The Northern Rockfish, *Sebastes polyspinis,* in Alaska: Commercial Fishery, Distribution, and Biology

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Introduction

The northern rockfish, *Sebastes polyspinis*, is one of the most abundant and commercially valuable members of its genus in Alaska waters. As implied by its common name, this fish has one of the most northerly distributions among the 60+ species of *Sebastes* in the North Pacific Ocean. It ranges from extreme northern British Columbia around the northern Pacific Rim to eastern Kamchatka and the northern Kurile Islands and also north into the eastern Bering Sea (Allen and Smith, 1988; Orlov[1]), but is common only in Alaska waters.

Bottom trawl surveys of the Gulf of Alaska and Aleutian Islands regions indicate that northern rockfish is the second most abundant rockfish species there, surpassed only by Pacific ocean perch, *S. alutus* (Harrison, 1993; Ronholt et al., 1994; Stark and Clausen, 1995; Martin and Clausen, 1995; Martin, 1997). Amongst all species caught in three surveys of each region that were conducted in the 1990's, northern rockfish ranked tenth in average biomass in the Gulf of Alaska, and fourth in the Aleutian Islands.[2] Since 1990, northern rockfish has supported a valuable domestic trawl fishery in Alaska; for the Gulf of Alaska region alone, gross wholesale value of this fishery was estimated at $3.5 million in 1995 and $1.2 million in 1999 (Bibb[3]).

Despite this ecological and commercial importance, little has been published on the biology of northern rockfish or its fishery. The species was first described by Taranetz and Moisev (Taranetz, 1933) based on a specimen from the eastern Bering Sea. The only biological study to deal exclusively with northern rockfish is that of Westrheim and Tsuyuki (1971). Their report presented information on many aspects of northern rockfish biology, including taxonomy, distribution and abundance, size composition, age and growth, and size at maturity. Although this study still provides valuable information, much of it now has to be considered somewhat outdated. The distribution and abundance data came from research

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[1] Orlov, Alexie, Russian Federal Research Institute of Fisheries and Oceanography (VNIRO), 17 Krasnoselskaya, Moscow, 107140, Russia. Personal commun., May 2000.

[2] Based on data in the "RACEBASE" database, the trawl survey database maintained by the NMFS, NOAA, Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering (RACE) Division, February 2000.

[3] Bibb, Sally, Sustainable Fisheries Division, NOAA, Natl. Mar. Fish. Serv., Alaska Regional Office, Juneau, AK. Personal commun., April 1997 and June 2000.

ABSTRACT—The northern rockfish, Sebastes polyspinis*, is the second most abundant rockfish in Alaska, and it supports a valuable trawl fishery. Little information is available, however, on either the biology of this species or its commercial fishery. To provide a synopsis of information on northern rockfish in Alaska, this study examined data for this species from commercial fishery observations in 1990–98 and from fishery-independent trawl surveys in 1980–99. Nearly all the commercial catch came from bottom trawling, mostly by large factory-trawlers, although smaller shore-based trawlers in recent years took an increasing portion of the catch in the Gulf of Alaska.*

Most of the northern rockfish catch in the Gulf of Alaska was taken by a directed fishery, whereas that of the Aleutian Islands predominantly came as discarded bycatch in the Atka mackerel fishery. In both regions, most of the catch was taken from a number of relatively small and discrete fishing grounds at depths of 75–150 m in the Gulf of Alaska and 75–175 m in the Aleutian Islands. These grounds, especially in the Gulf of Alaska, are on shallow rises or banks located on the outer continental shelf, and often are surrounded by deeper water. Five fishing grounds were identified in the Gulf of Alaska, and eleven in the Aleutian Islands. One fishing ground in the Gulf of Alaska, the "Snakehead" south of Kodiak Island, accounted for 46% of the total northern rockfish catch in this region.

Analysis of the survey data generally revealed similar patterns of geographic distribution as those seen in the fishery, although some of the commercial fishing grounds did not stand out as areas of special abundance in the surveys. The surveys also found two areas of abundance that were not evident in the fishery data. Relatively few juvenile northern rockfish were caught in any of the surveys, but those taken in the Gulf of Alaska tended to occur more inshore and at shallower depths than adults. Individual size of northern rockfish was substantially larger in the Gulf of Alaska than in the Aleutian Islands according to both fishery and survey data. Analysis of age data from each region supports this, as Gulf of Alaska fish were found to grow significantly faster and reach a larger maximum length than those in the Aleutian Islands. Sex ratio in the Gulf of Alaska was nearly 50:50, but females predominated in the Aleutian Islands by a ratio of 57:43. In both regions, size of females was significantly larger than males.

trawling conducted in the Gulf of Alaska over 30 years ago, and the age results are based on surface readings of otoliths, a technique which is now thought to substantially underage rockfish.

More recent information on northern rockfish can be gleaned from trawl survey data reports such as those referenced in the second paragraph of this section, or from annual stock assessment documents for rockfish (e.g. Heifetz et al., 1999). Also, a population dynamics modeling analysis of northern rockfish in the Gulf of Alaska has been completed to quantitatively assess stock condition of these fish, and this study presents some data on the fishery and on survey results (Courtney et al., 1999). In addition, a limited amount of food habits information is available for northern rockfish in the Gulf of Alaska and Aleutian Islands (Yang, 1993, 1996). Most recently, a small and preliminary genetics study of northern rockfish was conducted to determine if any stock structure for this species was readily apparent (Gharrett et al.[4]). Except for the Courtney et al. (1999) and Gharrett et al.[4] studies, however, none of these recent reports focuses completely on northern rockfish, and none discusses the biology of this species in any detail.

This report provides an updated synopsis of available information on northern rockfish and is based on two major data sources: 1) data collected from the commercial fishery in the years 1990–98 by the National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center's (AFSC) fisheries Observer Program and contained on the Program's "NORPAC" database, and 2) data from various bottom trawl surveys conducted between 1980 and 1999 by the AFSC's Resource Assessment and Conservation Engineering (RACE) Division and contained on their "RACEBASE" database.

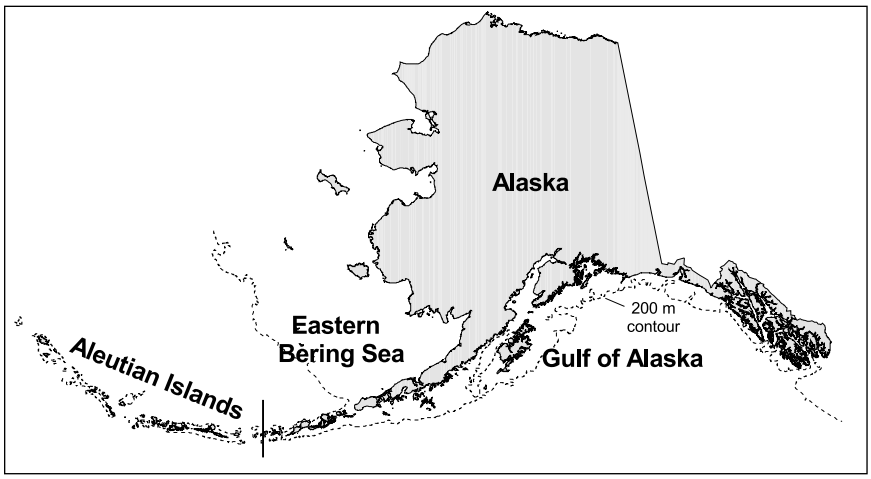

Figure 1.—The three major fishery management regions that are discussed in this report: Gulf of Alaska, Aleutian Islands, and eastern Bering Sea.

First, we use the fishery data to describe the commercial fishery and to present information on the distribution and biology of northern rockfish. Then, we analyze the survey data to present alternative information on the distribution and biology of northern rockfish and to provide a comparison with the results from the fishery data. As part of the survey analysis, we also present age and growth information for northern rockfish.

This report focuses particularly on northern rockfish in the Gulf of Alaska and the Aleutian Islands regions (Fig. 1). Although the species is also found on the outer continental shelf and slope of the eastern Bering Sea, its abundance there has been very low in trawl surveys (Ito et al., 1999), and commercial catches of northern rockfish in this region have been much less than in the other two regions. Consequently, for northern rockfish in the eastern Bering Sea, only fishery data will be presented in this report, and these data will be analyzed in less detail than those for the Gulf of Alaska and Aleutian Islands. The three regions also correspond to major fishery management regions for Federal waters off Alaska.

Commercial Fisheries

Foreign Fishery

Directed fishing for rockfish in Alaska waters began in 1960 with the first catches by Soviet and Japanese bottom trawlers (Balsiger et al., 1985), and foreign catches of rockfish continued until 1987. Most of the fishery was for Pacific ocean perch, *Sebastes alutus*, and massive fishing effort targeting this species in the 1960's caused a precipitous decline in its abundance throughout Alaska waters that has been well documented (Ito[5]). To what extent the foreign rockfish fishery was also taking northern rockfish, and whether there was directed fishing for this species, is unknown for the years through 1976, as there are no available summaries of northern rockfish catches over this period. Foreign catches of all rockfish were often reported simply as "Pacific ocean perch" (Murai et al., 1981), with no attempt to differentiate species. In other instances, Pacific ocean perch were separated out, but all other *Sebastes* were assigned the category of "other rockfish," and there is still no way to determine the catch of northern rockfish.

With the advent of a substantial NMFS observer program aboard foreign fishing vessels in 1977, enough information on species composition of rockfish catches was collected so that estimates of the northern rockfish foreign catch can be

[4]Gharrett, A. J., A. K. Gray, S. Lyons, D. Clausen, and J. Heifetz. 2003. A preliminary study of population structure in Alaskan northern rockfish, *Sebastes polyspinis*, based on microsatellite and mtDNA variation. *In* A. J. Gharrett (Editor), Population structure of rougheye, shortraker, and northern rockfish based on analysis of mitochondrial DNA variation and microsatellites: completion, p. 1–16. Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 11120 Glacier Hwy., Juneau, AK 99801.

[5]Ito, D. H. 1982. A cohort analysis of Pacific ocean perch stocks from the Gulf of Alaska and Bering Sea regions. NOAA, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., Bldg. 4, 7600 Sand Point Way N.E., Seattle, WA 98115. NWAFC Processed Rep. 82-15, 157 p.

made for 1977–87 (Tables 1–3). The relatively large catch estimates for 1977–78 in the Aleutian Islands and 1982–83 in the Gulf of Alaska are an indication that at least some directed fishing probably occurred in those years. Except for reporting the foreign catches in Tables 1–3, however, we have decided to omit the foreign fishery observer data from our analyses and to focus instead on the more recent domestic fishery.

Joint Venture Fishery

A new era in Alaska commercial fishing began in 1976 with the passage of the Magnuson Fishery Conservation and Management Act, later renamed the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA; Anonymous, 1996). This Act gave the United States jurisdiction over all groundfish resources within 200 nautical miles (n.mi.) of its shoreline, and set in place regulatory policies that eventually resulted in domestic fishermen replacing the foreign fishermen. The Act also created the North Pacific Fishery Management Council (NPFMC) as an advisory body to develop and implement management plans for Alaska groundfish.

As an interim step in the transition from foreign to domestic fishing, joint venture fisheries developed in the early 1980's in which U.S. fishing boats caught and delivered fish to foreign processing vessels (Megrey and Wespestad, 1990). Although joint venture catches were sizeable for some species, they were relatively modest for northern rockfish (Tables 1–3). By 1990, both the foreign and the joint venture fisheries for rockfish in Alaska had ended.

Domestic Fishery

Management History and Catch Statistics

Since passage of the MSFCMA, northern rockfish have been assigned to various management groupings (Table 4). Until the early 1990's, they were always managed as part of a "complex" or assemblage of rockfish species. Presumably, the original reason for this assemblage management was because it was thought to be too difficult for fisher-

Table 1.—Commercial catch of northern rockfish in the Gulf of Alaska, 1977–99.[1,2]

	Catch (t)			
Year	Foreign	Joint venture	Domestic	Total
1977	622	0	0	622
1978	553	0	0	553
1979	666	3	0	669
1980	809	Tr.[3]	0	809
1981	1,469	0	0	1,469
1982	3,914	0	0	3,914
1983	2,705	911	0	3,616
1984	489	492	N.a.[4]	N.a.
1985	Tr.	108	N.a.	N.a.
1986	Tr.	11	N.a.	N.a.
1987	0	51	N.a.	N.a.
1988	0	Tr.	N.a.	N.a.
1989	0	0	N.a.	N.a.
1990	0	0	1,697	1,697
1991	0	0	4,528	4,528
1992	0	0	7,770	7,770
1993	0	0	4,825	4,825
1994	0	0	5,968	5,968
1995	0	0	5,634	5,634
1996	0	0	3,386	3,386
1997	0	0	2,947	2,947
1998	0	0	3,051	3,051
1999	0	0	5,397	5,397

[1] Catches for 1977–92 are estimates based on extrapolation of catch composition data from the foreign and domestic observer programs.

[2] Data Sources:

1977: Wall, J., R. French, R. Nelson Jr., and D. Hennick. 1978. Data from the observations of foreign fishing fleets in the Gulf of Alaska, 1977. (Document submitted to the International North Pacific Fisheries Commission by the U.S. National Section.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1978: Wall, J., R. French, and R. Nelson Jr. 1979. Observations of foreign fishing fleets in the Gulf of Alaska, 1978. (Document submitted to the International North Pacific Fisheries Commission by the U.S. National Section.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1979: Wall, J., R. French, and R. Nelson Jr. 1980. Observations of foreign fishing fleets in the Gulf of Alaska, 1979. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Anchorage, Alaska, September 1980.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1980: Wall, J., R. French, and R. Nelson Jr. 1981. Observations of foreign fishing fleets in the Gulf of Alaska, 1980. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Vancouver, B. C., Canada, September 1981.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1981: Wall, J., R. Nelson Jr., and J. Berger. 1982. Observations of foreign fishing fleets in the Gulf of Alaska, 1981. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Vancouver, B. C., Canada, October 1982.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1982: Nelson, R., Jr., J. Wall, and J. Berger. 1983. Summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1982. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Anchorage, Alaska, October 1983.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1983: Berger, J., J. Wall, and R. Nelson Jr. 1984. Summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1983. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Vancouver, B.C., Canada, October 1984.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1984: Berger, J., J. Wall, and R. Nelson Jr. 1985. Summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1984. (Document submitted to the annual meeting of the International North Pacific Fisheries Commission, Tokyo, Japan, October 1985.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, Building 4, 7600 Sand Point Way N. E., Seattle, WA 98115.

1985: Berger, J., J. Wall, and R. Nelson Jr. 1987. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1985. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-112, 169 p.

1986: Berger, J., R. Nelson Jr., J. Wall, H. Weikart, and B. Maier. 1988. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-128, 167 p.

1987: Berger, J., and H. Weikart. 1988. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1987. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-148, 141 p.

1988: Berger, J., and H. Weikart. 1989. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1988. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-172, 118 p.

1989: Heifetz, J., J. N. Ianelli, D. M. Clausen, and J. T. Fujioka. 1999. Slope rockfish. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 309–360. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

1990–91: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802 and Domestic Observer Program, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way N. E., Seattle, WA 98115.

1992–98: Heifetz, J., J. N. Ianelli, D. M. Clausen, and J. T. Fujioka. 1999. Slope rockfish. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 309–360. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

1999: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802.

[3] Tr. = trace

[4] N.a. = not available

men to accurately identify the individual rockfish species, which are superficially similar in appearance. Also, many species were believed to sometimes co-occur in catches, which would make sorting to species a time consuming process.

Each year, the NPFMC assigned a single level of acceptable biological catch (ABC) and fishing quota (since 1988 the quota has been called "total allowable catch" (TAC)) for the entire complex or assemblage in each region.[6] Consequently, fishermen and processors were only required to report catches as "Pacific Ocean Perch Complex," "Slope Rockfish Assemblage," etc., without regard to which exact species in the assemblage they were actually taking. The assemblage approach as applied to northern rockfish management had a de facto ending in the Aleutian Islands in 1992, when the "Sharpchin/Northern" management subgroup was established in this region (Ito and Ianelli, 1994; sharpchin rockfish are so rare in the Aleutian Islands that the grouping is effectively northern rockfish alone). Likewise, northern rockfish were separated as a distinct management entity in the Gulf of Alaska in 1993 (Heifetz et al., 1993). In the eastern Bering Sea, however, northern rockfish in the years 1993–99 continued to be managed as part of the "Other Red Rockfish Assemblage" (Ito et al., 1999) .

A completely domestic fishery for rockfishes, in which U.S. vessels both caught and processed the fish, began in the Gulf of Alaska and eastern Bering Sea in 1984, and in the Aleutian Islands in 1985 (Tables 1–3). Catches of northern rockfish in this fishery, however, cannot be determined for years before 1990. During these years, northern rockfish were part of either the Pacific Ocean Perch Complex or the Slope Rockfish Assemblage, so directly reported catch statistics for individual species are unavailable. This was not a problem in the foreign or joint venture fisheries because U.S. observers aboard foreign vessels collected species composition data that could be used to estimate the catch of northern rockfish. Unfortunately, a comparable observer program for domestic vessels was not implemented

Table 2.—Commercial catch of northern rockfish in the Aleutian Islands, 1977–99.[1,2]

	Catch (t)			
Year	Foreign	Joint venture	Domestic	Total
1977	5,311	0	0	5,311
1978	3,782	0	0	3,782
1979	997	0	0	997
1980	374	0	0	374
1981	138	2	0	140
1982	193	0	0	193
1983	28	Tr.[3]	0	28
1984	12	173	0	185
1985	Tr.	196	N.a.[4]	N.a.
1986	Tr.	200	N.a.	N.a.
1987	0	253	N.a.	N.a.
1988	0	441	N.a.	N.a.
1989	0	0	N.a.	N.a.
1990	0	0	1,273	1,273
1991	0	0	251	251
1992	0	0	1,041	1,041
1993	0	0	4,486	4,486
1994	0	0	4,667	4,667
1995	0	0	3,873	3,873
1996	0	0	6,708	6,708
1997	0	0	1,997	1,997
1998	0	0	3,675	3,675
1999	0	0	5,255	5,255

[1] Catches for 1977–91 are estimates based on extrapolation of catch composition data from the foreign and domestic observer programs. Catches for 1992–99 may include very small amounts of sharpchin rockfish.

[2] Data sources:

1977–86: Ito, D. H. 1988. Other rockfish. *In* R. G. Bakkala (Editor), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1987, p. 139–146. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-139.

1987–88: Berger and Weikart (1988, 1989; for references, see Table 1).

1989: Guttormsen, M., R. Narita, and J. Berger. 1990. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1989. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-189, 84 p.

1990–91: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802 and Domestic Observer Program, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way N. E., Seattle, WA 98115.

1992–99: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802.

[3] Tr. = trace

[4] N.a. = not available

[6] In actual practice, the ABC and quota for the Gulf of Alaska were further subdivided into three management areas: Western, Central, and Eastern.

Table 3.—Commercial catch of northern rockfish in the eastern Bering Sea, 1977–99.[1,2]

	Catch (t)			
Year	Foreign	Joint venture	Domestic	Total
1977	322	0	0	322
1978	119	0	0	119
1979	126	0	0	126
1980	58	11	0	69
1981	31	0	0	31
1982	68	2	0	70
1983	10	24	0	34
1984	19	13	N.a.[3]	N.a.
1985	5	2	N.a.	N.a.
1986	6	36	N.a.	N.a.
1987	2	51	N.a.	N.a.
1988	0	7	N.a.	N.a.
1989	0	12	N.a.	N.a.
1990	0	0	180	180
1991	0	0	623	623
1992	0	0	328	328
1993	0	0	959	959
1994	0	0	47	47
1995	0	0	287	287
1996	0	0	116	116
1997	0	0	118	118
1998	0	0	54	54
1999	0	0	145	145

[1] Catches for 1977–91 are estimates based on extrapolation of catch composition data from the foreign and domestic observer programs. Catches for 1992–99 may include very small amounts of sharpchin rockfish.

[2] Data sources:

1977–86: Ito (1988; see Table 2 for reference).

1987–88: Berger and Weikert (1988, 1989; see Table 1 for references).

1989: Guttormsen et al. (1990; see Table 2 for reference).

1990–91: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802 and Domestic Observer Program, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way N. E., Seattle, WA 98115.

1992–99: Data on file at National Marine Fisheries Service, Alaska Region, P.O. Box 21668, Juneau, AK 99802.

[3] N.a. = not available

Table 4.—Management groupings[1] that northern rockfish were assigned to in the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea, 1979–99.

Region and year	Management grouping
Gulf of Alaska	
1979–87	Pacific ocean perch complex
1988–90	Slope rockfish assemblage
1991–92	Other slope rockfish
1993–99	Northern rockfish
Aleutian Islands	
1979–90	Pacific ocean perch complex
1991–99	Sharpchin/northern
Eastern Bering Sea	
1979–90	Pacific ocean perch complex
1991–99	Other red rockfish

[1] Definition of management groupings:

Pacific ocean perch complex: Pacific ocean perch, *Sebastes alutus*; northern rockfish, *S. polyspinis*; rougheye rockfish, *S. aleutianus*; shortraker rockfish, *S. borealis*; and sharpchin rockfish, *S. zacentrus*.

Slope rockfish assemblage: The five species in the Pacific ocean perch complex, plus redstripe rockfish, *S. proriger*; harlequin rockfish, *S. variegatus*; silvergrey rockfish, *S. brevispinis*; and 13 minor species of *Sebastes*.

Other slope rockfish: Northern, sharpchin, redstripe, harlequin, and silvergrey rockfish and 13 minor *Sebastes* sp.

Northern rockfish: Northern rockfish only.

Sharpchin/northern: Sharpchin and northern rockfish.

Other red rockfish: Northern, rougheye, shortraker, and sharpchin rockfish.

until 1990, which left a gap in the catch estimates for the domestic fishery from 1984 to 1989. The domestic trawl fishery for rockfish developed rapidly over these years, especially in the Gulf of Alaska, where the reported catch of the Pacific ocean perch complex/slope rockfish assemblage increased from 119 metric tons (t) in 1984 to 19,002 t in 1989 (Heifetz et al., 1999). Presumably, some northern rockfish were taken, but most of the catch by the domestic fishery in this period is believed to be Pacific ocean perch, shortraker rockfish, *Sebastes borealis*; and rougheye rockfish, *Sebastes aleutianus*. These latter three species have traditionally been more valuable than northern rockfish on a price-per-pound basis, and there is evidence that some domestic fishermen were selectively harvesting them rather than northern rockfish (Heifetz and Clausen, 1990).

With the start of an observer program on U.S. groundfish vessels in 1990 (NPFMC, 1989a, 1989b), detailed information on domestic catches of rockfish in Alaska finally became available. In the Gulf of Alaska, catches of northern rockfish increased sharply from 1,697 t in 1990 to 7,770 t in 1992, and diminished somewhat in the years following (Table 1). This catch trend can be related to management actions of the NPFMC and NMFS during this period. In 1990, northern rockfish were in the Slope Rockfish Assemblage, along with Pacific ocean perch, shortraker and rougheye rockfish, and other species (Table 4). Fishermen were free to catch any of these species within the Slope Rockfish quota. Given the comparatively low market value of northern rockfish, fishing was apparently directed toward the three other species in the assemblage mentioned above. The result was a relatively moderate catch of northern rockfish that year. In 1991, however, the NPFMC separated Pacific ocean perch, shortraker rockfish, and rougheye rockfish from the rest of the Slope Rockfish Assemblage and assigned individual ABC's and TAC's for these three species (Heifetz and Clausen, 1992). These ABC's and TAC's were considerably less than the values in previous years, when a single ABC and TAC was set for all Slope Rockfish species combined. As a result of this more restrictive management policy, the rockfish fleet redirected more of its effort to northern rockfish, and catches for the species greatly increased in both 1991 and 1992. The high catches of northern rockfish in these two years raised concern among fishery assessment scientists that fishermen were selectively overharvesting this species within the "Other Slope Rockfish" management subgroup (Gulf of Alaska Groundfish Plan Team, 1992). Consequently, in 1993 the NPFMC implemented another change in rockfish management policy by separating out northern rockfish as its own distinct management subgroup in the Gulf of Alaska. The NPFMC assigned northern rockfish its own ABC and TAC, and since 1993, the restrictions imposed by this quota have resulted in the catches listed in Table 1. To ensure the TAC was not exceeded, and to limit bycatch of other species, catches in 1996–98 were further reduced due to in-season management actions by NMFS, which closed the fishery early.

In the Aleutian Islands, annual domestic catches of northern rockfish increased at a slower rate than those in the Gulf of Alaska (Table 2). Although northern rockfish in the Aleutian Islands were separated from the Pacific ocean perch complex in 1991 and assigned their own ABC and TAC, catches that year totaled only 251 t. A large increase in catches was finally seen in 1993, when nearly 4,500 t were taken, and catches have remained relatively large in the years thereafter. In 1994–96, catches were limited by mid-season closures for targeted fishing to ensure that the TAC was not exceeded. Since 1997, NMFS has prohibited targeted fishing for northern rockfish in the Aleutian Islands, and northern rockfish have been taken only as bycatch in other fisheries. This bycatch-only fishery was deemed necessary to prevent the closure of other more valuable fisheries in the Aleutian Islands, such as those for Atka mackerel and Pacific ocean perch (Smoker[7]). Such closures may have occurred if both targeted and bycatch fishing for northern rockfish were allowed and, in combination, were to cause the TAC for this species to be exceeded.

Annual domestic catches of northern rockfish in the eastern Bering Sea have consistently been much less than those in the Gulf of Alaska or Aleutian Islands (Table 3). Catches were highest in the years 1991–93, when targeted fishing was allowed during some periods. After 1993, catches for the "Other Red Rockfish" assemblage (of which northern rockfish was a member), were usually limited to bycatch only. TAC's for this assemblage were also quite small after 1993, which restricted the catches even further.

Targeted vs. Bycatch Fishing in the Gulf of Alaska and Aleutian Islands

Our analysis of the observer data indicates that in the Gulf of Alaska, the majority of northern rockfish catch has been taken by vessels specifically targeting this species, whereas in the Aleutian Islands it has been taken mostly as bycatch in other fisheries. As mentioned, management regulations since 1997 have limited the Aleutians fishery to bycatch only, but even before 1997, most of the catch was taken as bycatch. Because the observer database does not contain information on the intended target species for each haul, we used procedures described in Ackley and Heifetz (2001) to determine the probable target species. In these procedures, the predominant species by weight in a haul was usually determined to be the target. The results showed that for the overall period 1990–98, an estimated 81.8% of the northern rockfish catch in the Gulf of Alaska came from hauls that targeted this species, whereas only 20.6% of the northern rockfish catch in the Aleutian Islands came from targeted fishing (Table 5).

Most of this large bycatch of northern rockfish in the Aleutian Islands has been taken in the trawl fishery for Atka mackerel, *Pleurogrammus monopterygius*. For 1990–98, our targeting analysis indicated that 68.8% of the northern rockfish catch in the Aleutian Islands came from hauls that were actually targeting Atka mackerel (Table 6). Except for 1990, the

[7]Smoker, Andrew, Sustainable Fisheries Division, NOAA, Natl. Mar. Fish. Serv., Alaska Regional Office, Juneau, AK. Personal commun., April 2003.

Table 5.—Estimated percent of northern rockfish commercial catch in the Gulf of Alaska and Aleutian Islands that came from targeted fishing for northern rockfish, 1990–98, based on data in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database.

Year	Gulf of Alaska	Aleutian Islands
1990	47.1	26.2
1991	91.3	20.0
1992	82.8	5.9
1993	81.3	13.2
1994	92.3	15.3
1995	89.9	22.3
1996	74.1	35.3
1997	68.8	11.5
1998	53.8	18.9
All years comb.	81.8	20.6

Table 6.—Estimated percent of northern rockfish commercial catch in the Aleutian Islands taken as bycatch in the Atka mackerel targeted fishery, 1990–98, based on data in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database.

Year	Percent
1990	31.0
1991	66.4
1992	75.9
1993	78.2
1994	75.8
1995	68.4
1996	57.7
1997	79.7
1998	71.7
All years comb.	68.8

Table 7.—Summary of information on the commercial fishery for northern rockfish in the Gulf of Alaska and Aleutian Islands, 1990–99.[1]

Region and year	Catch (t)	ABC[2] (t)	TAC[2] (t)	% discarded	% caught by factory trawlers	% caught by shore-based trawlers	No. vessels in fishery[3]	Mean duration of tow (min)[4]
Gulf of Alaska								
1990	1,697			N.a.[5]	N.a.	N.a.	12	124
1991	4,528			N.a.	N.a.	N.a.	21	68
1992	7,770			N.a.	N.a.	N.a.	28	119
1993	4,825	5,760	5,760	26.5	99.2	0.8	21	151
1994	5,968	5,760	5,760	17.7	93.8	6.2	21	116
1995	5,634	5,270	5,270	12.7	91.4	8.6	24	127
1996	3,343	5,270	5,270	16.5	69.2	30.8	30	113
1997	2,947	5,000	5,000	28.0	68.9	31.1	22	156
1998	3,051	5,000	5,000	18.3	46.9	53.1	22	94
1999	5,397	4,990	4,990	11.1	60.2	39.8	N.a.	N.a.
Aleutian Islands								
1990	1,273			N.a.	N.a.	N.a.	10	171
1991	251	3,440	3,440	N.a.	N.a.	N.a.	2	60
1992	1,041	5,670	5,670	N.a.	N.a.	N.a.	11	94
1993	4,486	5,670	5,100	92.9	100.0	0.0	17	124
1994	4,667	5,670	5,670	82.9	100.0	Tr.[6]	11	129
1995	3,873	5,670	5,103	68.8	100.0	0.0	14	82
1996	6,708	5,810	5,229	64.5	100.0	0.0	11	109
1997	1,997	4,360	4,360	92.7	100.0	0.0	4	144
1998	3,675	4,230	4,230	89.5	100.0	Tr.	8	164
1999	5,255	4,230	4,230	90.1	100.0	Tr.	N.a.	N.a.

[1] Data sources: For catch, percent discarded, percent caught by factory trawlers, and percent caught by shore-based trawlers: National Marine Fisheries Service, Alaska Region, P. O. Box 21688, Juneau, AK 99802-1668. For ABC and TAC: North Pacific Fishery Management Council, 605 W. 4th. Avenue, Suite 306, Anchorage, AK 99501-2252. For number of vessels in fishery and mean duration of tow: Observer Program database, National Marine Fisheries Service, Alaska Fisheries Science Center, REFM Division, 7600 Sand Point Way N. E., Seattle, WA 98115.

[2] Acceptable biological catch (ABC) and total allowable catch (TAC) are not listed for 1990–92 in the Gulf of Alaska and for 1990 in the Aleutian Islands because northern rockfish were not in their own management category these years.

[3] Number of vessels that had at least one haul in the observer database for which northern rockfish was determined to be the target species.

[4] Time between brake-set and haulback (generally equivalent to time on bottom) for hauls in which northern rockfish was determined to be the target species.

[5] N.a. = data not available.

[6] Tr. = trace.

majority of the northern rockfish catch in the Aleutians has consistently been taken as bycatch in the Atka mackerel targeted fishery. In reality, the actual percentage of northern rockfish caught in the Atka mackerel fishery was likely even higher than the data in Table 6 indicate. For example, there were many incidences in the observer database where a vessel made a series of hauls in the same general location, and all but one or two caught predominantly Atka mackerel. In these exceptions, northern rockfish often comprised a dominant percentage of the catch, and in our targeting analysis, these hauls were identified as targeting northern rockfish. In such cases, however, the vessel was more likely directing its efforts toward Atka mackerel, but had unintentionally encountered a large catch of northern rockfish.

Because of the bycatch nature of the northern rockfish catch in the Aleutian Islands, the reader is cautioned that much of the information in this report from commercial fishery data in the Aleutian Islands may be somewhat biased in regards to northern rockfish. The fishery data may be more an indication of how the Atka mackerel fishery operates rather than what a true directed fishery for northern rockfish would show.

Description of the Fishery in the Gulf of Alaska and Aleutian Islands

The domestic rockfish fishery in Alaska was pioneered by factory-trawler vessels that catch and process fish at sea, and these catcher-processors have generally dominated the northern rockfish fishery in the Gulf of Alaska (Table 7). The majority of these vessels are about 150–250 ft in length, and carry a crew of about 30–40, including processors.[8] Northern rockfish in the Gulf of Alaska are generally caught with bottom trawls identical to those used in the Pacific ocean perch fishery. Many of these nets are equipped with so-called "tire gear," in which automobile tires are attached to the footrope of the net to facilitate towing over rough substrates. The fish are headed, gutted, and frozen on board, and then exported to markets in Asia, primarily Japan and South Korea. The Japanese market, in particular, esteems fish that are red in color; because northern rockfish tend to have less red coloration than Pacific ocean perch, they are correspondingly lower in value and are generally marketed as a low-cost substitute for Pacific ocean perch.

Northern rockfish have also been caught by shore-based trawlers in the Gulf of Alaska since 1993 (Table 7). This fishery remained relatively small until 1996, when it expanded substantially and took nearly 31% of the Gulfwide catch. The shore-based vessels are much

[8]This description of the factory-trawler fishery was based on interviews in August 1997 with the following individuals: Andrew Smoker, Sustainable Fisheries Division, NOAA, Natl. Mar. Fish. Serv., Alaska Regional Office, Juneau, AK; Eric Hollis, Fishing Company of Alaska, Seattle, WA; Laurie Bowen, Tyson Seafood, Seattle, WA; and Tim Meintz, Cascade Fishing, Seattle, WA.

smaller than the factory-trawlers and range in length from about 70–120 ft; crew size is roughly 3–5 (Blackburn[9]). The fish are caught and retained on board in tanks of refrigerated seawater for as long as 3 days, after which they are delivered to shore-side plants in the port of Kodiak for processing and freezing. Because of the economic advantages of operating close to port, virtually all the shore-based catches have come from waters around Kodiak Island.

The annual number of vessels in the Gulf of Alaska that our analysis determined to have targeted northern rockfish has ranged from 12 to 30 (Table 7). The actual number of vessels in the fishery after 1995 is probably underestimated in Table 7, however, because the smaller shore-based vessels that entered the fishery during these years had a lower level of observer coverage than the larger factory trawlers.[10] Consequently, some of these smaller vessels likely were not listed in the observer database each year. Mean duration of an individual tow in the Gulf of Alaska that targeted northern rockfish has usually been about 2 hours on bottom (Table 7). Duration of individual tows, however, has been quite variable, and has ranged from 2 to 570 min.

In the Aleutian Islands, the number of vessels determined to be targeting northern rockfish has been fewer than in the Gulf of Alaska, and has ranged from 2 to 17 in the years 1990–98 (Table 7). As discussed, some of these vessels in reality may have been attempting to catch Atka mackerel rather than northern rockfish. The lower number of vessels in the Aleutian Islands is due in part to the near absence of any shore-based fishing in this region. Most of the vessels in the Atka mackerel fishery have a history of also participating in Gulf of Alaska and Aleutian Islands rockfish fisheries, so the previous description of rockfish factory-trawlers applies equally to these vessels.

[9]Blackburn, Chris, Alaska Groundfish Data Bank, Kodiak, AK. Personal commun., May 1997.

[10]NPFMC regulations require only 30% of the vessels less than 125 ft to have an observer on board, whereas all vessels over 125 ft must have an observer.

Discard Rates for Northern Rockfish

The amount of the northern rockfish catch discarded and not retained for processing has differed markedly between the Gulf of Alaska and Aleutian Islands (Table 7). In the Gulf of Alaska, annual discard rates have been relatively low, ranging from 26.5% in 1993 to only 11.1% in 1999. In contrast, annual discards of northern rockfish in the Aleutian Islands have been consistently very high, with several years showing discard rates of around 90%. This difference can be explained by a combination of two factors: 1) because northern rockfish in the Aleutian Islands are mostly caught as bycatch in the Atka mackerel fishery, catcher-processors in this fishery are not set up for processing northern rockfish, and 2) northern rockfish in the Aleutian Islands appear to be much smaller in size than those in the Gulf of Alaska (data supporting this observation are presented later in this report). These small fish are of lower market value; consequently, there is less economic incentive for fishermen to retain them.

Seasonality of Fishery

The distribution of the northern rockfish catch by month for both the Gulf of Alaska and Aleutian Islands is shown in Figure 2 for the years 1990–98 combined. The seasonal distribution of catches has been very different in each region. In the Gulf of Alaska, the majority of the catch has been taken in July, with a secondary peak in October. In the Aleutian Islands, however, most of the catch has come in the spring, although sizeable catches are also seen in other months. These seasonal catch patterns are largely determined by fishery opening and closing regulations enacted by NMFS. In the Gulf of Alaska, the directed rockfish trawl fishery during these years has traditionally opened on 1 July, which accounts for the large catches during this month. Rockfish trawlers usually direct their efforts first toward Pacific ocean perch because of its higher value relative to other rockfish species; after the TAC for Pacific ocean perch has been reached and NMFS closes directed fishing for this species, trawlers then switch and target northern rockfish. In some years, the northern rockfish fishery extended into August until it was closed, which explains the catches seen for this month in Figure 2. In other instances, directed fishing was closed in July or August before the TAC was achieved. The rockfish trawl fishery was then opened again in October to allow the remainder of the quota to be filled, which accounts for the relatively large catches seen in this month. In the Aleutian Islands, the monthly distribution of northern rockfish catches is chiefly related to the timing of the Atka mackerel fishery, in which the majority of northern rockfish are caught. Due to NMFS regulations, the Atka mackerel fishery in recent years has mostly occurred in the spring, resulting in a large bycatch of northern rockfish during March, April, and May.

This seasonal pattern of the fishery, especially in the Gulf of Alaska, needs to be kept in mind when considering some of the results presented in this paper. For example, examination of the depth distribution of northern rockfish in the Gulf based on fishery data will emphasize the summer distribution of the fish because this is when most of the data have been collected.

Catch by Gear Type and On-bottom vs. Off-bottom Catches

According to the observer database, bottom trawls have accounted for over 99% of the northern rockfish catch in both the Gulf of Alaska and Aleutian Islands (Table 8). A very small amount has been taken by pelagic trawls. Bottom trawls can be defined as nets specifically designed to handle the rigors of towing over the bottom, with weighty "doors" to sink and spread the net, and heavy footropes and webbing. In contrast, pelagic trawls are designed for off-bottom towing with lighter doors, footropes, and webbing, and they usually have a much larger vertical and horizontal spread at the mouth for capturing pelagic schools of fish. It should be noted, however, that bottom trawls are sometimes fished off bottom; likewise, skilled fishermen can fish pelagic trawls very near or just touching the bottom, especially where the substrate is smooth.

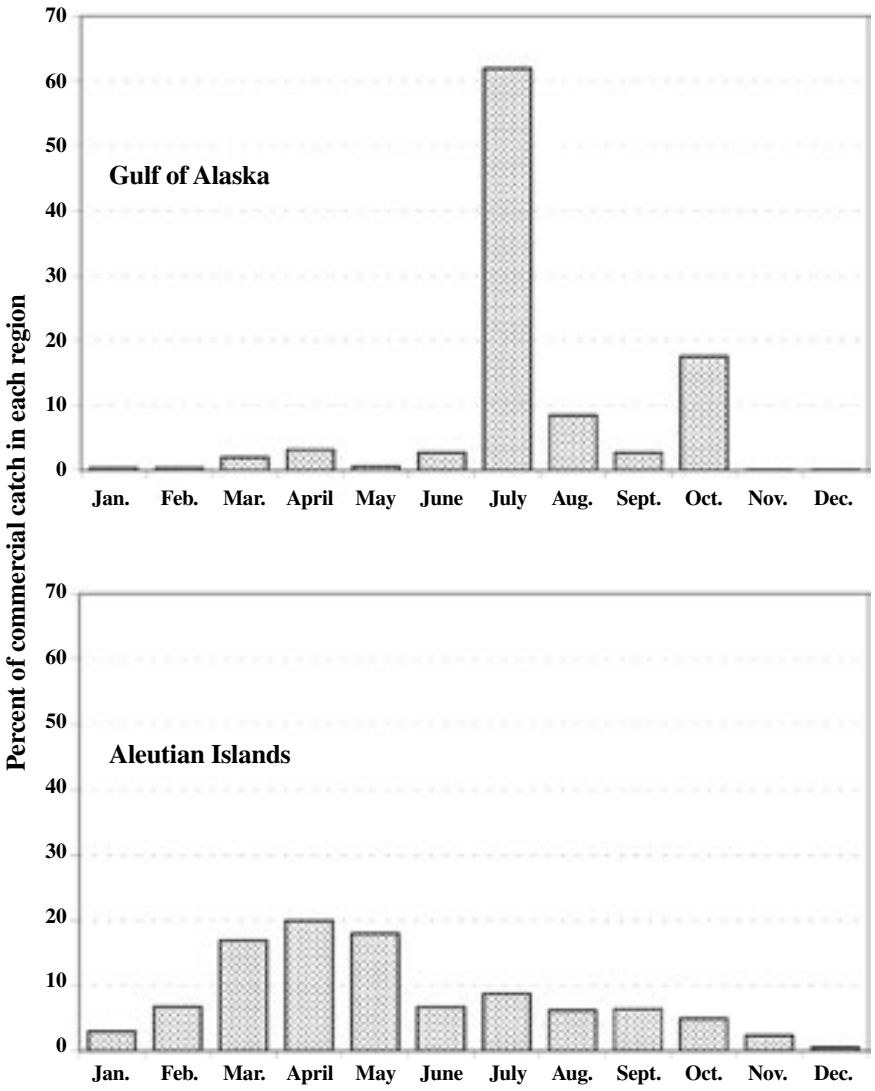

Figure 2. — Distribution by month of the northern rockfish commercial catch in the Gulf of Alaska and Aleutian Islands, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program.

Catches of northern rockfish in pots or on longlines have been very low (Table 8). Although in the Aleutian Islands this species has been taken relatively often on longlines (over 3,400 observed longline hauls have shown catches of northern rockfish), longline catches amount to only 0.5% of the total for this region. In the Gulf of Alaska, catches of these fish on longlines are much less frequent, and longlines account for only a trace of the region's total catch of this species. These low catches in pots or on longlines can be explained by the diet preferences of northern rockfish. Food studies of northern rockfish in both the Gulf of Alaska and Aleutian Islands indicate that the fish feed predominantly on plankton, especially euphausiids and copepods (Yang, 1993; 1996). Therefore, it is likely that northern rockfish are not attracted to baited gear such as pots or longlines.

In the eastern Bering Sea, bottom trawls have also been the predominant gear for catching northern rockfish, with an estimated 92% of the catch coming from bottom trawls. Compared to the Gulf of Alaska and Aleutian Islands, however, the frequency and percentage of catches of northern rockfish in the eastern Bering Sea coming from pelagic trawls has been much higher. This can be explained by the large amount of pelagic trawling for walleye pollock in the Bering Sea in which small amounts of northern rockfish may be taken as bycatch.

In both the Gulf of Alaska and Aleutian Islands, about 90% of the northern rockfish catch has been taken on bottom (Fig. 3). Furthermore, for the portion of the catch taken off bottom, there appears to be a trend toward larger catches as hauls are made increasingly close to bottom. For example, in the Gulf of Alaska, most (71%) of the off-bottom catch has been taken within the first 10 m of the bottom. These data suggest that adult northern rockfish are mostly demersal in nature, and that there may be little pelagic component to their distribution, at least during those times of the year when the commercial fishery has operated. Also, it should be noted that some of the vessels that fish for northern rockfish in the Gulf of Alaska have successfully used pelagic trawls for capturing off-bottom aggregations of rockfish, in particular Pacific ocean perch. The fact that they have not chosen to do this for northern rockfish is a further indication that northern rockfish are mostly bottom-oriented in their distribution.

Depth Distribution of the Catch

Observer data were analyzed to determine the depth distribution of commercial hauls that caught northern rockfish in the Gulf of Alaska and Aleutian Islands. Results showed most of the northern rockfish catch in both regions was taken from a relatively narrow depth range (Fig. 4). In the Gulf of Alaska, about 70% of the catch came from depths between 75 and 125 m, with the 75–100 m stratum showing the highest catches. In the Aleutian Islands, catches were distributed slightly deeper, with about 65% taken at depths 100–150 m, and the 100–125 stratum showing the highest catches. In both regions, the depth distribution was not symmetrical; catches abruptly dropped to near zero at depths less than 50 m, but gradually tapered off at depths

greater than 150–175 m. Even at depths exceeding 300 m, several hauls reported catches of northern rockfish in excess of 5–10 t. In the Gulf of Alaska, the deepest haul with a substantial catch of northern rockfish (>10 t) was at 387 m and in the Aleutian Islands at 604 m.

Location of Fishing Grounds

To determine the geographic distribution of northern rockfish catches in the commercial fishery, we examined data from the observer program for the years 1990–98. Geographic information system (GIS) plots of all hauls that contained any northern rockfish show that catches have been widespread along the outer continental shelf and upper continental slope in the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea (Fig. 5A, 6A, 7A). The Gulf of Alaska catches become relatively infrequent in the eastern Gulf, and southeastern Alaska is not included in Figure 5A because only a few hauls caught northern rockfish in this area.

To further examine the geographic distribution of catches, we arbitrarily selected only those hauls in the upper 20% of all northern rockfish catches, and we also plotted these catches (Fig. 5B, 6B, 7B). In the Gulf of Alaska, hauls in this upper 20% quantile (equivalent to a northern rockfish catch of ≥3,500 kg) comprised 86.3% of the total catch of this species in this region for the years 1990–98. Similarly, in the Aleutian Islands, the upper 20% quantile (equivalent to a northern rockfish catch ≥1,631 kg) amounted to 82.0% of the northern rockfish catch. Because of the much smaller catches of northern rockfish in the eastern Bering Sea, the upper 20% quantile level for the Aleutian Islands was used to make the plot for the eastern Bering Sea (Fig. 7B) comparable to that for the Aleutian Islands. This level (≥1,631 kg) comprised 72.6% of the total catch of northern rockfish in this region for the years 1990–98.

Thus, Figures 5B–7B show that the highest individual catches, and the bulk of the northern rockfish total catch, are concentrated at a number of discrete fishing grounds that are relatively small in size. Outside these grounds, northern rockfish are still often encountered

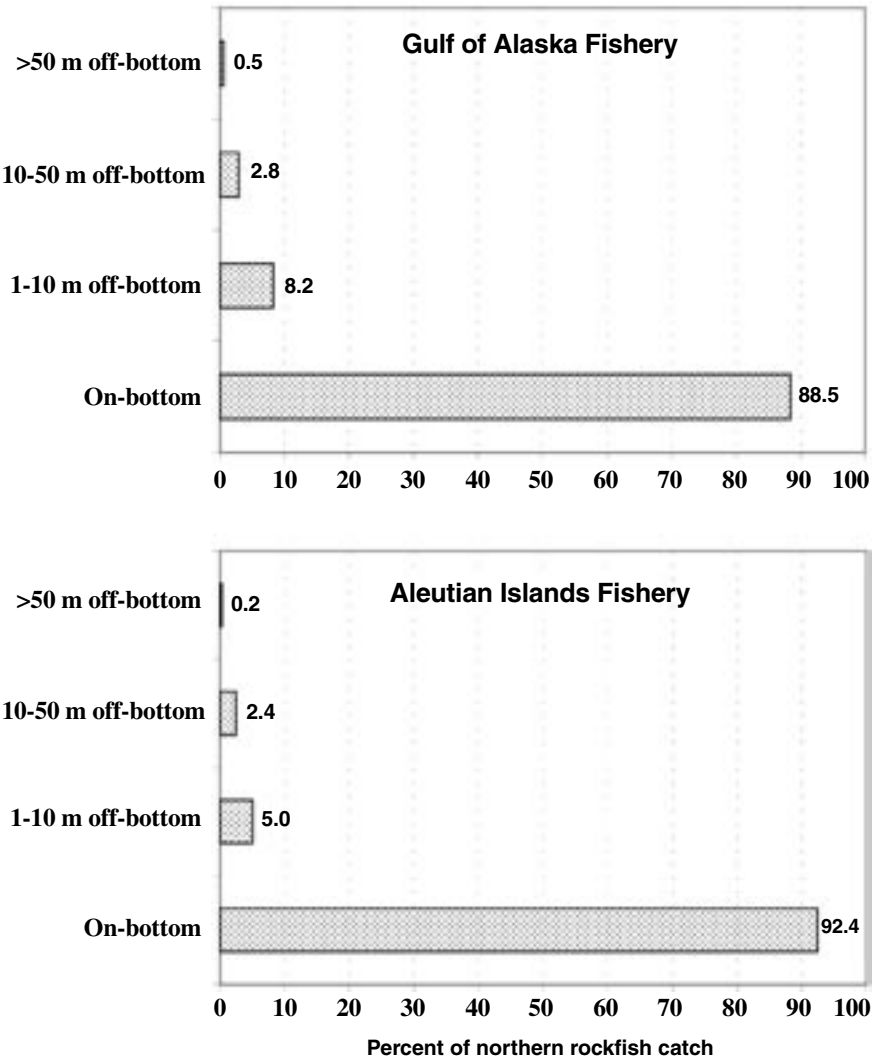

Figure 3.—On-bottom vs. off-bottom distribution of catches of northern rockfish in the Gulf of Alaska and Aleutian Islands commercial fisheries, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program.

Table 8.—Summary by region and gear type of northern rockfish (NR) commercial catches, 1990–98, based on data in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database.

Region and gear type	No. of observed hauls with NR catch	% of NR catch in region	Mean NR catch/haul (kg)	Maximum NR catch per haul (kg)
Gulf of Alaska				
bottom trawl	7,990	99.9	2,845.2	77,155.3
pelagic trawl	416	0.1	62.5	5,327.1
pot	39	Tr.[1]	2.8	19.0
longline	184	Tr.	10.4	75.0
Aleutian Islands				
bottom trawl	11,074	99.4	1,766.9	55,631.8
pelagic trawl	126	0.1	113.1	6,865.1
pot	157	Tr.	2.6	42.8
longline	3,459	0.5	30.3	747.6
Eastern Bering Sea				
bottom trawl	1,875	92.4	752.8	60,301.2
pelagic trawl	3,842	6.3	24.9	9,720.6
pot	429	0.1	3.6	75.8
longline	1,113	1.2	16.5	439.1

[1] Tr. = trace

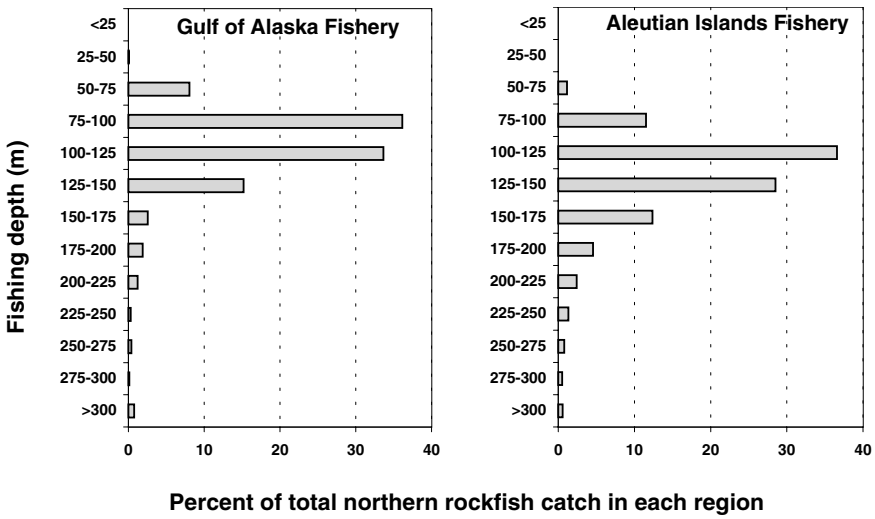

Figure 4.—Depth distribution of the catch of northern rockfish in the Gulf of Alaska and Aleutian Islands commercial fisheries, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program.

Table 9.—Major commercial fishing grounds for northern rockfish in the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea, 1990–98, based on data in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database. Data are for hauls using bottom trawls only and do not include hauls that did not catch northern rockfish.

Region and fishing ground	No. of hauls with NR[1] catch	% of NR catch in region	Mean NR CPUE[2] (kg/hr)	Mean depth of hauls (m)
Gulf of Alaska				
Portlock Bank	1,397	19.4	1,931.4	147
Albatross Bank	748	11.2	2,511.8	134
Snakehead	944	45.8	11,737.6	130
Shumagin Bank	668	7.9	2,194.4	90
Davidson Bank	319	4.4	1,873.5	128
All Gulf of Alaska	7,990	100.0	2,391.3	140
Aleutian Islands				
Seguam Pass	2,244	9.0	392.1	154
N & S of Amlia I.	591	4.2	599.0	158
Delarof I.	487	3.1	645.4	146
Petrel Bank	1,122	17.8	1,453.4	129
S of Amchitka I.	495	6.7	1,565.5	158
SW of Amchitka I.	491	3.6	1,000.7	151
Sturdevant Rock	1,625	19.5	1,202.4	103
Buldir Reef	560	6.6	1,050.7	133
W of Buldir I.	489	5.6	1,588.5	135
Tahoma Reef	252	4.5	1,893.1	190
Ingenstrem Rocks	69	3.3	3,350.2	117
All Aleutians	11,074	100.0	946.0	144
Eastern Bering Sea				
SE Zhemchug Canyon	353	61.7[3]	969.2	140
All Eastern Bering Sea	1,875	100.0	329.1	147

[1] NR = northern rockfish
[2] CPUE = catch per unit effort
[3] 57.0% of northern rockfish catch for all gear types in the eastern Bering Sea

(Fig. 5A–7A), but generally in sparse quantities.

In the Gulf of Alaska, there appear to be five major fishing grounds: Portlock Bank, Albatross Bank, an unnamed bank south of Kodiak Island that fishermen commonly refer to as the "Snakehead," Shumagin Bank, and Davidson Bank (Fig. 5B; Table 9). Cumulatively, commercial hauls from these five banks have yielded an estimated 88.7% of the total northern rockfish catch in the Gulf of Alaska. The Snakehead appears to be a particularly productive locality for northern rockfish; it accounted for nearly 46% of the Gulf of Alaska catch of northern rockfish in 1990–98, and had a much higher catch per unit effort (CPUE) than any of the other major fishing grounds.

These fishing grounds share some geographic and physical characteristics, which may be an indication of the preferred habitat for adult northern rockfish. All five banks appear to consist of relatively shallow, isolated rises or banks located on the outer continental shelf near the beginning of the upper continental slope (i.e. the 200 m depth contour). Mean depth of hauls made on the grounds ranges from 90 to 147 m (Table 9), which is shallower than what would be expected given their offshore location, and each is separated from land by an intervening stretch of deeper water.

A comparison of the depth distribution of the commercial catch (Fig. 4) with the mean depth of the fishing grounds (Table 9) shows that the commercial catch is distributed somewhat shallower than the mean depth of the fishing grounds. This indicates the shallower portions of the grounds account for a greater percentage of the catch.

In the Aleutian Islands, there are at least 11 identifiable major fishing grounds for northern rockfish (Fig. 6B; Table 9). This number is greater than the five major grounds identified in the Gulf of Alaska, and it may reflect the more complicated offshore topography of the Aleutian Islands, with their numerous passes between the Bering Sea and the North Pacific Ocean and many offshore reefs. Also, establishment of trawl exclusion zones in the Aleutian Islands in 1991 to protect Steller sea lions[11] (in which trawling was prohibited within 10 n.mi. of sea lion rookeries) may have caused the artificial separation of some of the grounds. For example, trawl exclusion zones lie between the Buldir Reef and west of Buldir Islands grounds and between the grounds south and southwest of Amchitka Island. If the trawl exclusion

[11]Steller Sea Lion Protection Measures Final Supplemental Environmental Impact Statement, Nov. 2001. Avail. from Natl. Mar. Fish. Serv., Alaska Region, P.O. Box 21668, Juneau, AK 99802-1668.

zone did not exist in the Buldir area, fishing might extend continuously between the two fishing grounds that are now found at this locality, and the same might also be true for the Amchitka area.

The 11 grounds identified in Figure 6B and Table 9 cumulatively account for 83.9% of the northern rockfish catch in the Aleutian Islands for the years 1990–98. The ground providing the highest percentage of northern rockfish catch is Sturdevant Rock, with 19.5% of the Aleutian Islands total. Other important grounds are Petrel Bank and Seguam Pass. The highest CPUE was at Ingenstrem Rocks, although this may be due to the relatively small effort (only 69 hauls in which northern rockfish were caught) at this locality.

Except for Amlia Island, all the fishing grounds for northern rockfish in the Aleutian Islands are also important fishing areas for Atka mackerel (Fritz[12]), which would be expected given that most northern rockfish in this region are taken as bycatch in the Atka mackerel fishery. Seguam Pass in particular appears to be an important fishing ground for northern rockfish not because of a high abundance of the species at this locality, but due to the intensive fishing effort for Atka mackerel that occurs there. This is shown by the data in Table 9, in which Seguam Pass had the third highest catch of northern rockfish in the Aleutian Islands and also the highest number of hauls, but had a CPUE much lower than any of the other grounds.

Similar to the Gulf of Alaska, several of the fishing grounds in the Aleutian Islands may be characterized as offshore banks or rises of relatively shallow depth, which are surrounded by deeper water on all sides. This appears to be the case particularly for Seguam Pass, Petrel Bank, and Tahoma Reef. Other fishing grounds, however, such as those off Amlia and Amchitka Islands, are located relatively close to shore where the shelf follows the more typical pattern

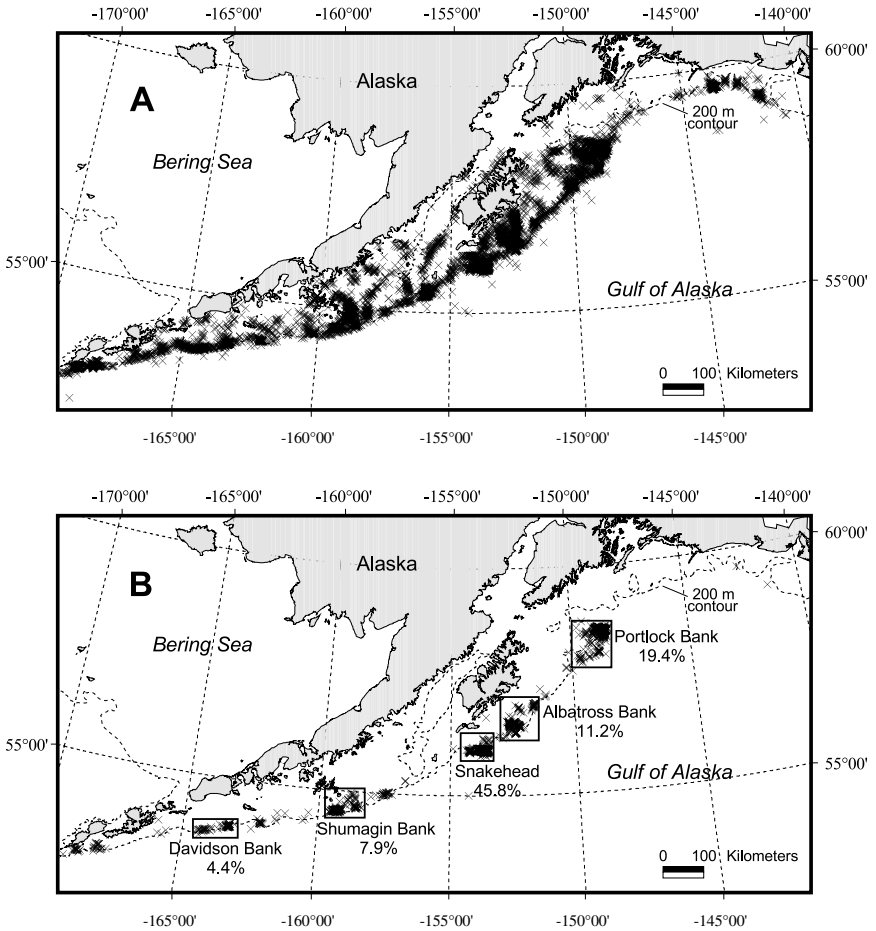

Figure 5.—Location of hauls that caught northern rockfish in the Gulf of Alaska commercial fishery, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program. A: All hauls that caught northern rockfish; B: Hauls in the upper 20% quantile of northern rockfish catches (= catch of northern rockfish ≥3.5 t). Also shown in B are the major commercial fishing grounds for northern rockfish in the Gulf of Alaska that were identified in this study, along with each ground's estimated percent by weight of the Gulfwide commercial catch of northern rockfish for the years 1990–98.

of sloping gradually into deeper water. Mean depth of the 11 fishing grounds ranges from 103 to 190 m (Table 9). Also similar to the Gulf of Alaska, a comparison of the depth distribution of the catch with the mean depth of the fishing grounds (Fig. 4 vs. Table 9) indicates that highest catches come from shallower portions of the grounds.

In the eastern Bering Sea, only one major fishing ground was evident (Fig. 7B.). In Figure 7B, we call this ground "Southeast Zhemchug Canyon," although it is actually located adjacent to rather than in the canyon. This fishing ground accounted for nearly 62% of all the northern rockfish catch taken by bottom trawls in this region (57% of the catch for all gear types (Table 9)). Comparing Figure 7A with Figure 7B shows that northern rockfish have been caught in very sparse amounts at many locations in the eastern Bering Sea, with Southeast Zhemchug Canyon the only significant locality where large catches were taken. The Southeast Zhemchug Canyon fishing ground can be physically characterized as a shallow offshore rise on the outer continental shelf, surrounded by deeper water, so it is similar topographically to

[12]Fritz, Lowell, NOAA, Natl. Mar. Fish. Serv., Alaska Fisheries Science Center, Resource Ecology and Fish Management Division, Bldg. 4, 7600 Sand Point Way N.E., Seattle, WA 98115. Unpubl. data, May 2000.

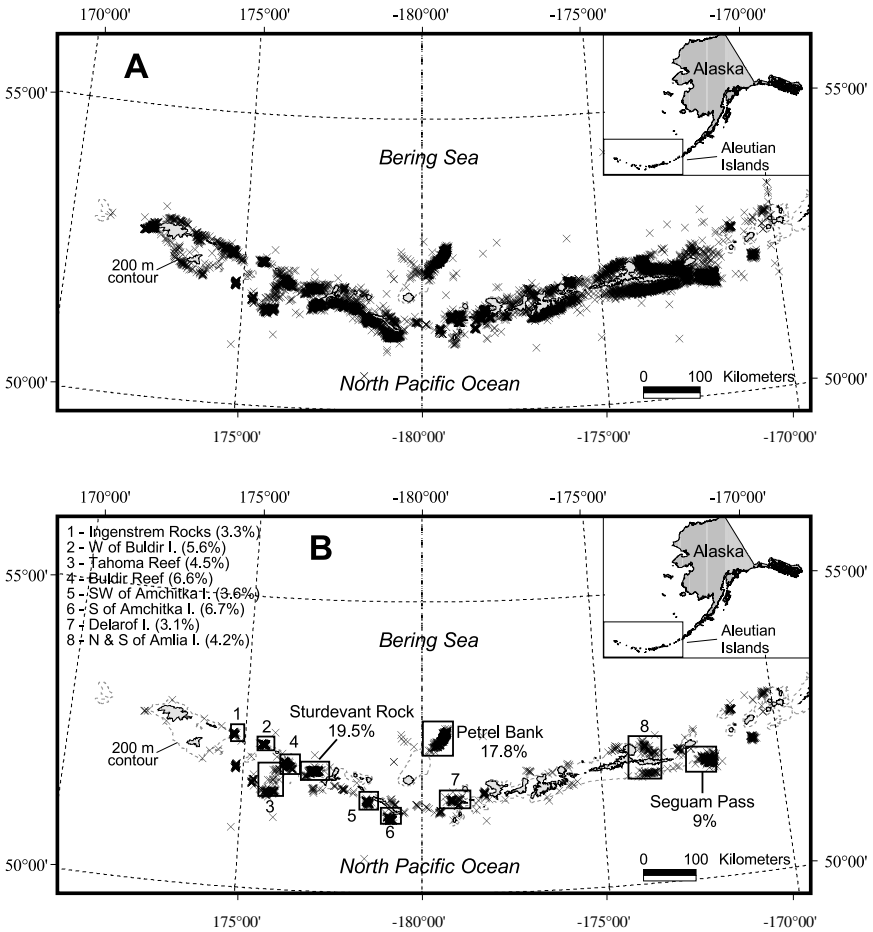

Figure 6.—Location of hauls that caught northern rockfish in the Aleutian Islands commercial fishery, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program. A: All hauls that caught northern rockfish; B: Hauls in the upper 20% quantile of northern rockfish catches (= catch of northern rockfish ≥1.631 t). Also shown in B are the major commercial fishing grounds for northern rockfish in the Aleutian Islands that were identified in this study, along with each ground's estimated percent by weight of the region's commercial catch of northern rockfish for the years 1990–98.

many of the other fishing grounds for northern rockfish.

Size of Fish Caught in the Fishery

Mean size of northern rockfish taken by the commercial fishery was significantly larger in the Gulf of Alaska compared to the Aleutian Islands. We used observer data for the years 1990–98 on the estimated total weight and numbers of northern rockfish in each haul to compute mean weight per fish. For each year, mean weight per fish was consistently greater in the Gulf of Alaska than in the Aleutian Islands (Fig. 8). Overall mean weight per fish during the entire period was 0.68 kg in the Gulf of Alaska and only 0.53 kg in the Aleutian Islands.

Data in the eastern Bering Sea were too sparse to compute mean weight per fish on an annual basis, but estimated mean weight for the years 1990–98 combined was 0.50 kg. Thus, size of northern rockfish caught in the eastern Bering Sea was similar to that of the Aleutian Islands.

Length frequency data for northern rockfish were collected by observers on a consistent basis only in the Gulf of Alaska. Generally, lengths were taken only from hauls with a large catch of northern rockfish where this species predominated in the catch. Most fish were between 30 and 42 cm fork length, and mean fork length was 36.1 cm (Fig. 9).

Table 10.—Sex composition of northern rockfish sampled by observers in the Gulf of Alaska commercial fishery, 1990–98.

Year	% male	% female	No. sexed
1990	52.4	47.6	2,786
1991	48.9	51.1	5,867
1992	44.2	55.8	10,628
1993	44.7	55.3	8,182
1994	46.4	53.6	6,696
1995	50.7	49.3	6,633
1996	51.0	49.0	5,049
1997	50.8	49.2	3,683
1998	47.9	52.1	5,787
Total	47.7	52.3	55,311

Sex was also determined for many of the northern rockfish sampled by observers for length in the Gulf of Alaska. Females had a mean fork length that was almost 1 cm longer than that for males (Fig. 10). A *t*-test of the difference between two means indicated that this difference was highly significant ($P < 0.0001$, $t = 38.57$, df = 55,309), which was not surprising given the large sample size that was taken.

Sex Ratio of Fish Caught in the Gulf of Alaska Fishery

Northern rockfish sex ratios determined from the observer data in the Gulf of Alaska were often close to 50:50 on an annual basis, but pooling these data over all years showed females predominated by a ratio of 52.3:47.7 (Table 10). This pooled ratio may have been affected by the fact that the 2 years with the highest percentage of females (1992 and 1993) also were the years in which the most number of fish were sexed.

To determine whether the sex ratio for all years combined differed significantly from 50:50, we conducted replicated tests of goodness of fit as described in Sokal and Rohlf (1969). In this procedure, each haul is treated as a replicate, and a chi-square test is then performed for each haul, which allows a pooled chi-square statistic to be computed for all the data combined. Our computed statistic for the pooled data was highly significant (chi-square = 119.9; df = 1; $P < 0.0001$; therefore, we reject the null hypothesis

of a 50:50 sex ratio and conclude there were significantly more females caught in the Gulf of Alaska fishery.

We further examined the sex composition of northern rockfish in individual hauls to see if the fish were aggregated by sex on a localized basis. For this, we selected only those hauls in which sex was determined for ≥40 northern rockfish. About two-thirds of the hauls were within 10% of a 50:50 sex ratio, but there were also many hauls in which either sex considerably predominated (Fig. 11). To determine whether the sex ratios in individual hauls differed significantly from 50:50, we again used replicated tests of goodness of fit similar to those described above. If each haul that had ≥40 sexed fish is treated as a replicate, and a chi-square test is performed for each haul, then a chi-square statistic can be computed among replicates to measure the significance of heterogeneity among hauls (Sokal and Rohlf, 1969). Our computed statistic was highly significant (chi-square = 2,453; df = 549; P <0.0001), which indicated that individual hauls were very heterogeneous and differed greatly from a 50:50 ratio. It should be noted, however, that the chi-square tests for individual hauls showed that in the majority of hauls (67.7%) the sex ratio was not significantly different than 50:50. Therefore, at most localities, the sex ratio could be characterized as uniform, but locations with a skewed sex ratio were sufficiently common to cause the replicated tests of goodness of fit to indicate a high degree of heterogeneity among hauls.

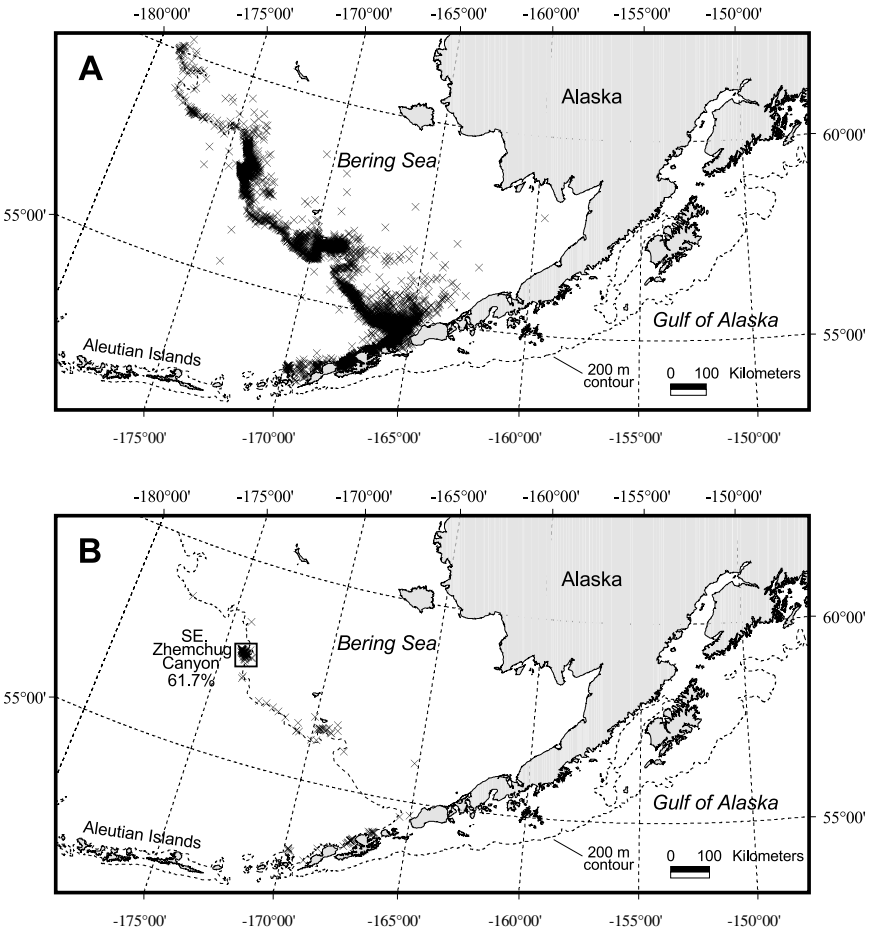

Figure 7.—Location of hauls that caught northern rockfish in the eastern Bering Sea commercial fishery, 1990–98, based on data collected by the NMFS Alaska Fisheries Science Center Observer Program. A: All hauls that caught northern rockfish; B: Hauls with a catch of northern rockfish ≥1.631 t. Also shown in B is the major commercial fishing ground for northern rockfish in the eastern Bering Sea that was identified in this study, along with the ground's estimated percent by weight of the region's commercial bottom trawl catch of northern rockfish for the years 1990–98.

CPUE in the Gulf of Alaska Fishery

We examined CPUE in the commercial fishery for northern rockfish in the Gulf of Alaska for the years 1990–98. In this analysis, CPUE (kilograms of northern rockfish caught per hour trawled) was calculated for each haul in the observer database that we had previously determined to be targeted on northern rockfish. The average of these values for each year was then computed to yield overall mean CPUE's. It is well known that commercial fishery CPUE data may be biased when used as an indicator of trends in stock abundance, especially when dealing with an aggregated species such as northern rockfish (Quinn and Deriso, 1999). Rather than determining abundance trends, the purpose of this analysis was to document the typical CPUE in the fishery, and to see if any gross temporal changes in CPUE were apparent.

Results showed mean annual CPUE was generally in the range of 5,000–9,000 kg/h (Table 11). The one exception was 1991, when mean CPUE was almost 18,000 kg/h. The high CPUE in 1991 appeared to be caused by one highly productive vessel that dominated the fishery that year in terms of hauls targeted on northern rockfish.

Table 11.—Mean CPUE (kg/h trawled) of northern rockfish (NR) in the Gulf of Alaska commercial fishery, 1990–98, based on hauls in the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program database that were determined to be targeted on northern rockfish.

Year	CPUE (kg/h)	No. hauls targeted on NR
1990	4,515.5	67
1991	17,942.6	359
1992	5,758.0	369
1993	4,932.9	251
1994	7,568.5	276
1995	6,500.9	267
1996	7,264.3	141
1997	5,772.2	78
1998	9,093.9	78
All years comb.	8,544.7	1,886

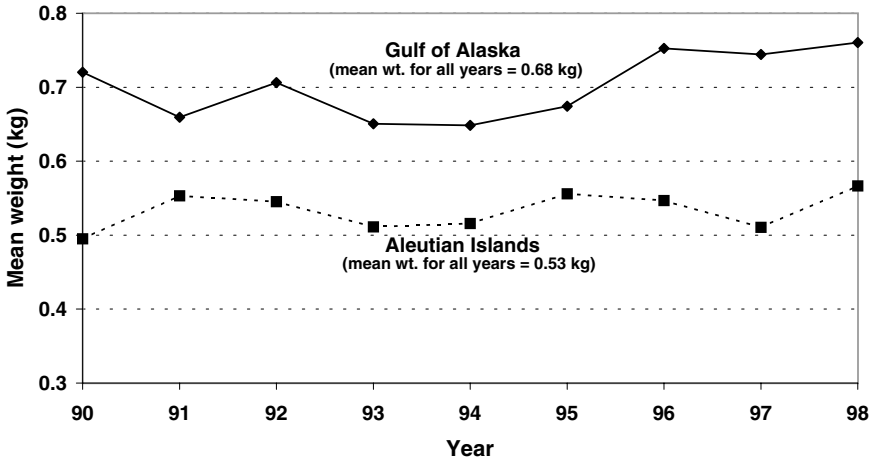

Figure 8.—Mean weight per fish of northern rockfish caught in the Gulf of Alaska and Aleutian Islands commercial fisheries, 1990–98, based on data collected by the National Marine Fisheries Service, Alaska Fisheries Science Center Observer Program.

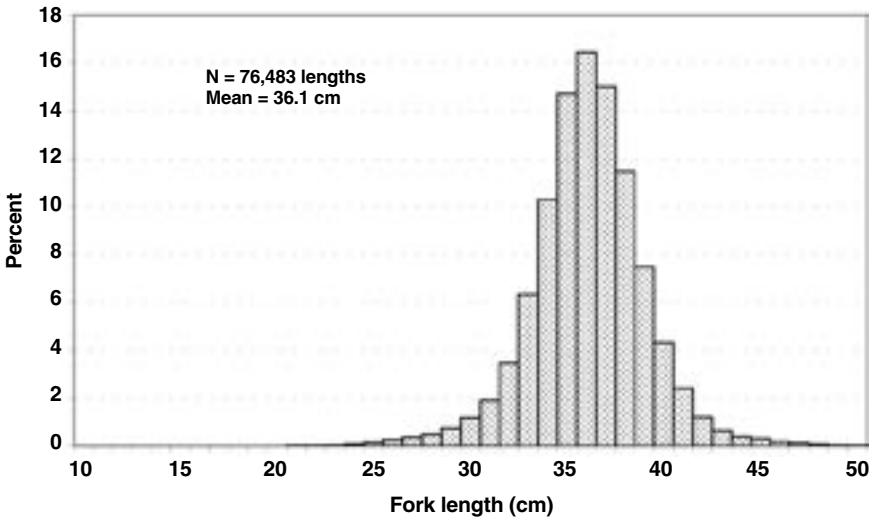

Figure 9.—Length frequency distribution of northern rockfish measured by observers in the Gulf of Alaska commercial fishery, 1990–98.

The highest CPUE for an individual haul was nearly 395,000 kg/h, which resulted from a catch of over 13,000 kg in a haul that was only 2 min in duration. Several other extremely large catches were seen from hauls that were less than 10 min long, which indicates that northern rockfish can sometimes be very densely aggregated.

A similar analysis was not done for northern rockfish CPUE in the Aleutian Islands because relatively few hauls in this region were identified as targeting on northern rockfish.

Trawl Surveys

Fishery-independent trawl surveys provide an alternative source of information on northern rockfish in Alaska. For this report, we examined data from six extensive bottom trawl surveys in the Gulf of Alaska and six in the Aleutian Islands (Table 12). These surveys were conducted by the AFSC's RACE Division from 1980 onward. The main objectives of the surveys in each region were to determine the distribution and abundance of principal groundfish and to collect ancillary biological information on these species, such as size, sex, and age composition. The surveys were conducted during the period May–September at depths ranging from about 10 to 500 m on the continental shelf and upper continental slope; in some years, depths to 1,000 m were sampled.

Each of the surveys used a stratified random design to select locations of trawl stations throughout each region, and fishing gear and procedures were standardized to allow comparisons between years. Standard duration of hauls on bottom was either 15 or 30 min, depending on the year, and detailed information was usually collected for each haul on width of the net opening and distance fished over the bottom. These measurements were used to calculate the area swept by the net over the bottom, and CPUE for species caught was then computed in terms of numbers and weight per square km. Biomass and population estimates were calculated by multiplying the mean CPUE's (kilogram per square km or numbers per square km) of each stratum by the stratum's areal size and summing the results to obtain estimates by management areas or by the total survey area (Wakabayashi et al., 1985). For more details on these surveys, the reader is referred to the following reports: Brown (1986); Harrison (1993); Ronholt et al. (1994); Stark and Clausen (1995); Martin and Clausen (1995); Martin (1997); and Britt and Martin (2001).

Bottom trawl surveys of the eastern Bering Sea have also been conducted by the RACE Division, but catches of northern rockfish have been exceedingly sparse. In a series of six surveys between 1979 and 1991, the largest biomass estimate for northern rockfish for the entire eastern Bering Sea region was only 53 t; two of the surveys reported no catches at all of northern rockfish (Ito et al., 1999). Because of this extremely limited information, we have chosen in this report to exclude analysis of RACE trawl survey data for northern rockfish in the eastern Bering Sea.

Survey Biomass Estimates

Biomass estimates for northern rockfish from the Gulf of Alaska and Aleutian Islands surveys suggest that the size of the northern rockfish resource in each region may be somewhat similar. Biomass estimates for the Gulf of Alaska have ranged from about 40,000 to 140,000 t between 1984 and 1996, and for the Aleutian Islands from about 40,000 to 190,000 t for the period 1980–97 (Fig. 12). One exception to this general similarity between regions is the 1999 biomass in the Gulf of Alaska of 242,000 t. This high biomass can be partially attributed to an extremely large catch of northern rockfish in one haul, so it may be an anomaly (Heifetz et al., 1999). More detailed information on these biomass estimates, especially concerning their precision and possible biases, may be found in annual rockfish stock assessments documents that were prepared for the NPFMC (e.g. Heifetz et al., 1994; Heifetz et al., 1999; and Ito et al., 1999).

Depth Distribution of Northern Rockfish in Surveys

An analysis of the depth distribution of northern rockfish in the surveys showed that in both the Gulf of Alaska and Aleutian Islands, northern rockfish were taken at generally similar depths, although the catches were distributed slightly deeper in the Aleutian Islands (Fig. 13). In the Gulf of Alaska, nearly all the catch came from depths between 50 and 200 m, with the majority (79.7%) in depths 75–150 m, and a peak at 100–125 m. In the Aleutian Islands, almost all the catch was taken at depths 75–200 m, with most (96.6%) at depths 75–175 m. In contrast to the Gulf of Alaska, no individual depth stratum predominated in the Aleutian Islands, and catches were rather evenly distributed at strata between 75 and 175 m. Shallow and deep extremes of northern rockfish distribution in the Gulf of Alaska surveys were 40 m and 649 m, respectively, and 62 m and 620 m, respectively, in the Aleutian Islands surveys.

Depth distribution of northern rockfish in the surveys was similar to that of the commercial fishery (compare Fig. 13 with Fig. 4). In the Gulf of Alaska, the

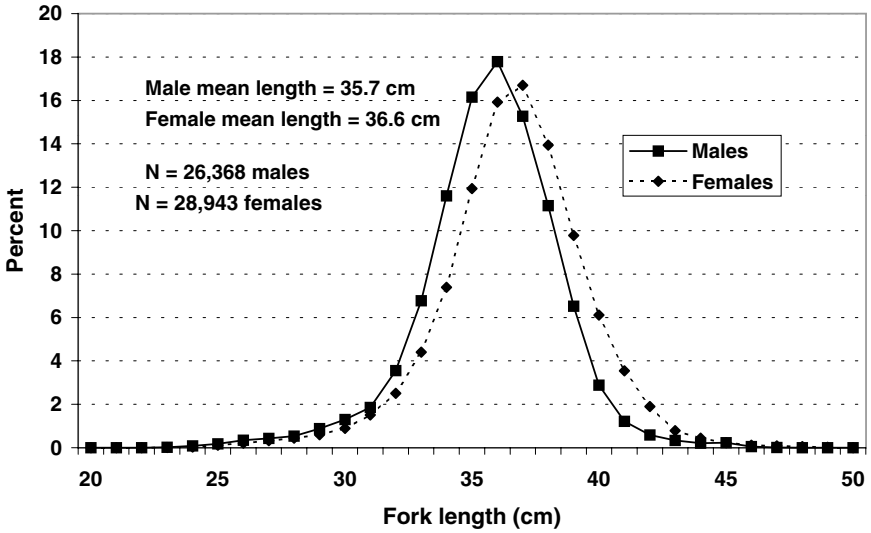

Figure 10.—Length frequency distribution, by sex, of northern rockfish measured by observers in the Gulf of Alaska commercial fishery, 1990–98.

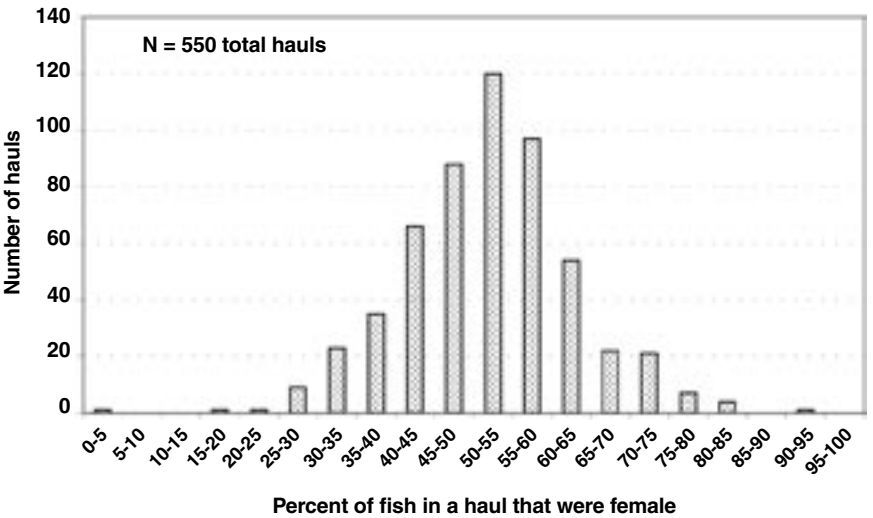

Figure 11.—Sex composition of northern rockfish in individual hauls determined by observers in the Gulf of Alaska commercial fishery, 1990–98. Hauls include only those in which sex was determined for ≥40 northern rockfish.

Table 12.—Summary of National Marine Fisheries Service bottom trawl surveys in the Gulf of Alaska and Aleutian Islands that were used in this report to provide information on northern rockfish (NR = northern rockfish).

Gulf of Alaska			Aleutian Islands		
Year of survey	No. of hauls	No. of hauls with NR catch	Year of survey	No. of hauls	No. of hauls with NR catch
1984	1,037	162	1980	435	120
1987	965	259	1983	425	159
1990	811	145	1986	499	155
1993	841	171	1991	379	131
1996	868	148	1994	449	128
1999	870	140	1997	498	158
All years	5,392	1,025	All years	2,685	851

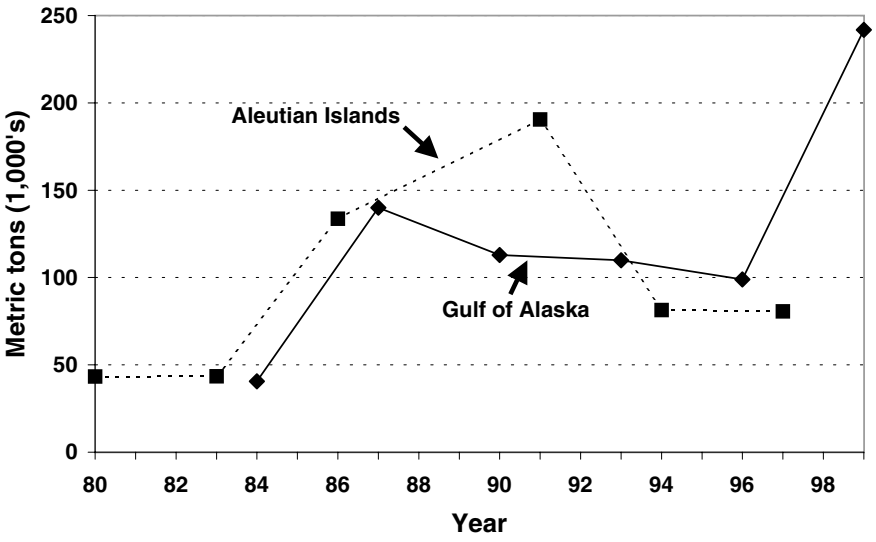

Figure 12.—Biomass estimates for northern rockfish in the Gulf of Alaska and Aleutian Islands, 1980–99, based on NMFS bottom trawl surveys.

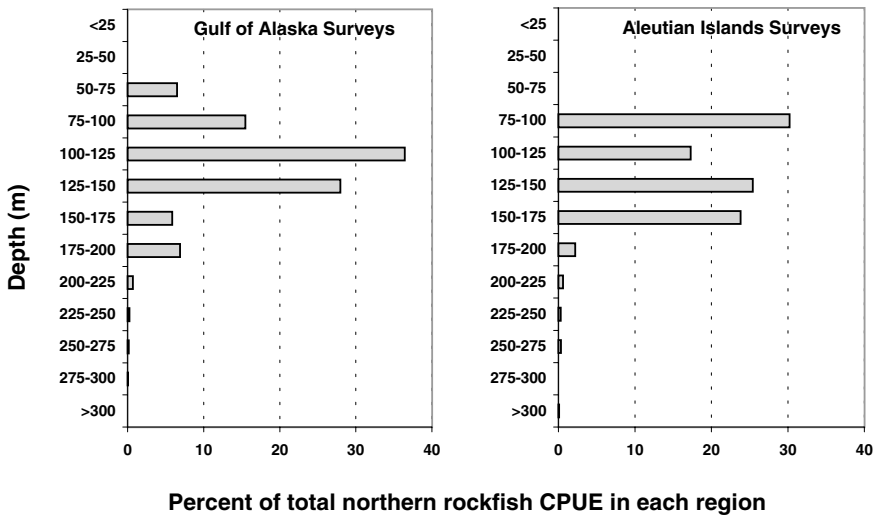

Figure 13.—Depth distribution of CPUE in kg/km^2 of northern rockfish in NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands, 1980–99.

fishery caught more fish at slightly shallower depths than did the surveys, but both data sources indicated that 80% or more of the catch came from depths of 75–150 m. Likewise, in the Aleutian Islands both the fishery and surveys agreed that around 90% or more of the fish were found in depths between 75 and 175 m. Both data sources also showed that catches were distributed a little deeper in the Aleutian Islands.

Geographic Distribution of Survey Catches and Comparison with Fishery Catches

Similar to the procedures used above in the analysis for the commercial fishery, a series of GIS plots was made to examine the geographic distribution of northern rockfish catches in the surveys. Plots of all survey hauls that reported any catch of northern rockfish, regardless of the amount, showed catches were widespread in both the Gulf of Alaska and Aleutian Islands (Fig. 14A and 15A). As in comparable plots for the commercial fishery (Fig. 5A and 6A), catches in the Gulf of Alaska tend to be more common on the outer continental shelf rather than inshore, whereas there is little discernible pattern to catches in the Aleutian Islands. Also, catches become more infrequent in the eastern Gulf of Alaska, and no fish were caught off southeastern Alaska.

To identify locations where northern rockfish were abundant in the surveys, additional plots were made for only those hauls with a relatively high CPUE (>5,000 kg/km^2) for northern rockfish (Fig. 14B and 15B). This amount was chosen so the plots would be comparable to those for the fishery (Fig. 5B and 6B) to determine where the catch was concentrated. A CPUE of 5,000 kg/km^2 is roughly equivalent to the 3,500 kg criterion we used in Figure 5B for plotting large catches of northern rockfish in the Gulf of Alaska fishery. (For a typical fishery haul, which uses commercial gear towed over the bottom for about 2 h, a catch of 3,500 kg approximately equals a CPUE of 5,000 kg/km^2.) Highest CPUE for any haul in the Gulf of Alaska was 405,438 kg/km^2, and in the Aleutian Islands, 180,943 kg/km^2. The hauls in Figures 14B and 15B accounted for most of the total northern rockfish CPUE in the surveys: for the Gulf of Alaska, they comprised 89.7% of the total CPUE for this species, and for the Aleutian Islands, 92.9%. For the Gulf of Alaska (Fig. 14B), these abundant catches were concentrated at various localities on the outer continental shelf just inside the 200 m depth curve. In the Aleutian Islands (Fig. 15B), hauls with large CPUE also were concentrated at several locations, but relatively few large catches were found in the eastern Aleutian Islands (i.e. the area east of Petrel Bank).

Locations of abundant northern rockfish catches in the fishery did not always coincide with those in the surveys, and vice versa. To compare these two data sources in terms of where most of the fish were caught, the major commercial fishing grounds identified previously in this report are superimposed on Figures

14B and 15B. In the Gulf of Alaska, the surveys and fishery agree that Portlock Bank and Davidson Bank are important fishing grounds for northern rockfish. Agreement is less certain, however, for the three remaining fishing grounds: Shumagin Bank, the Snakehead, and Albatross Bank. Several large catches in the surveys did occur within the latter three areas, but not enough to especially identify them as major areas of northern rockfish abundance. In particular, the Snakehead, which was the most important ground in the fishery, does not stand out in the survey catches. Furthermore, there is one area of high catches in the survey at the mouth of Shelikof Trough that had virtually no large fishery catches (compare Fig. 14B with Fig. 5B).

In the Aleutian Islands, a comparison between major fishing grounds in the fishery and large catches in the surveys also shows both similarities and differences (Fig. 15B). The fishery and survey data especially agree that Petrel Bank is an important area of northern rockfish abundance. To a lesser extent, there is also agreement that Tahoma Reef, Buldir Reef, Sturdevant Rock, and areas south of Amchitka Island and around Amlia Island are all localities of abundance. The survey data, however, does not show the large catches that were seen in the fishery for Ingenstrem Rocks, Buldir Island, the area southwest of Amchitka Island, Delarof Island, and Seguam Pass. In contrast, the surveys did show one location of abundance, Stalemate Bank, that was not evident from the fishery data.

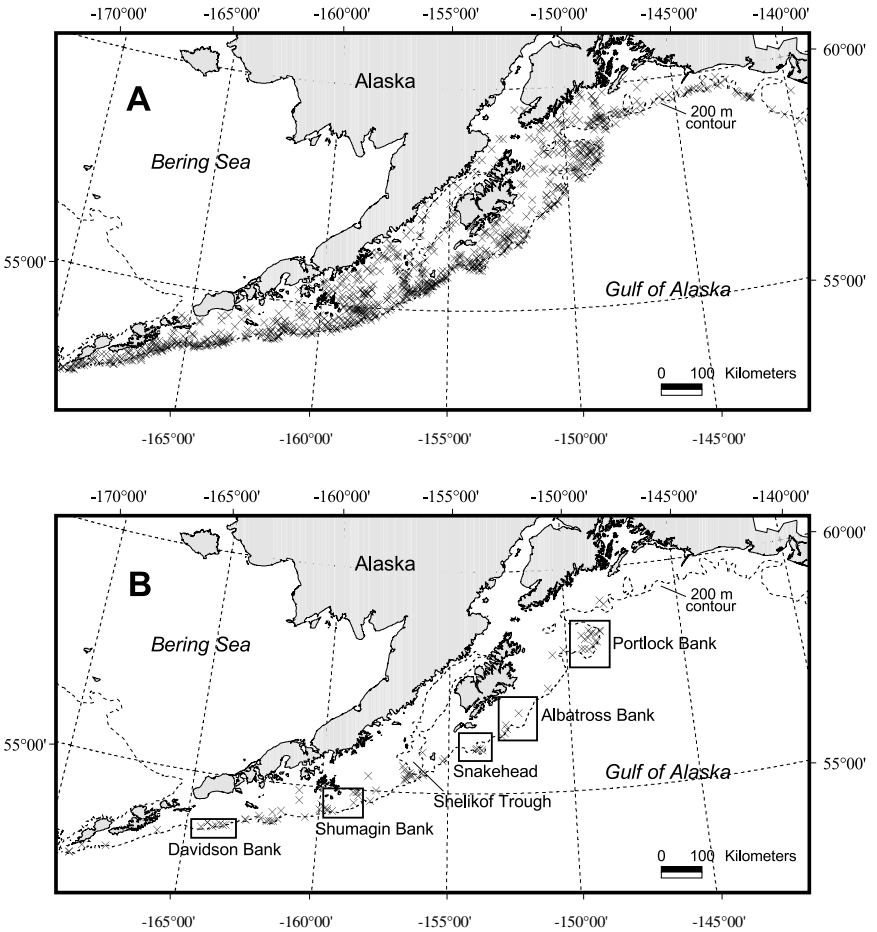

Figure 14.—Location of hauls that caught northern rockfish in NMFS bottom trawl surveys of the Gulf of Alaska, 1984–99. A: All hauls that caught northern rockfish; B: Hauls with a CPUE for northern rockfish of ≥5,000 kg/km^2. Also, the commercial fishing grounds for northern rockfish shown in Figure 5B have been superimposed on this plot.

Two factors may at least partially explain why the survey data did not always agree with the fishery data as to which fishing grounds are most important for northern rockfish:

1) The design of bottom trawls used in the fishery is considerably different than those used in the surveys. The fishery nets are of a relatively recent design that has been customized for catching large of amounts rockfish, and are generally of heavy-duty construction with "tire gear" on the footrope for towing over rough bottom. The survey nets have also been constructed for catching rockfish, but are an older design that does not use tire gear; they are also scaled down in size and weight so that relatively small trawlers chartered for the surveys are able to tow them. Consequently, the fishery nets are presumably more effective in catching rockfish over rougher substrates. If the preferred habitat of northern rockfish is rougher bottom (some evidence for this will be discussed later in this report), the survey nets, because of their lighter construction and lack of tire gear, would have more difficulty sampling this environment. Moreover, at many locations with very rough or steep bottoms, the survey nets cannot be fished at all, and these locations have remained unfished in the surveys. One possible hypothesis, therefore, would be that some locations within the boundaries of the fishing grounds may not be trawlable by the survey nets, and this could explain why the survey showed relatively few large catches at several of the grounds. However, when a comparison is made between Figure 14A (all catches of northern rockfish) and Figure 14B (large catches with fishing grounds superimposed) for an area such as the Snakehead, it is apparent that many survey hauls were successfully made within the Snakehead. Hence, the reason for the surveys having so few large catches in the Snakehead does not appear to be a simple inability to trawl this area due to the design of the survey's nets; other factors (particularly the one described

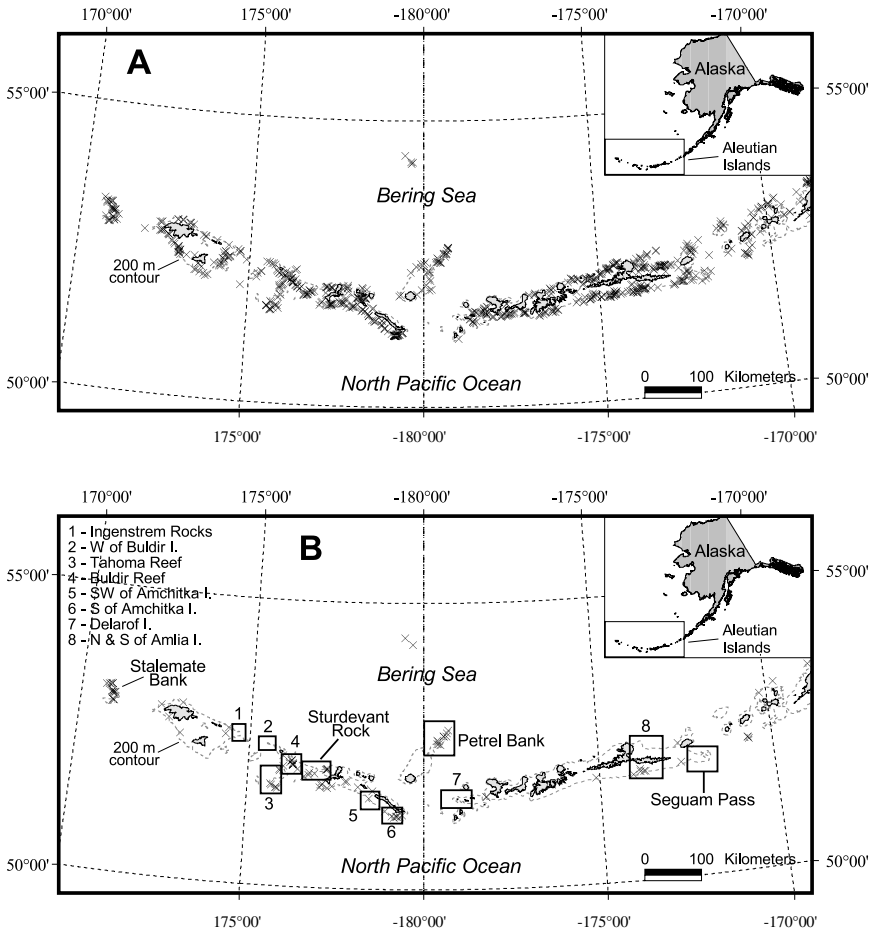

Figure 15.—Location of hauls that caught northern rockfish in NMFS bottom trawl surveys of the Aleutian Islands, 1980–97. A: All hauls that caught northern rockfish; B: Hauls with a CPUE for northern rockfish of ≥5,000 kg/km^2. Also, the commercial fishing grounds for northern rockfish shown in Figure 6B have been superimposed on this plot.

in the next paragraph) are likely more responsible for the survey's relatively low catch rates at this locality.

2) Commercial fishermen specifically search for and target large concentrations of northern rockfish, whereas haul locations in the surveys are selected randomly. When a fisherman finds a concentration of fish, he will repeatedly trawl at that vicinity as long as catches are good. However, when the surveys encounter a large catch, fishing is not continued at these localities; instead, the survey vessel moves on to the next random station, which may be many kilometers away. As a result of these different fishing strategies, the fishery would likely complete a much greater proportion of hauls with large catches at the fishing grounds than would the surveys.

The reason the surveys showed large catches of northern rockfish at the mouth of Shelikof Trough, whereas the fishery did not, cannot be easily explained. The fishery effort at this locality was relatively sparse in comparison to the large effort at the five major Gulf of Alaska fishing grounds, which may partially account for the scarcity of large fishery catches at Shelikof Trough. Still, enough hauls were made by the fishery at this locality (see Fig. 5A) that one would expect to find at least some large catches, based on the number of large catches seen here in the surveys. The surveys suggest that this area near the mouth of Shelikof Trough probably is a major area of northern rockfish concentration in the Gulf of Alaska, in addition to the five fishing grounds that were identified from the fishery data. Furthermore, it is interesting to note that examination of nautical charts for this site at the mouth of Shelikof Trough shows that its physical characteristics are very similar to those of the fishing grounds: the locality is an offshore bank of relatively shallow water which is surrounded by deeper depths.

Stalemate Bank was the only locality in the Aleutian Islands where large catches of northern rockfish were found in the surveys but not in the fishery. This difference is explained by the extremely low effort in this area by the fishery. Only two fishery hauls were found here that reported any catch of northern rockfish (Fig. 6A). Stalemate Bank is situated at the far western end of the Aleutian Islands, and the added expense of traveling to this isolated locality has probably deterred most fishermen from operating here. Stalemate Bank, however, definitely fits the geographic and physical pattern of so many of the other important fishing grounds, as it is far from land, surrounded by very deep water, and contains a substantial area of depth between 60 and 170 m, which corresponds to the preferred depths for northern rockfish found at the other grounds.

Substrate Preference for Northern Rockfish

Anecdotal observations from commercial fishermen and from scientists on trawl surveys indicate that northern rockfish are often caught in association with hard or rough substrates. To investigate the possibility that northern rockfish have a preference for rough substrates, we examined data on trawl performance of individual survey hauls to indirectly infer information on substrate type. (Actual data on substrate type were not collected for any hauls in the trawl surveys.) Of the 20 hauls in the Gulf of Alaska with the highest CPUE for northern rockfish, 5 (25%) were assigned a performance code of "unsatisfactory" in the database because the net hung up on the bottom

and/or was damaged. This compares with a total of only 5.7% that were assigned an unsatisfactory code for all hauls with any northern rockfish catch. In particular, three of the top four hauls in terms of CPUE were unsatisfactory tows in which the net hung up severely on the bottom. Such hang-ups are nearly always an indication of a hard, rocky, and/or steep bottom. The performance data, therefore, suggest that at least some large catches of northern rockfish appear to be associated with hard substrates.

Performance data from the trawl surveys in the Aleutian Islands are more equivocal in regards to large catches of northern rockfish being associated with rough substrate. Similar to the Gulf of Alaska, the haul with the highest northern rockfish CPUE of any in the Aleutian surveys was an "unsatisfactory" tow in which the net severely hung on the bottom. However, this was the only unsatisfactory haul among the top twenty tows in terms of CPUE. Overall, 3.3% of the survey hauls in this region that had catches of northern rockfish were rated as unsatisfactory because of hang-ups or net damage.

Although strong evidence was not apparent in the Aleutian Islands surveys of a northern rockfish association with hard substrate, the nature of the fishery in this region suggests that a relationship does exist between northern rockfish and hard substrates. As discussed previously in this paper, most of the northern rockfish catch in the Aleutian Islands has been taken as bycatch in the Atka mackerel fishery. This fishery is known to occur primarily over rocky, uneven bottom (NPFMC, 1998), and the northern rockfish caught in this fishery are presumably also taken in this habitat.

Size Composition of Northern Rockfish in Surveys

In each survey, length frequency data were collected for northern rockfish in individual hauls, and these data were later expanded over the entire survey area and weighted by the estimated population size to yield estimated population size compositions. Wakabayashi et al. (1985) provide a detailed explanation of the computations used in this procedure.

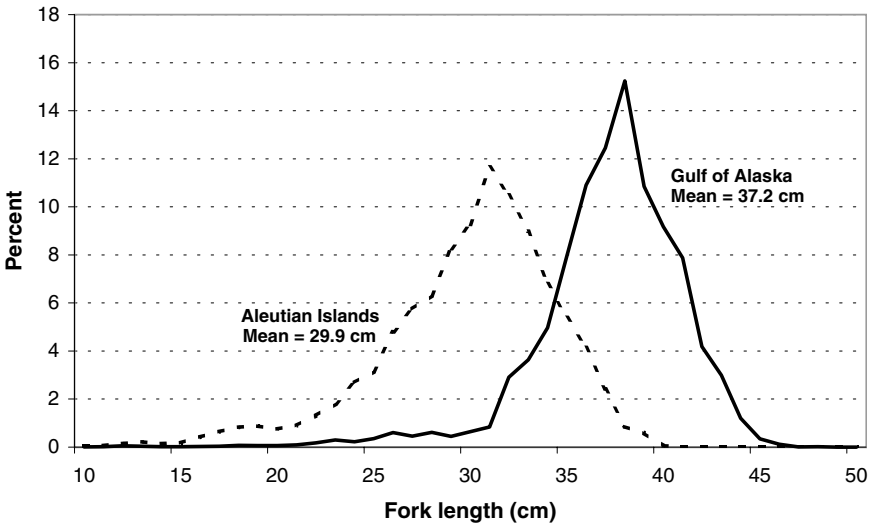

Figure 16.—Estimated population size compositions for northern rockfish in the Gulf of Alaska and Aleutian Islands, based on NMFS bottom trawl surveys in each region. Gulf of Alaska size compositions are from combined results of the 1993, 1996, and 1999 surveys; Aleutian Islands size compositions are from combined results of the 1991, 1994, and 1997 surveys.

Figure 16 shows a comparison for the size composition of northern rockfish between the Gulf of Alaska and Aleutian Islands surveys. This comparison is only for the last three surveys combined in each region because valid population size composition information is not available for the Aleutian surveys before 1991. The figure clearly shows that average length of northern rockfish is significantly greater in the Gulf of Alaska. Overall mean population length in the Gulf of Alaska was estimated to be 37.2 cm, as compared to only 29.9 cm in the Aleutian Islands. Virtually none of the population in the Aleutians Islands was greater than 40 cm in length, whereas about 26% of the Gulf of Alaska population was in this size category. These results are very similar to those presented earlier for size of fish taken in the commercial fishery, which also showed substantially larger fish were caught in the Gulf of Alaska.

Population size compositions for individual surveys in the Gulf of Alaska (Fig. 17) indicate that, in general, the surveys have taken relatively few small northern rockfish. Fish less than 30 cm in length were rarely caught in the last three surveys, and fish this size were also relatively sparse in the 1987 and 1990 surveys. Only the 1984 survey showed a substantial portion of the sampled population to be less than 30 cm in length. This lack of small fish in the surveys may be an indication that recruitment of young northern rockfish is a relatively uncommon event; alternatively, it may indicate that young fish reside in a habitat that is not effectively sampled by the survey's trawls.

Length frequency distributions of northern rockfish that were sexed in the surveys show that females averaged 1.3 and 1.7 cm larger than males in the Gulf of Alaska and the Aleutian Islands, respectively (Fig. 18). *T*-tests showed these differences were both highly significant (Gulf of Alaska, $P < 0.0001$, $t = 7.31$, df = 29,334; Aleutian Islands, $P < 0.0001$, $t = 9.96$, df = 32,259). These results are similar to those presented earlier for the Gulf of Alaska fishery data, which likewise indicated females were larger than males. Studies of most other *Sebastes* species have also shown that average length of females is greater than that of males (Lenarz and Wyllie Echeverria, 1991) probably because there is an evolutionary advantage for females to be larger and produce more eggs.

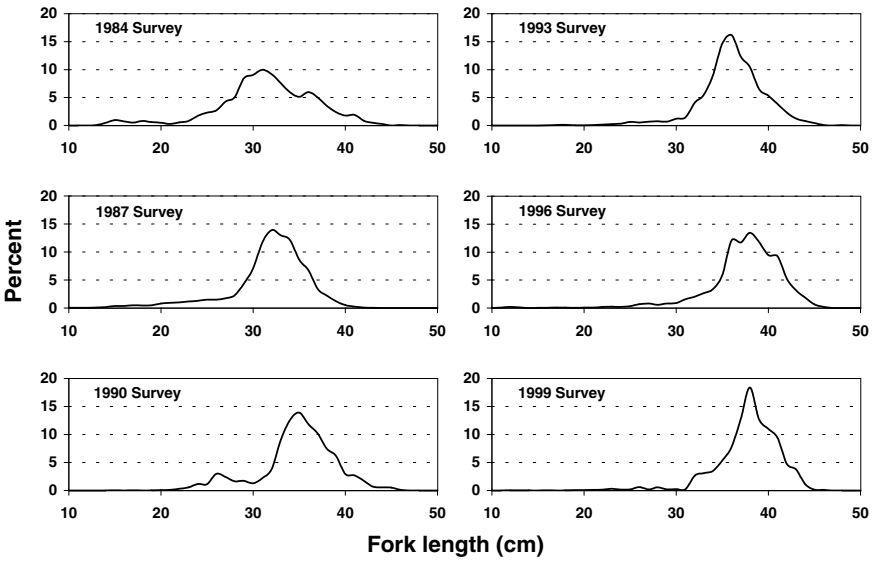

Figure 17.—Estimated population size compositions for northern rockfish in the Gulf of Alaska, based on NMFS bottom trawl surveys.

Maximum Length of Northern Rockfish in Surveys

Previous publications that are commonly used to identify rockfish in Alaska (e.g. Eschmeyer et al., 1983; Kramer and O'Connell, 1995; Orr et al., 2000; Mecklenburg et al., 2002) all list maximum length for northern rockfish as ranging from 38 to 41 cm FL, depending on the publication. This maximum length is erroneous for the Gulf of Alaska, as shown by the population size compositions for this region in Figure 16. Many individuals in the Gulf of Alaska surveys have measured between 40 and 45 cm FL. The maximum fork length observed for northern rockfish in all the Gulf of Alaska surveys was 48 cm, and, as previously mentioned, 26% of the estimated population for the combined 1991, 1994, and 1997 surveys was greater than 40 cm FL. Individual northern rockfish greater than 40 cm FL are also relatively common in the Gulf of Alaska commercial fishery (Fig. 9).

Locations and Depths of Juvenile Northern Rockfish in Surveys

Although small northern rockfish were only taken infrequently in the surveys, those that were caught provide some information as to where juveniles of this species may be found. A GIS plot of hauls in the Gulf of Alaska where small (≤25 cm FL) juvenile northern rockfish were caught shows that fish of this size were taken at many locations on the continental shelf (Fig. 19). In contrast to Figure 14A, which shows locations of all hauls that caught northern rockfish, the hauls that reported catches of these small fish tend to be more inshore and not as concentrated on the outer continental shelf. To identify locations where juvenile northern rockfish were especially abundant, Figure 19 also shows hauls in which 20 or more small fish (≤25 cm FL) were measured. The plot indicates that relatively few hauls met this criterion, and is additional evidence that juvenile northern rockfish have generally not been well sampled in the surveys. It does show, however, that locations in the surveys where small fish were caught in larger numbers tend to be distributed across the continental shelf and are not particularly concentrated on the outer shelf, as are adults. This tendency of small fish to be found more inshore than larger adults is also illustrated in Figure 20. This plot shows that catches of large adult fish (mean fork length ≥35 cm) are usually located on the outer continental shelf, whereas hauls in which smaller fish (mean fork length ≤30 cm) predominate are mostly located at more inshore localities throughout the shelf.

We also investigated the relationship between size of northern rockfish and depth of capture in the Gulf of Alaska surveys (Fig. 21). As might be expected given the more inshore distribution of smaller fish described in the previous paragraph, hauls in which the mean length of northern rockfish was less than about 28 cm FL were mostly found at relatively shallow depths less than 100 m. In contrast, hauls in which the mean fork length was greater than about 30 cm were located at a wide range of depths from around 70 to 300 m. This general bathymetric cline in size is also typical of other *Sebastes* species inhabiting the continental shelf and slope of the Gulf of Alaska (Major and Shippen, 1970; Martin and Clausen, 1995; Martin, 1997; Britt and Martin, 2001). In summary, the Gulf of Alaska surveys indicate that juvenile northern rockfish are generally found more inshore and at shallower depths than are larger adult fish.

To examine the distribution of juvenile northern rockfish in the Aleutian Islands surveys, we made a series of GIS plots and a depth graph analogous to those for the Gulf of Alaska surveys (Fig. 22–23, Fig. 21). (Because of the smaller size of northern rockfish in the Aleutian Islands, we chose to plot hauls with a mean northern rockfish length ≤25 cm FL and those with a mean length ≥30 cm FL in Figure 23, instead of ≤30 cm FL and ≥35 cm FL as was done for the Gulf of Alaska in Figure 20.)

In contrast to the Gulf of Alaska data, the Aleutian Islands surveys do not show much difference in geographic distribution between juvenile and adult northern rockfish. Figure 22 shows that small (≤25 cm FL) juvenile northern rockfish have been taken in at least small amounts at many locations throughout the Aleutian Islands, but that larger numbers of juveniles have only been caught infrequently in the surveys.

A comparison between Figure 22 and Figure 15A (Figure 15A shows all catches of northern rockfish in the surveys) indicates that smaller northern rockfish do not have a noticeably differ-

ent pattern of distribution than the overall population. This is further demonstrated in Figure 23, which shows that concentrations of small and large northern rockfish appear to mostly overlap in their distributions. Finally, the depth versus length graph for the Aleutian Islands in Figure 21 also does not indicate much difference in depth distribution between hauls with small or large fish.

The reason that smaller northern rockfish had a different distribution than larger fish in the Gulf of Alaska, but did not in the Aleutian Islands, may be related to the distinct bathymetric characteristics of each region. The Aleutian Islands do not have the broad continental shelf found in the Gulf of Alaska; instead, at most places in the Aleutian Islands, the bottom drops steeply from the shore to very deep depths in just a short distance. Because of the limited amount of shallow-water habitat in the Aleutian Islands, it may be necessary for juvenile northern rockfish to live in closer proximity to adult fish than is the case in the Gulf of Alaska.

Sex Ratio of Northern Rockfish in Surveys

Sex was determined in the surveys for nearly all the northern rockfish that were sampled for length frequencies. Sex compositions in the surveys indicate that the sex ratio was nearly equal in the Gulf of Alaska, but females predominated in the Aleutian Islands (Table 13). For all years combined in the Gulf of Alaska, 49.2% of the fish sampled were males, and 50.8% were females. There was some variation in the sex ratios between individual surveys in this region, however, with females ranging from 58% in 1984 to 45% in 1999. For all years combined in the Aleutian Islands, males comprised 42.9% and females 57.1% of all northern rockfish sampled. The predominance of females was consistent in all the Aleutian Islands surveys.

To analyze whether the sex ratios for all years combined in each region were significantly different from 50:50, we used the same statistical procedure as we used previously for the pooled sex ratio data in the Gulf of Alaska fishery, replicated tests of goodness of fit (Sokal and Rohlf, 1969). Results of these tests indicated that the sex ratio differed significantly from 50:50 in both the Gulf of Alaska and the Aleutian Islands (Gulf of Alaska: chi-square = 10.8; df = 1; $P <$

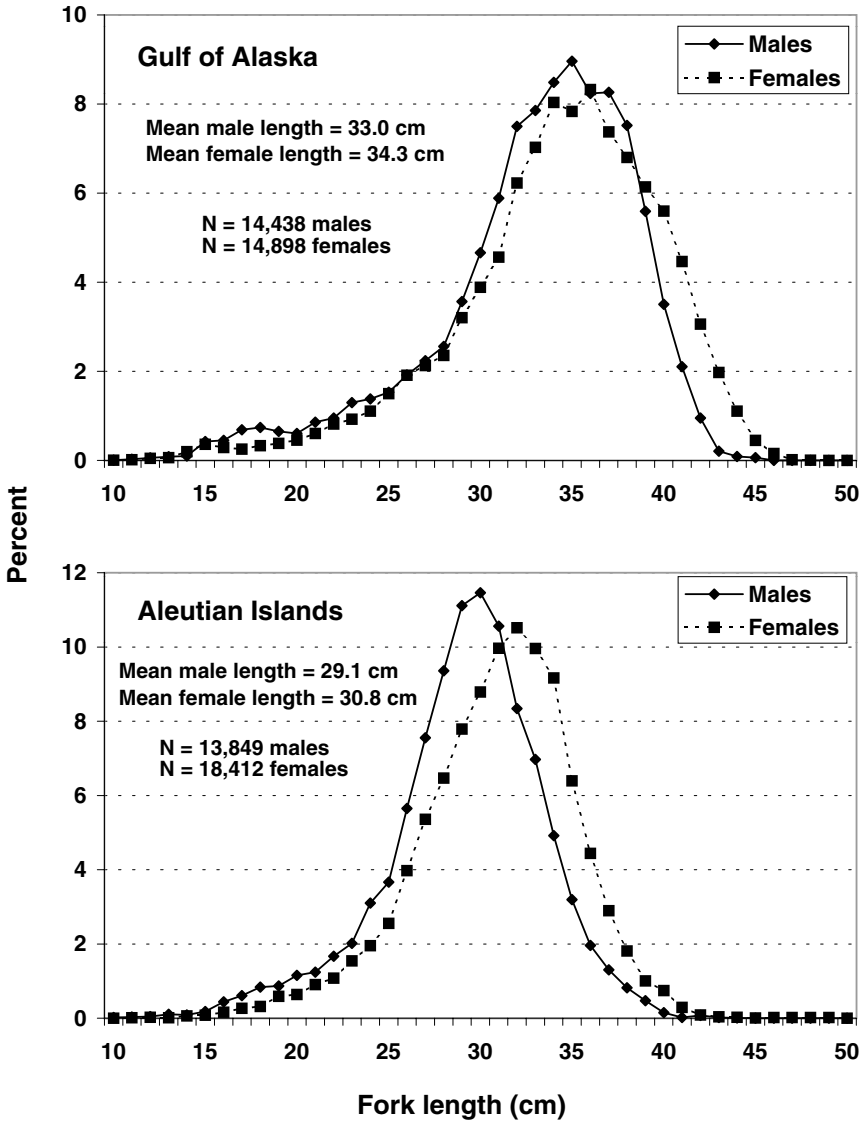

Figure 18.—Length frequency distribution, by sex, of northern rockfish measured in NMFS bottom trawl surveys in the Gulf of Alaska and Aleutian Islands, 1980–99.

Table 13.—Sex composition of northern rockfish sampled in NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands, 1980–99.

Gulf of Alaska surveys				Aleutian Island surveys			
Year	No. sexed	% male	% female	Year	No. sexed	% male	% female
1984	4,312	41.8	58.2	1980	1,539	42.6	57.4
1987	8,188	48.5	51.5	1983	6,535	42.3	57.7
1990	3,488	53.8	46.2	1986	5,881	47.2	52.8
1993	5,306	50.4	49.6	1991	4,853	45.2	54.8
1996	4,449	47.9	52.1	1994	6,250	38.4	61.6
1999	3,593	55.2	44.8	1997	7,461	42.2	57.8
Total	29,336	49.2	50.8	Total	32,519	42.9	57.1

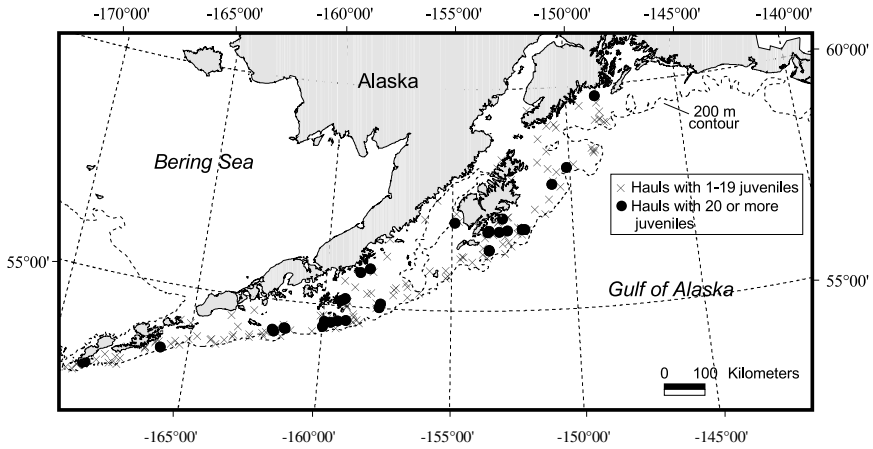

Figure 19.—Location of hauls in which small (≤25 cm FL) juvenile northern rockfish were measured in NMFS bottom trawl surveys of the Gulf of Alaska, 1984–99.

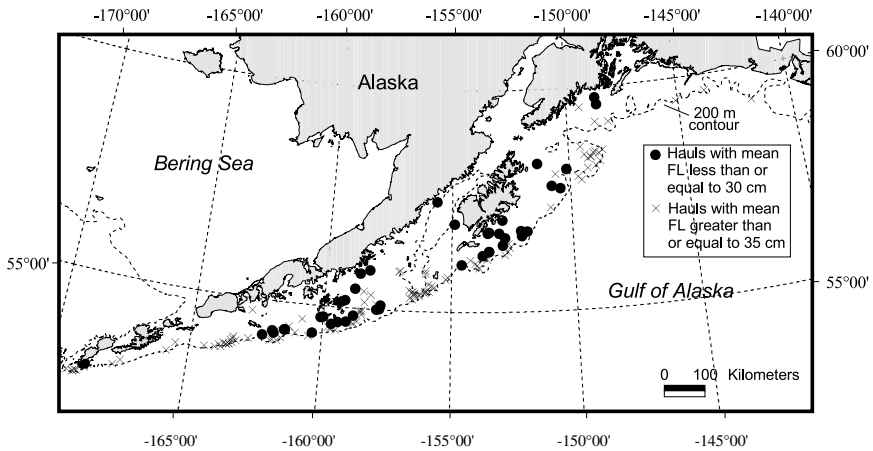

Figure 20.—Comparison of haul locations for small vs. large northern rockfish in NMFS bottom trawl surveys of the Gulf of Alaska, 1984–99. Hauls with "small" northern rockfish are those in which mean fork length was ≤30 cm; hauls with "large" northern rockfish are those in which mean fork length was ≥35 cm (plot only includes hauls in which ≥20 northern rockfish were measured).

0.01; Aleutian Islands: chi-square = 664.6; df = 1; $P < 0.0001$). Thus, in both regions, there appeared to be significantly more females in the population.

A comparison between the fishery and survey data for overall sex ratio in the Gulf of Alaska indicates that the fishery data also showed a significantly higher percentage of females (see previous section "Sex Ratio of Fish Caught in the Gulf of Alaska Fishery"). These statistical significances for the Gulf of Alaska, however, may not be of much biological importance. For each data source, the pooled sex ratio for all years combined was reasonably uniform (male/female ratios were 48:52 and 49:51 in the fishery and surveys, respectively), and the fact that females were significantly more abundant in our analysis may be a reflection mainly of the large sample size of fish that were sexed in both the fishery and the surveys. Other species of *Sebastes* have also been reported to have an overall sex ratio of 50:50. For example, Major and Shippen (1970) concluded that for Pacific ocean perch, "sex ratio, although it varies considerably with time of year and from sample to sample, probably is 1:1".

Our results for the Aleutian Islands surveys, however, were different in that they showed a clear predominance of female northern rockfish in this region. The reason for this difference is unknown.

The same methods we used previously to analyze sex ratios in the Gulf of Alaska fishery were also used to examine the sex composition of northern rockfish in individual survey hauls. Again, we selected only those hauls in which sex was determined for at least 40 northern rockfish. A considerable number of hauls differed substantially from a 50:50 sex ratio (Fig. 24). For example, in the Gulf of Alaska, there were nine hauls in which females comprised <20%, and in the Aleutian Islands, the catch in eleven hauls was 85% or more females. Replicated tests of goodness of fit among hauls indicated heterogeneity of sex ratios among hauls was highly significant in both regions (Gulf of Alaska: chi-square = 3,195.8; df = 198; $P < 0.0001$; Aleutian Islands: chi-square = 3,289.8.; df = 200; $P < 0.0001$). Despite this very high heterogeneity, chi-square tests for individual hauls showed that 37% of the hauls in both the Gulf of Alaska and Aleutian Islands had a sex ratio that was not significantly different than 50:50. We conclude that during the summer months (when the surveys were conducted), the sex ratio of northern rockfish is highly dependent upon the specific location that is sampled, and that some degree of localized aggregation by sex often occurs.

Age and Growth of Northern Rockfish Based on Survey Samples

Ages have been determined for northern rockfish sampled in five of the surveys in the Gulf of Alaska and three in the Aleutian Islands (Table 14). In each of these surveys, otolith pairs were collected from a subsample of male and female northern rockfish in selected hauls, usually those with a large catch of this species. Generally, about 10–30 fish of each sex were sampled per haul, although sometimes fewer were sampled. Attempts were made to disperse the

sampled hauls over the survey area so the samples were not concentrated in one locality. All ages were determined for the otoliths by the "break-and-burn" method (Beamish, 1979).

Similar to aging studies of most other rockfish species (Archibald et al., 1981; Pearson et al., 1991; Bechtol, 2000), there was a large variation in length-at-age amongst individual fish (Fig. 25). The maximum age of northern rockfish was 44 years in the Gulf of Alaska and 72 years in the Aleutian Islands (Table 14). Based on these results, we computed von Bertalanffy growth parameters for males, females, and sexes combined for both the Gulf of Alaska and the Aleutian Islands (Table 15).

The growth curves based on these parameters indicate that growth of northern rockfish in the Gulf of Alaska is considerably different than in the Aleutian Islands (Fig. 26). Gulf of Alaska fish of both sexes appear to grow faster when young and reach a larger maximum size. To test the significance of this apparent regional difference in growth, and to also test possible differences in growth by sex, we used the *F*-test procedure in Quinn and Deriso (1999). This procedure tests whether a "full" model with separate growth parameters for each data set is significantly different from the "reduced" model with common parameters among data sets. The *F*-statistic is

$$F = \frac{RSS_y - RSS_x}{f_y - f_x} / \hat{\sigma}_x^2$$

where RSS_y is the residual sums of squares for fitting a reduced model, RSS_x is the residual sums of squares of fitting the full model, f_y is the degrees of freedom for the reduced model, and f_x is the degrees of freedom for the full model, and $\hat{\sigma}_x^2$ is the residual mean square. If there are R data sets, p parameters, and n data points, then $f_x = n - Rp$, $f_y = n - p$, and $\hat{\sigma}_x^2 = RSS_x/f_x$. The F-statistic is compared to the $F_{crit}(f_y - f_x, f_x, \alpha)$. Results of the F-tests indicated there were highly significant ($P < 0.001$) differences in growth between regions and sexes (Table 15). For the data pooled among sexes, the estimated asymptotic size (L_∞) was 39.2 cm

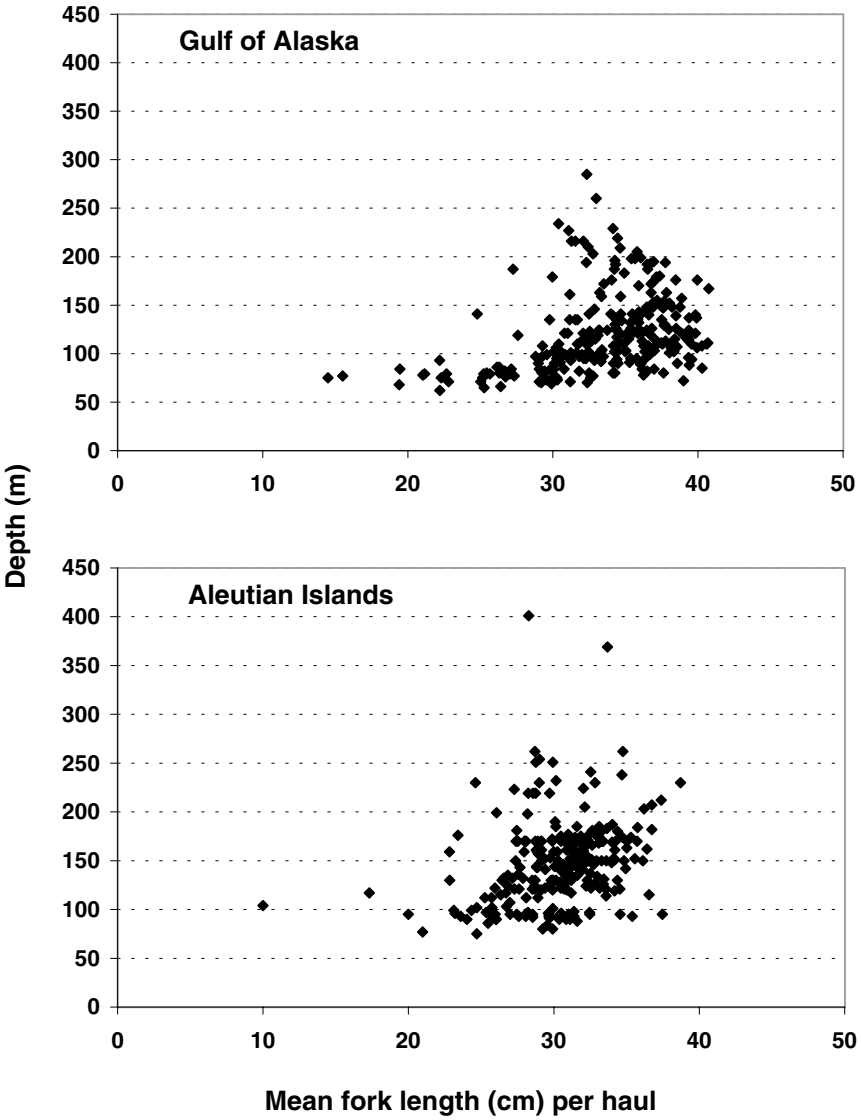

Figure 21.—Depth vs. length relationship for northern rockfish in NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands, 1980–99 (plot only includes hauls in which ≥20 northern rockfish were measured).

Table 14.—Summary of northern rockfish age samples from NMFS bottom trawl surveys in the Gulf of Alaska and Aleutian Islands that were analyzed in this report.

Region and year	No. of hauls sampled	Total no. of fish aged	No. of males aged	No. of females aged	Min. age	Max. age
Gulf of Alaska						
1984	6	356	175	181	5	43
1987	17	497	235	262	3	44
1990	13	439	202	237	2	33
1993	20	354	173	181	2	40
1996	19	462	248	214	2	43
Total	75	2,108	1,033	1,075	2	44
Aleutian Islands						
1986	18	565	279	286	4	57
1994	19	409	195	214	3	66
1997	67	630	301	329	2	72
Total	104	1,604	775	829	2	72

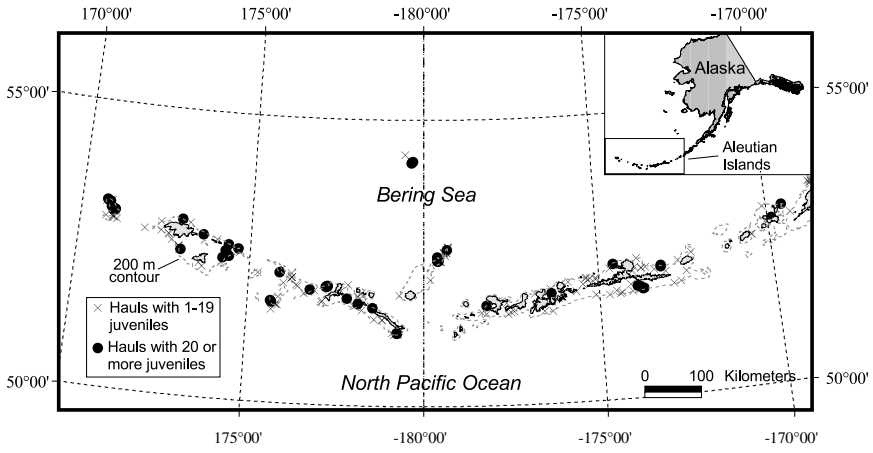

Figure 22.—Location of hauls in which small (≤25 cm FL) juvenile northern rockfish were measured in NMFS bottom trawl surveys of the Aleutian Islands, 1980–97.

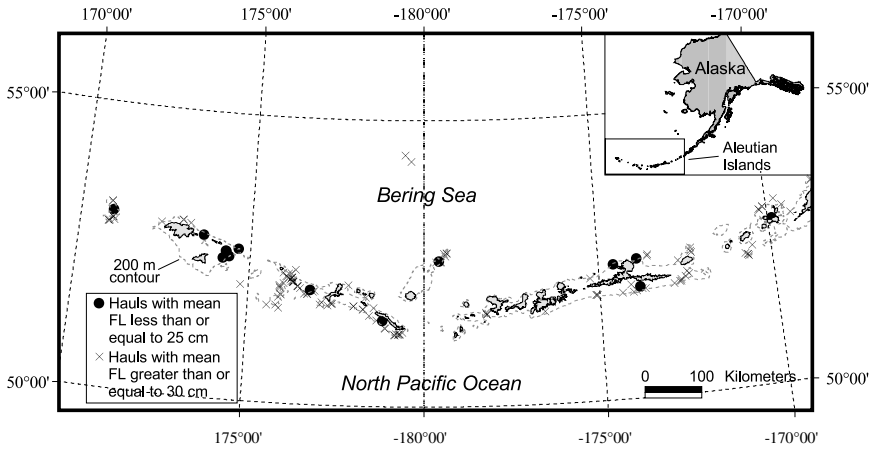

Figure 23.—Comparison of haul locations for small vs. large northern rockfish in NMFS bottom trawl surveys of the Aleutian Islands, 1980–97. Hauls with "small" northern rockfish are those in which mean fork length was ≤25 cm; hauls with "large" northern rockfish are those in which mean fork length was ≥30 cm (plot only includes hauls in which ≥20 northern rockfish were measured).

in the Gulf of Alaska and only 33.7 cm in the Aleutian Islands. Females in both areas had a larger asymptotic size than males with divergence in size at about age 10. The asymptotic size was 37.8 cm and 40.2 cm for Gulf of Alaska males and females, respectively, and 32.6 cm and 34.5 cm for Aleutian Islands males and females, respectively.

Summary and Conclusions

In this report, we analyzed data from the U.S. commercial fishery (collected by observers) and from AFSC bottom trawl surveys to describe the fishery for northern rockfish in Alaska and to provide information on distribution and biology of northern rockfish. Although the amount of northern rockfish catch in both the Gulf of Alaska and the Aleutian Islands has been similar in recent years, the fishery in each region is very different.

In the Gulf of Alaska, most of the catch is taken in a directed fishery for northern rockfish in which the catch is retained for processing and subsequent sale. In the Aleutian Islands, however, the catch predominantly comes as bycatch in the Atka mackerel fishery, and most northern rockfish are discarded.

In both regions, nearly all the catch is the result of bottom trawling. In the Aleutian Islands, this trawl catch has been exclusively taken by factory-trawlers. Factory-trawlers have also predominated in the Gulf of Alaska fishery, but since 1996, smaller shore-based trawlers operating from the port of Kodiak have also taken a substantial portion of the catch. Commercial catch of northern rockfish in the eastern Bering Sea has generally been insignificant compared to that in the Gulf of Alaska and Aleutian Islands, especially in recent years.

The fishery and survey data provide much information on the geographic distribution of adult northern rockfish. Adults in the Gulf of Alaska, and to a lesser degree also in the Aleutian Islands, are mostly found on relatively shallow, offshore banks of the outer continental shelf that are relatively small in size. The major fishing grounds in the Gulf of Alaska correspond to five of these banks that together accounted for an estimated 89% of the Gulfwide catch of northern rockfish in the years 1990–98: Portlock Bank, Albatross Bank, the Snakehead, Shumagin Bank, and Davidson Bank. Of these, the Snakehead has been the most important and has yielded nearly 46% of the catch during these years. Survey data indicate that one other bank at the mouth of Shelikof Trough is also an area of northern rockfish abundance, but for unknown reasons little commercial catch has been taken at this site. These banks are all characterized by their offshore locations near the start of the continental slope, relatively shallow depths of 75–150 m, and the fact that they are rises or humps surrounded by deeper water.

Of the 11 major fishing grounds for northern rockfish identified in the Aleutian Islands, several are also offshore banks similar to those in the Gulf of Alaska. These include Seguam Pass, Petrel Bank, and Tahoma Reef. Other fishing grounds in the Aleutian Islands are closer to shore and are not rises or humps, and therefore differ from the Gulf grounds in terms of their physi-

cal characteristics. Combined, these 11 grounds produced an estimated 84% of the northern rockfish catch in the Aleutians Islands during the period 1990–98. Depths of northern rockfish catches on fishing grounds in the Aleutian Islands are slightly deeper than in the Gulf, and range from 75 to 175 m. One other area of northern rockfish abundance was found in the Aleutian surveys but not in the fishery: Stalemate Bank at the far western end of the Aleutian chain. For the relatively small catch of northern rockfish in the eastern Bering Sea, only one important fishing ground was identified, near Southeast Zhemchug Canyon.

In addition to these geographic preferences for northern rockfish, other indications of their preferred adult habitat can be inferred from fishery and survey data. The fishery data suggest that adult northern rockfish are mostly demersal in their distribution, as virtually all the catch has been taken by bottom trawls fished on or near the bottom, and very few fish have been caught in mid-water or by pelagic trawls. The survey data for the Gulf of Alaska suggest that large catches of northern rockfish may be associated with rocky and steep habitats. Further evidence of a rocky habitat for northern rockfish comes from the fact that these fish in the Aleutian Islands are predominantly caught as bycatch in the fishery for Atka mackerel, which takes place mostly over rough bottoms. Additional research is needed, however, to definitively confirm that northern rockfish prefer a demersal, rocky bottom habitat.

Although the fishery and survey data generally agree regarding the geographic distribution and abundance of northern rockfish, there are some discrepancies between the two data sources as to the specific localities of abundance. Albatross Bank, Shumagin Bank, and especially the Snakehead were identified as major grounds for northern rockfish in the Gulf of Alaska fishery, but relatively few large catches were found there in the surveys. Similarly, several of the fishing grounds found in the Aleutian Islands did not show abundant catches of northern rockfish in the surveys.

Regarding these discrepancies, it is likely the fishery data in general show a more accurate picture of where northern rockfish are most abundant. The number of hauls with catches of northern rockfish is much larger in the fishery data, the commercial trawl gear is stronger and more modern in design than the gear in the surveys and is therefore more effective at catching rockfish, and commercial fishermen especially seek out locations of northern rockfish abundance. The surveys, however, did show two locations of northern rockfish abundance that were not evident in the fishery.

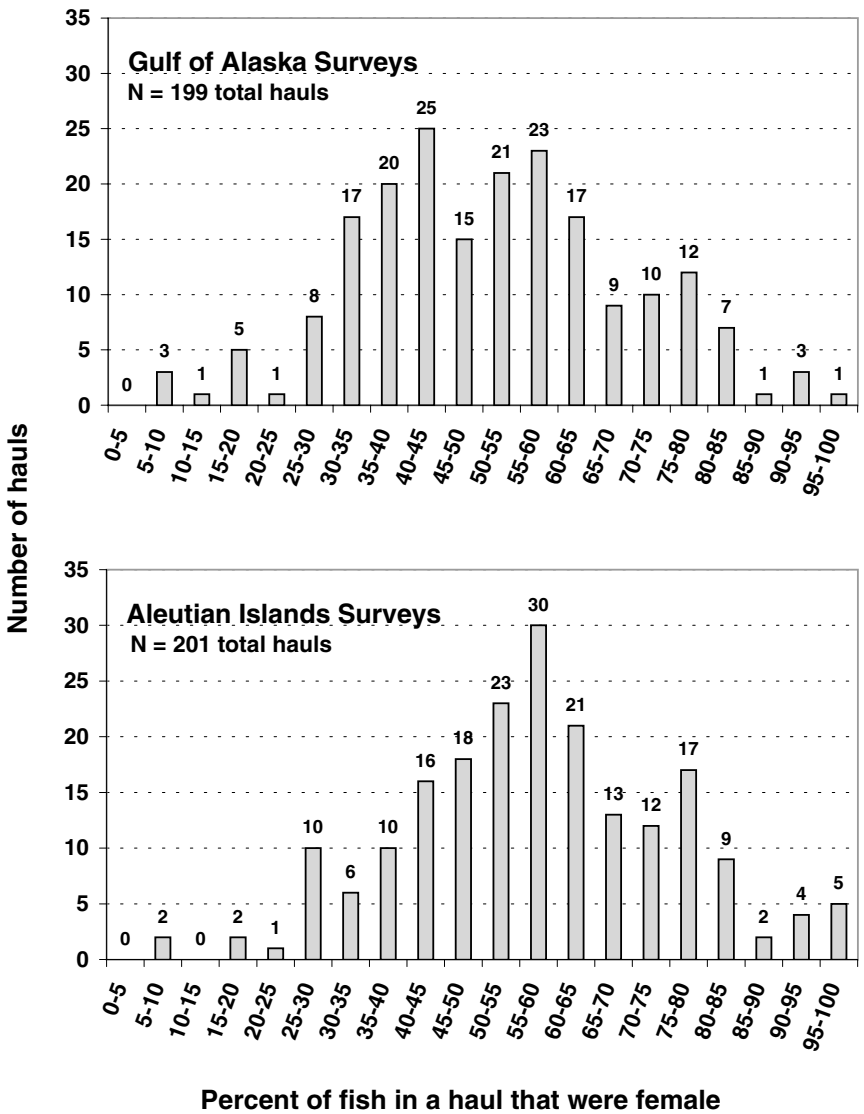

Figure 24. — Sex composition of northern rockfish in individual hauls of NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands, 1980–1999. Hauls include only those in which sex was determined for ≥40 northern rockfish.

The survey data indicate that small, juvenile northern rockfish in the Gulf of Alaska tend to live more inshore and at shallower depths than adults. In the Aleutian Islands surveys, there appeared to be little difference in the distribution of juveniles and adults. However, catches of juveniles in the surveys of both regions were generally sparse, and studies specifically directed toward young fish

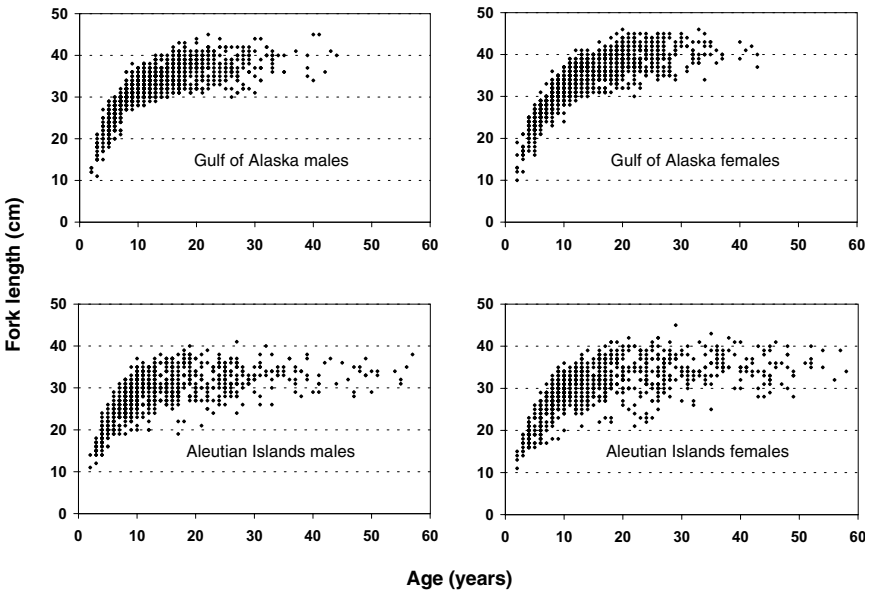

Figure 25.—Length vs. age results for northern rockfish age samples collected in NMFS bottom trawl surveys of the Gulf of Alaska and Aleutian Islands. Gulf of Alaska results are from the 1984, 1987, 1990, 1993, and 1996 surveys; Aleutian Islands results are from the 1986, 1994, and 1997 surveys. Each data point represents the length and age of an individual fish. Where more than one fish had the same length and age, data points have been plotted on top of each other and appear as a single point.

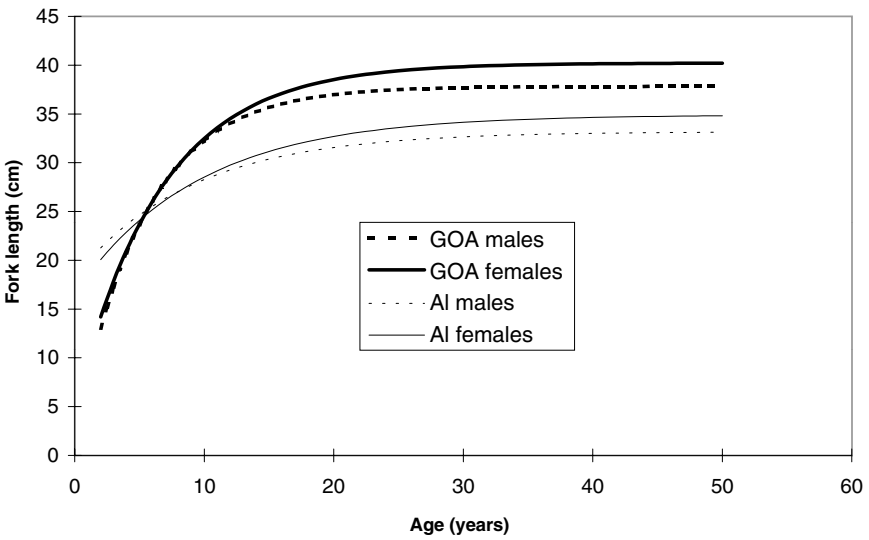

Figure 26.—Growth curves for male and female northern rockfish in the Gulf of Alaska (GOA) and Aleutian Islands (AI), based on the von Bertalanffy growth parameters given in Table 15.

will probably be necessary to better determine their distribution and habitat requirements.

Sex ratio of northern rockfish in the Gulf of Alaska appears to be close to 50:50 based on both fishery and survey data. In contrast, females in the Aleutian Islands appear to predominate; surveys there indicated a female/male ratio of 57:43. Why the sex ratios were so different in each region is unknown. Sex ratios in individual hauls of surveys in both regions often differed significantly from 50:50, which indicates some degree of aggregation by sex at certain localities and/or times.

Both the fishery and the surveys show that northern rockfish are significantly larger in the Gulf of Alaska than in the Aleutian Islands, and that females are significantly larger than males in each region. The small size of northern rockfish in the Aleutian Islands has likely been a major cause of the high discard rate for these fish in this region's fishery. This size difference between the two regions was further confirmed by our age and growth analysis, which showed Gulf of Alaska fish grew significantly faster and reached a larger maximum size.

The large difference between the Gulf of Alaska and Aleutian Islands in size and growth of northern rockfish suggests that separate populations may exist in each region. However, a preliminary genetics study of northern rockfish sampled from three localities in Alaska waters (around Kodiak Island, the central Aleutian Islands, and the western Aleutian Islands) found no evidence of stock structure (Gharrett et al.[4]). Because of the limited scope of this latter study, a more thorough genetic or morphometric study may be warranted to determine if subpopulations of northern rockfish occur in Alaska.

Acknowledgments

We especially thank Betty Goetz and her staff at the AFSC's Resource Ecology and Fishery Management Division's Age and Growth Task in Seattle, who aged all the northern rockfish that were used in this study's growth analysis. We also thank the following individuals for helpfully providing descriptive information about the northern rockfish commercial fishery: Andy Smoker, Eric Hollis, Laurie Bowen, Tim Meintz, and Chris Blackburn (for affiliations, see footnotes 7, 8, and 9).

Table 15.—Von Bertalanffy parameter estimates of non-linear least squares fit to northern rockfish age and length data, and *F*-tests for comparison of growth models by region and sex. Northern rockfish age and length data were based on the samples listed in Table 14.

		Gulf of Alaska			Aleutian Islands		
Parameter	Pooled[1]	Male	Female	Pooled[2]	Male	Female	Pooled[2]
n	3,712	1,033	1,075	2,108	775	829	1,604
L_∞	36.3	37.8	40.2	39.2	32.6	34.5	33.7
k	0.189	0.187	0.152	0.165	0.214	0.175	0.188
t_0	–0.179	–0.262	–0.870	–0.636	0.100	–0.562	–0.303
F-tests:	By region		Gulf of Alaska by sex			Aleutian Islands by sex	
RSSy	5029826		1572479			1945986	
RSSx	3518465		1512591			1899649	
σ_x^2	949.4		719.6			1188.8	
f_y	3709		2105			1601	
f_x	3706		2102			1598	
F-statistic	530.6		27.7			13.0	
P	6.9E-287		1.4E-17			2.2E-08	

[1] Pooled = Gulf of Alaska and Aleutian Islands data combined for both sexes.

[2] Pooled = male and female data combined.

Literature Cited

Ackley, D. R., and J. Heifetz. 2001. Fishing practices under maximum retainable bycatch rates in Alaska's groundfish fisheries. Alaska Fish. Res. Bull. 8(1):22–44.

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 66, 151 p.

Anonymous. 1996. Magnuson-Stevens Fishery Conservation and Management Act. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/SPO-23, 121 p.

Archibald, C. P., W. Shaw, and B. M. Leaman. 1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977–1979. Can. Tech. Rep. Fish. Aquat. Sci. 1048, 57 p.

Balsiger, J. W., D. H. Ito, D. K. Kimura, D. A. Somerton, and J. M. Terry. 1985. Biological and economic assessment of Pacific ocean perch (*Sebastes alutus*) in waters off Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-72, 210 p.

Beamish, R. J. 1979. New information on the longevity of Pacific ocean perch (*Sebastes alutus*). J. Fish. Res. Board Can. 36:1395–1400.

Bechtol, W. R. 2000. Rockfish assessment in Prince William Sound, Alaska. Alaska Dep. Fish Game, Reg. Info. Rep. 2A99-34, 36 p. (avail. from Alaska Dep. Fish Game, Div. Commer. Fish., 333 Raspberry Road, Anchorage, AK 99518-1599).

Britt, L. L., and M. H. Martin. 2001. Data report: 1999 Gulf of Alaska bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-121, 249 p.

Brown, E. S. 1986. Preliminary results of the 1984 U.S.-Japan cooperative bottom trawl survey of the central and western Gulf of Alaska. *In* R. L. Major (Editor), Condition of groundfish resources of the Gulf of Alaska region as assessed in 1985, p. 259–296. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-106.

Courtney, D. L., J. Heifetz, M. F. Sigler, and D. M. Clausen. 1999. An age-structured model of northern rockfish, *Sebastes polyspinis*, recruitment and biomass in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 361–404. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

Eschmeyer, W. N., E. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America from the Gulf of Alaska to Baja California. Houghton Mifflin, Boston, Peterson Field Guide 28, 336 p.

Gulf of Alaska Groundfish Plan Team. 1992. Current status of stocks and acceptable biological catches. *In* Stock assessment and fishery evaluation report for the 1993 Gulf of Alaska groundfish fishery, p. 13–33. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

Guttormsen, M., R. Narita, and J. Berger. 1990. Summary of U.S. observer sampling of foreign and joint venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1989. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-189, 84 p.

Harrison, R. C. 1993. Data report: 1991 bottom trawl survey of the Aleutian Islands area. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-12, 144 p.

Heifetz, J., and D. M. Clausen. 1990. Slope rockfish. *In* Stock assessment and fishery evaluation report for the 1991 Gulf of Alaska groundfish fishery, p. 140–165. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

_____ and _____ . 1992. Slope rockfish. *In* Stock assessment and fishery evaluation report for the 1993 Gulf of Alaska groundfish fishery, p. 5-2–5-37. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

_____ , _____ , and J. N. Ianelli. 1993. Slope rockfish. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska as projected for 1994, p. 5-2–5-34. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

_____ , _____ , and _____ . 1994. Slope rockfish. *In* Stock assessment and fishery evaluation report for the 1995 Gulf of Alaska groundfish fishery, p. 5-1–5-24. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

_____ , J. N. Ianelli, D. M. Clausen, and J. T. Fujioka. 1999. Slope rockfish. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 309–360. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

Ito, D. H. 1988. Other rockfish. *In* R. G. Bakkala (Editor), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1987, p. 139–146. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-139.

_____ and J. N. Ianelli. 1994. Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions as projected for 1995, p. 9-2–9-37. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

_____ , P. D. Spencer, and J. N. Ianelli. 1999. Pacific ocean perch. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 519–557. North Pacific Fishery Management Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

Kramer, D. K., and V. M. O'Connell. 1995. Guide to northeast Pacific rockfishes genera *Sebastes* and *Sebastolobus*. Univ. Alaska, Fairbanks, Sea Grant Mar. Advis. Bull. 25. 77 p.

Lenarz, W. H., and T. Wyllie Echeverria. 1991. Sexual dimorphism in *Sebastes*. Environ. Biol. Fishes 30:71–80.

Major, R. L., and H. H. Shippen. 1970. Synopsis of biological data on Pacific ocean perch, *Sebastodes alutus*. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv. Circ. 347, 38 p.

Martin, M. H. 1997. Data report: 1996 Gulf of Alaska bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-82, 235 p.

_____ and D. M. Clausen. 1995. Data report: 1993 Gulf of Alaska bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-59, 217 p.

Mecklenburg, C. W., T. A. Mecklenburg, and L. K. Thorsteinson. 2002. Fishes of Alaska. Am. Fish. Soc., Bethesda, Maryland, 1,037 p.

Megrey, B. A., and V. G. Wespestad. 1990. Alaskan groundfish resources: 10 years of management under the Magnuson Fishery Conservation and Management Act. N. Am. J. Fish. Manage. 10(2):125–143.

Murai, S., H. A. Gangmark, and R. R. French. 1981. All-nation removals of groundfish, herring, and shrimp from the eastern Bering Sea and northeast Pacific Ocean, 1964–80. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-14, 40 p.

NPFMC (North Pacific Fishery Management Council). 1989a. Amendment 18 to the fishery management plan for groundfish in the Gulf of Alaska. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

_____ . 1989b. Amendment 13 to the fishery management plan for groundfish in the Bering Sea/Aleutian Islands areas. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501.

_____ . 1998. Essential fish habitat assessment report for the groundfish resources of the Bering Sea and Aleutian Islands region.

North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK 99501, 125 p.

Orr, J. W., M. A. Brown, and D. C. Baker. 2000. Guide to rockfishes (Scorpaenidae) of the genera *Sebastes*, *Sebastolobus*, and *Adelosebastes* of the northeast Pacific Ocean, second edition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-117, 47 p.

Pearson, D. E., J. E. Hightower, and J. T. H. Chan. 1991. Age, growth, and potential yield for shortbelly rockfish *Sebastes jordani*. Fish. Bull. 89:403–409.

Quinn, T. J., and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford Univ. Press, N. Y., 542 p.

Ronholt, L. L., K. Teshima, and D. W. Kessler. 1994. The groundfish resources of the Aleutian Islands region and southern Bering Sea 1980, 1983, and 1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-31, 351 p.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Franc., 776 p.

Stark, J. W., and D. M. Clausen. 1995. Data report: 1990 Gulf of Alaska bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-49, 221 p.

Taranetz, A. 1933. New information on the fish fauna of the Bering Sea. Vestn. Dal'nevostochnogo Filiala Akad. Nauk SSR 1-3:67–68 (In Russ.).

Wakabayashi, K., R. G. Bakkala, and M. S. Alton. 1985. Methods of the U.S.–Japan demersal trawl surveys. *In* R. G. Bakkala and K. Wakabayashi (Editors), Results of cooperative U.S.–Japan groundfish investigations in the Bering Sea during May–August 1979, p. 7–29. Int. North Pac. Fish. Comm. Bull. 44.

Westrheim, S. J., and H. Tsuyuki. 1971. Taxonomy, distribution, and biology of the northern rockfish, *Sebastes polyspinis*. J. Fish. Res. Board Can. 28:1621–1627.

Yang, M-S. 1993. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-22, 150 p.

_____ . 1996. Diets of the important groundfishes in the Aleutian Islands in summer 1991. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-60, 105 p.