consumed by pinnipeds in central California during the spring–summer spawning season, which coincides with the local fishery. Although only about 10% of the total California landings are currently from this area, localized interactions could still be significant.

Herring is an important forage fish for many of the pinnipeds discussed here, particularly for harbor seals in the northwest. With the Washington and Oregon harbor seal stocks increasing, impacts on prey and prey availability may arise. The Puget Sound herring stocks are commercially valuable and utilized by a growing population of harbor seals, whose estimated level of predation exceeds current fishing mortality (Schmitt et al., 1995; Lemberg et al., 1997). The herring fishery in Puget Sound is presently relatively small and the stock status variable and spawning stock dependent.

Given the level of predation by seals in Puget Sound, some impact upon the stocks is possible, especially on a localized level, and for those stocks in a depressed—or endangered—state. The fishery and stocks are closely monitored and regulated and harvest rates are low. Although prey studies indicate that harbor seals consume herring in the Columbia River, Oregon coast, Grays Harbor, and Willapa Bay, insufficient information on those herrings stocks precludes evaluating predator-prey-fishery interactions. Fishing activity on these stocks of herring, however, is either negligible or nonexistent.

The larger herring stocks of central California, notably San Francisco Bay, are also utilized by pinnipeds. Pinniped predation is highest during the fall–winter spawning season, which coincides with the fishery. Interactions with the fishery are mentioned above. There do not appear to be any conflicts over prey availability, and both the herring spawning stock biomass and pinniped populations are at healthy levels. However, herring abundance decreases during El Niños, causing declines in landings, and could affect forage availability and fishery interactions.

The abundance and availability of northern anchovies and Pacific sardines appear important to the diet of pinniped populations along the coast, especially at the California sea lion rookeries, which are situated near large spawning aggregations of these small forage fish. The central subpopulation of anchovies was commonly exploited on the southern rookeries, where its predominance in the diet was year-round and less impacted by El Niños than some of the other forage species. The northern subpopulation was utilized by pinnipeds from central California and northward during the summer months. The anchovy fishery in southern California peaked in the mid 1970's and has been fairly small since the early 1980's. The most intensive fishing period then overlapped little with the period of greatest pinniped population increase in that area. Anchovy abundance recently declined, while Pacific sardine abundance is rapidly growing and expanding northward.

Sardines are important forage fish, with juveniles and adults preyed upon by numerous marine mammals, including seals and sea lions. However, there is little information available regarding sardines as prey because of their scarcity until recently. They will likely regain importance as a forage species as abundance increases, perhaps replacing anchovies in the diet of some pinnipeds (PFMC, 1998b). Since sardine is an important forage fish, management considerations include maintaining a forage reserve and incorporating forage requirements into harvest formula options and overfishing definitions (PFMC, 1998b).

As an addendum, eulachon in the Columbia River deserve mention. The importance of eulachon in the winter diet of harbor seals is well documented, but the fishery is not reviewed here because of its small size and localized use of the resource. The highest counts of harbor seals in the Columbia River frequently coincide with winter spawning of eulachon (Bargmann, 1998). Eulachon are both commercially and recreationally harvested during the winter spawn and pinniped consumption was estimated as 26% of the commercial catch (NMFS, 1997a). However, the eulachon population is declining and harvest levels dwindled to less than 5 t per year over the last few years (Bargmann, 1998; PacFIN[42]).

Conclusions

Since passage of the MMPA in 1972, most pinniped populations in New England and the contiguous U.S. west coast have grown exponentially, and the Oregon and Washington coast stock of harbor seals may even be approaching OSP. The U.S. west coast component of the eastern stock of Steller sea lions increased more gradually and less conspicuously. The population is relatively stable from at least northern California northward, but is declining from central California southward. The Steller sea lion is the only pinniped species included in this review that is listed as threatened, based on the status of the entire eastern stock.

The harbor seal, gray seal, California sea lion, and Steller sea lion populations described here exploit a broad assemblage of locally abundant and available fish and invertebrates, the relative significance of which is largely dictated by location, season, year, and environmental perturbations. Dietary differences are also related to age and sex class of the pinniped. All seem to maintain a degree of diet diversity and have the ability to "prey switch" in response to changes in prey availability and abundance.

A diverse diet may be essential for population stability (Merrick et al., 1997; Williams, 1999). Merrick et al. (1997) found a strong correlation between diet diversity and the Steller sea lion population decline in the Gulf of Alaska and Aleutian Islands; the decline was greatest where diversity was lowest. They concluded that a diverse diet—with at least two major prey resources—may enhance foraging efficiency and buffer fluctuations in availability of any one prey item. The California sea lion's dietary and foraging strategy flexibility and adaptability are considered key elements in their recovery and continued population growth (Lowry et al., 1991; Melin et al., 2000).

The availability of small, schooling forage fish, alternative prey, and the ability to utilize that prey, are instrumental in adapting to fluctuating or limited prey resources. In both the New England and west coast regions, where most pinniped populations are thriving, small forage fish were nearly continuously available for exploitation. Fluctuations in abundance and availability, resulting from natural cycles and overexploitation, were frequently countered by availability of similar, alternative prey. Atlantic herring, for example, were apparently replaced by sand lance (and vice versa) when herring stocks collapsed in New England. Although both northern anchovy and Pacific sardine populations fluctuate widely, in approximately 60 year cycles (Baumgartner et al., 1992), anchovy abundance was high during much of the recent period of low sardine abundance along the U.S. west coast. Similarly, the resurgence of herring following the collapse of the capelin stocks in the Barents Sea was instrumental in alleviating the effects of prey limitations on harp seals (Haug and Nilssen, 1995). Comparative analysis by Shima (1996) and Shima et al. (2000) concur. Available alternative prey, dietary flexibility, and large or expanding pinniped populations were common to the California Current, Benguela Current, and Barents Sea, whereas alternative prey was either unavailable or inaccessible in areas of the Gulf of Alaska where age-1 walleye pollock dominated the diet of the declining Steller sea lion population. Merrick (1997) considered the decline in abundance of forage fish a possible factor in the decline of apex predators in the Gulf of Alaska and Bering Sea.

Pinnipeds frequently prey upon commercially valuable fish and invertebrates, including Atlantic cod, silver hake, Atlantic herring, Pacific whiting, market squid, northern anchovy, Pacific herring, and Pacific sardine. Direct resource competition is then possible, as is competition for the prey of commercial species. This may be compounded by expanding pinniped populations, the sometimes vast fluctuations in commercial fish biomass, the fishery's exploitation level, and the availability of alternative prey.

Given the current status of most pinniped populations described here, concerns over their impacts upon fisheries (especially those with localized spawning stocks, or at critically low biomass levels) are more prevalent than concerns over fisheries impacts on pinnipeds (DeMaster and Sisson, 1992; NMFS, 1997a). Although pinniped predation is one component of natural mortality estimates (M), few fish stock assessments explicitly address pinniped predation or the temporal-spatial elements of fishery competition.

Overlap in pinniped and fishery resource utilization exists in New England and the U.S. west coast, yet the extent to which biological interactions may be occurring cannot presently be determined. More extensive and detailed research and evaluation are needed to augment the baseline information and trends presented here. Future endeavors would benefit from updated and more detailed prey information, including seasonality of prey preferences, and pinniped foraging depths and locations compared to specific times, locations, and depths of fishery removals. Evaluating these variables on smaller geographic scales could reveal localized interactions that would otherwise be overlooked in broad scaled analyses. Reviewing management measures, particularly time/area closures, relative to pinniped movements and foraging locations may also prove instructive.

Potential biological interactions between pinnipeds and fisheries should be considered within a broader ecological context. This includes the impact of environmental changes on species composition and availability, especially when coupled with the effects of fishing (Shima, 1996; Mueter and Norcross, 2000), and accounting for predation by other species, fish and marine mammals included, when assessing fisheries and prey resources (Hollowed et al, 2000; Shima et al., 2000). Complex trophic interactions, environmental change, and management actions form a suite of interconnected variables that need to be considered when evaluating the causes and effects of biological interactions between pinnipeds and commercial fisheries.

Acknowledgments

B. Stenberg and W. Daspit, the PacFIN database managers, were extremely helpful in providing data and in answering a multitude of questions. L. Fritz, M. Dorn, A. Williams, G. Waring, K. Thounhurst, J. Gilbert, P. Fiorelli, C. Kellogg, T. Nies, D. Hanan, K. Hill, D. Watters, G. Bargmann, D. Bodenmiller, G. Early, R. DeLong, D. DeMaster, P. Gearin, P. S. Hill, H. Huber, K. Hughes, J. Laake, P. M. Payne, M. Lowry, and J. Barlow provided insight, information, and clarification of data. K. Laidre and L. Compton were invaluable in assisting with maps and graphics. Reviews by G. Duker, L. Fritz, W. Hobart, H. Huber, J. Lee, K. Wynne, and two anonymous reviewers greatly improved the manuscript. This work was funded by the National Marine Mammal Laboratory through contract number 40AB NF801451 to LB.

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