NATURAL RESOURCE RESPONSE GUIDE:

MARINE FISH

OCEAN ASSESSMENTS DIVISION
OFFICE OF OCEANOGRAPHY & MARINE SERVICES
NATIONAL OCEAN SERVICE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

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MARINE FISH

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TERMS AND DEFINITIONS

Acid — A large class of chemicals that ionize in water to form hydronium ions (H_3O^+ or H^+), resulting in decrease in pH. Strong acids ionize completely and create more acidic solutions than weak acids which ionize partially.

Alkane hydrocarbons — A major group of petroleum hydrocarbons characterized by a straight or branched chain of carbon atoms. Depending on molecular weight, they range from gases (methane) to liquids (hexane) to waxy solids. Alkanes are generally less soluble but more toxic to aromatic hydrocarbons of equal molecular weight.

Anadromous — Pertaining to marine fish that ascend coastal river to spawn in fresh waters. Anadromous fish are NOAA trustee resources.

Aromatic hydrocarbons — A major group of cyclic petroleum hydrocarbons such as benzene and toluene that are moderately soluble in water and are generally highly toxic to aquatic organisms.

Base — A large class of chemicals that ionize in water to form hydroxide ions (OH^-) resulting in increase in pH. Strong bases ionize completely and weak bases ionize partially.

Benthic — Pertaining to the sea floor and deep ocean waters. Benthic fish typically live on, in, or near the sea floor.

Buffering capacity — The ability of an aqueous solution to resist changes in pH.

Crude oil — A black or brown liquid that contains a complex mixture of petroleum hydrocarbons and a variety of inorganic chemicals that is extracted and transported in its natural, unaltered state.

Demersal — See benthic.

Epipelagic — Pertaining to the upper water layer of the pelagic zone.

Estuarine — Pertaining to semienclosed coastal waters characterized by mixing of fresh and marine waters.

Filter-feeding — Feeding on small food particles extracted from large volume of water, usually with the aid of filter-like structures in the mouth or throat.

Juvenile — The intermediate life stage that has assumed many adult characteristics but is not sexually mature.

Larva — The immature life stage that emerges from the egg and undergoes a series of morphological changes before assuming adult characteristics. Larval fish usually live off an attached yolk sac for the first days or weeks of life and are not strong swimmers.

LC-50 — The concentration of a toxicant that causes 50 percent mortality in a test population. The LC-50 is usually defined for a given time interval (e.g., 96-hour LC-50). Also commonly known as LD-50 and acute toxicity value.

Nursery — A habitat used by larval or juvenile fish.

Omnivorous — Feeding on a wide range of plant and animal materials.

Pelagic — Pertaining to the open ocean; pelagic fish reside in the mid-to-upper water column and are able to move freely throughout this zone.

pH — A unitless value taken to represent the acidity or alkalinity of an aqueous solution. Based on a scale of 1 to 14, 7 is considered neutral and values below are considered acidic and values above 7 are considered alkaline or basic.

Planktonic — Pertaining to those organisms that reside in the water column and whose large-scale movements are controlled by water currents.

Predatory — Actively pursuing and feeding on living animals, usually with the aid of large jaws, sharp teeth, or other adaptations for capturing live prey.

Refined oil — The product of distillation of crude oil into light or heavy components. Light refined oils include gasoline, kerosene, diesel oil, and individual components such as benzene or toluene. Heavy refined oils include fuel oil Nos. 4, 5, and 6.

Semipelagic — Pertaining to those organisms that are free-swimming in the water column but are also associated with benthic habitats, especially reefs. Also known as benthopelagic.

Smolt — A juvenile salmonid up to two years old that is undergoing certain physiological and morphological changes that enable it to live in the ocean.

Water-soluble fraction — That portion of an oil that is soluble in water under equilibrium conditions. Usually prepared by mixing a volume of water and oil followed by a period of settling and then filtration of the water. The WSF of petroleum hydrocarbons is composed mostly of aromatic hydrocarbons.

INTRODUCTION

Fish are one of the most important components of marine and estuarine ecosystems. They inhabit a wide range of habitats and are frequently the focus of commercial and recreational harvest. The National Oceanic and Atmospheric Administration (NOAA) is vested with management responsibilities over these organisms under a variety of laws, including the Endangered Species Act and the Magnuson Fishery Conservation and Management Act; has trustee responsibilities under the Clean Water Act and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); and is authorized to manage or protect marine fish during oil and hazardous materials spills.

In order to carry out these responsibilities, the NOAA Scientific Support Coordinator (SSC) and other NOAA representatives must have access to detailed and accurate biological information on which to base spill response decisions for natural resource protection. This report is the second in a series of Natural Resource Response Guides that are intended to provide a brief but comprehensive summary of biological information pertinent to the management of oil and hazardous materials spills. Included are summaries of potential impacts of oil and hazardous materials, and information on habitat, behavior, and physiology that will allow rapid evaluation of potential effects on biological resources present in the vicinity of a spill.

The information presented here was summarized from a variety of published reports, articles, books, and conference proceedings. A comprehensive review of the literature was conducted using manual and computerized searches of bibliographic data bases and reviews of other summary reports to identify primary data sources. These in turn were used to identify other publications not previously found. Each publication was reviewed and pertinent data summarized into the present text. The data sources used in this report include articles from scientific journals, reports prepared for NOAA, Minerals Management Service, and U.S. Fish and Wildlife Service (USFWS), and papers presented at conferences sponsored by the American Petroleum Institute, American Society of Testing and Materials, U.S. Environmental Protection Agency (USEPA), Environmental Protection Service (Canada), and NOAA.

The information presented in this guidebook is divided into two major sections. The first section consists of a summary of biological information of five major groups of finfish:

- Anadromous fish.
- Marine pelagic fish.
- Demersal groundfish.
- Reef fish.
- Estuarine fish.

The second section consists a summary of toxicological information of three classes of chemical products:

- Crude and refined petroleum products.
- Acids and bases.
- Anhydrous ammonia.

USE OF THE GUIDEBOOK

In the event of an oil or hazardous materials spill, it is necessary to determine the seasonal presence and activities of potential resources at risk and then to evaluate the probability and types of expected impacts to these resources. A number of data sources are available that provide detailed information on the distribution and seasonality of fish and wildlife resources in the spill area. The Environmental Sensitivity Index (ESI) atlases prepared by RPI for NOAA are a good source of detailed, site-specific data on the distribution and seasonality of fish and wildlife resources. Almost all navigable waters of the United States under Coast Guard and NOAA jurisdiction have been mapped using the ESI. Biological information is presented using a set of color- and number-coded symbols placed on each map. Information on the identity of fish species present is given by a number or set of numbers referenced in an accompanying species list. Seasonal data are provided by a series of dots placed on the perimeter of each round symbol; the presence of a dot corresponding to a given season indicates that one or more life stages of that species are present in the area indicated. Distributional data are indicated by means of range bars that show the extent of known concentration areas; arrows that indicate the location of known migration routes; and written messages that indicate broad distributional patterns. By examining these atlases, the user is able to quickly determine which species are present in a given area during each season. In some situations, it may be necessary to have more detailed information than can be provided on an ESI map; in these cases, it is recommended that the user contact local resource experts.

Information on the distribution of fish on a regional basis is provided by the USFWS Ecological Inventory map series (Becassio et al., 1980, 1981, 1982), and the Strategic Assessment data atlas series (Strategic Assessment Branch, 1985). These sources should be consulted to determine which species are likely to occur in the spill area during the appropriate season. As mentioned above, local resource experts are also an excellent source of detailed, site-specific information.

After identifying those species likely to occur in the spill area, the Natural Resource Response Guide may be consulted to obtain information regarding life history, habitat preferences, behavior, and other ecological factors that influence sensitivity to spilled pollutants, and toxicological information on selected chemicals. Information on the individual species of concern may be located by consulting the Table of Contents or Index. The biological information sections give a brief summary of the life cycle, habitat requirements, diet, and commercial/recreational importance of each group of fish (as they are organized in this report). This information provides an overview of the major ecological parameters that should be considered during a spill. This is followed by an evaluation of the susceptibility of each life stage to spilled chemicals in order to determine the likelihood of impacts to those stages. Species-specific information on habitat requirements, diet, and behavior is presented in tabular form at the end of each section. These tables are intended to provide detailed information for each species included in the major groupings, with emphasis on those factors that influence sensitivity and susceptibility to spilled chemicals. The toxicological information sections give a summary of the effects of selected chemicals on fish, including lethal and sublethal effects as they relate to species, life stage, chemical type, and other factors.

As noted above, three broad classes of chemicals are included in this report (petroleum hydrocarbons, acids and bases, and anhydrous ammonia). These classes include those compounds most likely to be involved in spills in navigable waters that pose a significant threat to marine fish. Other compounds such as pesticides, heavy metals, and various organic and inorganic compounds are infrequently involved in spills in navigable waters and are thus not included here. However, there are several references which have comprehensive toxicological information for specific chemicals. These references are discussed in the toxicological information section.

SUMMARY OF BIOLOGICAL INFORMATION

Fish are one of the most important animal groups present in the world's oceans. They form a very large and diverse group of vertebrates that are found in a wide range of habitats and have evolved many different life cycles adapted to these habitats.

In terms of the potential for adverse effects from spilled chemicals, habitat use is one of the most important factors since it has a major influence on the likelihood of exposure to waterborne pollutants. Habitat use is strongly influenced by the life-history-specific characteristics such as behavior, diet, and salinity preference. Therefore, the biological information presented here is organized according to multifamily groups that are characteristic of marine, estuarine, and riverine habitats that occur in U.S. navigable waters, with emphasis placed on those life-history characteristics that influence sensitivity to spilled pollutants. No attempt has been made to adhere to traditional phylogenetic groupings, although in many cases, genera and even entire families are characteristic of certain habitats.

The fish groups discussed here are as follows:

- Anadromous fish.
- Marine pelagic fish.
- Demersal groundfish.
- Reef fish.
- Estuarine fish.

It is recognized that these are somewhat artificial groupings and that many species could be included in more than one group.

Species discussed in each section were chosen on the basis of ecological, commercial, or recreational importance. Those species listed are intended to be representative of each family discussed, rather than a complete listing of all species in each family.

There are several recent series of publications that provide more detailed biological data on fish, including the National Estuarine Inventory and the Strategic Assessment Data Atlas series, prepared by the Strategic Assessment Branch, Ocean Assessments Division of NOAA, and the Species Profiles, prepared by the USFWS and U.S. Army Corps of Engineers. These reports and atlases are intended to provide detailed information on life history, distribution, abundance, and environmental requirements of coastal and pelagic fish species and other organisms. Much of the information presented in this report was derived from these publications.

HABITAT AND LIFE-HISTORY CONSIDERATIONS

The probability of adverse impacts to marine fishes from spilled pollutants is influenced by the inherent sensitivity of the fish and their susceptibility to exposure. Sensitivity and susceptibility are functions of life-history stage and, in turn, habitat preference, behavior, diet, and other factors. Each stage has characteristics that should be considered when evaluating spill impacts. These factors are discussed below.

EGGS

There are two general categories of eggs: benthic eggs that adhere to bottom sediments or are buried in sediments, and pelagic eggs that float in the water column.

The sensitivity of fish eggs is reduced somewhat in comparison to larval fish due to the presence of protective membranes that may reduce exposure of the developing embryo to pollutants. Chronic exposures, especially to slowly developing eggs such as salmon eggs, may result in accumulation of toxicants and associated toxic effects.

Susceptibility of eggs is highly variable. Benthic eggs released in deep water are unlikely to encounter significant concentrations of waterborne pollutants resulting from spills and are therefore not likely to be affected. Benthic eggs released in shallow waters are vulnerable to exposure to those chemicals that are soluble in water or have specific gravities greater than that of the receiving waters. Many acids and bases have these characteristics and, therefore, pose a threat to eggs spawned in shallow waters typical of estuaries and nearshore marine areas.

Benthic eggs spawned on intertidal and very shallow subtidal substrates are highly vulnerable to petroleum hydrocarbons and ammonia spills due to the tendency of these chemicals to float on water or to spread through the surface water layers during the immediate postspill period. Petroleum products pose the greatest threat due to their persistence on the water and their tendency to adhere to intertidal sediments. In areas with large tidal ranges or strong mixing action from waves, spilled oil products may contaminate sediments in relatively deep water (up to several meters below mean low water) and thus affect benthic eggs in these areas.

LARVAE

The larval stages of most marine fish are planktonic; they live in the open-water column, and their large-scale movements are controlled by water currents. They have poorly developed swimming abilities that are useful for short-range movements within the parcel of water they inhabit. For this reason, they are vulnerable to exposure to waterborne pollutants, especially water-soluble chemicals. Larvae of anadromous fish and estuarine fish that inhabit river channels or estuaries may be more susceptible to spills than other fish groups that occur in open-ocean waters.

Planktonic larvae feed on an attached yolk sac during the first few days or weeks of life and then feed on phytoplankton and zooplankton. These food items are concentrated in the upper water column (photic zone); therefore, planktonic fish larvae will be most abundant in the same area. The depth of the photic zone can be highly variable but extends at least several meters deep, and this zone is usually well-mixed as a result of surface waves and currents. Although their use of surface waters may increase the probability of exposure to spilled chemicals, especially oil products, the expected exposure levels below the top microlayer will usually be well below toxic levels. For this reason, planktonic larvae in the open ocean are unlikely to experience acute toxic effects on significant percentages of their population during an oil spill event. Exceptions include large spills in restricted areas with very low flushing rates.

Benthic larvae, such as those of the salmon and, to a lesser degree, the sturgeon, are found on or in bottom sediments. Salmon larvae actually live in the interstitial spaces in the bottoms of spawning streams and do not emerge for several weeks or months after hatching. Sturgeon larvae generally live on or near the bottom. The movement of these larval forms is influenced less by water movement than planktonic larvae, and they are therefore less susceptible to waterborne pollutants. However, a number of waterborne pollutants (especially acids and bases) have relatively high specific gravities and are likely to sink to the bottom and affect benthic larvae during the early stages of a spill before appreciable mixing occurs. Benthic larvae also are more susceptible to chemicals that tend to adhere to bottom sediments, including oils under certain conditions.

ADULTS AND JUVENILES

Later life stages of marine fish are considered to be the least sensitive to chemical pollutants. They are generally very mobile and are better able to detect and avoid spills. They also inhabit deeper waters or are able to tolerate a wider range of environmental conditions and thereby resist low-level exposures or move to less optimal habitats.

ANADROMOUS FISH

Anadromous fish are those species that live in brackish or salt water as adults and ascend coastal rivers to freshwater spawning and nursery grounds. Species from the eight different families of fish managed in the United States as anadromous fish under the Anadromous Fish Conservation Act are given below:

STURGEON FAMILY (Acipenseridae)

- White sturgeon (*Acipenser transmontanus*)
- Green sturgeon (*Acipenser medirostris*)
- Atlantic sturgeon (*Acipenser oxyrhynchus*)
- Shortnose sturgeon (*Acipenser brevirostrum*)
- Lake sturgeon (*Acipenser fulvescens*)

HERRING FAMILY (Clupeidae)

- Blueback herring (*Alosa aestivalis*)
- Skipjack herring (*Alosa chrysochloris*)
- Alabama shad (*Alosa alabamae*)
- Hickory shad (*Alosa mediocris*)
- Alewife (*Alosa pseudoharengus*)
- American shad (*Alosa sapidissima*)

SALMON FAMILY (Salmonidae)

- Arctic cisco (*Coregonus autumnalis*)
- Bering cisco (*Coregonus laurettae*)
- Least cisco (*Coregonus sardinella*)
- Pink salmon (*Oncorhynchus gorbuscha*)
- Chum salmon (*Oncorhynchus keta*)
- Coho salmon (*Oncorhynchus kisutch*)
- Sockeye salmon (*Oncorhynchus nerka*)
- Chinook salmon (*Oncorhynchus tshawytscha*)
- Atlantic salmon (*Salmo salar*)
- Steelhead trout (*Salmo gairdneri*)
- Cutthroat trout (*Salmo clarki*)
- Brown trout (*Salmo trutta*)
- Brook trout (*Salvelinus fontinalis*)
- Arctic char (*Salvelinus alpinus*)
- Dolly Varden (*Salvelinus malma*)
- Inconnu (*Stenodus leucichthys*)

SMELT FAMILY (Osmeridae)

- Longfin smelt (*Spirinchus thaleichthys*)
- Eulachon (*Thaleichthys pacificus*)
- Rainbow smelt (*Osmerus mordax*)

SEABASS FAMILY (Percichthyidae)

- Striped bass (*Morone saxatilis*)
- White bass (*Morone chrysops*)

PERCH FAMILY (Percidae)

- Walleye (*Stizostedion vitreum vitreum*)
- Sauger (*Stizostedion canadense*)

COD FAMILY (Gadidae)

- Tomcod (*Microgadus tomcod*)
- Burbot (*Lota lota*)

SUCKER FAMILY (Catostomidae)

- Longnose sucker (*Catostomus catostomus*)
- White sucker (*Catostomus commersoni*)

Lake sturgeon, white bass, white perch, walleye, sauger, burbot, longnose sucker, and white sucker are typically freshwater fish that are considered to be anadromous fish in the Great Lakes where they ascend tributary rivers during spawning. All other species given above live in brackish water or salt water as adults, although there are landlocked populations of many anadromous species.

The anadromous life cycle may be summarized as follows. Adult male and female fish that usually reside in offshore, coastal or estuarine environments enter coastal rivers and migrate upstream to freshwater spawning grounds. These areas may be great distances from the ocean or in the lower reaches of the river. In many cases, spawning occurs in the same location where the adult fish were spawned. Adults of some species die after spawning (e.g., Pacific salmon and many Clupeids), while others survive and spawn in later years (e.g., sturgeon and striped bass). Spawning may occur at any time of the year depending on species, but spring is usually a peak spawning time. Eggs and sperm are released into the water where fertilization occurs. Fertilized eggs then either sink to the bottom and mix with gravel or, in some cases, sandy sediments, or they float with the current. The salmonids typically create nesting depressions or redds in the streambed. The adult female excavates the redd by moving gravel to form a shallow cavity into which the eggs are released and fertilized and then buried by gravel. Length of incubation is highly variable; most species hatch within a few days or weeks, whereas salmon eggs require several months' incubation in gravel sediments. Larval fish are usually very small and are poor swimmers. They feed at first on an attached yolk sac and then, as they mature, start feeding on a variety of planktonic food items. Larvae and juveniles generally remain in freshwater nursery grounds for a few days to months and then migrate to estuarine and then marine habitats where they live as adults until reaching sexual maturity when the entire process is repeated. Juveniles of some species, especially salmon and sturgeon, may remain in freshwater nursery areas for many months or years.

There is considerable interspecies variation in this general scheme in terms of preference for substrate for spawning, length of egg incubation and larval development, spawning time and frequency, and other factors.

Susceptibility to Spilled Contaminants

All anadromous species are considered to be at moderate-to-high risk from oil and hazardous materials spills occurring in navigable waters due to their dependence on certain nearshore and shallow-water habitats for critical stages of their life cycle.

Adults

° *Moderate risk of exposure during spawning runs.*

Adult anadromous fish must pass through nearshore areas where spills are likely to pose a significant threat of toxic exposure.

Eggs and Larvae

° *High risk of exposure at freshwater spawning areas.*

Spills occurring in spawning areas have a high probability of affecting eggs and newly hatched larvae. These life stages are unable to avoid waterborne pollutants due to poor swimming ability or dependence on certain habitats such as gravel streambeds. Spills that result in contamination of bottom sediments pose the most serious threat to anadromous fish populations because eggs of many species adhere to or are buried in sediments. Salmonids are probably the most sensitive to contamination of spawning areas because their eggs are spawned in shallow waters, and they remain in the sediments for many months prior to hatching and downstream migration.

Juveniles

° *Moderate-to-high risk of exposure in nursery areas.*

Juveniles of many species are dependent on shallow, nearshore nursery areas that may be exposed to toxic concentration of pollutants during spills.

Notes:

Family and Species Descriptions

A brief description of each family is given below, followed by detailed tables of ecological factors that influence the effects of oil and hazardous materials on them.

Sturgeon Family (Acipenseridae)

° *LIFE CYCLE*

Sturgeon are medium-to-large, long-lived anadromous fish. They grow very slowly and require many years to reach maturity. Spawning occurs infrequently (every 2-5 years). Because of these life-history characteristics, sturgeon populations are unable to recover quickly from drastic reductions in numbers from pollution, habitat alteration, or overfishing. Sturgeon release large quantities of demersal, adhesive eggs during spawning. Eggs hatch within a few weeks, and the larval sturgeon slowly move downstream from freshwater spawning areas to estuarine nursery areas.

° *HABITAT REQUIREMENTS*

Adult sturgeon inhabit nearshore coastal areas and the lower reaches of coastal rivers. They frequently feed in very shallow water. Spawning occurs in freshwater riverine habitats during the spring. Eggs are released in moving fresh water over gravel substrate. Larvae and juveniles remain in freshwater habitats for several years.

° *FOOD AND FEEDING*

Sturgeon are benthic omnivores that eat a variety of food items, including insect larvae, molluscs, worms, crustaceans, small fish, and some plant material.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

The shortnose sturgeon is an endangered species, and all other sturgeon species are greatly reduced in abundance compared to historical levels. There are limited commercial and recreational fisheries in the lower reaches of spawning rivers and estuaries.

REFERENCES

Eddy, 1969; Gussey, 1977, 1981; Hart, 1973; Huff, 1975; Mansueti and Hardy, 1967; Scott and Crossman, 1973; Thompson, 1980.

		Atlantic sturgeon Green sturgeon White sturgeon
ADULT:	Habitat	Coastal, estuarine, and riverine
	Diet	Benthic invertebrates, fish and plants
	Reproduction	Spawn in freshwater rivers over gravel sediments
	Behavior	Benthic
EGGS:	Type	Benthic, adhesive; hatch in 5-8 days
	Habitat	Gravel sediments in freshwater rivers
LARVAE:	Habitat	Shallow estuarine and riverine
	Diet	Benthic invertebrates
	Behavior	Benthic; remain in nursery grounds for long periods
JUVENILE:	Habitat	Shallow estuarine and riverine
	Diet	Benthic invertebrates
	Behavior	Benthic; remain in nursery grounds for long periods

Lake sturgeon	Shortnose sturgeon
Freshwater lakes and rivers	Coastal, estuarine and riverine
Benthic invertebrates and fish	Benthic invertebrates, fish and plant material
Spawn in rivers or shallow lake waters over sand or gravel	Spawn in freshwater rivers over rock and gravel sediments
Benthic	Benthic
Benthic, adhesive; hatch in 5-8 days	Benthic, adhesive
Gravel sediments in freshwater rivers and shallow lake waters	Gravel sediments in freshwater rivers
Shallow lake waters	Fresh and brackish estuaries and rivers
Benthic invertebrates	Benthic invertebrates
Benthic; remain in nursery grounds for long periods	Benthic; remain in nursery grounds for long periods
Shallow lake waters	Fresh, brackish and salt water rivers, estuaries, and coastal areas
Benthic invertebrates	Benthic invertebrates, plant material
Benthic; remain in nursery grounds for long periods	Benthic; remain in nursery grounds for long periods

Notes:

Herring Family (Clupeidae)

° *LIFE CYCLE*

The anadromous Clupeids (American shad, hickory shad, blueback herring, and alewife) are small- to medium-sized fish that live in marine waters as adults. They spawn in fresh-to-brackish water where eggs are released over suitable substrate. The eggs are generally nonadhesive and demersal. They hatch within 3-6 days, and the larvae and juveniles eventually migrate to the ocean within 1 year.

° *HABITAT REQUIREMENTS*

Adult anadromous Clupeids live in coastal and offshore marine habitats. They enter traditional spawning rivers in late winter to summer and migrate to upstream freshwater areas. Eggs are released over sand or gravel substrate in swiftly-flowing or slow-moving water, depending on species. Larvae and juveniles remain in fresh and brackish water until the fall or early spring of the next year when migration to the ocean occurs.

° *FOOD AND FEEDING*

They feed on a wide variety of planktonic organisms, including crustaceans, larval fish, fish eggs, and planktonic larvae of numerous invertebrate species.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

Anadromous shad and herring once supported large fisheries, especially in the northeastern United States. Destruction of spawning habitat and construction of dams have greatly reduced their populations, and they now support small, localized fisheries. Recent efforts have been made to restore shad and herring spawning runs throughout their range.

REFERENCES

Atlantic States Marine Fisheries Commission, 1985; Facey and Van Den Aryle, 1986; Fay et al., 1983a; Hart, 1973; Mansueti and Hardy, 1967; Mullen et al., 1986; Richkus and DiNardo, 1984; Scott and Crossman, 1973; Weiss-Glanz et al., 1986.

		Blueback herring Alewife
ADULT:	Habitat	Coastal marine waters
	Diet	Zooplankton, fish, eggs
	Reproduction	Spawn in freshwater streams, and rivers over gravel
	Behavior	Pelagic schooling, repeat spawner
EGGS:	Type	Adhesive, later pelagic; incubate 3-4 days
	Habitat	Running freshwater streams with gravel sediments
LARVAE:	Habitat	Shallow freshwater streams
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Freshwater riverine
	Diet	Zooplankton
	Behavior	Pelagic, schooling

American shad	Hickory shad
Coastal marine waters	Coastal marine waters
Zooplankton, fish, eggs	Zooplankton
Spawn in freshwater rivers in open water	Spawn in freshwater rivers gravel sediments
Pelagic schooling, many repeat spawners	Pelagic schooling; many repeat spawners
Planktonic, nonadhesive; incubate 4-6 days	Planktonic, nonadhesive; incubate 2-3 days
Riverine	Riverine
Riverine, estuarine	Riverine, estuarine
Zooplankton	Zooplankton
Planktonic	Planktonic
Estuarine and coastal marine areas	Estuarine
Insects, zooplankton	Zooplankton
Pelagic, schooling	Pelagic, schooling

Notes:

Salmon Family (Salmonidae)

° *LIFE HISTORY*

Salmon and many related species are large, migratory anadromous fish. Adults of most species return to their natal stream to spawn. Members of the genus *Oncorhynchus* die after spawning, while the other salmonids may return to the ocean and spawn again in subsequent years. Eggs develop slowly and hatch after several months. Larvae and juveniles remain in freshwater habitats for up to 18 months and then migrate to the ocean.

° *HABITAT REQUIREMENTS*

Adult salmon inhabit cool-water coastal and offshore marine habitats and frequently migrate over very large distances. Spawning occurs in swiftly-flowing freshwater streams with gravel substrates. Eggs are released in specially-prepared nests or redds and then buried with gravel. Eggs and larvae remain in the gravel substrate for extended periods and eventually emerge as free-swimming juveniles. Juveniles then migrate to estuarine and marine environments, where they reside in shallow nearshore waters prior to migration to offshore waters.

° *FOOD AND FEEDING*

Adult salmon are highly predatory and feed mainly on smaller fish and crustaceans. Larvae and juveniles feed on insect larvae, small crustaceans, and fish.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

Salmon are extremely important fisheries species, particularly in the north Pacific. They also are very important in subsistence harvests by native Americans.

REFERENCES

Allen and Hassler, 1986; Barnhart, 1986; Beauchamp et al., 1983; Behnke, 1979; Hart, 1973; Laufle et al., 1986; Pauley et al., 1986; Scott and Crossman, 1973.

		Coho salmon
ADULT:	Habitat	Pelagic, marine
	Diet	Fish
	Reproduction	Spawn in freshwater rivers and streams over gravel sediments
	Behavior	Die after spawning
EGGS:	Type	Benthic in gravel; incubate 1-3 months
	Habitat	Freshwater rivers and streams
LARVAE:	Habitat	Freshwater rivers and streams
	Diet	Insects
	Behavior	Benthic in gravel sediments
JUVENILE:	Habitat	Freshwater rivers and nearshore coastal waters
	Diet	Insects, crustaceans, fish
	Behavior	Pelagic

Sockeye salmon	Pink salmon
Pelagic, marine	Pelagic, marine
Fish	Fish, crustaceans
Spawn in freshwater rivers and lakes over gravel sediments	Spawn in lower reaches of freshwater rivers over gravel
Die after spawning	Die after spawning
Benthic in gravel; incubate 1-5 months	Benthic in gravel; incubate 2-4 months
Freshwater rivers, streams, and lakes	Lower reaches of freshwater rivers
Freshwater rivers and lakes	Freshwater rivers
Insects, zooplankton	Zooplankton
Benthic in gravel sediments	Benthic in gravel sediments
Nearshore estuarine and marine	Riverine and estuarine areas
Zooplankton, fish	Zooplankton, fish
Pelagic	Pelagic

		Chum salmon
ADULT:	Habitat	Pelagic, marine
	Diet	Fish, crustaceans
	Reproduction	Spawn in upper or lower reaches of freshwater rivers
	Behavior	Die after spawning
EGGS:	Type	Benthic; incubate 2-3 months
	Habitat	Freshwater rivers
LARVAE:	Habitat	Freshwater rivers
	Diet	Zooplankton
	Behavior	Benthic in gravel sediments
JUVENILE:	Habitat	Riverine and estuarine areas
	Diet	Zooplankton, fish
	Behavior	Pelagic, schooling

Chinook salmon	Atlantic salmon
Pelagic, marine	Pelagic, marine
Fish, crustaceans	Fish, crustaceans
Spawn in freshwater rivers over gravel sediment	Spawn in freshwater rivers over gravel sediment
Die after spawning	Many repeat spawners
Benthic in gravel; incubate 2-4 months	Benthic in gravel; incubate 3-5 months
Freshwater rivers	Freshwater rivers
Freshwater rivers	Freshwater rivers
Insects, zooplankton	Insects, zooplankton
Benthic in gravel sediments	Benthic in gravel sediments
Freshwater, estuarine	Freshwater, estuarine
Zooplankton, fish	Zooplankton, fish
Pelagic	Pelagic

		Steelhead trout
ADULT:	Habitat	Pelagic marine
	Diet	Fish, crustaceans
	Reproduction	Spawn in freshwater rivers over gravel sediments
	Behavior	Many repeat spawners
EGGS:	Type	Benthic; incubate 1-2 months
	Habitat	Freshwater streams in gravel
LARVAE:	Habitat	Freshwater streams
	Diet	Insects, crustaceans
	Behavior	Pelagic
JUVENILE:	Habitat	Freshwater rivers, coastal marine waters
	Diet	Fish, zooplankton
	Behavior	Pelagic

Cutthroat trout	Dolly Varden
Pelagic marine	Pelagic marine, coastal, some landlocked
Fish, crustaceans	Fish, crustaceans
Spawn in freshwater rivers over gravel sediments	Spawn in freshwater streams over gravel sediments
Many repeat spawners	Repeat spawners
Benthic	Benthic; incubate 4-8 months
Freshwater streams in gravel	Freshwater streams in gravel
Freshwater streams	Freshwater streams
Insects, crustaceans	Insects, crustaceans
Pelagic	Pelagic
Freshwater rivers, coastal marine waters	Freshwater streams and lakes
Fish, zooplankton	Insects, molluscs, fish
Pelagic	Pelagic

		Arctic char
ADULT:	Habitat	Pelagic, marine, coastal, some landlocked
	Diet	Fish, crustaceans
	Reproduction	Spawn in freshwater lakes and rivers on gravel sediments
	Behavior	Repeat spawners
EGGS:	Type	Benthic; incubate 4-8 months
	Habitat	Freshwater lakes and rivers in gravel
LARVAE:	Habitat	Freshwater lakes and rivers in gravel
	Diet	Insects, crustaceans
	Behavior	Pelagic
JUVENILE:	Habitat	Freshwater streams and lakes
	Diet	Insects, molluscs, fish
	Behavior	Pelagic

Ciscos
Inconnu

Primarily freshwater rivers and lakes, also estuaries

Molluscs, insects, crustaceans

Spawn in rivers over gravel or sand sediments

Repeat spawners

Benthic; incubate 1-4 months

Freshwater rivers

Freshwater rivers

Insects, crustaceans

Benthic

Freshwater rivers and estuaries

Insects, crustaceans

Pelagic

Notes:

Smelt Family (Osmeridae)

° *LIFE HISTORY*

Smelt are small, predaceous, anadromous fish. They spawn in freshwater streams and rivers during late winter to summer. Many adults die after spawning; survivors return to the ocean and may spawn again. Eggs hatch within a few weeks, and larval smelt drift downstream to estuarine habitats where they eventually develop into adults.

° *HABITAT REQUIREMENTS*

Adult smelt live in nearshore coastal habitats. Spawning occurs in freshwater riverine habitats over sand or gravel substrate on submerged vegetation. Larval and juvenile smelt live in estuarine habitats where they develop into adults after a few years.

° *FOOD AND FEEDING*

Smelt are predatory fish that feed on eggs, larvae, and adults of various invertebrate and fish species.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

There are limited commercial and recreational harvests.

REFERENCES

Eddy, 1969; Eschmeyer et al., 1983; Hart, 1973; Scott and Crossman, 1973; Thompson, 1980.

		Longfin smelt
ADULT:	Habitat	Pelagic, estuarine and marine
	Diet	Zooplankton
	Reproduction	Spawn in freshwater over gravel and submerged plants
	Behavior	Most die after spawning
EGGS:	Type	Benthic, adhesive; incubate 1-2 months
	Habitat	Freshwater riverine and estuarine
LARVAE:	Habitat	Freshwater riverine, estuarine and coastal marine
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Estuarine
	Diet	Zooplankton
	Behavior	Pelagic

Eulachon	Rainbow smelt
Pelagic, estuarine and marine	Marine, estuarine
Zooplankton	Zooplankton, fish, crustaceans
Spawn in freshwater rivers over sand	Spawn in freshwater streams over many substrates, may spawn in brackish lagoons
Most die after spawning	Most die after spawning
Benthic, adhesive; incubate 2-3 weeks	Benthic, adhesive; incubate 2-4 weeks
Freshwater rivers	Freshwater rivers
Freshwater riverine, estuarine and coastal marine	Freshwater rivers, estuaries, and marine waters
Phytoplankton, zooplankton	Zooplankton, insects
Planktonic	Planktonic
Estuarine	Coastal marine and estuarine
Zooplankton	Zooplankton, fish, crustacean
Pelagic	Pelagic

Notes:

Seabass Family (Percichthyidae)

° *LIFE CYCLE*

The striped bass is the only true anadromous species in this family. It is a large, predatory fish that ascends coastal rivers to spawn in fresh water in the spring, usually in tidally influenced reaches of coastal rivers and estuaries. Adults release nonadhesive, semi-buoyant eggs that flow with the current and then hatch within a few days. Larvae and juveniles frequently move farther upstream and then eventually migrate to estuarine and marine habitats.

° *HABITAT REQUIREMENTS*

Adult striped bass use a variety of habitats, including coastal marine areas, estuaries, and rivers. Certain stocks are highly migratory (especially in the mid- and north Atlantic Ocean), while others reside permanently in their areas of origin. Coastal migrations are generally north-south movements associated with the seasons. Striped bass eggs and larvae require flowing water to develop; otherwise, they are susceptible to smothering by sediments. They are generally tolerant of a wide salinity range but develop best in low-salinity conditions. Juveniles are typically found in shallow-water riverine and estuarine habitats of low-to-moderate salinity.

° *FOOD AND FEEDING*

Adult striped bass are predaceous and feed on fish and crustaceans; juveniles feed on zooplankton, small fish, and insect larvae.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

The striped bass was at one time a very important fisheries species, but recent closures of major concentration areas (Chesapeake Bay and the Hudson River) to fishing have resulted in greatly reduced commercial and recreational harvests. In other areas, it remains a highly popular sportfish. Overfishing, habitat loss, and other factors have contributed to the decline in populations in Chesapeake Bay and elsewhere, prompting the closure of these areas.

REFERENCES

Hart, 1973; Mid-Atlantic Fishery Management Council, 1984; Nicholson et al., 1986; Scott and Crossman, 1973; Stanley and Danie, 1983.

		Striped bass
ADULT:	Habitat	Coastal marine, estuarine, and riverine areas
	Diet	Fish, crustaceans
	Reproduction	Spawn in freshwater rivers, and estuaries
	Behavior	Repeat spawners
EGGS:	Type	Planktonic, nonadhesive; Incubate 1-4 days
	Habitat	Freshwater rivers and estuaries
LARVAE:	Habitat	Freshwater rivers and estuaries
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Freshwater rivers and estuaries
	Diet	Zooplankton, fish
	Behavior	Pelagic

White bass

Coastal marine, estuarine, and riverine areas

Fish, crustaceans, insects

Spawn in freshwater rivers and lakes, and estuaries

Repeat spawners

Benthic, adhesive, or planktonic; incubate 1-5 days

Freshwater rivers and lakes, and estuaries

Freshwater rivers and lakes, and estuaries

Zooplankton

Planktonic

Estuaries

Zooplankton, fish

Pelagic

Notes:

Other Anadromous Fish

Certain freshwater fish have assumed life cycles similar to true anadromous fish in the Great Lakes and Lake Champlain, where these species are known to ascend tributary streams to spawn. These species are discussed briefly below.

Perch Family (Percidae)

Walleye and sauger are predators that spawn in the spring and generally inhabit shallow- to medium-depth lake and river habitats. They eat fish and insects.

Cod Family (Gadidae)

The burbot is the only strictly freshwater species of cod in the United States. It inhabits deep-water lake habitats and spawns in rivers and streams in winter. The tomcod is a related species that assumes a more traditional anadromous life cycle but is not considered a true anadromous fish. It lives in marine waters and spawns in the lower reaches of coastal rivers. It is a small, benthic omnivore.

Sucker Family (Catostomidae)

Suckers are benthic omnivores found in a variety of freshwater habitats. They spawn in spring, often in small tributary streams. They feed on a wide range of plant and animal material.

References

Eddy, 1969; Herdendorf et al., 1981; Mansueti and Hardy, 1967; Scott and Crossman, 1973; Thompson, 1980.

		Walleye Sauger
ADULT:	Habitat	Freshwater lakes and rivers
	Diet	Fish
	Reproduction	Spawn in tributary streams
	Behavior	Pelagic
EGGS:	Type	Benthic
	Habitat	Freshwater streams
LARVAE:	Habitat	Freshwater streams
	Diet	Insects, zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Freshwater streams and lakes
	Diet	Insects, fish
	Behavior	Pelagic

Tomcod	Burbot
Coastal marine waters	Freshwater lakes
Crustaceans, fish, molluscs	Fish
Spawn in estuaries and freshwater rivers over sand or gravel	Spawn in lakes and tributary streams over gravel
	Pelagic
Benthic, adhesive; hatch in 3-4 weeks	Semipelagic
Estuaries and rivers	Lakes and tributary streams over sand or gravel
Estuarine	Lakes and streams
Zooplankton	Insects and crustaceans
Planktonic	Planktonic
Estuarine	Lakes and streams
Zooplankton, fish, molluscs	–Fish, crustaceans
Pelagic	Pelagic

		Suckers
ADULT:	Habitat	Freshwater lakes and rivers
	Diet	Benthic invertebrates and plants
	Reproduction	Spawn in tributary streams over sand, mud, vegetation
	Behavior	Benthic
EGGS:	Type	Benthic, adhesive; hatch in 8-11 days
	Habitat	Sand, gravel and vegetated streambeds
LARVAE:	Habitat	Freshwater rivers and lakes
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Freshwater rivers and lakes
	Diet	Benthic invertebrates and plants
	Behavior	Benthic

MARINE PELAGIC FISH

Eight families of pelagic marine fish that occur in offshore waters are represented in this group, although there are many other species that have pelagic life-history stages. These families and the most important species of each family are listed below.

BILLFISH (Istiophoridae)

Sailfish (*Istiophorus platypterus*)
Blue marlin (*Makaira nigricans*)
White marlin (*Tetrapturus albidus*)
Black marlin (*Makaira indica*)
Striped marlin (*Tetrapturus audax*)
Longbill spearfish (*Tetrapturus pfleugeri*)

SWORDFISH (Xiphiidae)

Swordfish (*Xiphius gladius*)

SHARKS (Lamnidae, Carcharhinidae, Sphyrnidae, Alopiidae)

Blue shark (*Prionace glauca*)
Longfin mako shark (*Isurus paucus*)
Shortfin mako shark (*Isurus oxyrinchus*)
Smooth hammerhead shark (*Sphyrna zygaena*)
Scalloped hammerhead shark (*Sphyrna lewini*)
Great hammerhead shark (*Sphyrna mokarran*)
Leopard shark (*Trakis semifasciata*)
Thresher shark (*Alopias vulpinus*)
Oceanic whitetip shark (*Carcharhinus longimanus*)
Tiger shark (*Galeocerdo cuvieri*)
Porbeagle shark (*Lamna nasus*)
Bigeye thresher shark (*Alopias superciliosus*)
Thresher shark (*Alopias vulpinus*)
Night shark (*Hypoprion signatus*)
Bignose shark (*Carcharhinus altimus*)
Spinner shark (*Carcharhinus maculipinnis*)
Galapagos shark (*Carcharhinus galapagensis*)

DOLPHIN (Coryphaenidae)

Dolphin (Coryphaena hippurus)

COBIA (Rachycentridae)

Cobia (*Rachycentron canadum*)

MACKEREL (Scombridae)

King mackerel (*Scomberomorus cavalla*)
Spanish mackerel (*Scomberomorus maculatus*)
Atlantic mackerel (*Scomber scombrus*)
Wahoo (*Acanthocybium solanderi*)
Yellowfin tuna (*Thunnus albacares*)
Bluefin tuna (*Thunnus thynnus*)
Skipjack tuna (*Katsuwonus pelamis*)
Albacore (*Thunnus alalunga*)
Bigeye tuna (*Thunnus obesus*)
Blackfin tuna (*Thunnus atlanticus*)

JACKS (Carangidae)

Jack mackerel (*Trachurus symmetricus*)

As previously discussed, many anadromous fish inhabit offshore pelagic areas, especially salmon, and many noncommercial marine fish also occur there.

° *LIFE CYCLE*

Marine pelagic fish are all highly mobile as adults, and many undergo extensive migrations between northern and southern waters, offshore and nearshore waters, and east-west migrations. In most cases, spawning occurs in offshore waters; many species produce very large quantities of eggs that are semibuoyant and hatch within a few days. The eggs and larvae are planktonic and tend to concentrate in the upper water column. Sharks are somewhat different from other pelagic species in that they produce smaller numbers of relatively large, demersal or neutrally buoyant eggs or, in some cases, produce live young.

° *HABITAT REQUIREMENTS*

Most species in this group are epipelagic in deep-water marine habitats, but some regularly enter coastal waters, especially the sharks and certain mackerels. Spanish mackerel frequently enter estuaries to feed and are generally restricted to coastal waters. Little is known of the habitat requirements of larval and juvenile forms except that they frequently occur in coastal waters and are also epipelagic.

° *FOOD AND FEEDING*

All species in this group are very active predators, with the sharks being a notorious example. They feed on fish, squid, and other prey items.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

These species are, in most cases, very important commercial and recreational species and, in many cases, are considered some of the most sought-after sportfish in the world.

° *SUSCEPTIBILITY*

Adults

° *Low risk of exposure to spilled contaminants.*

Adult pelagic species are highly mobile and live in deep water where spills are rapidly diluted or dispersed.

Eggs and Larvae

° *Low-to-moderate risk of exposure.*

Many species have buoyant, epipelagic eggs and larvae that may experience brief exposures to pollutants in the upper water column. The high dilution and mixing that occurs in offshore waters generally results in areally limited risk of toxic exposure to spilled chemicals.

Juveniles

- *Low-to-moderate risk in nursery areas.*

  Juveniles of many species are found in nearshore areas where they are more likely to encounter spills.

REFERENCES

Godcharles and Murphy, 1986; Moss, 1984; Pacific Atlantic Fishery Management Council, 1979; South Atlantic Fishery Management Council, 1982, 1985a, 1985b; Strategic Assessment Branch, 1985.

		Mackerels (including Jack mackerel)
ADULT:	Habitat	Offshore coastal waters
	Diet	Fish, squid, crustaceans
	Reproduction	Spawn in coastal or offshore waters
	Behavior	Pelagic; some highly migratory
EGGS:	Type	Planktonic, buoyant
	Habitat	Epipelagic in offshore and coastal waters
LARVAE:	Habitat	Offshore and coastal waters
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Offshore and coastal waters
	Diet	Fish, squid, crustaceans
	Behavior	Pelagic

Cobia	Billfish Swordfish Dolphin
Offshore, coastal, estuarine waters, near reefs, floating objects	Offshore marine waters
Fish, molluscs, crustaceans	Fish, cephalopods
Spawn in coastal waters	Spawn in offshore waters
Pelagic and epibenthic	Pelagic
Planktonic	Planktonic, buoyant
Estuarine and coastal areas	Epipelagic in offshore marine waters
Coastal and estuarine waters	Epipelagic in offshore marine waters
Zooplankton	Unknown, probably zooplankton
Planktonic	Planktonic
Coastal and estuarine waters	Epipelagic in offshore waters
Fish, crustaceans	Fish
Pelagic	Pelagic

		Sharks
ADULT:	Habitat	Offshore, coastal and estuarine waters
	Diet	Fish, crustaceans, cephalopods, marine mammals, turtles
	Reproduction	Spawn in all habitats
	Behavior	Pelagic or demersal
EGGS:	Type	Demersal; some produce live young
	Habitat	Demersal or pelagic in all habitats
LARVAE:	Habitat	Offshore, coastal and estuarine waters
	Diet	Fish, crustaceans
	Behavior	Pelagic or demersal
JUVENILE:	Habitat	Offshore, coastal and estuarine waters
	Diet	Fish, crustaceans
	Behavior	Pelagic or demersal

DEMERSAL GROUNDFISH

Demersal groundfish species comprise a large and economically important group of fish that typically inhabit shallow- to deep-water benthic marine habitats with rocky, sandy, or muddy bottom areas on the continental shelf. Six families are commonly represented in this group, and there are numerous others that may occur in these habitats. The six major families are listed below:

SABLEFISH (Anoplopomatidae)

Sablefish (*Anoplopoma fimbria*)

ROCKFISH (Scorpaenidae)

Redfish (*Sebastes marinus*)
Black rockfish (*Sebastes melanops*)
Blue rockfish (*Sebastes mystinus*)
Bocaccio (*Sebastes paucispinis*)
Pacific Ocean perch (*Sebastes alutus*)

COD (Gadidae)

Haddock (*Melanogramus aeglefinus*)
Atlantic cod (*Gadus morhua*)
Pacific cod (*Gadus macrocephalus*)
Pollock (*Pollachius virens*)
Red hake (*Urophycis chuss*)
Silver hake (*Merluccius bilinearis*)
White hake (*Urophycis tenuis*)

FLATFISH (Bothidae, Pleuronectidae, and Soleidae)

Southern flounder (*Paralichthys lethostigma*)
Gulf flounder (*Paralichthys albigutta*)
Pacific halibut (*Hippoglossus stenolepis*)
Atlantic halibut (*Hippoglossus hippoglossus*)
Yellowtail flounder (*Limanda ferruginea*)
Winter flounder (*Pseudopleuronectes americanus*)
Summer flounder (*Paralichthys dentatus*)
Petrale sole (*Eopsetta jordani*)
Flathead sole (*Hippoglossoides elassodon*)
Dover sole (*Microstomus pacificus*)
English sole (*Parophrys vetulus*)
Starry flounder (*Platichthys stellatus*)
California halibut (*Paralichthys californicus*)
Sand sole (*Psettichthys melanostictus*)
Lined sole (*Archirus lineatus*)

° *LIFE CYCLE*

The life cycle of most groundfish is typical of many other marine fish species. Adults release buoyant eggs into the water where fertilization occurs. Spawning usually occurs in relatively deep water during the late winter, spring, or summer. The eggs are pelagic and generally float toward the surface. Hatching occurs after several days or weeks, and the planktonic larvae develop in the upper water column for several weeks or months. Juveniles of many species occur in nearshore, shallow waters and may remain in these areas for several years before migrating to deeper waters.

Rockfish are somewhat different from other demersal groundfish in that almost all species produce live young that are spawned as planktonic larvae. Their development from this point is similar to other groundfish.

° *HABITAT REQUIREMENTS*

Adults tend to occupy rocky, sandy, or muddy bottom habitats over a wide range of depths. Some species may feed throughout the water column, but benthic habitats are preferred by most. Many species undergo seasonal onshore and offshore migrations. Eggs are buoyant and tend to concentrate in midwater or surface water habitats. Larvae also are most abundant in surface waters, and larval and juvenile stages of many species inhabit nearshore waters.

° *FOOD AND FEEDING*

Demersal groundfish eat primarily benthic crustaceans and worms, although fish and squid are also important food items for midwater feeders such as cod, pollock, and the larger individuals of most species.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

Demersal groundfish are some of the most important commercial fish catches in the United States, and many species are also popular recreational catches.

° *SUSCEPTIBILITY TO SPILLED CONTAMINANTS*

Adults

° *Low risk of exposure due to preference for deep-water habitats.*

Adult demersal groundfish may occur in shallow, nearshore waters, but most species prefer water depths of at least 10 meters (m) and are frequently found in water over 100 m. They are unlikely, therefore, to encounter significant concentrations of spilled pollutants.

Eggs and Larvae

° *Low-to-moderate risk to buoyant, epipelagic eggs and larvae.*

The tendency of eggs and larvae to float in surface waters creates a risk of exposure to spilled pollutants. Mixing and dilution in deep marine waters will generally reduce risk of toxic exposure to spilled chemicals.

Juveniles

- *Low-to-moderate risk to shallow-water, nearshore juveniles.*

  Juveniles found in relatively shallow, nearshore nursery areas may be exposed to toxic concentrations of spilled chemicals, but in most cases, they are highly mobile and may be able to avoid prolonged exposures.

REFERENCES

Gilbert, 1986b; Kucas and Hassler, 1986; New England Fishery Management Council, 1985; Reagan and Wingo, 1985; Rogers and Van Den Aryle, 1983; Scarlett, 1981; Strategic Assessment Branch, 1985.

		Cod
ADULT:	Habitat	Medium to deep water marine waters over a variety substrates
	Diet	Fish, crustaceans, molluscs, and worms
	Reproduction	Spawn over offshore shoals and banks
	Behavior	Demersal or semipelagic
EGGS:	Type	Mostly buoyant, pelagic, some benthic, adhesive (Pacific cod); incubate 1-4 weeks
	Habitat	Offshore epipelagic waters
LARVAE:	Habitat	Offshore epipelagic waters
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Offshore and coastal shoals and banks
	Diet	Zooplankton, crustaceans
	Behavior	Demersal or semipelagic

Flounder Sole Halibut	Winter flounder
Estuarine and marine waters over a wide range of depths and substrates	Estuarine and coastal waters over a wide range of substrates
Fish, crustaceans, worms	Worms, sea anemones, plant material
Spawn in coastal or offshore waters	Spawn in shallow estuaries
Demersal	Demersal
Planktonic, buoyant, or demersal (California halibut); incubate 1-10 days	Demersal, adhesive; incubate 10-12 days
Offshore marine waters	Sandy sediments in estuaries
Offshore and coastal waters	Estuaries
Zooplankton	Zooplankton, phytoplankton
Planktonic	Planktonic
Coastal and estuarine areas	Estuarine and coastal waters
Fish, crustaceans	Zooplankton, crustaceans, worms, plants
Demersal	Demersal

		Rockfish
ADULT:	Habitat	Coastal and offshore waters over varying substrates and depths
	Diet	Crustaceans
	Reproduction	Produce live young
	Behavior	Demersal
EGGS:	Type	None; produce live young
	Habitat	Planktonic in coastal and offshore waters
LARVAE:	Habitat	Coastal and offshore waters over varying substrates and depths
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Coastal and offshore waters over varying substrates and depths
	Diet	Crustaceans
	Behavior	Demersal

Sablefish

Deep-water offshore areas over soft bottoms

Fish, molluscs, crustaceans

Spawn offshore in midwinter

Demersal or semipelagic, feed in midwater area

Planktonic, nonadhesive

Planktonic in deep water

Coastal and offshore areas

Zooplankton

Planktonic

Offshore areas over soft substrates

Zooplankton, fish

Demersal or semipelagic

REEF FISH

Reef fish are semipelagic or demersal fish that occupy reefs and similar hard-bottom habitats on the continental shelf, primarily off the southeastern United States. Five major families are commonly represented in this group, but in most areas, reef habitats support extremely diverse fish communities that are beyond the scope of this guidebook. The families and some representative species included are listed below.

SEA BASSES (Serranidae)

Yellowfin grouper (*Mycteroperca venenosa*)
Nassau grouper (*Epinephelus striatus*)
Red hind (*Epinephelus guttatus*)
Jewfish (*Epinephelus itajara*)
Black sea bass (*Centropristis striata*)
Graysby (*Epinephelus cruentatus*)
Speckled hind (*Epinephelus drummondhayi*)
Red grouper (*Epinephelus morio*)
Black grouper (*Mycteroperca bonaci*)
Gag (*Mycteroperca microlepis*)
Scamp (*Mycteroperca phenax*)
Kelp bass (*Paralabrax clathratus*)

SNAPPERS (Lutjanidae)

Red snapper (*Lutjanus campechanus*)
Gray snapper (*Lutjanus griseus*)
Lane snapper (*Lutjanus synagris*)
Mutton snapper (*Lutjanus analis*)
Yellowtail snapper (*Ocyurus chrysurus*)
Vermillion snapper (*Rhomboplites aurorubens*)

JACKS (Carangidae)

Greater amberjack (*Seriola dumerili*)
Crevalle jack (*Caranx hippos*)
Blue runner (*Caranx crysos*)
Bar jack (*Caranx ruber*)

PORGIES (Sparidae)

Scup (*Stenotomus chrysops*)
Red porgy (*Pagrus pagrus*)

GRUNTS (Pomadasyidae)

Tomtate (*Haemulon aurolineatum*)
White grunt (*Haemulon plumieri*)

° *LIFE CYCLE*

All families listed above produce eggs that are fertilized externally. Eggs are planktonic and generally hatch within a few days. Larvae are also planktonic and, in most species, are transported by currents to nearshore, estuarine nurseries where they develop into juveniles. Juveniles may remain in nearshore habitats for several years and eventually migrate to deeper water reefs and other rocky-bottom habitats.

° *HABITAT REQUIREMENTS*

Adults are generally found in relatively deep waters (10-200 m) associated with coral or rock reefs. Eggs and larvae are planktonic; water currents tend to disperse them toward shallow-water nursery areas, especially seagrass and algae beds, mangroves, and marshes where juveniles are most abundant. In almost all species, adults are found in deeper waters than juveniles.

° *FOOD AND FEEDING*

Almost all species in this group are predators. Common prey items include fish, crustaceans, molluscs, and other invertebrates.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

Reef fish support very important recreational fisheries throughout their range and are important commercial species in localized areas.

° *SUSCEPTIBILITY TO SPILLED CONTAMINANTS*

Adults

° *Low-to-moderate risk of exposure in reef habitats.*

Adults are found in relatively deep waters and are unlikely to encounter toxic levels of spilled contaminants except in reef habitats occurring in more shallow waters. The primary threat to these species is from habitat loss due to destruction of reefs.

Eggs and Larvae

° *Moderate risk of exposure in planktonic stages.*

Risk of exposure increases as eggs and larvae drift toward shallow-water nursery areas.

Juveniles

° *High risk of exposure in shallow estuarine habitats.*

Juveniles residing in shallow nearshore waters may experience direct toxic effects from spills occurring in estuarine nursery areas. Indirect effects resulting from destruction of critical habitats (especially mangroves and marshes) may have long-term impacts to juvenile populations.

REFERENCES

Bortone and Williams, 1986; Gussey, 1981; South Atlantic Fishery Management Council, 1983; Strategic Assessment Branch, 1985.

		Snappers Porgies Grunts
ADULT:	Habitat	Reefs in medium-to-deep marine waters
	Diet	Fish, crustaceans, invertebrates
	Reproduction	Spawn in offshore reefs
	Behavior	Semipelagic around reefs
EGGS:	Type	Planktonic, nonadhesive; incubate 1-2 days
	Habitat	Offshore reefs, drift toward shallow nursery areas
LARVAE:	Habitat	Offshore reefs, drift toward shallow nursery areas
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Nearshore seagrass beds, mangroves, marshes
	Diet	Zooplankton, fish, crustaceans
	Behavior	Semipelagic in shallow-water nursery areas

Sea basses	Jacks
Reefs in medium-to-deep marine waters	Shallow-to-deep reef, pelagic marine, some brackish or fresh
Fish, crustaceans, invertebrates	Fish, invertebrates, some plankton
Spawn in offshore reefs	Spawn in offshore waters
Semipelagic around reefs	Pelagic around reefs and other habitats
Planktonic, nonadhesive; incubate 1-3 days	Planktonic, nonadhesive
Offshore reefs, drift toward shallow nursery areas	Offshore marine waters
Offshore reefs, drift toward shallow nursery areas	Offshore marine waters
Zooplankton	Zooplankton
Planktonic	Planktonic
Nearshore reefs and other hard substrate areas	Coastal and estuarine waters
Zooplankton, fish, crustaceans	Fish, crustaceans
Semipelagic in shallow-water nursery areas	Often found near floating objects

ESTUARINE AND NEARSHORE FISH

There is a large group of fish that spend much or all of their life cycle in estuaries and nearshore marine waters. Many marine fish use these habitats during some stage of their life cycle, but the fish species listed below tend to be associated more with estuaries and nearshore waters than with other marine habitats.

BLUEFISH (Pomatomidae)

Bluefish (*Pomatomus saltatrix*)

MULLET (Mugilidae)

Striped mullet (*Mugil cephalus*)
White mullet (*Mugil curema*)

HERRINGS (Clupeidae)

Atlantic menhaden (*Brevoortia tyrannus*)
Gulf menhaden (*Brevoortia patronus*)
Atlantic herring (*Clupea harengus harengus*)
Pacific herring (*Clupea harengus pallasi*)

ANCHOVIES (Engraulidae)

Northern anchovy (*Engraulis mordax*)
Bay anchovy (*Anchoa mitchilli*)
Striped anchovy (*Anchoa hepsetus*)

SMELTS (Osmeridae)

Surf smelt (*Hypomesus pretiosus*)
Capelin (*Mallotus villosus*)

DRUM (Sciaenidae)

Atlantic croaker (*Micropogonias undulatus*)
White croaker (*Genyonemus lineatus*)
Spotted seatrout (*Cynoscion nebulosus*)
Weakfish (*Cynoscion regalis*)
Spot (*Leiostomus xanthurus*)
Kingfish (*Menticirrhus* spp.)
Red drum (*Sciaenops ocellatus*)
Black drum (*Pogonias cromis*)
Queenfish (*Seriphus politus*)

SILVERSIDES (Atherinidae)

Atlantic silverside (*Menidia menidia*)
Jack smelt (*Atherinopsis californiensis*)

KILLIFISH (Cyprinodontidae)

Gulf killifish (*Fundulus grandis*)
Mummichog (*Fundulus heteroclitus*)
Striped killifish (*Fundulus majalis*)

SNOOKS (Centropomidae)

Snook (*Centropomus undecimalis*)

PORGIES (Sparidae)

Sheepshead (*Archosargus probatocephalus*)
Pinfish (*Lagodon rhomboides*)

JACKS (Carangidae)

Florida pompano (*Trachinotus carolinus*)

° *LIFE CYCLE*

The life cycles of estuarine fish are very similar to most other marine fish. In most species, eggs are released into the water and fertilized externally. The eggs may be planktonic and buoyant and drift with the currents until hatching. Pacific herring, killifish, silversides, and smelts produce eggs that are demersal and adhesive to subtidal or intertidal substrates. Larval forms are usually planktonic, and in most cases, development into juvenile and then adult forms is rapid.

° *HABITAT PREFERENCE*

Adults of most species live in relatively shallow estuaries and nearshore waters during the late spring, summer, and early fall, and migrate to deeper-water habitats in late fall and winter. These overwintering areas may be far offshore, and in many species, spawning occurs there during the late winter.

The larvae of those species that spawn offshore are also usually most abundant in offshore areas, but they eventually drift toward shallow-water habitats where they mature into juveniles and adults. This group includes mullet, pinfish, sheepshead, pompano, and croaker.

Species that spawn close to shore generally spawn in summer or fall, and eggs may be planktonic or demersal. This group includes red drum, black drum, seatrout, weakfish, and anchovy. A number of species spawn over intertidal or shallow subtidal substrates, such as sand or gravel beaches, marshes, tidal flats, and seagrass beds. These species are Pacific herring, smelts, and silversides.

° *FOOD AND FEEDING*

Most of the fish in this group are generalist feeders that consume a wide range of food items. Many are filter-feeders that consume small planktonic or benthic organisms such as fish and invertebrate larvae and eggs, zooplankton, and phytoplankton. This grouping includes mullets, herrings, and anchovies. Other species in this group are benthic and midwater omnivores that feed on organisms such as clams, crabs, shrimp, and other fish. This group includes spot, red drum, black drum, pompano, butterfish, silversides, and killifish.

Several species are predators, such as bluefish, weakfish, spotted seatrout, and snook. They capture relatively large animals, especially other fish.

° *COMMERCIAL/RECREATIONAL IMPORTANCE*

The herrings, especially menhaden, are the most important commercially harvested species in this country in terms of the total weight harvested each year. The drums also support commercial fisheries, but they are much more important as sportfish, as are snook.

Mullet and anchovies are taken in relatively small numbers by commercial fisheries, and many of the smaller species (especially silversides and killifish) are captured for use as bait.

° *SUSCEPTIBILITY TO SPILLED CONTAMINANTS*

Adults

° *Low-to-high depending on season.*

Offshore migrations in winter reduce risk of exposure to spills, but contamination of estuarine habitats may pose long-term hazard to local adult populations.

° *Intertidal spawners at high risk during spawning events.*

Pacific herring, surf smelt, capelin, and Atlantic silversides spawn on intertidal or shallow subtidal substrates and are more susceptible to oil and hazardous material spills occurring in shallow nearshore waters during spawning.

Eggs and Larvae

° *Moderate-to-high risk.*

Eggs or larvae of almost all species are present in shallow, nearshore habitats susceptible to chemical spills.

° *Intertidal spawners at very high risk.*

Eggs laid on intertidal substrates are likely to experience severe toxic effects from spilled chemicals, especially oils and floating chemicals.

Juveniles

° *Moderate-to-high risk.*

Use of shallow-water habitats increases likelihood of exposure to spills.

REFERENCES

Abraham, 1985; Collins, 1985a, 1985b; Fay et al., 1983b; Gilbert, 1986a; Hart, 1973; Jennings, 1985; Johnson et al., 1986; Kelly and Moring, 1986; Kucas, 1986; Lassuy, 1983a, 1983b, 1983c; Mercer, 1984, 1985; Muncy, 1984; Obrebski, 1981; Pacific Fishery Management Council, 1982; Robinette, 1983; Rogers and Van Den Aryle, 1983; Seaman and Collins, 1983; Strategic Assessment Branch, 1985; Sutter et al., 1986.

		Bluefish
ADULT:	Habitat	Coastal and estuarine waters
	Diet	Fish, crustaceans, squid
	Reproduction	Spawn in offshore waters
	Behavior	Pelagic
EGGS:	Type	Planktonic; incubate 2-3 days
	Habitat	Offshore waters
LARVAE:	Habitat	Offshore or coastal waters
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Offshore, coastal or estuarine waters
	Diet	Fish, crustaceans
	Behavior	Pelagic

Drum	**Killifish Silversides**
Coastal and estuarine waters	Estuaries
Fish, crustaceans, molluscs	Zooplankton, crustaceans, algae
Spawn in estuaries and nearshore coastal areas	Spawn in shallow marshes on intertidal sediments
Benthic or pelagic	Pelagic in shallow waters
Planktonic, semibuoyant	Adhesive, intertidal; incubate 1-2 weeks
Estuarine, nearshore coastal areas	Intertidal substrate
Estuaries	Shallow marshes
Zooplankton	Zooplankton, algae
Planktonic	Planktonic in intertidal areas
Estuaries	Estuaries
Zooplankton, fish, crustaceans	Zooplankton, crustaceans, algae
Benthic or pelagic	Pelagic in shallow waters

		Snook
ADULT:	Habitat	Estuaries, especially mangrove and marsh habitats
	Diet	Fish, crustaceans
	Reproduction	Spawn in coastal areas near rivers, canals, and passes
	Behavior	Pelagic
EGGS:	Type	Planktonic
	Habitat	Estuaries
LARVAE:	Habitat	Estuaries
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Estuaries, especially mangrove and marsh habitats
	Diet	Crustaceans, fish
	Behavior	Pelagic

Anchovies	**Atlantic herring**
Coastal waters	Coastal waters
Zooplankton, phytoplankton, fish	Zooplankton
Spawn in coastal waters	Spawn in coastal waters on gravel bottoms and algae beds
Pelagic	Pelagic
Planktonic, buoyant; incubate 2-4 days	Benthic, adhesive; incubate 1-3 weeks
Coastal waters	Coastal waters, often large mass
Coastal waters	Coastal waters and estuaries
Zooplankton, phytoplankton	Zooplankton
Planktonic	Planktonic
Coastal waters	Estuaries
Zooplankton, phytoplankton	Zooplankton
Pelagic	Pelagic

		Porgies
ADULT:	Habitat	Coastal and estuarine waters
	Diet	Crustaceans, molluscs, fish, plants
	Reproduction	Spawn in offshore waters
	Behavior	Benthic near reefs, seagrasses
EGGS:	Type	Planktonic, buoyant; incubate 2-3 days
	Habitat	Offshore waters
LARVAE:	Habitat	Offshore, coastal, and estuarine waters
	Diet	Zooplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Estuaries and coastal waters
	Diet	Molluscs, crustaceans, plants
	Behavior	Benthic near reefs, seagrasses

Smelts	Pacific herring
Coastal and estuarine waters	Offshore waters
Zooplankton	Zooplankton
Spawn on intertidal sand beaches	Spawn on intertidal, subtidal algae, seagrass beds
Pelagic	Pelagic
Benthic, adhesive; incubate 1-4 weeks	Benthic, adhesive; incubate 2 weeks
Sand beaches	Sheltered sandy or rocky beaches with algae or seagrass
Coastal and estuarine waters	Coastal and estuarine waters
Zooplankton	Zooplankton
Planktonic	Planktonic
Estuaries and coastal waters	Offshore and coastal waters
Zooplankton	Zooplankton
Pelagic	Pelagic

		Mullet
ADULT:	Habitat	Estuaries and coastal waters
	Diet	Benthic algae and organic material
	Reproduction	Spawn in coastal and offshore waters
	Behavior	Pelagic
EGGS:	Type	Planktonic; incubate 2-3 days
	Habitat	Coastal and offshore waters
LARVAE:	Habitat	Coastal and estuarine waters
	Diet	Zooplankton, phytoplankton
	Behavior	Planktonic
JUVENILE:	Habitat	Coastal and estuarine waters
	Diet	Benthic algae and organic material
	Behavior	Pelagic

Menhaden

Estuaries and coastal waters

Zooplankton, phytoplankton

Spawn in coastal and offshore waters

Pelagic

Planktonic; incubate 2-3 days

Coastal and offshore waters

Coastal and estuarine waters

Zooplankton, phytoplankton

Planktonic

Estuaries

Zooplankton, phytoplankton

Pelagic

TOXICOLOGICAL INFORMATION

SELECTION OF CHEMICALS

A recent survey of major port facilities in the United States identified the major chemical products most likely to be involved in oil and hazardous materials spills (Savitsky and Michel, 1986). The most commonly cited chemicals are crude and refined oils, including single hydrocarbon compounds such as benzene and toluene, acids and bases such as hydrochloric acid and sodium hydroxide, and anhydrous ammonia.

Numerous other chemicals are commonly transported in U.S. coastal waters, but those groups listed above include most compounds that are likely to be involved in spills and have the potential for impacts to marine fish. This report, therefore, focuses on the effects of these chemicals only.

OTHER SOURCES OF TOXICOLOGICAL INFORMATION

There are a variety of published sources of detailed toxicological information on the chemical groups discussed here, as well as the thousands of individual compounds not discussed herein. Two of the most comprehensive data sources are discussed below.

Chemical Hazards Response Information System (CHRIS), U.S. Coast Guard

CHRIS consists of four manuals, a Hazard Assessment Computer System (HACS), and technical support personnel located at Coast Guard headquarters. The *Hazardous Chemical Data Manual* provides summaries of specific chemical, physical, and biological data on over 500 chemicals. Selected information from this manual is summarized in the *Condensed Guide to Chemical Hazards*.

These manuals provide a very broad base of information that can be used to evaluate the potential for environmental impacts from a wide range of chemicals.

Quality Criteria for Water, USEPA

The criteria published by USEPA are intended to reflect accurately the latest scientific knowledge on the effects of waterborne pollutants on a variety of aquatic organisms and habitats. They provide relatively detailed summaries of toxicological information and quantitative estimates of pollutant concentrations above which toxic effects may occur.

Other Summary Reports

Other summary reports of acute toxicity data for fish and other aquatic animals include the following:

- *Mayer, F.L., and M.R. Ellersieck, 1986, Manual of acute toxicity: interpretation and data base for 410 chemicals and 66 species of freshwater animals: U.S. Fish and Wildlife Service, Resource Publ. 160, 579 pp.*

Toxicity data for 410 chemicals (mainly pesticides) and 66 species of aquatic animals (including some anadromous fish) are summarized and evaluated, to make taxonomic comparisons and assess the influence of various test parameters.

- *Lewis, R.J., and R.L. Tatken, 1980, Registry of toxic effects of chemicals substances: National Institute for Occupational Safety and Health Publ. No. 80-111, 1979 Ed., 1598 pp.*

The registry contains listings of over 39,000 chemical substances, providing very brief summaries of primarily mammalian and, in some cases, aquatic toxicity values. A more recent edition will be available in late 1987.

CRUDE AND REFINED OILS

TOXICITY

The toxic effects of crude and refined oils on fish has been the subject of much research in recent years. A variety of factors have been found to influence the sensitivity of fish and their likelihood of exposure to petroleum hydrocarbons. These are discussed below.

Oil Type

Crude and refined oils are a diverse group of liquids and semisolids that contain an even more diverse group of hydrocarbons and inorganic materials. They are highly variable in composition and physical properties. They all contain aromatic and alkane hydrocarbons, but the relative proportion of each varies, as does the proportion of low- and high-molecular-weight hydrocarbons. Each hydrocarbon compound present in oils has its own unique characteristics of toxicity, solubility, and viscosity, and they are all combined into a mixture whose properties reflect those of the various components.

The adverse impacts associated with spills of crude and refined oils are primarily caused by the chemical toxicity of the soluble low-molecular-weight aromatic and alkane hydrocarbons (McAuliffe, 1987). These compounds have relatively high toxicities and are the dominant component of the water-soluble fraction (WSF) of the oil.

The WSF is the portion of oil that marine fish are most likely be exposed to during an oil spill. Toxicity is usually expressed as the concentration of oil that causes a specified percent mortality after a given time (usually 50 percent mortality after 96 hours, called the 96-hour LC_{50}). The 96-hour LC_{50} for most petroleum products and fish species tested to date are approximately 1-10 parts per million (ppm) when the WSF of the oil is used (Tables 1 and 2). Oils that are relatively soluble in water will be more likely to cause toxic effects to fish than relatively insoluble oils.

TABLE 1. Approximate range of toxicities (96-hour LC_{50}s in parts per million aromatic hydrocarbons) for marine fishes of different habitat groups exposed to crude oils. [Data from Rice et al., 1975, 1976, 1979; Moles et al., 1979; Anderson et al., 1974; Neff et al., 1976.]

Habitat Group	*Acute Toxicity Values*
Pelagic fishes (Salmon, trout, herring)	1 – 4
Demersal fishes (Cod, pollock, flounder, sculpin)	2 – > 5
Estuarine fishes (Killifish, silversides)	6 – 17
Intertidal fishes (Pricklebacks, gunnels)	> 12

Petroleum products vary in total solubility depending on the relative proportion of soluble compounds present. Solubility tends to decrease with increasing molecular weight so light refined oils are more soluble than crude and heavy refined oils. The following solubilities for various crude and refined oils have been reported (in ppm total hydrocarbons in the WSF):

Oil Type	*Solubility*	*Reference*
La Rosa crude	*19.9 ppm*	*McAuliffe, 1977*
Murban crude	*27.9 ppm*	*McAuliffe, 1977*
Kuwait crude	*21.7 ppm*	*Anderson et al., 1974*
South Louisiana crude	*23.4 ppm*	*Anderson et al., 1974*
Prudhoe Bay crude	*23.9 ppm*	*Rice et al., 1976*
Cook Inlet crude	*41.7 ppm*	*Rice et al., 1976*
No. 2 fuel oil	*10,000 ppm*	*Coleman et al., 1984*
Kerosene	*7,000 ppm*	*Coleman et al., 1984*
Gasoline	*120,000 ppm*	*Coleman et al., 1984*

The values reported above reflect the maximum solubility attained under laboratory conditions. From the solubility data presented above, it is clear that refined petroleum products (especially gasoline) present a much more severe threat to open-water marine fish than do crude oils.

A review of experimental and accidental oil spills shows that the actual concentration

TABLE 2. Acute toxicity values for various marine fishes. Values presented are 96-hour LC_{50}s of the water-soluble fractions (total aromatics) of crude oils.

Species	*Habitat*	*96-hr LC_{50}*	*Reference*
Pink salmon	Pelagic	1.4 – 2.9	Rice et al., 1975, 1976, 1979
Coho salmon	Pelagic	3.7	Moles et al.,1979
Dolly Varden	Pelagic	1.1 – 2.9	Rice et al., 1975 1976, 1979
Pacific herring	Pelagic	1.2	Rice et al., 1979
Tubesnout	Pelagic	1.3 – 2.5	Rice et al.,1976 1979
Walleye pollock	Demersal	1.7	Rice et al., 1979
Starry flounder	Demersal	> 5.3	Rice et al., 1979
Saffron cod	Demersal	2.3	Rice et al., 1976
Great sculpin	Demersal	4.0	Rice et al., 1979
Sheepshead minnow	Estuarine	19.8	Anderson et al., 1974 Neff et al., 1976
Inland silverside	Estuarine	5.5 – 8.7	Anderson et al., 1974 Neff et al., 1976
Gulf killifish	Estuarine	10.4 – 16.8	Anderson et al., 1974 Neff et al., 1976
Crescent gunnel	Intertidal	> 11.7	Rice et al., 1979
Cockscomb prickleback	Intertidal	> 11.7	Rice et al., 1979

of water-soluble hydrocarbons under open-water slicks is much lower than the acute toxicity values of most fish species. McAuliffe (1987) reviewed a number of such spills and found that the highest concentrations reported are about 1 to 2 ppm, and average concentrations in the top 3-10 m of water range from 1 to 15 parts per billion (ppb). Thus, the average concentrations of oil likely to be encountered by open-water fish are about 100 to 10,000 times lower than the acute toxicity values of most petroleum hydrocarbons. Therefore, an oil slick floating on the water surface is unlikely to affect adult fish, but there is some potential for toxic effects to planktonic eggs and larvae. For many species, these life stages tend to concentrate in the upper water column and may be exposed to soluble hydrocarbons and physically dispersed oil droplets.

Toxic effects also may occur as a result of direct contamination of intertidal or shallow subtidal habitats used by fish. Such contamination may result in acute short-term toxic effects from the oil or long-term effects from residual hydrocarbons that are persistent in sediments. These hydrocarbons tend to have relatively high molecular weights and are less volatile and soluble than those associated with direct chemical toxicity in water. Heavy refined oils (including Nos. 4 and 6 fuel oils) and many crude oils contain a high proportion of these hydrocarbons and are known to cause chronic contamination of shorelines, especially in sheltered areas where low physical energy allows retention of oil in or on the sediments. This type of contamination can cause toxic effects to fish species that spawn in intertidal and shallow subtidal areas, and these effects may occur long after the spawning sites were initially exposed to oil.

Life Stage

The life stages of marine fish may exhibit differential sensitivity to petroleum hydrocarbons. McKim (1977), Neff et al. (1976), Rice et al. (1977), and Rossi and Anderson (1976) have found that the early life stages of many marine organisms are more sensitive to environmental pollutants than are the later life stages. However, Neff et al. (1976) point out that there are many exceptions, and it is difficult to predict in advance the relative sensitivity of different life stages. In those cases where differential sensitivity of life stages has been found, the hierarchy of sensitivity to short-term exposures is usually as follows in order of increasing sensitivity:

Adult < *Egg* < *Larva*

The basis for differential sensitivity is not completely known but is believed to be a function of morphological, physiological, and behavioral differences that influence sensitivity to natural stresses.

Presented below is a discussion of the relative sensitivity of different life stages and the various factors that influence sensitivity.

Eggs

Eggs are generally considered to be less sensitive than larvae but more sensitive than adults. Eggs have protective barriers that may reduce the sensitivity of the developing embryo to short-term exposures to water-borne pollutants (Rice et al., 1977). The eggs of marine fish typically fall into 1 of 2 categories: demersal (bottom dwelling) or pelagic (or, more appropriately, floating). Pelagic or floating eggs are found in the upper water column within a relatively short distance from the surface. These eggs are more likely to be exposed to floating spilled oil. Demersal eggs tend to sink to the bottom and may even be incorporated into the bottom sediments, and are more likely to be exposed to oil residues and other contaminants that tend to bind with sediments. Certain fish species (Pacific herring, surf smelt, and grunion) deposit their eggs on intertidal habitats such as rocky shores and beaches, shallow subtidal habitats such as seagrass beds, or kelp beds. The eggs of these species are particularly vulnerable to spilled oil.

Studies conducted by Kuhnhold (1972) and Rice et al. (1975) found that the eggs of cod, herring, plaice, and pink salmon were less sensitive than the larvae of these species. Laboratory studies conducted by Pearson et al. (1985) found that short-term exposure of Pacific herring eggs to the WSF of Prudhoe Bay crude oil did not result in any significant effects on fertilization or hatching success, but exposure to physically dispersed oil droplets caused several types of physical abnormalities in newly hatched herring larvae. These effects appeared to be correlated with direct contact between oil and egg such as would occur on an oil-contaminated spawning beach.

A number of investigators have found that egg sensitivity tends to decrease with time as the embryo develops (Rosenthal and Alderdice, 1976; Sharp et al., 1979). This relationship may be due to changes in permeability of the egg membrane to hydrophobic compounds.

The developmental time of different species varies widely; some eggs hatch within hours or a few days, while the eggs of other species, especially salmon, hatch after many months. Slowly developing eggs probably are more sensitive to chronic pollution since they may slowly accumulate hydrocarbons into yolk reserves during incubation.

Larvae

Larvae are considered to be the most sensitive life stage of most marine fish, although there are many exceptions to this as noted above. The basis for increased larval sensitivity is not completely understood but probably is related to those intrinsic and extrinsic factors that result in high natural mortality of larval populations.

Larval fish often have very specific habitat preferences or requirements that may increase their probability of exposure to spilled oil. Estuarine-dependent species may be found very close to shore in shallow water; oil contamination of adjacent shorelines may result in chronic exposure to hydrocarbons leaching from these areas. Conversely, larvae present in offshore, pelagic waters generally would not be exposed to oil except as a transient exposure to floating slicks. Rice (1973) showed that pink salmon fry avoided lethal concentrations of the WSF of Cook Inlet crude but did not detect or avoid lower, sublethal concentrations.

Adults

Adult fish are considered to be the least sensitive life stage. They have well-developed senses, are very mobile, and have physiological functions that may allow them to detect and avoid oil pollution or to resist the toxic effects of oil (Sharp et al., 1979). However, many adult fish also have habitat requirements that may increase the probability of exposure to oil, particularly in connection with reproduction. Estuarine-dependent species and anadromous species must enter nearshore waters to spawn, thereby increasing their chances of exposure to spilled oil and oil-contaminated shoreline and bottom environments.

Species Differences

Comparative studies have found that adult sensitivities are fairly similar but that certain fish species are somewhat more sensitive than others. The 96-hour $LC_{50}s$ reported by Rice et al. (1979) ranged from 1.22 to >11.72 ppm total aromatics. Species differences appeared to be correlated with habitat type (Table 2). Pelagic fish were found to be the most sensitive, demersal fish were moderately sensitive, and estuarine and intertidal fish were the least sensitive. These results are easily explained on the basis of natural adaptations to the requirements of each habitat; pelagic fish are adapted to very constant, stable conditions, while estuarine and intertidal fish are adapted to a wide range of conditions, including variations in temperature, water quality, physical energy, etc.

Relatively small differences in inherent sensitivity are probably less important than differences in susceptibility to exposure to spilled oil. Estuarine fish and anadromous fish may occur in very shallow nearshore waters and are much more likely to encounter toxic concentrations of petroleum hydrocarbons from oil spills than pelagic, demersal, or reef fish which inhabit much deeper water.

Physiological Condition

Relatively little is known about how changes in physiology affect sensitivity to pollutants. In one study of outmigrating fry and smolts of pink salmon, sockeye salmon, and Dolly Varden, the sensitivity of these species was twice as high in salt water as in fresh water, suggesting that the physiological changes occurring during outmigration of salmon may increase their sensitivity to oil (Moles et al., 1979).

Sublethal Effects

Uptake, Metabolism, and Depuration

Marine fish readily absorb petroleum hydrocarbons into their body tissues and fluids (Varanasi and Malins, 1977). Uptake of hydrocarbons can occur at any exposure concentration; that is, there does not appear to be any threshold level below which uptake does not occur. Laboratory studies have shown that petroleum hydrocarbons (especially aromatic hydrocarbons) are rapidly concentrated in fish tissues to levels many times ambient concentrations, but metabolism and depuration act to slowly reduce these levels (Malins and Hodgins, 1981). Neff et al. (1976) reported that killifish (*Fundulus similis*) exposed to the water-soluble fraction (WSF) of Number 2 fuel oil for 2 hours accumulated aromatic hydrocarbons in the gall bladder, liver, brain, and muscle at levels 600 to 2,300 times the exposure concentration. When placed in clean seawater, the aromatic hydrocarbons were depurated over a 15-day period. There are many similar examples.

Fish accumulate hydrocarbons primarily through the gills, although uptake can occur from eating small oil particles or oil-contaminated food (Lee, 1977). In short-term laboratory tests, complete depuration of accumulated hydrocarbons may take 7 to 15 days in clean seawater at which time the parent hydrocarbons are not detectable. Absorbed or ingested oil may be metabolized into more water-soluble compounds that are then excreted through the urine or feces (Lee, 1977; Malins and Hodgins, 1981). Chronic exposures to hydrocarbons in water or sediments may result in persistent body burdens of parent compounds or their metabolites, some of which may be carcinogenic or mutagenic, causing production of tumors and other abnormalities (Malins and Hodgins, 1981; Varanasi and Malins, 1977).

Behavior

Changes in the normal behavior of fish may have effects on their ability to feed, avoid predation, and reproduce, and on other activities that affect long-term survival. The ability of fish to detect and then avoid petroleum hydrocarbons has been investigated in a number of species. Most species tested have demonstrated an ability to detect petroleum, but there is considerable variability in the detection limit. Some species are able to detect concentrations as low as 0.5 ppb of pure hydrocarbon compounds, while other species did not react to similar or much higher concentrations (Patten, 1977). There is some evidence to suggest that the chemosensory ability of fish may be overwhelmed by high concentrations of petroleum.

Rice et al. (1977) reported convulsive respiratory reactions or coughing behavior in pink salmon fry exposed to 0.3 to 2.2 ppm of the WSF of crude and refined oils. This behavior was accompanied by an increase in breathing rate and may have been an attempt to increase oxygen consumption. Later studies by Thomas and Rice (1979) found that oxygen consumption did increase and was proportional to the concentration of aromatic hydrocarbons.

Petroleum hydrocarbons can have a narcotic effect on fish, causing reduction in activity. Patten (1977) reviewed several studies in which the larvae of flounder, salmon, cod, herring, plaice, and other species exhibited reduced activity following exposure to various oil mixtures. Their behavior was marked by inactivity, lack of response to prodding, reduced feeding activity, reduced schooling behavior, and other behaviors indicative of reduction in locomotion and activity. In many of these tests, the narcotic behavior was preceded by irregular and sometimes violent swimming behavior, accompanied by disequilibrium. Removal of surviving fish to clean water resulted in recovery of normal behavior in some cases.

Growth

The growth rates of juvenile salmon, Pacific herring larvae, juvenile striped bass, and other species have been found to be reduced following long-term exposure (4 to 60 days) to petroleum hydrocarbons (Anderson, 1979; Korn et al., 1976; Rice et al., 1975; Struhsaker et al., 1974). The concentrations used in these studies ranged from approximately 1 to 10 ppm aromatic hydrocarbons. Anderson (1979) points out that these studies relate to chronic hydrocarbon releases such as those resulting from refinery effluents. The relatively short-term exposures resulting from oil spills probably would not have an effect on growth rate unless a contaminated area acted as a chronic source of contamination.

Physiology

Changes in normal physiology can result in a wide range of effects that may reduce the survival rate of fish. The respiration rate of fish exposed to petroleum hydrocarbons is a commonly measured physiological parameter. Laboratory studies have shown that respiration may be increased, decreased, or unaffected and that it is not necessarily dependent on exposure concentration (Anderson, 1979). In most studies, exposure to low concentrations resulted in increased respiration; high concentrations resulted in decreased or normal rates. Elevated respiration is believed to be a consequence of metabolism of hydrocarbons in body tissues. The ecological significance of elevated respiration rate is related to diversion of energy to detoxification or depuration of hydrocarbons, away from growth, reproduction, and other functions.

Reproduction

Relatively little is known about the effects of petroleum on reproduction in fish. Aside from direct toxic effects on eggs, exposure of adults to petroleum is not believed to have significant effects on reproductive success. Hodgins et al. (1977) found that adult rainbow trout that had been fed oil-contaminated food for several months produced eggs that had normal hatching and survival rates. Adult salmon have been shown to avoid oil-contaminated waters (McAuliffe, 1987; Weber et al., 1981), but when exposed for short periods in oil-contaminated waters, no effects on homing ability or the timing of homing during spawning migrations have been noted (Nakatani et al., 1985).

ACIDS AND BASES

Description and Behavior in Water

Acids (such as acetic acid, hydrochloric acid, phosphoric acid, and sulfuric acid) and bases (such as potassium hydroxide, sodium hydroxide, and ammonium hydroxide) are compounds that dissociate in water to form hydronium ions (H_3O^+ or H^+) or hydroxyl ions (OH^-), respectively. An excess of hydronium ions causes a reduction in pH (acidic conditions), and conversely, an excess of hydroxyl ions causes an increase in pH (basic conditions).

Acids and bases are referred to as strong or weak according to the concentration of hydronium or hydroxyl ions that result from dissociation in water (Hawley, 1981). Common examples of strong acids and bases are sulfuric, nitric, hydrochloric, and phosphoric acids, and sodium, potassium, and ammonium hydroxides, respectively. Acetic acid is a common, weak acid, and ammonia is a weak base. Strong acids and bases dissociate much more completely than weak acids and bases and thus produce larger changes in pH. Spills of strong acids or bases pose a higher environmental risk than equal-sized spills of weak acids or bases.

The pH of most freshwater systems is 6.0-7.0, while seawater pH is slightly higher (about 8.2). Freshwater systems may be buffered against pH changes by the presence of various carbonate compounds that are collectively referred to as total alkalinity.

Many freshwater systems are able to resist pH changes within a certain range close to pH of 7.0, but addition of large volumes of acid or base may overwhelm the buffering capacity and result in significant pH changes, especially in small lakes and ponds. The buffering capacity of freshwater is highly variable, ranging from very low buffering capacity in areas with little carbonate material in the soils to waters with buffering capacity exceeding that found in seawater. Seawater generally has a much higher buffering capacity than fresh water due to the higher concentration of carbonate compounds and is better able to resist pH changes from acid or base spills. The higher buffering capacity of seawater and the usually larger dilution factor combine to reduce the environmental effects of acid and base spills in marine waters.

ACUTE EFFECTS

Large, rapid changes in pH of natural waters caused by spills of acids or bases can have toxic effects on local fish populations through a number of pathways, primarily direct physical damage to gills and skin (Reichenbach-Klinke, 1973), and chemical denaturing of proteins, especially enzymes (Lehninger, 1970). Externally visible effects include brown coloration or physical deterioration of the gills, severe mucous secretion, fraying of the fins, and inflammation or redness of the skin.

Most fish species can tolerate small changes in pH within the range of 6.5 to 9.0 without suffering adverse physiological effects. Changes in pH outside this range, or rapid changes within this range, can result in adverse effects that increase in severity as the degree of deviation increases (USEPA, 1986). The acidic and basic death points are pH of approximately 4.0 and 11.0 for most marine and freshwater fish species (Boyd, 1979).

The relative sensitivity of different species or life stages to changes in pH is not well known. Every species has a preferred or optimal pH, but in most cases, pH falls within a narrow range between about 6.5 and 9.0. Many freshwater species have adapted to life in slightly acidic waters that contain relatively high concentrations of organic acids and have little buffering capacity, such as occurs in "black-water" rivers and swamps. In shallow, tropical or subtropical marine habitats, some marine communities have adapted to changes in pH that occur daily because of photosynthesis and respiration of marine organisms. High photosynthesis during the day removes carbon dioxide which causes increase in pH up to about 7.0 (Parsons and Takahashi, 1975).

Ability to avoid waters with excessively low or high pH may play an important role in determining impacts to fish populations. Eggs and larvae of most species are not highly mobile and may be unable to leave contaminated waters.

ANHYDROUS AMMONIA

Anhydrous ammonia is an inorganic compound used in a variety of applications, including production of fertilizers, dyes, explosives, synthetic fibers, and numerous other products. It was the third highest-volume chemical produced in the United States in 1979 (Hawley, 1981) and is frequently transported in coastal port facilities (Savitsky and Michel, 1986). Anhydrous ammonia is a colorless gas with a pungent odor at ambient temperature and atmospheric pressure, but it is usually transported as a pressurized or refrigerated liquid. It is highly soluble in water and reacts strongly with water, forming an ammonium hydroxide solution accompanied by release of heat and vaporized ammonia gas (Raj, 1982). Up to 50 percent of spilled ammonia can go into solution; the ammonium hydroxide solution is warm and will tend to form a stable stratified layer at the water surface until it cools and disperses into the water column (Raj and Reid, 1978).

Ammonium hydroxide solution exists in an equilibrium in which ammonia (NH_3), ammonium (NH_4^+), and ammonium hydroxide (NH_4OH) occur simultaneously. The toxicity of this solution is attributed primarily to ammonia (USEPA, 1986). The relative concentration of ammonia present depends on the volume of product spilled, pH, temperature, and ionic strength of the receiving waters (Stickney, 1979; USEPA, 1986). The interaction of these factors results in a highly complex pattern of increasing or decreasing toxicity, but in general, the toxicity of the ammonia solution decreases with increasing pH, hardness, and salinity, and increases with increasing temperature. These various factors affect toxicity of ammonia solutions by changing the equilibrium balance between the more toxic unionized form (ammonia) and the less toxic ionized form (ammonium) of ammonia.

The toxic effects of ammonia include damage to mucous membranes, especially gills, intestine, and skin, and damage to the blood and nervous system; affected fish show external bleeding and internal hemorrhaging (Reichenbach-Klinke, 1973).

The USEPA has established water-quality criteria for ammonia; permissible levels of total ammonia (ammonia and ammonium) of varying pH and temperatures have been established for 1-hour and 4-day exposure periods. Permissible levels are highly variable depending on pH and temperatures. For most conditions occurring in coastal waters (pH = 8.00 and temperature = 0°-32°C), the 1-hour permissible limits are 3.5-8.0 ppm total ammonia (0.065-0.26 ppm unionized ammonia). For typical freshwater conditions (pH = 7.0, temperature = 0°-30°C), the 1-hour permissible limits are 11.6-28.0 ppm total ammonia (0.02-0.09 ppm unionized ammonia). Short-term exposure to ammonia at higher concentrations is likely to result in toxic effects to most fish species.

Ammonia will biodegrade following release into water. The rate at which this occurs depends on temperature and other factors, but in most situations, excess ammonia will be removed eventually. The rate at which this occurs depends on the rate at which bacteria and plants use ammonia and related compounds as nutrients.

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