CHAPTER 9

Fish and Shellfish

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9.1 INTRODUCTION

The Gulf of Alaska (GOA) is well known for its fish and shellfish because of its long-standing and highly valuable commercial and recreational fisheries. Less well known are the noncommercial fish and invertebrate species that compose the bulk of the animal biomass in the GOA. As a rule, the economically important species are fairly well known from trawl, trap, and hook catches made by research and commercial vessels (Cooney 1986a, Martin 1997a, Witherell 1999a, Kruse et al. 2000a). By the same rule, the majority of fish and shellfish species are less well known, having been sampled during research investigations of limited duration (Feder and Jewett 1986, Rogers et al. 1986, Highsmith et al. 1994, Purcell et al. 2000, Rooper and Haldorson 2000). Species not commercially harvested are less well studied than commercially harvested species, such as Tanner crab. For example, because no commercial fisheries are allowed for such forage fishes as eulachon, sand lance, capelin, and lanternfish, the fluctuations of their populations are not well documented. More detailed consideration of some of the less economically important, but more ecologically prominent, forage species is found in this chapter's section 9.4, Forage Species, and some of the less common shellfish species are considered in chapter 7, Nearshore Benthic Communities.

The marine fish and shellfish of the GOA fall into two major groups (Feder and Jewett 1986, Rogers et al. 1986, Cooney 1986a, Cooney 1986a, Martin 1997b):

1. *Fish*—bony fish, sharks, skates, and rays; and
2. *Shellfish*—the mollusks (bivalves including scallops, squid and octopus); and crustaceans—crabs and shrimp.

Note that three other ecologically important groups, the pelagic jellyfish (Cnidaria), the bottom dwelling sea stars and urchins (Echinodermata), and the segmented worms (Annelida) are not included in the category of the fish and shellfish. All the scientific names and many common names of the species accessible to trawl gear on the continental shelf and shelf break of the GOA (see shelf topography map, Figure 5.1 a and b, chapter 5) are in Table 9.1.

As would be expected with high marine productivity, the fish and shellfish fisheries of the GOA have been among the world's richest in the second half of the twentieth century. Major fisheries include, or have included, halibut, groundfish (Pacific cod, pollock, sablefish, Pacific ocean perch and other rockfish, flatfish such as soles and flounders), Pacific herring, multiple species of pandalid shrimp and red king crab, five species of Pacific salmon, scallops, and other invertebrates (Cooney 1986a, Kruse et al. 2000a, Witherell and Kimball 2000). The status of major fisheries and stocks of interest are addressed in the subsections below.

9.2 OVERVIEW OF FISH

Most of the approximately 287 known GOA fish species are bony fish, and the largest number of species is in the sculpin family (Cottidae), followed in order of number of species by the snailfish family (Cyclopteridae), the rockfish family (Scorpaenidae), and the flatfish family (Pleuronectidae) (Tables 9.2 and 9.3). The bony fish dominate the number of species in the GOA, with less than 10 percent of species being cartilaginous fishes (Petromyzontidae to Acipenseridae, Table 9.2). Species diversity in the fish depends on the type of gear used to sample (Table 9.2). It is important to keep in mind that trawl gear surveys are not designed or intended to estimate species diversity. A comparison of the known fish species composition to the species composition in the predominant types of trawl gear surveys shows that trawl gear samples underestimate the fish species diversity of the GOA (Cooney 1986b). The longest standing trawl gear surveys for the GOA are limited to the continental shelf and the shelf break (to 500 m before 1999 and to 1,000 m thereafter). The National Marine Fisheries Service (NMFS) has measured relative abundance and distribution of the principal groundfish and commercially important

Table 9.1. Fish and Invertebrate Species from 1996 NMFS Trawl Surveys of the Gulf of Alaska.

Fish Species

Family	Species name	Common name
Lamnidae	*Lamna ditropis*	salmon shark
Squalidae	*Squalus acanthias*	spiny dogfish
	Somniosus pacificus	Pacific sleeper shark
Rajidae	*Bathyraja interrupta*	Bering skate
	Bathyraja trachura	black skate
	Bathyraja parmifera	Alaska skate
	Bathyraja aleutica	Aleutian skate
	Raja binoculata	big skate
	Raja rhina	longnose skate
Chimaeridae	*Hydrolagus colliei*	spotted ratfish
Bothidae	*Citharichthys sordidus*	Pacific sanddab
Pleuronectidae	*Atheresthes evermanni*	Kamchatka flounder
	Atheresthes stomias	arrowtooth flounder
	Eopsetta jordani	petrale sole
	Glyptocephalus zachirus	rex sole
	Hippoglossoides elassodon	flathead sole
	Hippoglossus stenolepis	Pacific halibut
	Isopsetta isolepis	butter sole
	Lepidopsetta bilineata	southern rock sole
	Limanda asper	yellowfin sole
	Lyopsetta exilis	slender sole
	Microstomus pacificus	Dover sole
	Parophrys vetulus	English sole
	Platichthys stellatus	starry flounder
	Pleuronectes quadrituberculatus	Alaska plaice
	Psettichthys melanostictus	sand sole
Agonidae	*Aspidophoroides bartoni*	Aleutian alligatorfish
	Bathyagonus nigripinnis	blackfin poacher
	Bathyagonus pentacanthus	bigeye poacher
	Hypsagonus quadricornis	fourhorn poacher
	Podothecus acipenserinus	sturgeon poacher
	Sarritor frenatus	sawback poacher
	Xeneretmus leiops	smootheye poacher
Ammodytidae	*Ammodytes hexapterus*	Pacific sand lance
Anarhichadidae	*Anarrhichthys ocellatus*	wolf-eel
Anoplopomatidae	*Anoplopoma fimbria*	sablefish
Argentinidae	*Nansenia candida*	bluethroat argentine
Bathylagidae	*Leuroglossus schmidti*	northern smoothtongue
Bathymasteridae	*Bathymaster caeruleofasciatus*	Alaskan ronquil
	Bathymaster signatus	searcher
Chauliodontidae	*Chauliodus macouni*	Pacific viperfish
Clupeidae	*Clupea pallasii*	Pacific herring
Macrouridae	*Albatrossia pectoralis*	giant grenadier
	Coryphaenoides cinereus	popeye grenadier
Cottidae	*Artediellus* sp.	
	Dasycottus setiger	spinyhead sculpin
	Eurymen gyrinus	smoothcheek sculpin
	Gymnocanthus galeatus	armorhead sculpin
Cottidae (Continued)	*Gymnocanthus pistilliger*	threaded sculpin
	Hemilepidotus hemilepidotus	red Irish lord
	Hemilepidotus jordani	yellow Irish lord
	Hemilepidotus papilio	butterfly sculpin
	Hemitripterus bolini	bigmouth sculpin
	Icelinus borealis	northern sculpin
	Icelinus tenuis	spotfin sculpin
	Icelus spiniger	thorny sculpin
	Malacocottus zonurus	darkfin sculpin
	Myoxocephalus jaok	plain sculpin
	Myoxocephalus polyacanthocephalus	great sculpin
	Nautichthys oculofasciatus	sailfin sculpin
	Nautichthys pribilovius	eyeshade sculpin
	Psychrolutes paradoxus	tadpole sculpin
	Rhamphocottus richardsoni	grunt sculpin
	Thyriscus anoplus	
	Triglops forficata	scissortail sculpin
	Triglops macellus	roughspine sculpin
	Triglops pingeli	ribbed sculpin
	Triglops scepticus	spectacled sculpin
Trichodontidae	*Trichodon trichodon*	Pacific sandfish
Gadidae	*Microgadus proximus*	Pacific tomcod
	Gadus macrocephalus	Pacific cod
	Theragra chalcogramma	walleye pollock
Hexagrammidae	*Hexagrammos decagrammus*	kelp greenling
	Hexagrammos octogrammus	masked greenling
	Hexagrammos stelleri	whitespotted greenling
	Ophiodon elongatus	lingcod
	Pleurogrammus monopterygius	Atka mackerel
Cyclopteridae	*Aptocyclus ventricosus*	smooth lumpsucker
	Careproctus melanurus	blacktail snailfish
	Careproctus gilberti	smalldisk snailfish
	Eumicrotremus birulai	round lumpsucker
	Eumicrotremus orbis	Pacific spiny lumpsucker
	Paraliparis sp.	
Melamphaeidae	*Poromitra crassiceps*	crested bigscale
Melanostomiidae	*Tactostoma macropus*	longfin dragonfish
Merluccidae	*Merluccius productus*	Pacific hake
Myctophidae	*Diaphus theta*	California headlightfish
	Lampanyctus ritteri	broadfin lanternfish
	Lampanyctus jordani	brokenline lampfish
	Stenobrachius leucopsarus	northern lampfish
Paralepidae	*Paralepis atlantica*	duckbill barracudina
Osmeridae	*Hypomesus pretiosus*	surf smelt
	Mallotus villosus	capelin
	Spirinchus thaleichthys	longfin smelt
	Thaleichthys pacificus	eulachon
Salmonidae	*Oncorhynchus gorbuscha*	pink salmon
	Oncorhynchus keta	chum salmon
	Oncorhynchus kisutch	coho salmon

Martin (1997).

The maximum depth of sampling was 500 meters.

Fish Species

Family	Species name	Common name
Salmonidae (Continued)	*Oncorhynchus nerka*	sockeye salmon
	Oncorhynchus tshawytscha	chinook salmon
	Salvelinus malma	Dolly Varden
Cryptacanthodidae	*Cryptacanthodes giganteus*	giant wrymouth
Stichaeidae	*Chirolophis decoratus*	decorated warbonnet
	Lumpenus maculatus	daubed shanny
	Lumpenus sagitta	snake prickleback
	Lumpenella longirostris	longsnout prickleback
	Poroclinus rothrocki	whitebarred prickleback
Zaproridae	*Bothrocara pusillum*	Alaska eelpout
	Lycodapus sp.	
	Lycodes palearis	wattled eelpout
	Lycodes diapterus	black eelpout
	Lycodes brevipes	shortfin eelpout
	Lycodes pacificus	blackbelly eelpout
	Zaprora silenus	prowfish
Scorpaenidae	*Sebastes aleutianus*	rougheye rockfish
	Sebastes alutus	Pacific ocean perch
	Sebastes babcocki	redbanded rockfish
	Sebastes borealis	shortraker rockfish
	Sebastes brevispinis	silvergray rockfish
	Sebastes ciliatus	dark dusky rockfish
	Sebastes crameri	darkblotched rockfish
	Sebastes elongatus	greenstriped rockfish
	Sebastes entomelas	widow rockfish
	Sebastes flavidus	yellowtail rockfish
	Sebastes helvomaculatus	rosethorn rockfish
	Sebastes maliger	quillback rockfish
	Sebastes melanops	black rockfish
	Sebastes nigrocinctus	tiger rockfish
	Sebastes paucispinis	bocaccio
	Sebastes pinniger	canary rockfish
	Sebastes polyspinis	northern rockfish
	Sebastes proriger	redstripe rockfish
	Sebastes reedi	yellowmouth rockfish
	Sebastes ruberrimus	yelloweye rockfish
	Sebastes variegatus	harlequin rockfish
	Sebastes wilsoni	pygmy rockfish
	Sebastes zacentrus	sharpchin rockfish
	Sebastolobus alascanus	shortspine thornyhead

Invertebrate Species

Phylum	Species name	Common name
Cnidaria	*Alcyonium* sp.	
	Amphilaphis sp.	
	Anthomastus sp.	
	Arthrogorgia sp.	
	Callogorgia sp.	
	Cyanea capillata	
	Cyclohelia lancellata	
	Errinopora sp.	
	Fanellia compressa	
	Gersemia sp.	sea raspberry
	Liponemis brevicornis	
	Metridium senile	
	Muriceides sp.	
	Paragorgia arborea	
	Pavonaria finmarchica	
	Plumarella sp.	
	Primnoa willeyi	
	Ptilosarcus gurneyi	
	Stylaster brochi	
	Stylatula sp.	slender seawhip
	Thouarella sp.	
Annelida	*Carcinobdella cyclostomum*	striped sea leech
	Cheilonereis cyclurus	
	Eunoe nodosa	giant scale worm
	Eunoe depressa	depressed scale worm
	Serpula vermicularis	
Arthropoda	*Acantholithodes hispidus*	fuzzy crab
	Argis dentata	Arctic argid
	Argis lar	kuro argid
	Balanus evermanni	giant barnacle
	Balanus rostratus	beaked barnacle
	Cancer gracilis	graceful rock crab
	Cancer magister	Dungeness crab
	Cancer oregonensis	Oregon rock crab
	Chionoecetes angulatus	triangle tanner crab
	Chionoecetes bairdi	bairdi tanner crab
	Chionoecetes tanneri	grooved tanner crab
	Chorilia longipes	longhorned decorator crab
	Crangon communis	twospine crangon
	Crangon dalli	ridged crangon
	Crangon septemspinosa	sevenspine bay shrimp
	Elassochirus cavimanus	purple hermit
	Elassochirus gilli	Pacific red hermit
	Elassochirus tenuimanus	widehand hermit crab
	Eualus macilenta	
	Hapalogaster grebnitzkii	
	Hyas lyratus	Pacific lyre crab
	Labidochirus splendescens	splendid hermit
	Lebbeus groenlandicus	
	Lithodes aequispinus	golden king crab
	Lopholithodes foraminatus	box crab
	Munida quadrispina	
	Oregonia gracilis	graceful decorator crab
	Pagurus aleuticus	Aleutian hermit
	Pagurus brandti	sponge hermit
	Pagurus capillatus	hairy hermit crab
	Pagurus confragosus	knobbyhand hermit

Table 9.1. Fish and Invertebrate Species from 1996 NMFS Trawl Surveys of the Gulf of Alaska (Continued).

Invertebrate Species

Phylum	Species name	Common name
Arthropoda (Continued)	*Pagurus dalli*	whiteknee hermit
	Pagurus kennerlyi	bluespine hermit
	Pagurus ochotensis	Alaskan hermit
	Pagurus rathbuni	longfinger hermit
	Pagurus tanneri	longhand hermit
	Pandalopsis dispar	sidestriped shrimp
	Pandalus borealis	northern shrimp
	Pandalus goniurus	humpy shrimp
	Pandalus hypsinotus	coonstriped shrimp
	Pandalus jordani	ocean shrimp
	Pandalus platyceros	spot shrimp
	Pandalus tridens	yellowleg pandalid
	Paralithodes camtschaticus	red king crab
	Paralithodes platypus	blue king crab
	Pasiphaea pacifica	Pacific glass shrimp
	Pasiphaea tarda	crimson pasiphaeid
	Pinnixa occidentalis	pea crab
	Placetron wosnessenskii	scaled crab
	Pugettia sp.	kelp crab
	Rhinolithodes wosnessenskii	rhinoceros crab
	Sclerocrangon boreas	sculptured shrimp
Mollusca	*Aforia circinata*	keeled aforia
	Arctomelon stearnsii	Alaska volute
	Astarte crenata	crenulate astarte
	Bathybembix bairdii	
	Beringius kennicottii	
	Beringius undatus	
	Berryteuthis magister	magistrate armhook squid
	Buccinum plectrum	sinuous whelk
	Buccinum scalariforme	ladder whelk
	Chlamylla sp.	
	Chlamys rubida	reddish scallop
	Cidarina cidaris	
	Clinocardium californiense	California cockle
	Clinocardium ciliatum	hairy cockle
	Clinocardium nuttallii	Nuttall cockle
	Colus herendeenii	thin-ribbed whelk
	Cranopsis major	
	Cyclocardia crebricostata	many-rib cyclocardia
	Cyclocardia ventricosa	stout cyclocardia
	Fusitriton oregonensis	Oregon triton
	Limopsis akutanica	Akutan limops
	Mactromeris polynyma	Arctic surfclam
	Modiolus modiolus	northern horsemussel
	Musculus discors	discordant mussel
	Musculus niger	black mussel
	Mytilus edulis	blue mussel
	Natica clausa	arctic moonsnail
	Natica russa	rusty moonsnail
	Neptunea amianta	
	Neptunea lyrata	lyre whelk
	Neptunea pribiloffensis	Pribilof whelk
	Nuculana sp.	
	Octopus dofleini	giant octopus
	Opisthoteuthis californiana	flapjack devilfish
	Patinopecten caurinus	weathervane scallop
	Plicifusus kroyeri	
	Pododesmus macroschisma	Alaska falsejingle
Mollusca (Continued)	*Polinices pallidus*	pale moonsnail
	Rossia pacifica	eastern Pacific bobtail
	Serripes groenlandicus	Greenland cockle
	Serripes laperousii	broad cockle
	Siliqua sp.	
	Tochuina tetraquetra	giant orange tochui
	Tridonta borealis	boreal tridonta
	Tritonia diomedea	rosy tritonia
	Volutopsius callorhinus	
	Volutopsius fragilis	fragile whelk
	Volutopsius harpa	left-hand whelk
	Yoldia scissurata	crisscrossed yoldia
	Yoldia thraciaeformis	broad yoldia
Echinodermata	*Allocentrotus fragilis*	orange-pink sea urchin
	Amphiophiura ponderosa	
	Asterias amurensis	purple-orange sea star
	Asteronyx loveni	
	Bathyplotes sp.	
	Brisaster latifrons	
	Ceramaster japonicus	red bat star
	Ceramaster patagonicus	orange bat star
	Crossaster borealis	
	Crossaster papposus	rose sea star
	Ctenodiscus crispatus	common mud star
	Cucumaria fallax	
	Diplopteraster multipes	
	Dipsacaster borealis	
	Echinarachnius parma	Parma sand dollar
	Evasterias echinosoma	
	Evasterias troschelii	
	Gephyreaster swifti	
	Gorgonocephalus caryi	
	Henricia leviuscula	
	Henricia sanguinolenta	
	Hippasteria spinosa	
	Leptasterias hylodes	
	Leptasterias polaris	
	Leptychaster pacificus	
	Lethasterias nanimensis	
	Lophaster furcilliger	
	Luidia foliata	
	Luidiaster dawsoni	
	Mediaster aequalis	
	Molpadia intermedia	
	Ophiopholis aculeata	
	Ophiura sarsi	
	Orthasterias koehleri	
	Parastichopus californicus	
	Pedicellaster magister	
	Pentamera lissoplaca	
	Poraniopsis inflata	
	Pseudarchaster parelii	
	Psolus fabricii	
	Pteraster militaris	
	Pteraster obscurus	
	Pteraster tesselatus	
	Pycnopodia helianthoides	
	Rathbunaster californicus	
	Solaster dawsoni	

Invertebrate Species

Phylum	Species name	Common name
Echinodermata (Continued)	*Solaster endeca*	
	Solaster paxillatus	
	Solaster stimpsoni	
	Stichopus japonicus	
	Strongylocentrotus droebachiensis	green sea urchin
	Strongylocentrotus franciscanus	red sea urchin
	Strongylocentrotus pallidus	white sea urchin
	Stylasterias forreri	
Porifera	*Aphrocallistes vastus*	clay pipe sponge
	Halichondria panicea	barrel sponge
	Hylonema sp.	fiberoptic sponge
	Mycale loveni	tree sponge
	Myxilla incrustans	scallop sponge
	Suberites ficus	hermit sponge
Bryozoa	*Eucratea loricata*	feathery bryozoan
	Flustra serrulata	leafy bryozoan
Brachiopoda	*Laqueus californianus*	
	Terebratalia transversa	
	Terebratulina unguicula	
Chordata	*Styela rustica*	sea potato
	Aplidium sp.	
	Boltenia sp.	
	Halocynthia aurantium	sea peach
	Molgula griffithsii	sea grape
	Molgula retortiformis	sea clod
	Synoicum sp.	

invertebrate species (Martin 1997b), and before 1980, the International Pacific Halibut Commission (IPHC) collected information on the abundance, distribution, and age structure of halibut. Hook and line surveys for Pacific halibut, sablefish, rockfish, and Pacific cod on the continental shelf in the GOA have been conducted by the IPHC since 1962 (Clark et al. 1999).

On the basis of the biomass available to trawl gear on the continental shelf and shelf break, flatfish and rockfish dominate the fish fauna in most areas of the GOA. As of 1996, a flatfish species, arrowtooth flounder, dominated the overall trawl survey of the fish biomass in the GOA, followed by Pacific ocean perch (rockfish), walleye pollock (gadid), Pacific halibut (flatfish), and Pacific cod (gadid) (Martin 1997a). Biomass of the arrowtooth flounder is approaching two million metric tons, and its biomass has been steadily increasing since 1977 (Witherell 1999a). Of the next fifteen largest biomasses of species in the 1996 NMFS survey, six were flatfish and five were rockfish.

Geographic distributions of GOA fish biomass in the NMFS trawl surveys are different from the overall total. In the western GOA, Atka mackerel (Hexagrammidae) had the highest biomass in the Shumagin Islands, but this species was not among the twenty largest biomasses of species in the four other International North Pacific Fisheries Commission (INPFC) areas of the GOA. Arrowtooth flounder dominate the trawl survey biomass throughout the GOA. They are the most or second-most abundant in all five areas. Flatfish and especially soles make up a large number of high-biomass species in the western and northwestern GOA (Shumagin Islands, Chirikof, and Kodiak), and rockfish have a large number of high-biomass species in the northeastern and eastern GOA (Yakutat and Southeast). Pollock and cod are a dominant part of the biomass in the western GOA, but less so in the east. Pacific sleeper sharks are among the twenty largest biomasses of species in the north (Chirikof, Kodiak, and Yakutat), but not in the south (Shumagin Islands and Southeast). The only anadromous species, the eulachon, occurs among the twenty largest biomasses in the north, but not in the south.

With the use of a variety of gear types, including trawl net, try net, trammel net, beach seine, and tow net in waters less than 100 m, Rogers et al. (1986) provided a detailed image of the distribution of fish species and biomass with depth and by region. As was the case for the 1996 NMFS trawl surveys, species composition and relative biomass of fish species in multi-gear surveys change substantially in moving from the nearshore toward offshore areas in the GOA, as well as from one region to the next. The findings of the multiple gear surveys were consistent with the trawl survey observations in that shallow (smaller than 100 m) fish assemblages were more diverse in the north and west of the GOA than in the northeast and east (Table 9.4 in comparison to Table 9.2).

Other trends in distribution correspond to reproduction and seasonal changes in shallow waters in some species of nearshore fishes. Estuarine bays in the Kodiak archipelago are nursery areas, with larvae and juveniles being found in nearshore and pelagic habitats within bays (Rogers et al. 1986). Blackburn (1979 in Rogers et al. 1986) found a trend of larger fish with increasing depth in studies of Ugak Bay and Alitak Bay on Kodiak Island. Most species of nearshore fish apparently move to deeper water in the winter. In Lower Cook Inlet and Southeast

Table 9.2. Fish Families and the Approximate Number of Genera and Species Reported from the Gulf of Alaska.

	Quast and Hall[1]		Miscellaneous surveys[2]	
Family	Number of genera	Number of species	Number of genera	Number of species
Petromyzontidae	2	3	–	–
Hexanchidae	1	1	–	–
Lamnidae	2	2	1	1
Carcharhinidae	1	1	–	–
Squalidae	2	2	1	1
Rajidae	1	7	1	4
Acipenseridae	1	2	–	–
Clupeidae	2	2	1	1
Salmonidae	6	12	1	3
Osmeridae	5	6	5	6
Bathylagidae	1	4	–	–
Opisthoproctidae	1	1	–	–
Gonostomatidae	2	4	–	–
Melanostomiidae	1	1	–	–
Chauliodontidae	1	1	1	1
Alepocephalidae	1	1	–	–
Anotopteridae	1	1	–	–
Scopelarchidae	1	1	–	–
Myctophidae	7	10	1	1
Oneirodidae	1	3	–	–
Moridae	1	1	–	–
Gadidae	5	5	5	5
Ophidiidae	2	2	–	–
Zoarcidae	6	11	4	7
Macrouridae	1	3	1	1
Scomberesocidae	1	1	1	1
Melamphaidae	3	3	–	–
Zeidae	1	1	–	–
Lampridae	1	1	–	–
Trachipteridae	1	1	–	–
Gasterosteidae	2	2	–	–
Scorpaenidae	2	22	2	30
Hexagrammidae	3	6	3	5
Anoplopomatidae	2	2	1	1
Cottidae	30	54	15	24
Psychrolutidae	1	1	–	–
Agonidae	8	12	8	9
Cyclopteridae	12	38	5	7
Bramidae	1	1	–	–
Pentacerotidae	1	1	–	–
Sphyracnidae	1	1	–	–
Trichodontidae	2	2	1	1
Bathymasteridae	2	4	2	2
Anarhichadidae	1	1	1	1
Stichaidae	10	15	4	6
Ptilichthyidae	1	1	–	–
Pholididae	2	4	–	–
Scytalinidae	1	1	–	–
Zaproridae	1	1	1	1
Ammodytidae	1	1	1	1
Scombridae	2	2	–	–
Centrolophidae	1	1	–	–
Bothidae	1	1	–	–
Pleuronectidae	15	17	15	16
Cryptacanthodidae[3]	2	2	2	2
Totals	**167**	**287**	**84**	**138**

Sources: Hood and Zimmerman 1986 (after Ronholt et al. 1978).

[1] After Quast and Hall (1972).

[2] Gulf of Alaska exploratory, BCF, IPHC, and NNIFS trawl survey data.

[3] Quast and Hall (1972) include these genera and species in the family Stichaeidae while Hart (1973) recognizes a separate family.

Table 9.3. Proportion of the Total Species Composition of Gulf of Alaska Fish Fauna Contributed by the 10 Dominant Fish Families in Two Different Surveys.

Family[1]	Percentage of total fish species	Family[2]	Percentage of total fish species
Cottidae	19	Scorpaenidae	10
Cyclopteridae	13	Cottidae	8
Scorpaenidae	8	Pleuronectidae	6
Pleuronectidae	6	Agonidae	3
Stichaeidae	5	Zoarcidae	2
Salmonidae	4	Cyclopteridae	2
Agonidae	4	Stichaeidae	2
Zoaricidae	4	Osmeridae	2
Myctophidae	3	Gadidae	2
Rajidae	2	Hexagrammidae	2
Total	**68**		**39**

Source: Hood and Zimmerman 1986.

[1] From Quast and Hall (1972).

[2] From GOA exploratory cruises and resource assessment surveys.

Alaska, juveniles and other smaller size classes of the species of local fish assemblages are found close to shore, water temperatures permitting, and larger size classes are found farther offshore at depths greater than 30 m at all times of the year.

Nearshore areas of the GOA provide rearing environments for the juveniles of many fish species. Important nursery grounds for juvenile flatfishes, such as soles and Pacific halibut, are found in waters of Kachemak Bay and other waters of Lower Cook Inlet, as well as in Chiniak Bay on Kodiak Island (Norcross 1998). In Kachemak Bay, summer habitats of some juvenile flatfishes are shallower than winter habitats. Juvenile flatfish distributions in coastal waters are defined by substrate type, typically mud and mud-sand, and by depth, typically 10 to 80 m, and in the case of Chiniak Bay, by temperature. Deepwater and shallow-water assemblages were identified for the groundfish communities in both Kachemak and Chiniak bays; however, the limiting depths were different for these two localities (Norcross 1998, Mueter and Norcross 1999).

Both salmon and groundfish populations in the northeastern Pacific appear to vary annually in concert with features of climate, but the responses appear to be different (Francis et al. 1998). Annual groundfish recruitments follow a cycle with a roughly 10-year period that may be related to the El Niño Southern Oscillation (ENSO) (Hollowed and Wooster 1992), whereas salmon abundance changes sharply at intervals of twenty to twenty-five years in concert with the Pacific Decadal Oscillation (PDO) (Brodeur et al. 1996). The ENSO and the PDO were shown to be independent of one another (Mantua et al. 1997). The opposite responses of groundfish and salmon (positive) and crab (negative) recruitment to intensified Aleutian lows may be because different species-specific mechanisms are invoked by the same weather pattern. Because the groundfish species described by Hollowed and Wooster (1992, 1995) were mostly winter spawners, Zheng and Kruse (2000b) hypothesize that strengthened Aleutian Lows increase advection of eggs and larvae of groundfish toward onshore nursery areas, improving survival. Salmon, on the other hand, benefit from increased production of prey items under intense lows. The possible links between Aleutian lows, PDOs, and ENSO and populations of fish and other animals are discussed further below and in a recent review paper (Francis et al. 1998).

9.2.1 Salmon

The GOA is the crossroads of the world for Pacific salmon. Salmon from Japan, Russia, all of Alaska, British Columbia, and the Pacific Northwest spend part of each life cycle in the GOA (Myers et al. 2000). Five species of salmon—pink, chum, sockeye, coho, and chinook—are very common in the GOA. These species appear in the GOA as early as the first year of life (all pink, chum, and ocean type chinook and some sockeye); however, others may appear during the second (all coho and stream-type chinook and most sockeye) and rarely during the third or later years (some sockeye) (see Groot and Margolis 1991). Ecologically, the salmon species may be divided into two broad groups, marine planktivores (pink, chum, and sockeye) and marine piscivores (coho and chinook). Further ecological differentiation is apparent within planktivores. For example, the size groups of plankton consumed by chum and sockeye are inferred to be quite different, because chum use short stubby gill rakers to separate food from water, and sockeye have long feathery gill rakers as filters.

Distribution within the GOA changes with time after marine entry (Nagasawa 2000), as salmon disperse among coastal feeding grounds according to species and stock, age, size, feeding behavior, food preferences, and other factors (Myers et al. 2000). During the first year of marine life, salmon are located in estuaries, bays, and coastal areas within the Alaska Coastal Current (ACC) and continental shelf (Myers et al. 2000). With time and growth, first-year salmon move farther away from their river of origin and father offshore. First-year salmon move out of the

Table 9.4. Comparison of the Number of Fish Families and Species Found at Less Than 100 m in Different Regions of the Gulf of Alaska.

Location	Number of families	Number of species
Kodiak	22	101
Lower Cook Inlet	25	105
Prince William Sound	18	72
Southeast Alaska	NA	51

Information summarized from Rogers et al. (1986).
NA = not available.

ACC into colder waters in fall and winter of their first year at sea.

Salmon of all ages are thought to exhibit seasonal migrations in spring and fall between onshore and offshore marine areas. In the fall, salmon of all ages move offshore to spend the winter in waters between 4°C and 8°C that are relatively poor in food, perhaps as an energy conservation strategy for surviving the winter (Nagasawa 2000). In the spring, salmon move onshore into waters that may reach 15°C where food sources are relatively abundant.

Salmon populations overall are at very high levels in Alaska, with the notable exceptions of Western Alaska chum and chinook populations originating in drainages between Norton Sound in the north and the Kuskokwim River, west of Bristol Bay (ADF&G 1998). On Norton Sound, the chum salmon populations of the Penny and Cripple rivers have exhibited very low to zero spawning stocks in the past five years. Another notable exception to the record high levels of Alaska salmon production are the Kvichak River sockeye populations of Bristol Bay, which have faltered. Some "off-peak cycle" brood years have recently failed to produce as expected (Kruse et al. 2000b).

The situation in Western Alaska notwithstanding, the 1999 commercial harvest of 404,000 t of salmon in Alaska was the second largest in recorded history behind 1995 (451,000 t) (Kruse et al. 2000b). A large portion of the record harvests in 1999 was pink salmon from areas adjacent to the GOA, such as Prince William Sound (PWS), and Southeast Alaska. The status of salmon populations and fisheries in the following areas were recently evaluated in terms of levels of harvest and spawning escapements: areas coincident with habitats in the north central GOA of the Steller sea lion, which is listed as an endangered species under the Endangered Species Act of 1973 (ESA); Kodiak; the Alaska Peninsula; and Bristol Bay. All major commercial salmon stocks were judged to be healthy, with the exception of the Kvichak River off-cycle brood years (Kruse et al. 2000b).

Given that marine migration patterns of each stock are thought to be characteristic and somewhat unique (Myers et al. 2000), the contrast in the status of salmon stocks between Western Alaska, and Southcentral and Southeast Alaska, offers some intriguing research questions about the role of marine processes in salmon production (Cooney 1984). Understanding the processes that connect salmon production to climate, marine food production, and fishing requires understanding of the marine pathways of the salmon through time (Beamish et al. 1999). Therefore, research approaches to understanding changes in salmon abundance on annual and decadal scales need to encompass localities that are representative of the full life cycle of the salmon and, in particular, in estuarine and marine environments. Scientific information on freshwater localities is far more common than that available for estuarine and marine areas. Given the current state of information on both hatchery and wild salmon, it is highly desirable to focus current and future efforts on estuaries and marine areas for understanding migratory pathways and other habitats, physiological indicators of individual health, trophic dynamics, and the forcing effects of weather and oceanographic processes (Brodeur et al. 2000).

9.2.2 Pacific Herring

Pacific herring populations (Funk 2001) occur in the northeastern GOA, with commercial concentrations in Southeast Alaska (Sitka), PWS, western Lower Cook Inlet, and occasionally around Kodiak. Most of the historical information on herring in the GOA comes from coastal marine fisheries that started in Alaska in 1878 (Kruse et al. 2000b); however, intensive ecological investigations at the end of the twentieth century have added information on early life history (Norcross et al. 1999). Herring deposit eggs onto vegetation in the intertidal and near subtidal waters in late spring, undergo a period of larval drift, and spend the first summer and winter nearshore in sheltered embayments. Transport of larvae by currents in relation to sites that are suitable summer feeding and overwintering grounds is likely an important factor affecting survival in the first year of life in PWS (Norcross et al. 1999), as is the nutritional status of these age-0 herring in the fall of the year (Foy and Paul 1999). Some portion of the mature herring must migrate annually between onshore spawning grounds and offshore feeding grounds; however, the geography of the life cycle between spawning and maturation is less certain.

Although the geographic scope of the herring life cycle in the Bering Sea is fairly well understood, inferences from the Bering Sea to the GOA are not direct because of apparent differences in life history strategies between the herring of the two regions (Funk 2001). Adult herring in the GOA are smaller and have shorter life spans than those in the Bering Sea. Perhaps GOA herring migrate shorter distances to food sources that are not as rich as those available to Bering Sea herring, which migrate long distances from spawning to feed among the rich food sources of the continental shelf break (Funk 2001). Genetic analyses indicate that Bering Sea and GOA herring populations are reproductively isolated (Funk 2001).

Another ecologically significant characteristic of Pacific herring is the temporal change in size at age over time (E. Brown, University of Alaska Fairbanks pers. comm., 2000). Annual deviations from long-term (1927 to 1998) mean length at age for Sitka Sound herring indicate a decadal-scale oscillation between positive and negative deviations. This finding is consistent with the reported coincidence of size-at-age data for Pacific herring with the PDO (Ware 1991). Herring may be affected by ENSO events. Decreased catches, recruitments, and weight-at-age of herring are at times associated with ENSO events. Seabirds in the GOA that depend on herring and other pelagic forage species showed widespread mortalities and breeding failures during the ENSO events of 1983 and 1993 (Bailey et al. 1995b). The similarities between the annual patterns of abundance and the location of weather systems (annual geographically averaged sea-level atmospheric pressure) are not as clear with herring as for other fish species, such as salmon. The difference may result because herring populations tend to be dominated by the occasional strong year class, and show considerable variability in landings through the years.

The current status of herring populations may be closely related to historical fishing patterns. Long-term changes associated with commercial fishing have occurred in the apparent geographic distribution and abundance of GOA herring. Herring-reduction fisheries (oil and meal) from 1878 to 1967 reached a peak harvest of 142,000 t in 1934. That exploitation rates were high may be inferred from the fact that some locations of major herring-reduction fisheries, such as Seldovia Bay (Kenai Peninsula and Lower Cook Inlet) are now devoid of herring. It is speculated that reduction fisheries at geographic bottlenecks between herring spawning and feeding grounds, such as the entrance to Seldovia Bay and the passes of southwestern PWS, were able to apply very high exploitation rates to the adult population. Harvest management applied by the State of Alaska relies on biomass estimates, and harvests are held to a small fraction of the estimated biomass. Harvest is not allowed until the population estimate rises above a minimum or "threshold" biomass level.

Recent statewide herring harvests have averaged less than a third of the 1934 peak. Direct comparison of past and present catch statistics is problematic, however, because current rates of harvest are thought to be substantially below those applied in 1934 (Kruse et al. 2000b). Also note that recent statewide figures for herring harvests include substantial harvests from outside the GOA, and herring-reduction fisheries were located in the GOA. Populations of herring were targeted for sac roe starting in the 1970s and for sac roe and roe-on-kelp in the 1980s. Regional herring population status is variable. Population levels of herring in PWS remained at low levels in 2000, and commercial harvests were not allowed in 1994, 1995, and 1996, nor since 1998. In 1999, fishing operations were halted because of low biomass and poor recruitment. Disease is strongly suspected as a factor in keeping the population levels low. The herring fishery of Lower Cook Inlet in Kamishak Bay closed in 1999 after a very small catch in 1998 and remains closed because of low biomass levels. Catches in the Kodiak fishery for herring sac roe are declining. The bait fishery in Shelikof Strait was closed in 1999 because of its possible relation to depressed Kamishak Bay herring populations.

Significant questions remain about the geographic extent of the stocks to which the biomass estimates and fishing exploitation rates may apply in PWS (Norcross et al. 1999). The geomorphology of PWS in relation to currents plays an important role in determining the retention of larvae in nearshore areas conducive to growth and survival. The degree to which spawning aggregations of herring may represent individual stocks is a significant question, because the actual exploitation rate of herring in PWS depends on how many stocks are defined. Although it is not clear how many stocks of herring occupy PWS, conditions seem to favor more than one spawning stock (Norcross et al. 1999).

Water temperatures appear to play important roles in growth and survival of age-0 herring. Warm summer water temperatures may be conducive to growth and survival; however, the opposite seems to be true of warm water temperatures in spring and winter. Increased metabolic demands imposed by warm water on yolk-sac larvae and overwintering age-0 herring could decrease survival (Norcross et al. 1999). Availability of food before winter, and perhaps during winter, may be key to survival of age-0 herring. Input of food from the GOA may be an important key to survival for age-0 herring at some localities. Differential survival among nursery areas because of interannual variation in climate and accessibility of GOA food sources could be a key determinant of year-class strength in PWS. The sources of variability mean that geographic locality is no guarantee of any particular level of survival from year to year. Sampling whole body energy content of age-0 herring at the end of the first winter among bays could provide an indicator of year-class strength (Norcross et al. 1999).

Questions relating to the ability of disease outbreaks to control herring populations have recently been explored. Work has identified the diseases, viral hemorrhagic septicemia and a fungus, as factors potentially limiting the abundance of herring in PWS (Hostettler et al. 2000, Finney et al. 2000).

9.2.3 Pollock

Pollock are an ecologically dominant and economically important cod-like fish in the GOA. They appear to spawn at the same locations within the same marine areas each year, with location of spawning and migrations of adults linked to patterns of larval drift and locations of feeding grounds (Bailey et al. 1999). Spawning occurs at depths of 100 to 400 m, and as a result, the distributions of eggs and larvae in some areas may have been well below the depths of historical ichthyoplankton surveys. Pollock larvae feed on early developmental stages of copepods and, as juveniles, move on to feed on larger zooplankton such as euphausiids and small fishes, including pollock. Although cannibalism is regarded as significant in the Bering Sea, it is not thought to be a significant factor in the GOA. Pollock eggs and larvae are important sources of food for other zooplankters, and year-class strength in pollock is thought to be related to abundances of marine mammals and seabirds, at least in the Bering Sea.

Pollock mature at about age 4 and may live as long as twenty years (Bailey et al. 1999). Adult walleye pollock are distributed throughout the GOA at depths above 500 m. A substantial portion (45 percent) of the total pollock biomass as well as the highest catches per unit effort (CPUEs) of the 1996 NMFS survey were found at less than 200 m in the area between Kodiak and Chirikof islands (Martin 1997). In the western GOA, the highest pollock catches and CPUEs of the 1996 NMFS trawl survey were found at less than 200 m, whereas in Yakutat and Southeast Alaska the substantial availability of pollock to trawl gear persists above 300 m. Pollock larger than 30 cm were rarely found above 200 m in the eastern GOA in 1996 (Yakutat and Southeast), although pollock of all sizes (about 10 to 70 cm) were found at all depths down to 500 m in the western GOA (Martin 1997). Although pollock are commonly found in the outer continental shelf and slope, they may also be found in nearshore areas where they may be important predators and prey; for example, in PWS (Willette et al. 2001).

Populations of pollock in the GOA are considered to be separate from those in the Bering Sea (Bailey et al. 1999). Among the most commercially important of the GOA groundfish species, exploitable biomasses of pollock populations in 1999 were estimated at 738,000 t, down from a peak of about three million t in 1982 (Witherell 1999). Annual numbers of 2-year -old pollock entering the fishable population (recruitment) from 198 to 1987 were erratic and usually lower than recruitments estimated in 1977 to 1980.

Following the climatic regime shift in 1978, pollock and other cod-like fish have dramatically increased, replacing shrimp in nearshore waters as the dominant group of organisms caught in mid-water trawls on the shelf (Piatt and Anderson 1996). Recruitment in pollock is heavily influenced by oceanographic conditions experienced by the eggs and larvae. Good conditions for juveniles of the 1976 and 1978 year class contributed to the 1982 peak in pollock biomass in the GOA (Bailey et al. 1999). Populations have gradually declined since then (Witherell 1999). Increasing mortality schedules in 1986 to 1991 may indicate increasing predation and deteriorating physical conditions for both juveniles and adults in the GOA (Bailey et al. 99). The larger-than-average year class for GOA pollock in 1988 may be related to high rates of juvenile growth coincident with warm water temperatures, lack of winds, low predator abundance, and low larval mortality rates (Bailey et al. 1996). As has been shown to be the case with other groundfish species, GOA pollock recruitments are positively correlated with ENSO events (Bailey et al. 1995b).

Issues in the management of pollock that currently remain unresolved include the geographic boundaries of stocks, their extent of migration, the effects of fishing in one geographic locale on the populations of pollock and predators in other geographic locales, and what controls the annual recruitment of young pollock to the fishable populations (Bailey et al. 1999). In relation to stock structure, spawning aggregations in PWS, the Shumagin Islands (southwest Kodiak), and Shelikof Strait (separating Kodiak from the Alaska Peninsula) may represent separate stocks. Conditions of weather and changing ocean currents and eddies in the Shelikof Strait have the capacity to alter survival of pollock larvae from year to year (Bailey et al. 1995a). In particular, the effects of shifts in the strength of the ACC on larval transport pose important questions for how year-class strength is determined. In 1996, anomalous relaxation of winds resulted in a dramatic increase in larval retention in the Shelikof basin. Increased larval retention may be favorable to survival of pollock larvae in this area, with some exceptions (Bailey et al. 1999).

9.2.4 Pacific Cod

Pacific cod is a groundfish with demersal eggs and larvae found throughout the GOA on the continental shelf and shelf break. Pacific cod of the GOA are also an economically and ecologically important species. Pacific cod had an estimated fishable population of 648,000 t in 1999, which is on the low end of the range of 600,000 to 950,000 t estimated for 1978 to 1999. Annual recruitments of GOA Pacific cod have been relatively stable since 1978, with exceptionally large numbers of 3-year-old recruits appearing in 1980 and 1998.

Pacific cod are found throughout the GOA at depths less than 500 m. They are most abundant in the western GOA (Kodiak, Chirikof, and Shumagin islands) where Pacific cod larger than 30 cm are found at all depths above 300 m, but smaller individuals are rarely found at depths less than 100 m (Martin 1997).

9.2.5 Halibut

Pacific halibut are common throughout the GOA at depths less than 400 m, and halibut are available to trawl gear at depths of 500 m (Martin 1997). In the 1996 NMFS trawl survey, the largest catches and the highest CPUE were found at depths of less than 100 m east-southeast of Kodiak on the Albatross Banks (Figure 5.1, chapter 5). In most areas of the GOA, the average weight and length of halibut caught in trawl gear increases with depth, even though the CPUE declines with depth, particularly in the western GOA (Shumagin Islands, Chirikof, and Kodiak) (Martin 1997). The exploitable biomass of the highly prized Pacific halibut in 1999 was estimated at 258,000 t, which is above average for 1974 to 1999 (Witherell 1999). Exploitable biomass of Pacific halibut was also increasing from 1974 to 1988, after which it declined slightly.

Pacific halibut appear to undergo decadal-scale changes in recruitment, which have been correlated with both the 18.6 year cycle for lunar nodal tide (Parker et al. 1995) and the PDO.

Biomass of the dominant flatfish in the GOA, the arrowtooth flounder, is approaching two million t. Arrowtooth flounder is not heavily harvested, and their biomass has been steadily increasing since 1977.

9.3 SHELLFISH AND BENTHIC INVERTEBRATES

Shellfish are commonly found on or near the surface of the seafloor; they are epibenthic as adults, and in the water column (pelagic) for varying lengths of time as pre-adults. Exceptions to this rule abound, particularly among mollusks such as squid, which live free of the bottom as adults. Beyond the nearshore environment (at depths greater than 25 m), the shellfish and other invertebrates dominate the number of species and the biomass of the bottom, just as other assemblages of invertebrates dominate the nearshore (see chapter 7). Among the shellfish, the arthropods and mollusks often have the largest number of species. For example, of 287 species of bottom fauna identified in waters deeper than 25 m in Lower Cook Inlet, more than 67 percent were arthropods and mollusks (Feder and Jewett 1986). Many of the commercially important species of the GOA are dependent for food to a greater or lesser extent on benthic invertebrates discussed here. (Commercially important crabs and shrimp are discussed below.) Commercial crabs and shrimps, and scallops, join the fish species of Pacific cod, walleye pollock, halibut, and Pacific ocean perch as members of the subtidal benthic food web for part of each life cycle. Detritus, bacteria, and microalgae form the base for the benthic invertebrates of the GOA continental shelf, which are predominantly filter feeders (60 percent), and detritus eaters (33 percent) (Semenov 1965 in Feder and Jewett 1986). Small mollusks, small crustaceans, polychaete annelids, and other worm-like invertebrates make up the filter-feeding and detritivore component of this food web.

Regional differences are pronounced in the benthic food webs of the GOA. The eastern GOA has few filter feeders and lower average biomass relative to the northern and western GOA, in large part because of the nature of substrates and currents. In particular the benthic species composition and productivity in the GOA is determined in part by the Alaska Coastal Current (ACC), particularly in the embayments and fjords (Feder and Jewett 1986). The ACC brings freshwater to the environments containing the pelagic shellfish larvae and heavy sediment loads that define the bottom habitats of the later stages of the life cycle. Biomass of filter feeders on the continental shelf in the western GOA (138 grams per square meter [g m^{-2}]) is far higher than that found in the northeastern or eastern GOA combined (33.2 g m^{-2}). Biomasses of detritus feeders in the western (31 g m^{-2}) and eastern (12 g m^{-2}) GOA are lower than those found in the northeastern GOA (43 g m^{-2}). Biomasses of all trophic groups on the shelf break are lower than those of the adjacent shelf. The distribution of benthic invertebrates in the GOA attests to the validity of the hypothesis that the type of bottom sediment, as influenced by proximity to alluvial inputs and currents, determines the species composition, production, and productivities of benthic communities (Semenov 1965 in Feder and Jewett 1986). Sediment size is dominant among the factors controlling the distribution of benthic species (Feder and Jewett 1986).

9.3.1 Crab

The principal commercial crab species in the GOA are the king crabs (*Paralithodes* spp.), the tanner crab (*Chionoecetes bairdi*), and the Dungeness crab (*Cancer magister*). All species have benthic adults and pelagic larvae, although the life history strategies vary substantially within and among species. For example, the pelagic stages of the red king crab are herbivorous; those of the tanner crab are carnivorous; and those of the golden king crab do not feed until they metamorphose into the benthic stages. The benthic stages of all crab species feed to a large extent on the less well known invertebrates of the benthic environments (Feder and Paul 1980a, Jewett and Feder 1983, Feder and Jewett 1986) discussed briefly above under the shellfish overview.

The status of crab populations is relatively poor in comparison to the groundfish populations (Kruse et al. 2000a). Crab catches in the GOA have shown sharp changes with time, perhaps indicative of sensitivity to climatic forcing in some species, to fishing, or to a combination of factors (Zheng and Kruse 2000b). The red king crab stock of the GOA collapsed in the early 1980s and currently shows no signs of recovery. The tanner crab populations in PWS, Cook Inlet, Kodiak, and the Alaska Peninsula have declined to low levels in the early 1990s, and harvest levels have been sharply reduced (Kruse et al. 2000b).

In a study of time-series data on recruitment for fifteen crab stocks in the Bering Sea, Aleutian Islands, and GOA, time trends in seven of fifteen crab stocks are significantly correlated with time series of the strength of Aleutian Low climate regimes (Zheng and Kruse 2000a). Time trends in recruitments among some king crab stocks were correlated over broad geographic regions, suggesting a significant role of environmental forcing in regulation of population numbers for these species. The increased ocean productivity associated with the intense Aleutian Low and warmer temperatures was inversely related to recruitment for seven of the fifteen crab stocks. The seven significantly negative correlations between ocean productivity and crab recruitment were from Bristol Bay, Cook Inlet, and the GOA. Crab stocks declined as the Aleutian Low intensified. A significant inverse relation between the brood strength of red king crab and Aleutian Low intensity was reported earlier for one of the stocks in this study, red king crab from Bristol Bay (Tyler and Kruse 1996).

Tyler and Kruse (1996, 1997) and (Zheng and Kruse 2000a) have articulated an explicit series of hypotheses linking features of physical and geological oceanography to the reproductive and developmental biology of red king and tanner crab. The hypotheses explain observed relations between climate and recruitment. Tanner and red king crab in the Bering Sea are thought to respond differently to the physical factors associated with the Aleutian Low because of the distribution of the different types of sea bottom required by the post-planktonic stage of each species. Suitable bottom habitat for red king crabs in the Bering Sea is more generally nearshore, whereas suitable bottom habitat for tanner crab is offshore. Intense Aleutian Low conditions favor surface currents that carry or hold planktonic crab larvae onshore, whereas weak Aleutian Low conditions favor surface currents that move larvae offshore. The process may not be species specific, but stock specific, depending on the location of suitable settling habitat in relation to the prevailing currents. In the case of red king crab, Zheng and Kruse (2000b) explain the apparent paradox of lowered recruitment for red king crab during periods of increased primary productivity. Red king crab eat diatoms, and show a preference for diatoms similar to *Thalassiosira* spp., which dominate in years of weak lows and stable water columns. Strong lows contribute to well-mixed water columns and a diverse assemblage of primary producers, which may be unfavorable for red king crab larvae, but favorable for tanner crab larvae. Tanner crab larvae eat copepods, which are favored by the higher temperatures associated with intense lows.

Recently completed modeling studies (Rosenkranz 1998) support climatic variables as determinants of recruitment success in tanner crab. Predominant wind direction and temperature of bottom water were strongly related to strength of tanner crab year classes in the Bering Sea. Northeast winds are thought to set up ocean transport processes that promote year-class strength by carrying the larvae toward suitable habitat. Elevated bottom-water temperatures were expected to augment the effect of northeast wind by increasing survival of newly hatched larvae (Rosenkranz, G. 1998).

9.3.2 Shrimp

The shrimp were once among the dominant benthic epifauna in Lower Cook Inlet and Kodiak and along the Alaska Peninsula (Feder and Jewett 1986, Anderson and Piatt 1999) and of substantial commercial importance in the GOA. Five species of pandalid shrimp dominated the commercial catches, which occurred west of 144°W longitude in PWS, Cook Inlet, Kodiak, and along the Alaska Peninsula (Kruse et al. 2000b). Shrimp fisheries in the GOA peaked at 67,000 t in 1973, reached 59,000 t in 1977, and declined thereafter to the point where shrimp fishing is virtually nonexistent in the GOA today.

Regional fisheries follow the pattern seen for the GOA as a whole. The trawl fishery for northern shrimp *(Pandalus borealis)* in Lower Cook Inlet peaked at 2,800 t in 1980 to 1981 and was closed in 1987 to 1988. The fishery for northern and sidestriped shrimp (*P. dispar*) along the outer Kenai Peninsula peaked at 888 t in 1984 to 1985 and closed in 1997 to 1998. The pot fishery for spot (*P. platyceros*) and coonstriped shrimp (*P. hypsinotus*) in PWS increased rapidly after 1978 to its peak harvest of 132 t in 1986. This pot fishery then declined to its low of 8 t in 1991 and has been closed since 1992. The trawl shrimp fishery for northern shrimp in PWS peaked at 586 t in 1984 and switched to sidestriped shrimp in 1987. The PWS trawl fishery for sidestriped shrimp peaked at 89 t in 1992, and the northern shrimp catch was virtually zero at this time. The PWS catch of sidestriped shrimp in 1999 was 29 t and falling. The Kodiak trawl fishery for northern shrimp peaked at 37,265 t in 1971, and catch thereafter declined to 3 t in 1997 to 1998. In the Aleutian Islands, shrimp catches after the 1978 season declined precipitously, and the fishery has not rebounded since.

9.4 FORAGE SPECIES

9.4.1 Definition

Forage species in the GOA include a broad suite of species that are commonly consumed by higher trophic level species (fish, seabirds, and marine mammals). Specific species included in the forage species complex vary among authors and management agencies. The North Pacific Fishery Management Council (NPFMC) groundfish fisheries management plan defines the forage species complex as a group of species that includes the following (NMFS 2001):

- Smelts (capelin, rainbow smelt, eulachon, and family Osmeridae);
- Pacific sand lance (*Ammodytes hexapterus*);
- Lantern fishes (family Myctophidae);
- Deep-sea smelts (family Bathylagidae);
- Pacific sandfish (*Trichodon trichodon*);
- Euphausiids (*Thysanopoda, Euphausia, Thysanoesssa*, and *Stylocheiron*);
- Gunnels (family Pholidae);
- Pricklebacks (family Stichaeidae); and
- Bristlemouths, lightfishes, and anglemouths.

Springer and Speckman (1997) extend this definition to include juvenile stages of commercially exploited species such as Pacific herring (*Clupea pallasii*), walleye pollock (*Theragra chalcogramma*), and Pacific salmon (*Oncorhynchus* sp.). This background review focuses on a subset of species that are commonly found in coastal or oceanic regions in the *Exxon Valdez* oil spill (EVOS) GOA region. In the shelf environment, this subset includes euphausiids, capelin, eulachon, sand lance, juvenile pollock, juvenile herring, and juvenile pink salmon (*Oncorhynchus gorbuscha)*. In the offshore environment, this subset includes common myctophids, such as small-finned lantern fishes (*Stenobrachius leucopsarus* and *Diaphus theta*), and bathylagids, such as the northern smoothtongue (*Leuroglossus schmidti*).

A more complete description of the life history characteristics of forage species can be found in Hart (1973) and NMFS (2001). Table 9.5 summarizes key features of the life history characteristics.

9.4.2 Resource Exploitation

Small amounts of noncommercial forage species are taken as bycatch in federal and state fisheries in the GOA (NPFMC 2000, NMFS 2001). In an attempt to discourage the development of target fisheries for forage species, the NPFMC restricts the catch of forage species to no more than 2 percent of the total landed catch of commercial fisheries in federal waters (NMFS 2001). Although the bycatch of noncommercial forage species tends to be low relative to target fisheries for commercially exploited species, the percentage of the bycatch relative to regional abundances of individual forage species is often not known because of the difficulty involved in assessing these species.

Pacific salmon fisheries off the coast of Alaska are managed by a complex system of treaties, regulations, and international agreements. State and federal agencies cooperate in managing salmon resources. The State of Alaska regulates commercial fisheries for salmon within state waters where the majority of the catch occurs. Federal agencies control the bycatch of juvenile salmon in groundfish fisheries through prohibited-species bycatch restrictions (NMFS 2001). In the EVOS GOA region, pink salmon are primarily harvested by purse seines. Most of the pink salmon taken in PWS are of hatchery origin.

State and federal agencies also cooperate in managing Pacific herring fisheries. Most of the directed herring removals occur within state waters and are regulated by ADF&G. In federal waters, the removals of Pacific herring in groundfish fisheries are regulated through prohibited-species bycatch restrictions (NMFS 2001)

State and federal agencies regulate commercial removals of walleye pollock. The majority of the catch occurs in federal waters; however, small state fisheries have started in PWS. In federal waters, the catch is regulated by federal agencies based on recommended harvest regulations provided by the NPFMC. The catch of juvenile pollock is assessed within the stock assessment and fisheries evaluation (SAFE) reports. Juvenile pollock catch is included in considerations regarding annual quotas for this species. The lack of a market for juvenile pollock less than 30 cm in length serves as an incentive to industry to minimize the bycatch of juvenile pollock. Efforts to minimize bycatch of juvenile pollock in pollock target fisheries include the voluntary adoption of alternative mesh configurations designed to reduce the retention of small pollock (Erickson et al. 1999).

9.4.3 Assessment Methods and Challenges

There are several impediments to the development of forage species assessments. The diversity of life history characteristics confound efforts to develop a multipurpose survey to assess forage species as a single complex. In addition, several forage species are small and pelagic, making them less vulnerable to the standard trawl gear used in broad-scale surveys to assess stocks conducted by Alaska Department of Fish and Game or National Marine Fisheries Service. A high priority should be placed on research designed to overcome these impediments.

Several authors have reported on possible trends in forage species abundance in the shelf and offshore environment (Hay et al. 1997, Blackburn and Anderson 1997, Anderson and Piatt 1999, Beamish et al. 1999a). These papers rely on anecdotal information from surveys that were designed to assess the abundance of another species (such as shrimp, salmon, crab, or groundfish). Indices of abundance based on these data may be subject to error because of problems with the selectivity of the gear or the limited spatial or temporal scope of the surveys.

An assessment designed for forage species is needed to develop an accurate evaluation of the distribution and abundance of this important group of species. It is unlikely that a single survey would be adequate for all forage species; therefore, a variety of survey methods should be considered. Potential survey methods for forage species are identified in Table 9.6.

9.4.4 Hypotheses about Factors Influencing Food Production for Forage Fish Production

Several hypotheses (summarized below) have been advanced to explain trends in forage fish distribution and abundance. For the most part, these hypotheses are based on research in the shelf and coastal waters of the western central GOA ecosystem, including Prince William Sound. Detailed process-oriented research has been conducted to confirm hypotheses for a small number of forage species, although these studies were often conducted in a limited geographic area representing only a fraction of the range of the species.

Table 9.5. Summary of Key Life History Characteristics of Selected Forage Species.

Characteristics	Euphausiids: 11 species	Capelin *Mallotus villosus*	Eulachon *Thaleichthys pacificus*	Pacific sand lance *Ammodytes hexapterus*	Walleye pollock *Theragra chalcogramma*	Pacific herring *Clupea pallasii*	Pink salmon *Oncorhynchus gorbuscha*	Northern lanternfish *Stenobrachius leucopsarus*
Maximum age (years)	2	4	5	3	21	18	2	6
Maximum length (centimeters)	4	25	25	15	80	45	65	9
Prey	planktivorous	planktivorous	planktivorous	planktivorous	plankton and fish	planktivorous	plankton and fish	planktivorous
Peak spawning	spring	spring	spring	winter	winter-spring	winter-spring	summer	unknown—winter?
Spawn location	unknown	intertidal	rivers early winter	late fall,	pelagic on shelf	nearshore	rivers	unknown
Abundance trend	unknown	low stable (uncertain)	low stable (uncertain)	unknown	low stable	low	high stable	unknown
Foraging habitat	pelagic—mid-water over shelf	pelagic—mid-water over shelf	pelagic—mid-water over shelf	demersal—0-100 m	mesopelagic—demersal and over shelf	pelagic shelf	pelagic shelf and open ocean	mesopelagic—outer shelf and open ocean

1. *Feeding opportunities for early feeding larvae*: Shifts in large-scale atmospheric forcing controls the structure of marine fish communities in the western central GOA ecosystem through its role in determining the timing of peak production. Species that spawn in the winter and early spring will be favored by periods of early peak production, while species that spawn in the late spring and summer will be favored by periods of delayed production (Mackas et al. 1998, Anderson and Piatt 1999).

2. *Concentration of prey for early feeding larvae*: Ocean conditions that favor concentration of forage fish and their prey will enhance production of forage species. The FOCI program identified a potential mechanism linking increased precipitation to enhanced eddy formation and reduced larval mortality. Eddies are believed to provide a favorable environment for pollock larvae by increasing the probability of encounters between larvae and their prey (Megrey et al. 1996). Research is needed to determine whether this mechanism may be important for other forage fishes within the western and central GOA.

3. *Prey dispersal for early feeding larvae*: An inverse or dome-shaped relationship exists between the amount of wind mixing and forage fish production. Bailey and Macklin (1995b) compared hatch date distributions of larval pollock with daily wind mixing. This analysis showed that first-feeding larvae exhibited higher survival during periods of low wind mixing. Megrey et al. (1996) speculated that extremes in wind mixing would result in reduced pollock survival because low wind mixing would reduce the availability of nutrients in the mixed layer and high wind mixing would lead to reduced encounters between pollock and their prey.

4. *Competition for prey*: At finer spatial scales, prey resources for forage fish may be limited, leading to resource partitioning to minimize competition between forage fish species that occupy similar habitats. Willette et al. (1997) examined the diets of juvenile walleye pollock, Pacific herring, pink salmon, and chum salmon in PWS. Their study revealed that two species pairs (walleye pollock and Pacific herring, and pink and chum salmon) exhibited a high degree of dietary overlap. This finding suggests that in PWS, competition for food resources may occur within these pairs when food abundance is limited. Purcell and Sturdevant (2001) found evidence of potential competition between zooplanktivorous jellyfish and juvenile fishes in PWS. Their study showed a high rate of diet overlap in the diets of pelagic coelenterates and forage species and that these species co-occur spatially and temporally in PWS.

5. *Prey utilization*: Overwintering mortality of forage species is dependent on the amount of energy accumulated during the summer. Field and laboratory experiments suggest that the overwintering success of both age-0 Pacific herring and age-0 walleye pollock may be dependent on the amount of energy accumulated during summer (Foy and Paul 1999, Sogard and Olla 2000). However, the early life history strategy of walleye pollock may make them less susceptible to

Table 9.6. Potential Surveys for Assessment of Selected Forage Species.

Type	Candidate species
Small mesh mid-water surveys	Euphausiids, capelin, eulachon, juvenile pollock (age 0 and age 1), juvenile herring, small finned lanternfishes, northern smoothtongue
High-speed near-surface trawls	Juvenile salmon
Acoustic mid-water trawl surveys	Capelin, eulachon, juvenile pollock, juvenile herring, euphausiids
Small-mesh beach seines	Sand lance
Aerial spawning surveys	Pacific herring and capelin
Light detection and ranging (LIDAR)	Useful for species within the upper 50 m
Monitoring diets of key bird predators	Juvenile pollock, capelin, and sand lance

starvation during the winter period. Paul and Paul (1999) compared the growth strategies of larval and age-0 walleye pollock and Pacific herring. This comparison revealed that walleye pollock metamorphose early, allowing for an extended growth period, while Pacific herring metamorphose later and accumulate energy for overwintering. Rapid growth provides increased swimming speed leading to more successful prey capture and predator avoidance. The benefits of the pollock strategy may allow them to continue to grow through the winter (Paul et al. 1998).

9.4.4.1 Food Quality

Efforts to improve understanding of the mechanisms underlying the production of forage species would benefit from an improved understanding of the principal prey utilized by forage species. Although detailed information exists for commercial species such as juvenile pollock, salmon, and herring (Cianelli and Brodeur 1997, Willette et al. 1997), only limited information is available to describe the prey preferences of many members of the forage fish complex. In particular, information is lacking in the case of offshore species.

9.4.5 Hypotheses about Predation on Forage Fish

By definition, forage species represent an important prey resource for many higher-trophic-level consumers (fish, seabirds, and marine mammals). Top-down predation pressure on forage fish depends on several factors, including predator abundance, the abundance of alternative prey, the density of prey, and the patchiness of prey. Changes in these factors will influence the relative importance of top trophic-level forcing on forage fish production.

Evidence suggests that in some years, fish predation may exhibit a measurable effect on forage species production in the EVOS GOA region. Anderson and Piatt (1999) noted that the post regime shift increase in gadoid and pleuronectid fishes coincided with marked declines in capelin and shrimp populations. They proposed that this inverse relationship could be caused by increased predation mortality due to an increase in piscivorous (fish-eating) species. Consistent with this hypothesis, Bailey (2000) performed a retrospective analysis of factors influencing juvenile pollock survival. He provided evidence that during the 1980s, pollock populations were largely influenced by environmental conditions, and after the mid-1980s, juvenile mortality was higher, resulting from the buildup of large fish predator populations. In PWS, Cooney (1993) speculated that pollock predation could explain some of the observed trends in juvenile salmon survival. He suggested that years of high copepod abundance were associated with high juvenile salmon survival, because pollock relied on an alternative prey resource. In the open ocean, Beamish et al. (1999a) proposed that mesopelagic fishes transfer and redistribute energy through two primary trophic pathways: (1) abundant zooplankton to *Stenobrachius leucopsarsus* and then squid, and (2) *Stenobrachius leucopsarsus*, *Diaphus theta,* and *Leuroglossus schmidti* to walleye pollock, salmon, dolphin, and whales. The division of energy through these pathways is thought to influence the amount of energy reaching the seafloor.

The importance of forage fish in seabird and marine mammal diets has been demonstrated by a number of authors (Hatch and Sanger 1992, Springer et al. 1996, Kuletz et al. 1997, Ostrand et al. 1998). There is little evidence that seabird predation is sufficient to regulate the production of forage fishes in the EVOS GOA region, however. Therefore, key research elements for predation of forage species by marine mammals and seabirds should focus on the role of oceanographic features in concentrating forage species within the foraging range of seabirds and marine mammals.

While only a few studies have examined the importance of gradients (fronts) or water mass characteristics in aggregating forage species for top predators in the EVOS GOA region, the importance of these features is well known in other regions. In the Atlantic, aggregations of capelin appear to be associated with strong thermal fronts (Marchland et al. 1999). Likewise, climate impacts on the distribution and productivity of Antarctic krill (*Euphausia superba*) have been shown to produce important impacts on higher trophic level consumers (Loeb et al. 1997, Reid and Croxall 2001). Hay et al. (1997) found that, in warm years, eulachon off the coast of British Columbia were more abundant in the offshore environment, while in cool years, eulachon were more common in the nearshore environment. Consistent with the hypothesis of Hay et al. (1997), Carscadden and Nakashima (1997) noted a marked decline in offshore capelin abundance during a cool period in the 1990s in the Atlantic.

9.4.6 Hypotheses Concerning Contamination

Because of the broad distribution and abundance of contaminants, there is little evidence to suggest that contaminants regulate the production of forage species in Alaska waters. If forage species exhibit subpopulation genetic structure, contaminants could be influential in the local mortality rate of forage fish subpopulations. The small size, short life span, and importance as a prey item for higher trophic level foragers make forage species ideal indicators of regional contaminant levels (Yeardley 2000). For example, Roger et al. (1990) noted that the high lipid content of eulachons suggests that they may be potential integrators of low-level contaminants. If forage species are to be used as a regional indicator of ecosystem conditions, research is needed to determine whether forage species bioaccumulate toxic chemicals. Studies are needed to determine whether observed accumulations of toxic chemicals are sufficient to change the mortality rate of forage species. If forage species accumulate lethal levels of toxic chemicals at the regional level, genetic studies are needed to determine whether these populations represent genetically unique subpopulation segments.