Juvenile Groundfish Habitat in Kachemak Bay, Alaska, During Late Summer

Alisa A. Abookire, John F. Piatt, and Brenda L. Norcross

Reprinted from the
Alaska Fishery Research Bulletin
Vol. 8 No. 1, Summer 2001

The Alaska Fishery Research Bulletin can found on the World Wide Web
at URL: http://www.state.ak.us/adfg/geninfo/pubs/afrb/afrbhome.htm .

Alaska Fishery Research Bulletin 8(1):45–56. 2001.

Juvenile Groundfish Habitat in Kachemak Bay, Alaska, During Late Summer

Alisa A. Abookire, John F. Piatt, and Brenda L. Norcross

ABSTRACT: We investigated the habitat of juvenile groundfishes in relation to depth, water temperature, and salinity in Kachemak Bay, Alaska. Stations ranging in depth from 10 to 70 m and with sand or mud–sand substrates were sampled with a small-meshed beam trawl in August–September of 1994 to 1999. A total of 8,201 fishes were captured, comprising at least 52 species. Most fishes (91%) had a total length <150 mm and were in their juvenile stage. Overall, the most abundant fishes were the rock soles *Lepidopsetta* spp. and Pacific cod *Gadus macrocephalus*. Other common species (>5% of the total catch) were flathead sole *Hippoglossoides elassodon*, slim sculpin *Radulinus asprellus*, Pacific halibut *Hippoglossus stenolepis*, and arrowtooth flounder *Atheresthes stomias*. Depth accounted for most of the spatial variability in juvenile groundfish abundance, and neither temperature nor salinity was correlated with fish abundance. Juvenile groundfishes concentrated in either shallow (≤20 m) or deep (50–70 m) water, with co-occurrence of some species between 30–40 m. Shallow fishes were the rock soles, Pacific halibut, and great sculpin *Myoxocephalus polyacanthocephalus*. Deep species were flathead sole, slim sculpin, spinycheek starsnout *Bathyagonus infraspinatus*, rex sole *Glyptocephalus zachirus*, tadpole sculpin *Psychrolutes paradoxus*, and whitebarred prickleback *Poroclinus rothrocki*. This 6-year study provides baseline data on relative abundance and distribution of juvenile groundfishes in Kachemak Bay and may provide a useful tool for predicting the presence of species in similar habitats in other areas of Alaska.

INTRODUCTION

Knowledge about the habitat and distribution of juvenile groundfishes is essential to assess and interpret early life stage growth, survival, and subsequent recruitment to the stock. Growth rates of juvenile groundfishes have been related to various habitat characteristics such as water temperature (Deniel 1990; Gadomski and Caddell 1991; Ottersen and Loeng 2000) and sediment type (Moles and Norcross 1998). Recruitment has been shown to be positively related to the amount of available nursery habitat for both sole *Solea solea* (Zijlstra 1972; Rijnsdorp et al. 1992) and plaice *Pleuronectes platessa* (Zijlstra 1972). Similarly, the distribution and survival of juvenile Atlantic cod *Gadus morhua* appear to be habitat dependent (Lough et al. 1987).

We studied juvenile groundfishes in various habitats of Kachemak Bay, Alaska, during the late summers of 1994–1999. Kachemak Bay is located in eastern lower Cook Inlet and is a very productive estuarine system, largely because upwelling in lower Cook Inlet supplies nutrient-rich water to the bay (Muench et al. 1978). The 2 most abundant juvenile flatfishes in Kachemak Bay are the rock soles *Lepidopsetta* spp., which concentrate on sand substrates at depths <20 m, and flathead sole *Hippoglossoides elassodon*, which concentrate on mud substrates at depths of 40–60 m (Abookire and Norcross 1998). In this investigation we sampled stations that included these 2 distinct habitats. Our objectives were to describe: (1) the species composition of juvenile groundfishes and (2) the habitat of the most abundant fishes in relation to depth, temperature, and salinity. Kachemak Bay was offi-

Authors: ALISA A. ABOOKIRE is a research fisheries biologist with the National Marine Fisheries Service, Kodiak Laboratory, 301 Research Court, Kodiak, AK 99615. Email: alisa.abookire@noaa.gov. JOHN F. PIATT is a research wildlife biologist with the U.S. Geological Survey, Biological Resources Division, 1011 E. Tudor Road, Anchorage, AK 99503. BRENDA L. NORCROSS is an associate professor with the Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Fairbanks, AK 99775.
Acknowledgments: We extend our gratitude to the people who assisted with this project. Captain R. Geagel, Captain M. Geagel, Captain G. Snedgen, M. Arimitsu, E. Chilton, J. Figurski, and F. Mueter — assisted with fieldwork in multiple years. B. Holladay — identified newly settled flatfishes. D. Holt — processed sediment samples. C. Armistead — made Figure 1. M. Litzow, F. Mueter, J. Orr, D. Somerton, and 2 anonymous reviewers — reviewed manuscript.
Project Sponsorship: This project was funded from 1994–1996 by the Minerals Management Service (grant MMS-CMI #14-35-001-30661) through the University of Alaska Coastal Marine Institute. Funding from 1997–1999 was provided by the *Exxon Valdez* Oil Spill Trustee Council (Restoration Project 99163M) and the U.S. Geological Survey.

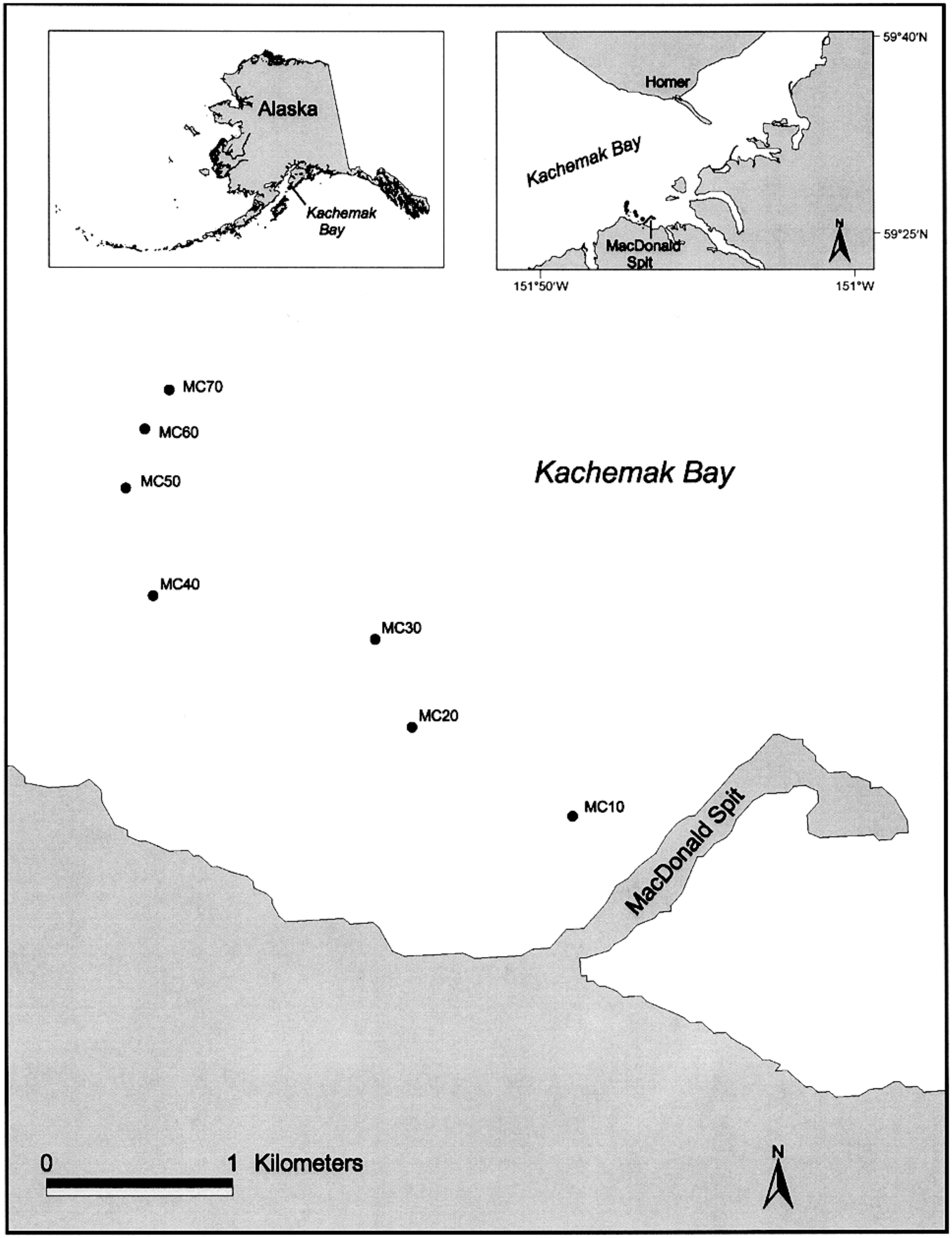


Figure 1. Stations sampled by beam trawl off MacDonald Spit in Kachemak Bay, Alaska, 1994–1999. The number in the station label indicates the depth in meters.

Table 1. Sampling stations in Kachemak Bay, Alaska. Station location, mininum and maximum depth, and sediment are listed for each station. Sediment data (percent gravel, sand, and mud) are averaged from samples collected in August 1995 and 1996.

	Station Location		Depth (m)		Mean Sediment Composition		
Station	North Latitude	West Longitude	Min	Max	% Gravel	% Sand	% Mud
MC10	59°28.82′	151°35.54′	10.2	11.5	0.0	95.3	4.7
MC20	59°29.16′	151°36.07′	18.5	20.6	0.1	96.1	3.8
MC30	59°29.39′	151°36.51′	28.2	31.4	0.9	80.4	18.7
MC40	59°29.51′	151°37.44′	39.1	41.3	0.1	76.9	23.0
MC50	59°29.83′	151°37.62′	49.3	49.8	0.1	83.0	16.9
MC60	59°30.00′	151°37.52′	60.4	61.1	0.3	80.0	19.8
MC70	59°30.09′	151°37.34′	69.5	70.4	0.0	76.9	23.1

cially designated a National Estuarine Research Reserve (NERR) in February 1998, and thus will likely support long-term estuarine research. Findings from this study provide baseline data for long-term studies on the distribution and habitat of juvenile groundfishes in Alaska.

METHODS

We sampled 6 stations off MacDonald Spit in Kachemak Bay, Alaska (Figure 1). Sampling occurred on September 27–30, 1994; August 1–2, 1995; August 10, 1996; August 17–18, 1997; August 15–16, 1998; and August 21, 1999. Station depths were 10, 20, 30, 40, 50, and 70 m, and all tows occurred within 2 m of the targeted depth. An additional station at 60 m, MC60, was sampled in 1995 and 1996 for a total of 7 stations in those years. We sampled in August and September because that is when most age-0 flatfishes have settled on the bottom from their pelagic stage and are large enough to be captured by our beam trawl (Abookire 1997). From an oceanographic context our sampling occurred during late summer because both surface- and bottom-water temperatures in Kachemak Bay usually reach an annual maximum in August (Abookire 1997). Stations were sampled in 1–2 days and were on a gradually sloping bottom, which allowed depth increments of 10 ± 2 m to be clearly defined.

From 1994 to 1997 we fished with a 9.3-m Munsen boat, and from 1998 to 1999 we used the 10-m R/V *David Grey*. A 3.05-m plumbstaff beam trawl equipped with a double tickler chain (Gunderson and Ellis 1986) was used to sample juvenile groundfishes. The net body was 7-mm square mesh with a 4-mm mesh codend liner. Standard tow duration was 10 min. Tidal range in Kachemak Bay is 7 m, so the depth at each station changes with tidal stage. The objective was to hold depth, not position, constant. Therefore, the position of each station was located (Table 1) and then varied with the tide to sample the desired depth. For each station, the exact start and end positions of every tow were recorded and used to calculate the distance trawled. All tows were in the direction of the tidal current. If the first tow at a station was bad, we resampled the station until we had a good tow. Tows were considered bad if the trawl twisted, broke a weaklink, tore, or if the net was full beyond the codend. Bad tows were omitted from data analysis.

Before each trawl a CTD (Seabird Electronics Inc, SBE-19 SEACAT profiler) was deployed to measure water temperature (°C), salinity (practical salinity units), and depth (in meters). These data were used for comparisons of bottom-water temperature and salinity, which were calculated by taking average values ($n \approx 12$) of data collected in 30 s within the deepest 5 m of water. Additionally, the top 3–7 cm of sediment was collected at each station in August 1995 and 1996 with a 0.06-m^3 Ponar grab. Samples were frozen and transported to the laboratory for grain-size analysis using a sieve/pipette procedure (Folk 1980) to determine percentage of cobble, gravel, sand, and mud using the Wentworth scale (Sheppard 1973). Sediment data for each station were averaged over the 2 years.

Fishes were identified in the field to the lowest possible taxon, counted, and measured to the nearest millimeter for total length. Newly settled flatfishes that could not be identified in the field were frozen and returned to the laboratory for identification. At the time of collection, all rock soles were identified as *Pleuronectes bilineatus*, but due to Orr and Matarese's (2000) revision of the genus we refer to these fishes as *Lepidopsetta* spp. in this paper. Both species, *L. bilineata* and *L. polyxystra*, were identified in the study area after our collections were made. All fish data were standardized to catch per unit effort (CPUE)

Table 2. Catch per unit effort (number/1,000 m^2) of fishes that each comprised at least 1% of the total catch in Kachemak Bay, Alaska. The CPUE data are presented for all years combined and for each year separately, 1994–1999. The number of trawls is given in parentheses.

Common Name	Scientific Name	1994–1999 (38)	1994 (6)	1995 (7)	1996 (7)	1997 (6)	1998 (6)	1999 (6)
Rock sole	*Lepidopsetta* spp.	36.3	31.2	14.4	60.4	29.5	47.5	29.5
Pacific cod	*Gadus macrocephalus*	19.2	0.1	48.7	0.0	50.3	0.2	0.6
Flathead sole	*Hippoglossoides elassodon*	6.5	14.1	8.3	3.2	2.9	7.3	7.6
Slim sculpin	*Radulinus asprellus*	6.4	17.3	2.7	4.0	1.5	3.5	12.8
Pacific halibut	*Hippoglossus stenolepis*	5.4	3.6	2.9	5.9	5.5	3.7	10.1
Arrowtooth flounder	*Atheresthes stomias*	5.0	5.3	0.5	3.9	3.3	3.2	15.1
Yellowfin sole	*Pleuronectes asper*	3.3	8.7	1.1	5.0	0.3	1.6	3.0
Walleye pollock	*Theragra chalcogramma*	2.8	0.0	9.9	4.0	0.5	0.0	0.0
Spinycheek starsnout	*Bathyagonus infraspinatus*	2.8	7.0	2.5	1.4	1.1	2.5	4.0
Rex sole	*Glyptocephalus zachirus*	1.8	0.7	0.9	2.2	1.1	3.5	3.2
Dover sole	*Microstomus pacificus*	1.4	2.3	0.5	1.0	0.8	5.8	1.0
Tadpole sculpin	*Psychrolutes paradoxus*	1.2	1.2	1.3	1.6	0.5	3.2	0.4
Snake prickleback	*Lumpenus sagitta*	0.9	0.6	0.7	1.0	0.0	2.8	1.4
Great sculpin	*Myoxocephalus polyacanthocephalus*	0.7	0.1	0.7	1.5	0.4	0.2	0.5
Whitebarred prickleback	*Poroclinus rothrocki*	0.6	0.1	0.8	0.9	0.1	0.8	0.7

for an area of 1,000 m^2. The area towed was calculated as the effective width of net (0.74 m, Gunderson and Ellis 1986), multiplied by the width of our trawl (3.05 m) and the distance trawled as determined from global positioning system data.

Length-frequency histograms were plotted for the 6 most abundant species, with fish lengths grouped in increments of 10 mm. Size classes were defined based on previous studies of length-at-age for flatfishes (Norcross et al. 1998; Bouwens et al. 1999) and Pacific cod *Gadus macrocephalus* (Takatsu et al. 1995). Because slim sculpin *Radulinus asprellus* length-at-age and maturity are not known, size groups for this species were based solely on the bimodal distribution of length data.

Canonical correlation analysis was used to examine CPUE of the most abundant fishes in relation to depth and bottom temperature and salinity. Each species that comprised at least 1% of the total catch for all years combined was analyzed separately, and all individuals with lengths <150 mm were combined for CPUE. Linear combinations of environmental variables were derived to produce canonical variables that summarize within-species variation in the CPUE data (Johnson and Wichern 1992). Samples from different years were considered replicates. Environmental variables were correlated with the canonical variables to produce canonical correlation components, with the first canonical correlation accounting for the maximal multiple correlation. A negative depth coefficient was interpreted to mean the species abundance increased as depth decreased. Two-factor analysis of variance (ANOVA) tests by year and depth were performed on thermohaline data, followed by a Bonferroni multiple comparison procedure. Thermohaline data from station MC60 were omitted from the two-way ANOVA because they were only sampled in 1995 and 1996. Alpha was 0.05 for all tests of significance.

RESULTS

A total of 8,201 fishes were captured in 38 tows. At least 52 species were captured, with an annual catch between 100 and 296 fish per 1,000 m^2 (Appendix 1). The 6-year average CPUE of juvenile rock soles and juvenile Pacific cod were an order of magnitude higher than other species (Table 2). Rock soles were the most frequently captured species (63% of trawls). Pacific cod were captured in 45% of the trawls, but 94% of the total catch accrued in 2 trawls (in 1995 and 1997). Fifteen species each comprised at least 1% of the total catch for all years (Table 2), and the abundant species were rock soles, Pacific cod, flathead sole, slim sculpin, Pacific halibut *Hippoglossus stenolepis*, and arrowtooth flounder *Atheresthes stomias*.

Fish lengths ranged from 12 mm for rock sole to 465 mm for starry flounder *Platichthys stellatus*. Most (91%) demersal fishes had total lengths <150 mm and were in their juvenile stage. There appeared to be multiple cohorts in several species (Figure 2). The 2 smallest size groups were determined from the length-frequency histograms and classified as young of the year and early juveniles, respectively (Table 3).

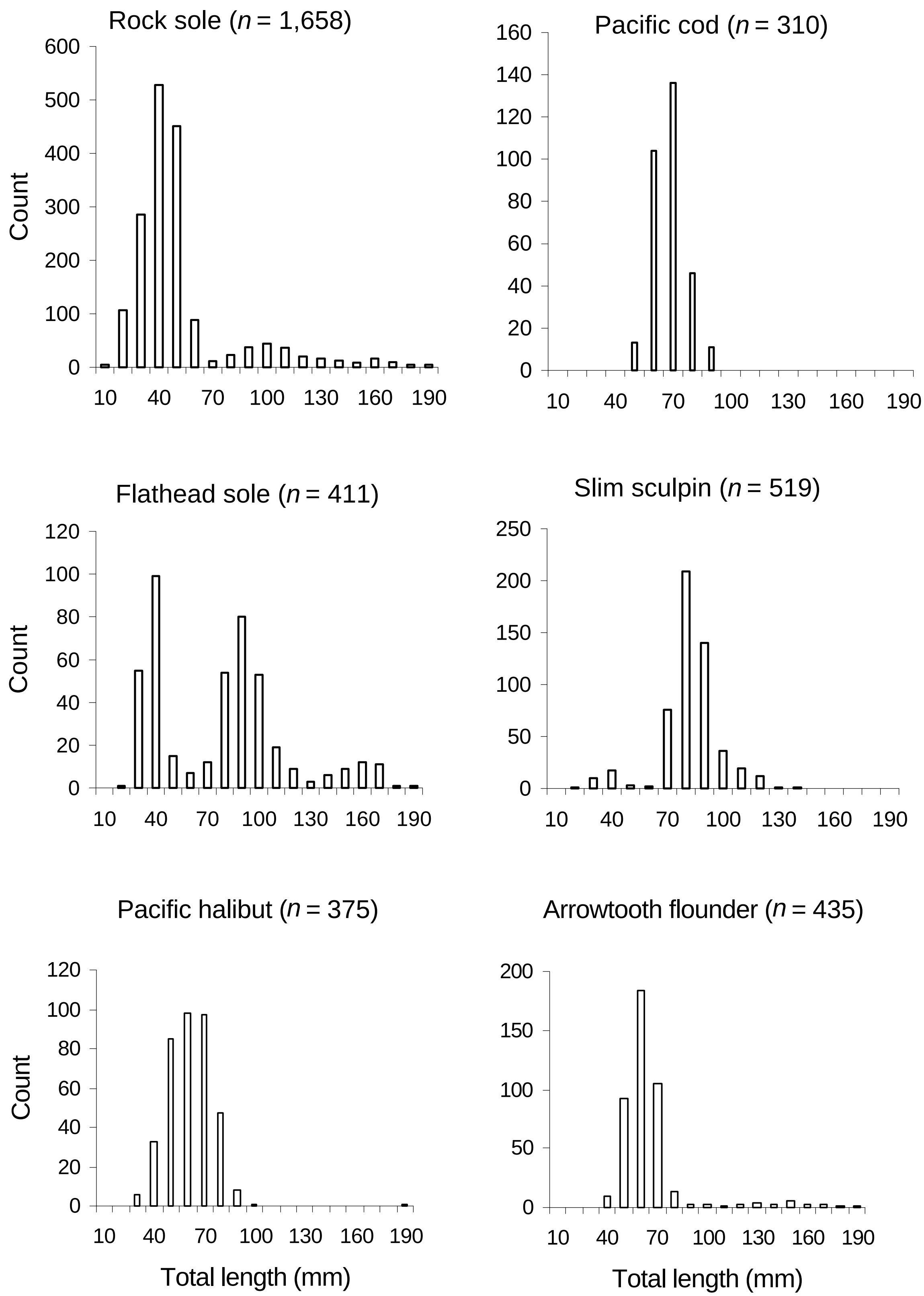


Figure 2. Length-frequency histograms for fishes that comprised at least 5% of the total catch. Data are combined for 1994–1999. Lengths were grouped in 10-mm intervals. The total numbers of fish measured are given in parentheses.

Table 3. The two smallest size groups as determined from length-frequency histograms for fishes that comprised at least 5% of the total catch in Kachemak Bay, Alaska. In each size group the minimum and maximum length (mm), number of fish measured (*n*), mean length (mm), and standard deviation (SD) are given.

		Young of the Year					Early Juvenile				
Common Name	Scientific Name	Min	Max	*n*	Mean	SD	Min	Max	*n*	Mean	SD
Rock sole	*Lepidopsetta* spp.	12	69	1,472	40.3	10.0	72	141	186	102.5	16.1
Pacific cod	*Gadus macrocephalus*	47	92	310	66.9	7.9					
Flathead sole	*Hippoglossoides elassodon*	21	56	171	37.2	5.5	60	139	240	91.8	14.2
Slim sculpin	*Radulinus asprellus*	18	48	31	37.5	6.1	63	118	488	83.6	10.2
Pacific halibut	*Hippoglossus stenolepis*	26	100	375	60.7	12.8					
Arrowtooth flounder	*Atheresthes stomias*	42	100	410	60.2	8.8	113	185	25	148.4	21.6

Depth and sediment type were related. Shallow (≤20 m) station sediments were at least 95% sand, and sediments from deeper stations were mixtures of 77–83% sand and 17–23% mud (Table 1). Bottom temperature varied among depths ($F = 3.58$, $P = 0.0140$, df = 5), although variation was greater among years ($F = 63.19$, $P < 0.0001$, df = 5). Warmest years were 1997 and 1998 (Table 4). Bottom salinity varied interannually ($F = 47.30$, $P < 0.0001$, df = 5), but not spatially ($F = 0.77$, $P = 0.5823$, df = 5).

Demersal fish habitat was defined more by depth than by temperature or salinity for most species because the highest canonical correlation coefficients were usually assigned to the depth variable (Table 5). Certain species were predominately captured at depths that were either shallow (≤ 20 m) or deep (50 to 70 m). Some co-occurrence of shallow and deep species occurred between depths of 30 and 40 m. Shallow species were rock soles, Pacific halibut, and great sculpin *Myoxocephalus polyacanthocephalus* (Figure 3). Although not statistically significant, juvenile Pacific cod also concentrated at shallow depths; 94% were captured at 10 m. Deep species were flathead sole, slim sculpin, spinycheek starsnout *Bathyagonus infraspinatus*, rex sole *Glyptocephalus zachirus*, tadpole sculpin *Psychrolutes paradoxus*, and whitebarred prickleback *Poroclinus rothrocki* (Figure 3).

Table 4. Bottom temperature and bottom salinity (practical salinity units) at stations in Kachemak Bay, Alaska, 1994–1999. Averages and standard error (SE) are given for all stations (depth range 10–70 m) within each year.

	Temperature (°C)		Salinity	
Year	Mean	SE	Mean	SE
1994	9.53	0.03	30.51	0.08
1995	9.13	0.13	31.29	0.04
1996	9.30	0.05	31.56	0.03
1997	11.11	0.19	31.34	0.09
1998	10.28	0.09	31.11	0.02
1999	9.73	0.02	31.50	0.01

Discussion

In late summer of 1994 to 1999, 6 species of juvenile groundfishes comprised 79% of the total catch in Kachemak Bay, Alaska. Rock soles were the most abundant species and were captured in high abundances consistently throughout the 6-year study. Pacific cod were the second most abundant species captured over all years, but catches were large in only 2 of 6 years. Other abundant species included flathead sole, slim sculpin, Pacific halibut, and arrowtooth flounder. Kachemak Bay is a nursery area for flatfishes (Abookire and Norcross 1998) and in some years may also serve as a nursery area for Pacific cod.

Habitat of juvenile groundfishes was defined more by depth than by water temperature or salinity. Depth accounted for the most variation in fish catches, with species assemblages concentrated in either shallow (≤20 m) or deep (50–70 m) water. Nursery areas for fishes are complex systems (Rogers 1992), and the habitat used by juvenile fishes may vary with the size (Stoner et al. *in press*) and age of the fish (Gibson 1994; Fraser et al. 1996) and may be subject to tidal and seasonal influences (Gibson 1973; Roper and Jillett 1981; Dorel et al. 1991). Although depth defined the species assemblages that were evident in our study, what we classify as a shallow-water group may in fact be a sand-substrate group. Juvenile groundfishes demonstrate selection for sediments (Scott 1982; Moles and Norcross 1995), in part to avoid predation (Rogers 1992; Gregory and Anderson 1997) and to feed (Rogers 1992). Both depth and sediment previously have been determined to define the habitats of juvenile rock sole, flathead sole (Norcross et al. 1995; Abookire and Norcross 1998), and juvenile Pacific halibut (Norcross et al. 1995, 1997, 1999).

Fishes generally seek water temperatures that maximize growth and survival (Malloy and Targett

Table 5. The first canonical correlation coefficients of the environmental variables depth, bottom temperature, and bottom salinity for fishes that comprised at least 1% of the total catch in Kachemak Bay, Alaska. Data are combined for all years, 1994–1999. Species are listed in order of abundance. Significant *P* values were assigned a depth group of shallow (S) or deep (D) based on the sign of the depth coefficient, and a hyphen (-) denotes a nonsignificant value of *P*.

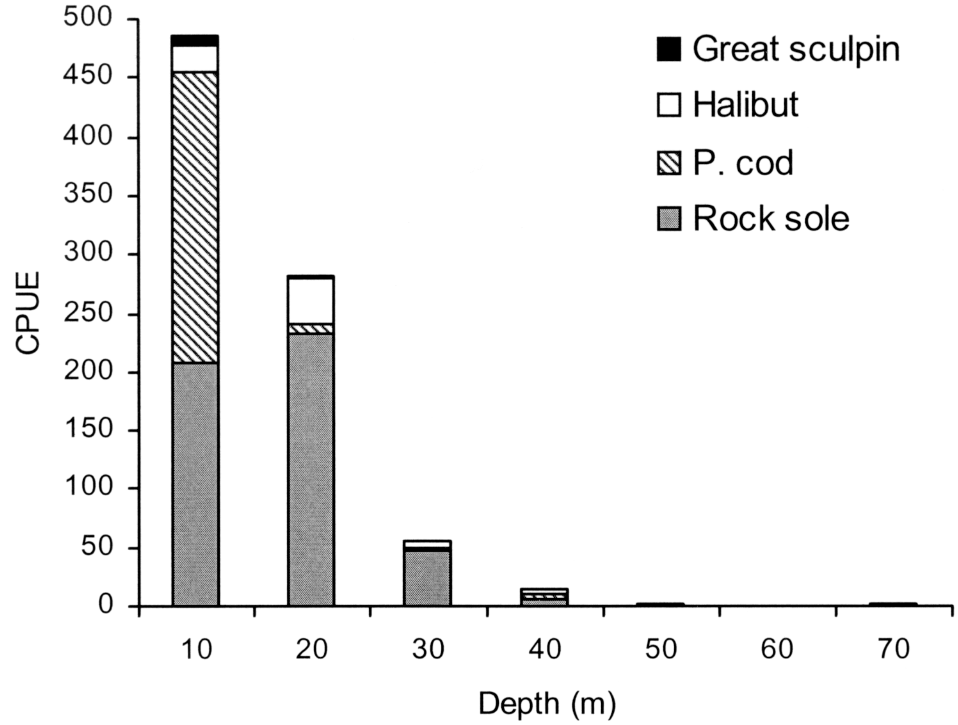
Common Name	Scientific Name	Depth	Temperature	Salinity	*P* (df = 34)	Depth Group
Rock sole	*Lepidopsetta* spp.	-1.038	-0.211	0.281	0.018	S
Pacific cod	*Gadus macrocephalus*	-0.798	0.454	0.201	0.151	-
Flathead sole	*Hippoglossoides elassodon*	0.894	-0.250	-0.387	< 0.001	D
Slim sculpin	*Radulinus asprellus*	0.924	-0.153	-0.441	0.008	D
Pacific halibut	*Hippoglossus stenolepis*	-0.999	-0.044	0.386	0.008	S
Arrowtooth flounder	*Atheresthes stomias*	0.593	-0.015	0.709	0.571	-
Yellowfin sole	*Pleuronectes asper*	-0.751	-0.656	-0.391	0.206	-
Walleye pollock	*Theragra chalcogramma*	-0.588	-0.783	0.603	0.372	-
Spinycheek starsnout	*Bathyagonus infraspinatus*	0.909	-0.189	-0.439	< 0.001	D
Rex sole	*Glyptocephalus zachirus*	0.911	0.005	0.290	0.018	D
Dover sole	*Microstomus pacificus*	0.894	0.503	-0.568	0.409	-
Tadpole sculpin	*Psychrolutes paradoxus*	0.930	-0.229	-0.084	< 0.001	D
Snake prickleback	*Lumpenus sagitta*	-0.495	-0.713	0.719	0.753	-
Great sculpin	*Myoxocephalus polyacanthocephalus*	-0.944	-0.391	0.545	0.031	S
Whitebarred prickleback	*Poroclinus rothrocki*	0.846	-0.335	0.093	0.003	D

1991), and these temperatures may differ with life history stage and age (Gadomski and Caddell 1991). Bottom temperatures at individual stations had a wide range during this study (8.4–11.6°C) and varied more interannually than spatially. In contrast with other studies (Norcross et al. 1997, 1999) we found no direct link between temperature and fish distribution. We note, however, that fish CPUE in Kachemak Bay was markedly low in 1998 following a winter with anomalously warm water temperatures due to the strong 1997/98 El Niño event (Piatt et al. 1999).

Mueter and Norcross (1999) studied juvenile groundfish community structure in coastal Alaska and defined nearshore fish assemblages around Kodiak Island using the same sampling gear and strategies that we employed. Demersal fish communities in nearshore areas around Kodiak Island are primarily structured along gradients of depth and sediment (Mueter and Norcross 1999). The shallow species we identified in Kachemak Bay were also shallow species near Kodiak Island. Shallow and deep assemblages around Kodiak Island are partitioned at a depth boundary of 50 m (Mueter and Norcross 1999), whereas in Kachemak Bay 30–40-m depth separates the 2 assemblages. Distinct fish associations are consistent regardless of actual depth, as *Psychrolutes* spp. (we captured tadpole sculpin), *Bathyagonus* spp. (we captured spinycheek starsnout), and flathead sole were grouped as deepwater fishes in both areas. The differential structure of the Kachemak Bay and Kodiak Island communities with respect to depth suggests that other factors also may influence juvenile groundfish distributions (e.g., food availability, predation, competition, or turbulence).

Similar juvenile fish assemblages in both Kachemak Bay and Kodiak Island were evident, but differences between areas were also found. Rex sole were in the deep group in our study and are found on the outer continental shelf (150–200-m depth) off the coast of Oregon (Pearcy et al. 1977), but they were rare around Kodiak Island (Mueter and Norcross 1999). Arrowtooth flounders are found in the deep group around Kodiak Island (Mueter and Norcross 1999), but they were not concentrated in either depth group in Kachemak Bay even though they comprised more than 5% of the catch.

Pacific cod is an economically important groundfish species ranging from southern California to the Chukchi Sea, and from Kamchatka to the Yellow Sea (Hart 1973). Adult Pacific cod can be found in both inshore and offshore environments extending out to the continental shelf, but very little is known about the habitat requirements or migration of juveniles (Dunn and Matarese 1987). Around Kodiak Island, juvenile Pacific cod were found in shallow water (Mueter and Norcross 1999). Although 94% of juvenile Pacific cod were captured at 10 m, depth was not a statistically significant parameter in the distribution of juvenile Pacific cod in our study. This may be due, in part, to the high interannual variability in cod CPUE. Catches of juvenile Atlantic cod are also known to fluctuate and have high interannual variability (Methven



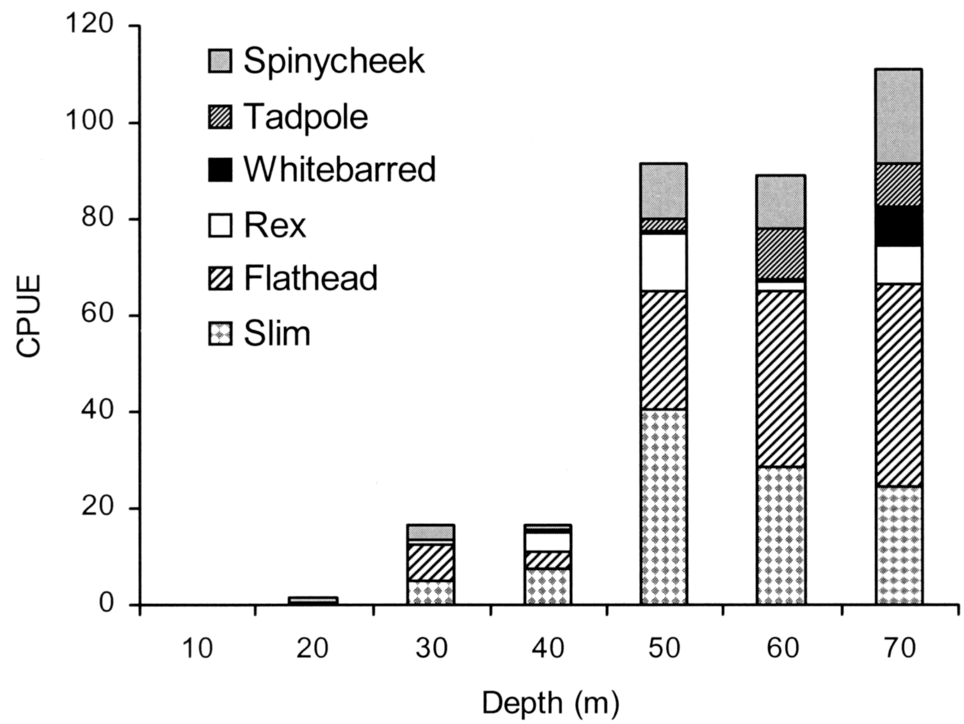


Figure 3. Mean CPUE of fishes captured from 10- to 70-m depth. Data are combined for all years. In the top graph, species with a negative depth canonical correlation coefficient are presented: great sculpin, Pacific halibut, and rock soles. Although their distribution was not significantly correlated with depth, Pacific cod also are shown. The lower graph shows species with a positive depth canonical correlation coefficient: spinycheek starsnout, tadpole sculpin, whitebarred prickleback, rex sole, flathead sole, and slim sculpin.

and Bajdik 1994). Age-0 Atlantic cod mainly inhabit nearshore areas at depths < 10 m (Methven and Schneider 1998), but they have also been found as deep as 130 m in inshore waters of Newfoundland (Gregory and Anderson 1997). As juvenile Atlantic cod grow they utilize a wide range of sediments including sand, gravel, and macroalgae (Keats et al. 1987; Fraser et al. 1996; Gregory and Anderson 1997).

For practical reasons, only a small fraction of the vast Alaskan coastline can be sampled for nearshore fish assemblages and habitats. Characterizing fish habitat with physical parameters such as depth, temperature, and sediment type may provide a useful tool for predicting the presence of fish species in unsampled areas. We recommend that further investigations be conducted in Kachemak Bay, which is a National Estuarine Research Reserve, in order to focus our scientific effort and advance our understanding of nearshore ocean ecology in Alaska. The findings of this study provide baseline data and a context within which future questions about the distribution, community dynamics, and recruitment of juvenile groundfishes might be framed.

LITERATURE CITED

Abookire, A. A. 1997. Environmental factors affecting seasonal habitat and distribution of flathead sole and rock sole in Kachemak Bay, Alaska. Master's thesis, University of Alaska Fairbanks.

Abookire, A. A., and B. L. Norcross. 1998. Depth and sediment as determinants of juvenile flathead sole (*Hippoglossoides elassodon*) and rock sole (*Pleuronectes bilineatus*) distribution in Kachemak Bay, Alaska. Journal of Sea Research 39:113–123.

Bouwens, K. A., R. L. Smith, A. J. Paul, and W. Rugen. 1999. Length at and timing of hatching and settlement for arrowtooth flounders in the Gulf of Alaska. Alaska Fishery Research Bulletin 6(1):41–48.

Deniel, C. 1990. Comparative study of growth of flatfishes on the west coast of Brittany. Journal of Fish Biology 37:149–166.

Dorel, D., C. Koutsikopoulos, Y. Desaunay, and J. Marchand. 1991. Seasonal distribution of young sole (*Solea solea* (L.)) in the nursery ground of the Bay of Vilaine (northern Bay of Biscay). Netherlands Journal of Sea Research 27:297–306.

Dunn, J. R., and A. C. Matarese. 1987. A review of the early life history of northeast Pacific gadoid fishes. Fisheries Research 5:163–184.

Folk, F. L. 1980. Petrology of sedimentary rocks. Hemphill Publishing Company, Austin, Texas.

Fraser, S., V. Gotceitas, and J. A. Brown. 1996. Interactions between age-classes of Atlantic cod and their distribution among bottom substrates. Canadian Journal of Fisheries and Aquatic Sciences 53:305–314.

Gadomski, D. M., and S. M. Caddell. 1991. Effects of temperature on early-life-history stages of California halibut *Paralichthys californicus*. Fishery Bulletin 89:567–576.

Gibson, R. N. 1973. The intertidal movements and distribution of young fish on a sandy beach with special reference to the plaice (*Pleuronectes platessa* L.). Journal of Experimental Marine Biology and Ecology 12:79–102.

Gibson, R. N. 1994. Impact of habitat quality and quantity on the recruitment of juvenile flatfishes. Netherlands Journal of Sea Research 32:191–206.

Gregory, R. S., and J. T. Anderson. 1997. Substrate selection and use of protective cover by juvenile Atlantic cod *Gadus morhua* in inshore waters of Newfoundland. Marine Ecology Progress Series 146:9–20.

Gunderson, D. R. and I. E. Ellis. 1986. Development of a plumb staff beam trawl for sampling demersal fauna. Fisheries Research 4:35–41.

Hart, J. L. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada. Bulletin 180.

Johnson, R. A., and D. W. Wichern. 1992. Applied multivariate statistical analysis. Prentice Hall, Englewood Cliffs, New Jersey.

Keats D. W., D. H. Steele, and G. R. South. 1987. The role of fleshy macroalgae in the ecology of juvenile cod (*Gadus morhua* L.) in inshore waters off eastern Newfoundland. Canadian Journal of Zoology 65:49–53.

Lough, R. G., P. C. Valentine, D. C. Potter, P. J. Auditore, G. R. Bolz, J. D. Neilson, and R. P. Perry. 1987. Ecology and distribution of juvenile cod and haddock in relation to sediment type and bottom currents on eastern Georges Bank. Marine Ecology Progress Series 56:1–12.

Malloy, K. D., and T. E. Targett. 1991. Feeding, growth and survival of juvenile summer flounder *Paralichthys dentatus:* experimental analysis of the effects of temperature and salinity. Marine Ecology Progress Series 72:213–223.

Methven, D. A., and C. Bajdik. 1994. Temporal variation in size and abundance of juvenile Atlantic cod (*Gadus morhua*) at an inshore site off eastern Newfoundland. Canadian Journal of Fisheries and Aquatic Sciences 51:78–90.

Methven, D. A., and D. C. Schneider. 1998. Gear-independent patterns of variation in catch of juvenile Atlantic cod (*Gadus morhua*) in coastal habitats. Canadian Journal of Fisheries and Aquatic Sciences 55:1430–1442.

Moles, A., and B. L. Norcross. 1995. Sediment preference in juvenile Pacific flatfishes. Netherlands Journal of Sea Research 34:177–182.

Moles, A., and B. L. Norcross. 1998. Effects of oil-laden sediment on growth and health of juvenile flatfishes. Canadian Journal of Fisheries and Aquatic Sciences 55:605–610.

Muench, R. D., H. O. Mofjeld, and R. L. Charnell. 1978. Oceanographic conditions in lower Cook Inlet: spring and summer 1973. Journal of Geophysical Research 83(C10):5090–5098.

Mueter, F. J., and B. L. Norcross. 1999. Linking community structure of small demersal fishes around Kodiak Island, Alaska, to environmental variables. Marine Ecology Progress Series 190:37–51.

Norcross, B. L., A. Blanchard, and B. A. Holladay. 1999. Comparison of models for defining nearshore flatfish nursery areas in Alaskan waters. Fisheries Oceanography 8:50–67.

Norcross, B. L., B. A. Holladay, A. A. Abookire, and S. C. Dressel. 1998. Defining habitats for juvenile groundfishes in Southcentral Alaska, with emphasis on flatfishes. Final Report, OCS Study Minerals Management Service (MMS 97-0046). Coastal Marine Institute, University of Alaska Fairbanks.

Norcross, B. L., B. A. Holladay, and F. J. Müter. 1995. Nursery area characteristics of pleuronectids in coastal Alaska, USA. Netherlands Journal of Sea Research 34:161–175.

Norcross, B. L., F. J. Müter, and B. A. Holladay. 1997. Habitat models for juvenile pleuronectids around Kodiak Island, Alaska. Fishery Bulletin 95:504–520.

Orr, J. W., and A. C. Matarese. 2000. Revision of the genus *Lepidopsetta* Gill, 1862 (Teleostei: Pleuronectidae) based on larval and adult morphology, with a description of a new species from the North Pacific Ocean and Bering Sea. Fishery Bulletin 98:539–582.

Ottersen, G., and H. Loeng. 2000. Covariability in early growth and year-class strength of Barents Sea cod, haddock, and herring: the environmental link. ICES Journal of Marine Science 57:339–348.

Pearcy, W. G., M. J. Hosie, and S. L. Richardson. 1977. Distribution and duration of pelagic life of larvae of Dover sole, *Microstomus pacificus*; rex sole, *Glyptocephalus zachirus*; and petrale sole, *Eopsetta jordani*, in waters off Oregon. Fishery Bulletin 75:173–183.

Piatt, J. F., G. Drew, T. Van Pelt, A. Abookire, A. Nielsen, M. Shultz, and A. Kitaysky. 1999. Biological effects of the 1997/98 ENSO in Cook Inlet, Alaska. PICES Scientific Report 10:93–99.

Rijnsdorp, A. D., F. A. van Beek, S. Flatman, R. M. Millner, J. D. Riley, M. Giret, and R. De Clerck. 1992. Recruitment of sole stocks, *Solea solea* (L.), in the northeast Atlantic. Netherlands Journal of Sea Research 29:173–192.

Rogers, S. I. 1992. Environmental factors affecting the distribution of sole (*Solea solea* (L.)) within a nursery area. Netherlands Journal of Sea Research 29:153–161.

Roper, D. S., and J. B. Jillett. 1981. Seasonal occurrence and distribution of flatfish (Pisces: Pleuronectiformes) in inlets and shallow water along the Otago coast. New Zealand Journal of Marine and Freshwater Research 15:1–13.

Scott, J. S. 1982. Selection of bottom type by groundfishes in the Scotian Shelf. Canadian Journal of Fisheries and Aquatic Sciences 39:943–947.

Sheppard, F. M. 1973. Submarine geology. 3rd edition. Harper and Row Publishers, New York.

Stoner, A. W., J. P. Manderson, and J. P. Pessutti. *In press*. Spatially-explicit analysis of estuarine habitat for juvenile winter flounder: combining generalized additive models and geographic information systems. Marine Ecology Progress Series.

Takatsu, T., T. Nakatani, T. Mutoh, and T. Takahashi. 1995. Feeding habits of Pacific cod larvae and juveniles in Mutsu Bay, Japan. Fisheries Science 61:415–422.

Zijlstra, J. J. 1972. On the importance of the Wadden Sea as a nursery area in relation to the conservation of the southern North Sea fishery resources. Symposium of the Zoological Society of London 29:233–258.

Appendix 1. List of all species captured by beam trawl in Kachemak Bay, Alaska, 1994–1999. Mean CPUE and standard deviation (SD) are listed for each year. Number of trawls is in parentheses. Species are listed in phylogenetic order.

		1994 (6)		1995 (7)		1996 (7)		1997 (6)		1998 (6)		1999 (6)	
Common Name	Scientific Name	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Alaska skate	*Bathyraja parmifera*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7
Big skate	*Raja binoculata*	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Longnose skate	*Raja rhina*	0.0	0.0	0.3	0.7	0.0	0.0	0.3	0.7	0.2	0.4	0.0	0.0
Pacific cod	*Gadus macrocephalus*	0.2	0.4	97.8	235.5	0.0	0.0	147.2	344.7	0.2	0.4	1.2	1.3
Saffron cod	*Eleginus gracilis*	0.0	0.0	0.0	0.0	0.9	1.9	0.0	0.0	0.2	0.6	0.0	0.0
Pacific tomcod	*Microgadus proximus*	1.9	2.7	0.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Walleye pollock	*Theragra chalcogramma*	0.0	0.0	19.9	45.9	11.8	21.8	1.5	3.2	0.0	0.0	0.0	0.0
Shortfin eelpout	*Lycodes brevipes*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.5	1.1
Sebastes spp.	*Sebastes* spp.	0.2	0.4	0.0	0.0	0.0	0.0	0.2	0.5	0.0	0.0	0.0	0.0
Whitespotted greenling	*Hexagrammos stelleri*	0.0	0.0	0.5	1.3	0.4	0.9	0.0	0.0	0.4	0.7	0.0	0.0
Lingcod	*Ophiodon elongatus*	0.2	0.4	0.0	0.0	0.0	0.0	0.2	0.4	0.2	0.6	0.9	0.7
Spinyhead sculpin	*Dasycottus setiger*	0.0	0.0	0.0	0.0	0.1	0.4	0.2	0.4	0.0	0.0	0.9	2.2
Gymnocanthus spp.	*Gymnocanthus* spp.	3.8	9.3	1.5	3.9	0.0	0.0	0.0	0.0	0.2	0.4	0.0	0.0
Armorhead sculpin	*Gymnocanthus galeatus*	0.2	0.4	0.0	0.0	0.0	0.0	0.3	0.7	0.2	0.5	3.5	3.2
Red Irish lord	*Hemilepidotus hemilepidotus*	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Yellow Irish lord	*Hemilepidotus jordani*	0.0	0.0	0.1	0.4	0.1	0.4	0.0	0.0	0.2	0.4	0.2	0.4
Northern sculpin	*Icelinus borealis*	1.1	1.3	0.7	1.3	2.1	2.8	0.5	1.3	0.9	1.3	0.3	0.4
Great sculpin	*Myoxocephalus polyacanthocephalus*	0.2	0.4	1.5	3.9	4.4	11.3	1.2	3.0	0.2	0.6	1.0	0.6
Sailfin sculpin	*Nautichthys oculofasciatus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.0	0.0
Eyeshade sculpin	*Nautichthys pribilovius*	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.0	0.0	0.0	0.1	0.3
Tadpole sculpin	*Psychrolutes paradoxus*	2.4	4.1	2.7	6.6	4.7	7.1	1.4	2.2	3.2	6.8	0.9	1.8
Slim sculpin	*Radulinus asprellus*	33.9	52.7	5.5	12.4	11.9	16.2	4.5	10.5	3.5	6.1	25.3	23.0
Roughspine sculpin	*Triglops macellus*	0.2	0.4	0.0	0.0	0.5	1.2	0.4	0.7	0.0	0.0	0.8	0.7
Ribbed sculpin	*Triglops pingeli*	0.0	0.0	1.5	3.1	0.0	0.0	0.3	0.7	4.0	9.8	0.3	0.8
Smooth alligatorfish	*Anoplagonus inermis*	0.0	0.0	0.3	0.5	0.0	0.0	0.5	1.3	0.3	0.7	0.0	0.0
Aleutian alligatorfish	*Aspidophoroides bartoni*	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Spinycheek starsnout	*Bathyagonus infraspinatus*	13.7	17.5	5.0	11.8	4.0	3.8	3.3	5.7	2.5	4.8	7.9	15.1
Fourhorn poacher	*Hypsagonus quadricornis*	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.0	0.0	0.0	0.0
Sturgeon poacher	*Podothecus acipenserinus*	1.0	2.0	0.2	0.5	0.1	0.4	0.3	0.5	1.1	2.0	0.7	1.6
Sawback poacher	*Sarritor frenatus*	0.0	0.0	0.0	0.0	0.5	0.9	2.3	3.8	0.2	0.4	1.3	1.3
Snailfishes	*Liparis* spp.	1.6	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.8	0.7

Appendix 1 (continued). List of all species captured by beam trawl in Kachemak Bay, Alaska, 1994–1999. Mean CPUE and standard deviation (SD) are listed for each year. Number of trawls is in parentheses. Species are listed in phylogenetic order.

		1994 (6)		1995 (7)		1996 (7)		1997 (6)		1998 (6)		1999 (6)	
Common Name	Scientific Name	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Searcher	*Bathymaster signatus*	1.2	2.6	0.1	0.4	0.1	0.2	0.3	0.7	0.0	0.0	2.4	3.3
Northern ronquil	*Ronquilus jordani*	0.4	0.7	0.8	1.8	0.0	0.0	0.0	0.0	3.0	6.9	1.8	2.2
Dwarf wrymouth	*Cryptacanthodes aleutensis*	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Longsnout prickleback	*Lumpenella longirostris*	0.7	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slender eelblenny	*Lumpenus fabricii*	0.0	0.0	0.0	0.0	2.3	5.1	0.5	1.3	0.2	0.4	2.6	4.2
Snake prickleback	*Lumpenus sagitta*	1.1	2.0	1.4	1.6	2.9	4.2	0.0	0.0	2.8	3.7	2.7	5.1
Daubed shanny	*Lumpenus maculatus*	0.0	0.0	0.7	1.0	3.6	7.4	0.0	0.0	0.0	0.0	0.0	0.0
Whitebarred prickleback	*Poroclinus rothrocki*	0.3	0.7	1.5	4.0	2.7	6.3	0.2	0.4	0.8	2.0	1.4	3.4
Crescent gunnel	*Pholis laeta*	0.0	0.0	0.0	0.0	0.3	0.9	0.0	0.0	0.0	0.0	0.2	0.4
Prowfish	*Zaprora silenus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3
Pacific sand lance	*Ammodytes hexapterus*	0.2	0.4	1.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pacific sanddab	*Citharichthys sordidus*	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.0	0.0	0.0
Righteye flounders	Pleuronectidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.6
Arrowtooth flounder	*Atheresthes stomias*	10.3	15.1	1.0	1.3	11.5	10.5	9.7	17.6	3.2	4.5	29.9	27.3
Rex sole	*Glyptocephalus zachirus*	1.4	2.6	1.8	3.3	6.6	11.1	3.3	6.4	3.5	5.6	6.3	6.8
Flathead sole	*Hippoglossoides elassodon*	27.7	34.7	16.7	37.9	9.6	9.2	8.4	16.7	7.3	11.3	15.1	22.5
Pacific halibut	*Hippoglossus stenolepis*	7.0	8.6	5.9	7.1	17.3	36.4	16.1	26.1	3.7	7.2	19.9	24.3
Dover sole	*Microstomus pacificus*	4.5	10.4	1.0	1.4	2.8	3.9	2.3	2.5	5.8	6.9	1.9	2.2
Starry flounder	*Platichthys stellatus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3
Rock sole	*Lepidopsetta* spp.	61.2	82.0	29.0	64.3	178.6	365.0	86.5	189.0	47.5	59.3	58.4	83.2
Yellowfin sole	*Pleuronectes asper*	17.1	41.3	2.2	4.0	14.7	23.7	0.8	0.7	1.6	2.4	5.8	11.4
Butter sole	*Pleuronectes isolepis*	0.2	0.4	0.0	0.0	0.2	0.6	0.0	0.0	0.0	0.0	0.8	1.3
English sole	*Pleuronectes vetulus*	2.1	4.0	0.2	0.5	0.0	0.0	0.0	0.0	0.5	1.3	0.3	0.8
Sand sole	*Psettichthys melanostictus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.2	0.0	0.0
Total catch		196.4	139.7	201.0	299.4	295.8	408.5	292.9	549.1	100.0	52.8	198.0	44.8