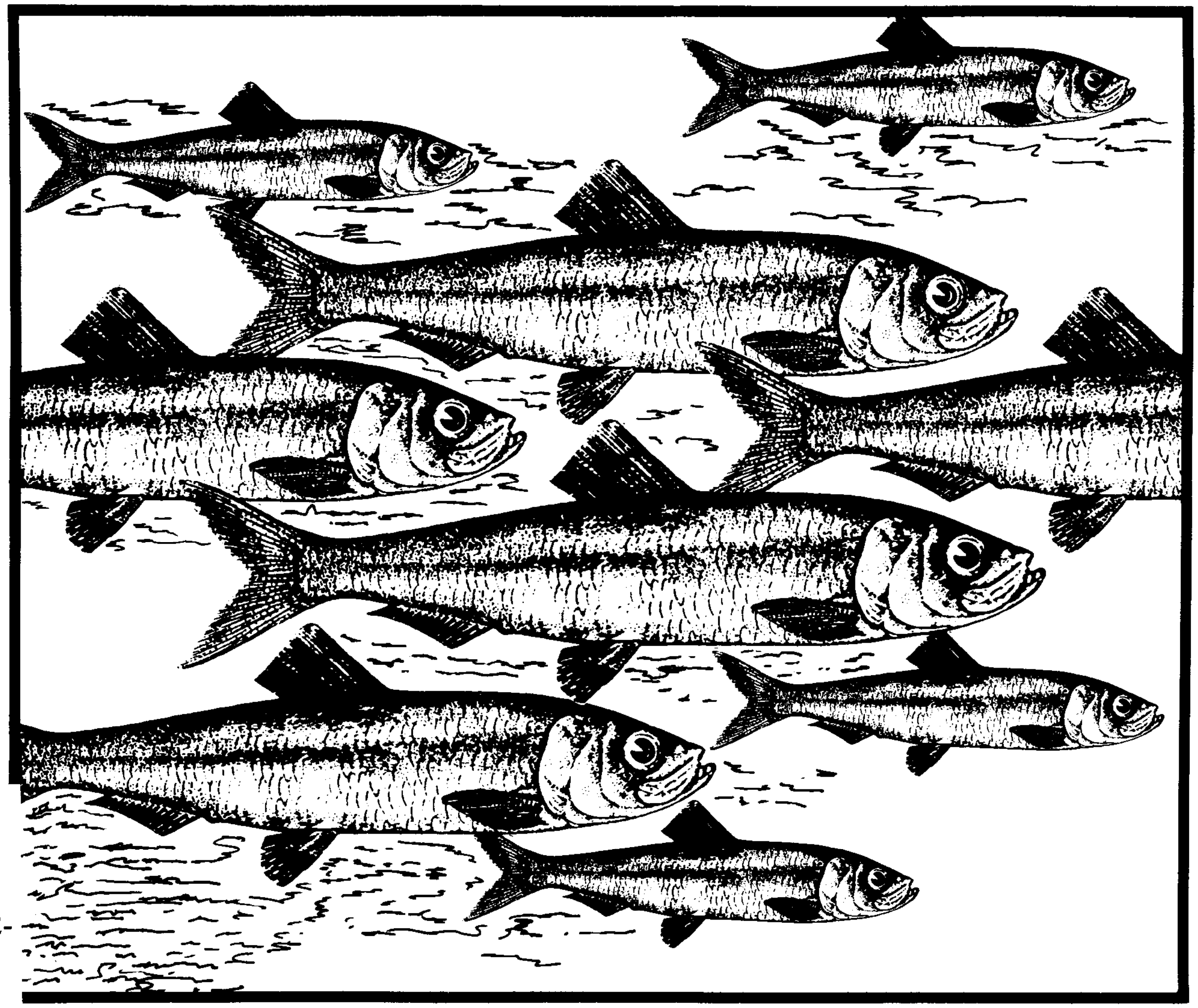
Biological Report 82(11.79)
February 1988

TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest)

PACIFIC HERRING



Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

Biological Report 82(11.79)
TR EL-82-4
February 1988

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest)

PACIFIC HERRING

by

Roger A. Barnhart
California Cooperative Fishery Research Unit
Humboldt State University
Arcata, CA 95521

Project Officer
David Moran
U.S. Fish and Wildlife Service
National Wetlands Research Center
1010 Gause Boulevard
Slidell, LA 70458

Performed for

Coastal Ecology Group
U.S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg, MS 39180

and

U.S. Department of the Interior
Fish and Wildlife Service
Research and Development
National Wetlands Research Center
Washington, DC 20240

This series may be referenced as follows:

U.S. Fish and Wildlife Service. 1983-19__. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates. U.S. Fish Wildl. Serv. Biol. Rep. 82(11). U.S. Army Corps of Engineers, TR EL-82-4.

This profile should be cited as follows:

Barnhart, R.A. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) -- Pacific herring. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.79). U.S. Army Corps of Engineers, TR EL-82-4. 14 pp.

PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

Information Transfer Specialist
National Coastal Ecosystems Team
U.S. Fish and Wildlife Service
NASA-Slidell Computer Complex
1010 Gause Boulevard
Slidell, LA 70458

or

U.S. Army Engineer Waterways Experiment Station
Attention: WESER-C
Post Office Box 631
Vicksburg, MS 39180

CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

CONTENTS

ACKNOWLEDGMENTS

I thank K. Chew, University of Washington, Seattle, and J. D. Spratt, California Department of Fish and Game, Monterey, for reviewing the manuscript; Thomas J. Hassler, California Cooperative Fishery Research Unit, for acting as liaison with the National Wetlands Research Center; and Delores Neher for greatly facilitating the preparation of this report.

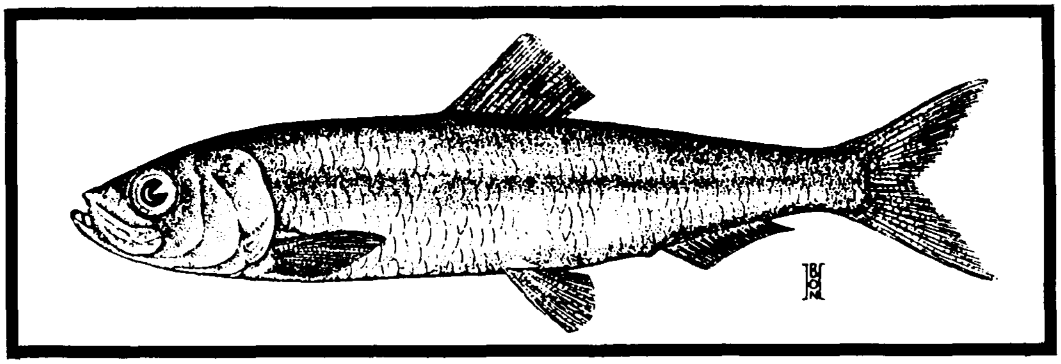


Figure 1. Pacific herring (after Hart 1973).

PACIFIC HERRING

NOMENCLATURE, TAXONOMY, AND RANGE

Scientific name . . . . *Clupea harengus pallasi* Valenciennes
Preferred common name . . . . Pacific herring (Figure 1)
Other common name . . . . . . Herring
Class . . . . Osteichthyes
Order . . . . Clupeiformes
Family . . . . . Clupeidae (herrings)

Geographic range: Waters of the continental shelf from northern Baja California to arctic Alaska and Japan (for distribution in Pacific Southwest, see Figure 2).

MORPHOLOGY AND IDENTIFICATION AIDS

The following descriptions were taken largely from Miller and Lea (1972), Hart (1973), and Eschmeyer et al. (1983).

Pacific herring are moderately compressed silvery fish with unspined fins, including a short dorsal near middle of back and abdominal pelvic fins beneath the dorsal. The caudal fin is deeply forked. Keeled scales (scutes) along the ventral midline are only moderately developed. Compared to other clupeid species there are no scales or striations on the head or gill cover, no spots on the sides, no lateral line canal, no modified scales or flaps on the side of the tail fin, no teeth on the jaw (although there are fine teeth on the vomer), and the last dorsal fin ray is not elongate.

Dorsal fin rays 15-21; anal 13-20; pectorals about 17; pelvics about 9, each with a fleshy scale above its insertion; vertebrae 46-55; large cycloid scales 38-54 midlaterally. Color dark bluish green to olive on dorsal surface, shading to silver on

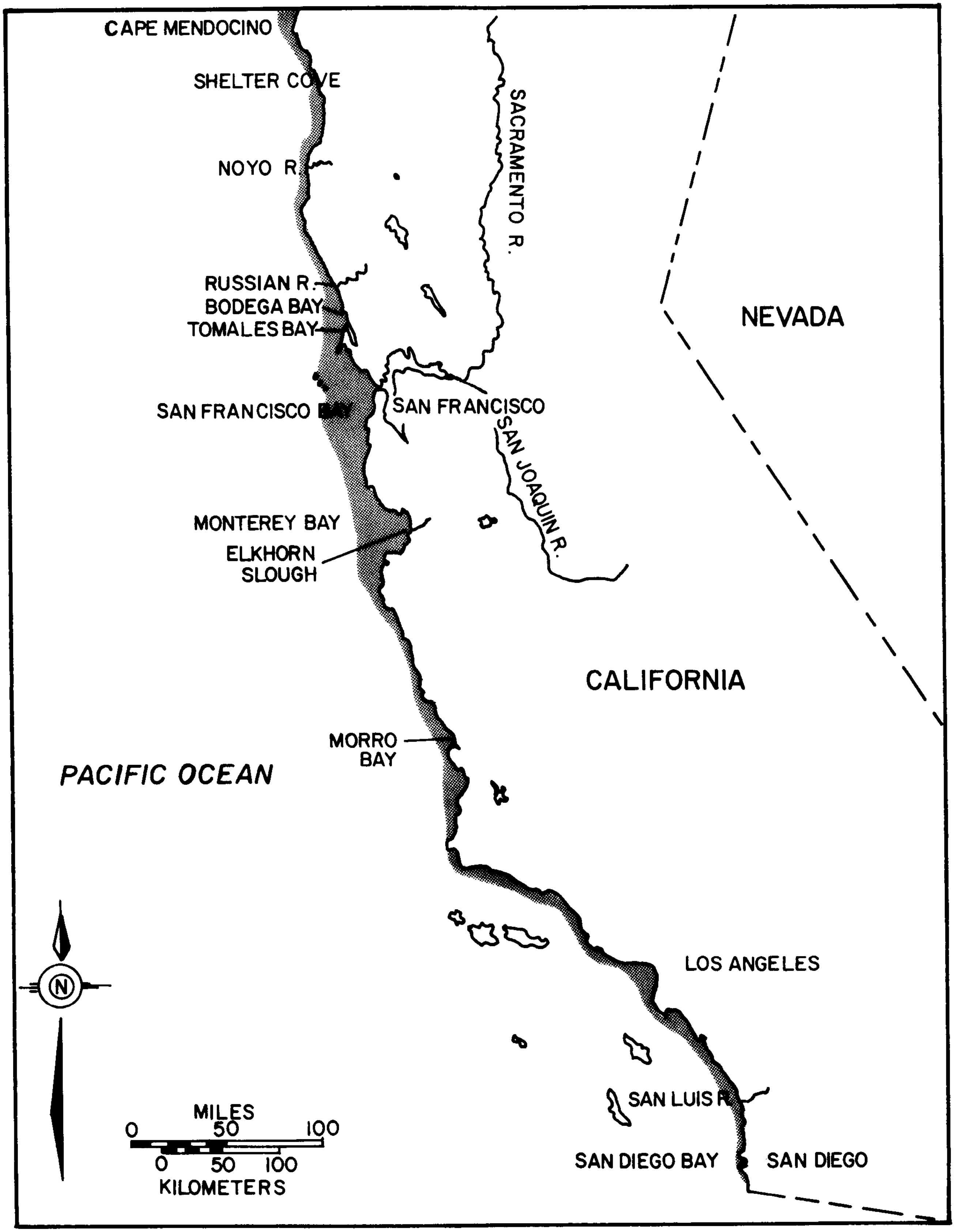


Figure 2. Pacific herring distribution in the Pacific Southwest (shaded) (adapted from Miller and Schmidtke 1956 and Spratt 1981).

sides and belly. Length usually less than 30 cm but occasionally to 46 cm standard length (SL).

REASON FOR INCLUSION IN SERIES

The herring is a much prized and widely and fully used commercial species. No major herring stock along the Pacific coast of the United States or Canada has a harvestable surplus that exceeds the harvesting capacity of the fishing fleet seeking it (Trumble and Humphreys 1985). In the Pacific Southwest, herring spawn primarily in bays and estuaries (Haegele and Schweigert 1985), and are sensitive to changes in habitat induced by man.

LIFE HISTORY

Spawning

Pacific herring spawn in many intertidal and subtidal locations along California's coast, but Tomales Bay and San Francisco Bay have the largest spawning populations (Spratt 1976). Other known spawning areas are San Diego Bay, San Luis River, Morro Bay, Elkhorn Slough, Bodega Bay, Russian River, Noyo River, Shelter Cove, Humboldt Bay, and Crescent City Harbor (Spratt 1981). In California herring spawn from November to June but primarily from December to February (Wilson 1937; Scofield 1952; Spratt 1981).

Adult herring typically congregate near the spawning grounds several weeks to months before spawning. In California, the first spawners gradually enter the bays, and build up into large aggregations for several weeks before spawning; later spawners move in just before they spawn (Miller and Schmidtke 1956). Maturing adults enter San Francisco, Tomales, and Humboldt Bays often several weeks before spawning, remaining in loosely aggregated schools in deep channels (Eldridge and Kaill 1973; Rabin and Barnhart 1986).

The stimuli that initiate spawning are not well understood. In northern latitudes spawning times are apparently synchronized with water temperatures, and spawning does not begin until incubation temperatures exceed 6°C (Haegele and Schweigert 1985). However, in California water temperatures are above 9°C throughout the winter-spring spawning season and the initiation of spawning is apparently not temperature related (Reilly and Moore 1982, 1983, 1984, 1985). When the right conditions prevail, schools of herring move into intertidal shallows and some subtidal areas, and spawn on any suitable substrate. However, herring appear to have substrate preferences: in San Francisco Bay they choose algae and grass first, then prominent rocks, and lastly flat surfaces (Eldridge and Kaill 1973). The principal substrate used in Tomales and Humboldt Bays is common eelgrass (<u>Zostera marina</u>), although in some years the areas with the lushest beds of eelgrass are not used for spawning (Miller and Schmidkte 1956; Rabin and Barnhart 1986). In Humboldt Bay, which generally exceeds 28 ppt salinity, Rabin and Barnhart (1986) suggested that the location of fresh water inflows probably influenced the location of herring spawning. Outram (1951) found that low-salinity water stimulated herring to spawn while in captivity. Taylor (1971) reported that hatching success decreased with increasing salinity. However, Reilly and Moore (1983) believed that extended periods of salinities below 20 ppt in San Francisco Bay inhibited herring spawning.

Both the male and female herring interact closely with the vegetation on which the highly adhesive eggs are laid. The ventral surface and genital papilla contact the spawning substrate and the fish deposit tracts of eggs and milt along its surface (Hourston et al. 1977). The texture and rigidity of the substrate are tested by the fish using the tips of the pelvic and pectoral fins before they spawn, and sediment on the substrate may inhibit spawning (Stacey and Hourston 1982). Extrusion of eggs appears to be impeded unless the vent is in contact with the substrate (Schaefer 1937). Hay (1985) suggested that male herring probably initiate the spawning act by releasing milt into the water; the females follow and deposit eggs on the substrate. Stacey and Hourston (1982) suggested that a sexual pheromone in herring milt triggers the actual spawning process. In large mass spawnings the water often appears "milky" over the entire spawning area due to the presence of milt. Herring sperm remain fertile for at least 3 hours in seawater at 8°C (Blaxter and Holliday 1963). The eggs are deposited in layers of one to two eggs thick in light intensity spawns to many egg layers in heavy spawns. Spratt (1976) reported a herring spawn in San Francisco Bay in January 1975 with some egg layers nearly 10 cm thick, which he calculated to be about 6 million eggs/m^2. Mass spawnings in San Francisco and Tomales Bays may take place in a few hours of one night or may continue as long as a week. Frequently two or more spawnings occur in the same location, separated roughly by 10-15 days (Hay 1985; Rabin and Barnhart 1986). In California adult herring return to sea immediately after spawning (Miller and Schmidtke 1956).

Fecundity

Fecundity is positively correlated with the size of the female. The number of eggs per gram of body weight is a useful measure of relative fecundity, particularly for herring spawn surveys used to estimate total biomass of spawning fish. Mean fecundity of females was 227 eggs per gram in Tomales Bay (Hardwick 1973) and San Francisco Bay (Reilly and Moore 1985) and 220 eggs per gram in Humboldt Bay (Rabin and Barnhart 1977). Thus a gravid female herring weighing 100 g would be expected to contain about 22,000 eggs. For Humboldt Bay herring, Rabin and Barnhart (1977) calculated a linear relation between body length and egg production, showing that a female herring about 177 mm long SL produced 22,000 eggs. Along the Pacific coast the total size-specific fecundity is inversely related to latitude (Hay 1985).

Egg Stage

Fertilized Pacific herring eggs are spherical, 1.2-1.5 mm in diameter; they have a yellowish granular yolk, no oil globule, a thick, tough, transparent chorion, and a wide perivitelline space, equal to 20%-30% of the egg diameter (Wang 1981). Incubation time was 6-10 days in water temperatures of 8-10°C in Tomales Bay (Miller and Schmidtke 1956) and 10.5 days at an average water temperature of 10°C in San Francisco Bay (Eldridge and Kaill 1973) . Outram (1955), who described the development of the Pacific herring egg, stated that the eyes become pigmented about halfway through the incubation period. Survival is reduced where the eggs are deposited several layers thick (Eldridge and Kaill 1973). Adequate respiration of eggs within an egg mass is assumed to require continuous movement and replacement of interstitial water (Alderdice and Hourston 1985). Egg mortality is occasionally high as a result of predation on deposited layers of eggs by gulls, diving birds, and fish; also, erratic major storms sometimes tear loose egg-laden vegetation and windrow it along beaches (Spratt 1981; Alderdice and Hourston 1985).

Larval and Juvenile Stages

At hatching, herring larvae are 5.6-7.5 mm long TL and have a small spherical, thoracic yolk sac that persists for a period of time that varies in length with water temperature, but does not usually exceed 2 weeks (Hart 1973; Wang 1981). At completion of the yolk sac stage the larvae are 9-10 mm long TL. Herring larvae have a long straight gut that becomes segmented in the postlarval stage. Pacific herring have a total of 45-57 myomeres, of which 37-44 are preanal. Herring larvae are characterized by having paired melanophores along the gut that are dorsal to mid-body and then ventral to the anus.

As soon as the yolk is exhausted herring larvae must begin exogenous feeding. This "critical period" (May 1974) at the onset of feeding generally results in high mortality because the margin between sufficient nutrition and starvation is exceedingly narrow (Blaxter 1962). The first food consists mainly of invertebrate eggs, copepod nauplii, and diatoms (Hart 1973). Within 2 months, young herring are 2.5-4.0 cm long and the diet has broadened to include larvae of barnacles, mollusks, bryozoans, rotifers, and fish -- though copepod nauplii and adults are the most important food. Since larval feeding is sight dependent, it occurs primarily during daylight (Blaxter 1965).

Surveys indicate that the abundance of Pacific herring larvae was highest in San Francisco Bay (Eldridge 1977) and second highest in Humboldt Bay (Eldridge and Bryan 1972). The larvae were captured only during winter, and only small numbers of juveniles were taken in spring. However, Samuelson (1973) reported that herring were caught in otter trawls in South Humboldt Bay in every month except December (no size data were given). In 1968, juvenile Pacific herring were caught in North Humboldt Bay with an otter trawl from March to July and in October and November (Sopher 1974). Sopher wrote that large numbers of juvenile herring were seen near the surface in August and September but that they were mostly uncatchable by bottom trawl. Juvenile Pacific herring were netted with a lampara bait seine in Humboldt Bay from April to October (Waldvogel 1977) and with a midwater trawl from January to October in many locations in San Francisco Bay (Messersmith 1966; Reilly and Moore 1984, 1985). Most juvenile herring congregate in bays during summer and move into deeper water in fall (Hourston 1958, 1959; Reilly and Moore 1983, 1984, 1985).

Adult Stage

Except for spawning habits and related behavior, little is known about adult herring along the coast in the Pacific Southwest. The offshore distribution is largely unknown, although there is a summer fishery for adults in Monterey Bay (Eldridge and Kaill 1973). Fishermen have also reported fairly large schools of herring offshore from the Farallon Islands in summer, but no samples have been obtained (Miller and Schmidtke 1956). Pacific herring have a homing instinct that brings them back to a certain area of the coast to spawn each year; consequently Miller and Schmidtke (1956) speculated that along the coast of California there may be four to eight or more stocks. However, Spratt (1981) stated that no evidence has been shown to indicate separate California stocks. In California some herring spawn at 2 years of age and all are mature by age 3 (Spratt 1981). Herring up to 11 years old are taken each year in the various fisheries, but fish of ages 2-6 are most common (Spratt 1981; Rabin and Barnhart 1986). The numerical ratio of females to males among adult herring captured by gears that are relatively non-selective for size does not differ significantly from 1:1 in Tomales, San Francisco, and Humboldt Bays (Spratt 1981; Rabin and Barnhart 1986). Hart (1973) stated that adult herring eat various crustaceans (preferring the larger forms), and juvenile stages of smelt, herring, sandlance, hake, and rockfish.

GROWTH CHARACTERISTICS

Spratt (1981), who used otoliths to age herring from Tomales and San Francisco Bays, calculated growth curves by least squares regression (Figure 3). His data started with yearling herring, which are about 120 mm from the tip of the snout to the end of the silvery pigment on the caudal peduncle (body length, BL). Sopher (1974), who trawled young-of-the-year herring in Humboldt Bay, gave the following total length ranges (millimeters) by date: March 10, 15-40; April 2, 25-45; April 27, 26-46; May 25, 34-44; June 20, 64-70; July 15, 64-80. Hart (1973) stated that herring growth in length slows after the fish mature.

Spratt (1981) found that the length-weight relationship for herring of 160-222 mm BL did not differ between San Francisco and Tomales Bays (Figure 4). He also stated that length-weight relations of male and female herring from the two bays were not significantly different.

COMMERCIAL AND SPORT FISHERIES

Commercial herring fishing in California dates back to at least the mid-1800's (Spratt 1981). Early catches, though not well documented, were small; most herring were eaten fresh but some were salted or smoked (Scofield 1952). From 1916 to 1919, most herring were canned or reduced to oil and meal; the catch reached 3,629 mt in 1918 (Spratt 1981). The Reduction Act of 1919, which prohibited the reduction of herring

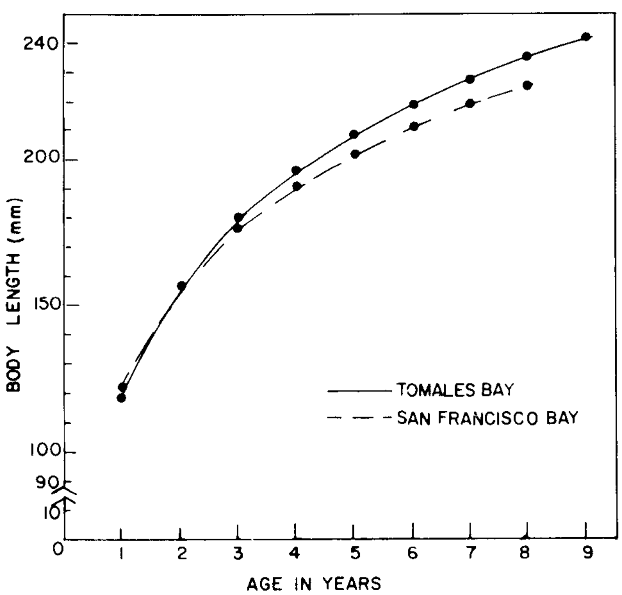


Figure 3. Herring growth curves for Tomales and San Francisco Bays calculated by least squares method (Spratt 1981).

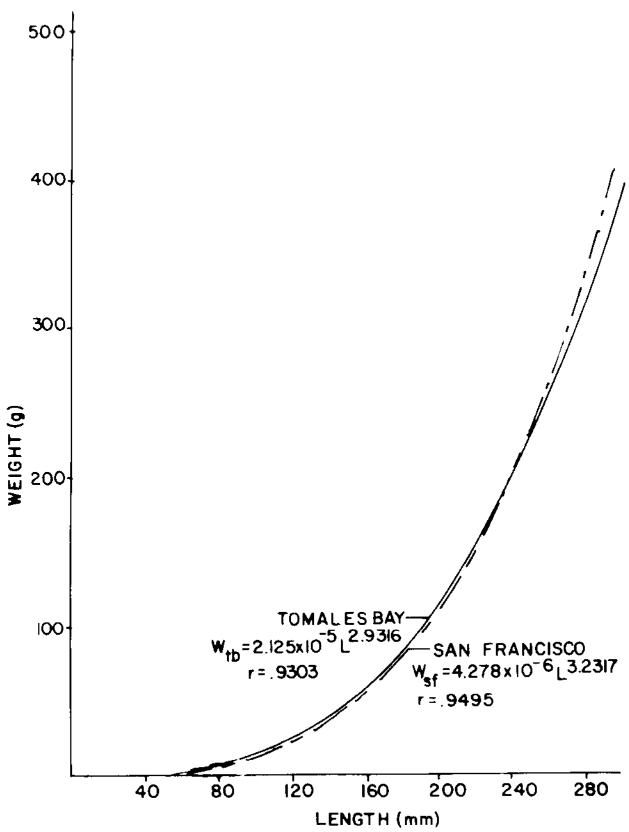


Figure 4. Length-weight relation for herring from Tomales and San Francisco Bays (Spratt 1981.

into fish meal, ended the largest component of the fishery. Annual landings remained low until 1948-62, when processors canned herring as a replacement for sardines (Scofield 1952; Spratt 1981). The product gradually lost acceptance, however; annual landings dropped to less than 286 mt during 1963-72 (Spratt 1981).

In 1965 a new use for California herring products developed when Japan began importing herring roe on seaweed, "Kazunoko Kombu," and herring roe alone, "Kazunoko," both of which are gourmet foods (Eldridge and Kaill 1973). Due to a series of international changes affecting Japan's supply of herring in the early 1970's, a demand for Pacific coast herring developed and Japan imported 8,000 mt of herring roe from the U.S. west coast in 1973 (Spratt 1981). The herring roe fishery gradually increased and 10,251 mt of herring were landed in California for this use in 1982. Most herring are frozen whole and shipped to Korea, where the roe is removed, salted, and shipped to Japan. The fish are dried and sold for human consumption in Korea (Eldridge and Kaill 1973).

The roe content, or percentage body weight of eggs, is highest just before spawning; thus fishing is concentrated during this short period, to ensure the collection of herring roe of the highest quality and weight. The herring are captured with purse seines, lampara seines, and gill nets; gill nets dominate the fishery because they take large fish and a higher percentage of females (Spratt 1981).

To prevent the overfishing of California's herring stocks, the State establishes quotas each year. Although there is not good evidence that separate stocks exist in California, herring at each major spawning area are managed separately (Spratt 1981). Each year the California Department of Fish and Game conducts spawning surveys in San Francisco and Tomales Bays. The total number of eggs spawned during the season is estimated, and the biomass of adult spawning herring is estimated on the basis of average fecundity. These estimates are then used to establish harvest quotas for the following season. Ware (1985) calculated that Pacific herring can sustain an exploitation rate of about 30%. He recommended, however, that herring fishery managers opt for a conservative harvesting policy. The California Department of Fish and Game sets quotas to harvest about 15%-16% of the spawning population (J.D. Spratt, Calif. Fish and Game, pers. comm.). The 1985-86 quotas were 6,800 mt for San Francisco Bay, 900 mt for Tomales Bay, 54 mt for Humboldt Bay, and 27 mt for Crescent City. The San Francisco Bay fishery involves about 390 gill net permittees and 40 round haul vessels fishing purse or lampara seines. To distribute the catch gill-netters are divided into 3 groups of about 130 boats each and each group has a harvest quota; seiners have individual quotas. For 1985-86 round haul vessels were allotted 54 mt each and gill-netters 1,437-1,526 mt each, depending on which period or day of the season they fished (J.D. Spratt, Calif. Fish and Game, pers. comm).

In San Francisco Bay the commercial harvest of herring eggs on seaweed is set at a quota of 4.5 mt (the total weight of the seaweed with eggs attached). The divers who harvest the eggs on seaweed usually do not attain this quota. Pacific herring taken in a small round haul summer fishery in Monterey Bay are processed primarily for animal food.

Some sport fishing occurs for herring, primarily in San Francisco Bay, when the herring move into shallow waters in large numbers to spawn (Spratt 1981). The fish are snagged by hook and line or captured with hand-held bag nets or throw nets. They are taken for their roe or for pickling. The collection of herring roe on seaweed by divers or at low tide by waders is popular in San Francisco Bay. The possession limit is 23 kg for sport-caught herring and 11 kg for eggs on seaweed.

ECOLOGICAL ROLE

In terms of consistent contribution to worldwide fish biomass, the herring has historically been extremely successful (Blaxter 1985). The herring is specially adapted in several respects. Pacific herring eggs can withstand extremes of temperature for at least a short time, as well as (presumably) some desiccation when the tide ebbs. This eurythermy, together with euryhalinity, means that the herring egg has a formidable ability to survive in harsh environments (Blaxter 1985). The herring also has a complex camouflage system based on silvery layers of guanine crystals in the skin which cause the undersides of the fish, seen from below, to blend in with the surface (a form of counter shading), a specialized retina for visul acuity, and a complex acoustico-lateralis system linked to the swimbladder that endows the herring with excellent hearing sensitivity independent of hydrostatic pressure change. It is physostomous (allowing rapid vertical movements of wide amplitude), strongly schooling in habit, and has the facility to switch from particulate to filter feeding. Blaxter (1985) concluded that the herring could be considered a successful species in terms of its ability to recover from drastic overfishing.

Hay and Fulton (1983) calculated that, for Canadian herring stocks, about 22% of the total herring spawning stock biomass is released annually as milt and eggs. They estimated that the carbon contribution of the products to the ecosystem is high relative to primary production. This material is a source of energy for secondary producers, particularly microzooplankton, such as protozoa, copepod nauplii, or larvae of benthic animals, all of which could serve as food for herring larvae.

Predators are attracted to herring spawn deposits and contribute significantly to egg mortality. In Canada, Outram (1958) reported that major egg depositions in the intertidal zone frequently were exploited by flocks of gulls, which consumed 30%-55% of the exposed eggs, mostly within 3 days after deposition. Hardwick (1973) observed that the extent of predation varies greatly. In Tomales Bay he speculated occasional predation rates of 90-100%, 5-7 days after deposition. Bird predators observed by Hardwick (1973) were the California gull <u>Larus californicus</u>, the mew gull <u>L. canus</u>, the glaucous-winged gull <u>L. glaucescens</u>, the western gull <u>L. occidentalis</u>, the American coot <u>Fulica americana</u>, and the surf scoter <u>Melanitta perspicillata</u>. Divers collecting herring eggs reported to Hardwick that various fish and crabs ate herring eggs: sturgeons <u>Acipenser</u> spp., smelts (Atherinidae), surfperches (Embiotocidae), and crabs (probably <u>Cancer</u> spp.). In Tomales Bay diving birds greatly reduce the density of eelgrass in herring spawning beds (Spratt 1981). They tear the leaves off and often pull whole plants out of the substrate. By the end of the spawning season, many lush beds of eelgrass have been cropped to within a few inches of the substrate.

Herring larvae are abundant in the ichthyoplankton of the bays where they hatch (Eldridge and Bryan 1972; Eldridge 1977) and presumably are preyed upon by older stages of many fish species. Hempel (1965) reported that predation and starvation are the two main causes of larval mortality in many stocks of marine fish. He stated that years of high abundance of fish that prey on larvae often are also years of rich food abundance for the fish larvae and that the food for larvae is often also the main food of the planktonic predators. Hart (1973) stated that, although juvenile herring are known to be eaten by other species, there is no evidence of excessive predation at that stage. Arai and Hay (1982) found that herring larvae were eaten by several species of medusae and stated that if a species of medusae reached peak abundance at the time of emergence of herring larvae, the survival of the larvae might be reduced. Ctenophores (Pleurobrachia spp.) and chaetognaths (Sagitta sp.) can also be important predators (Stevenson 1962). In laboratory rearing experiments, Hourston et al. (1981) observed that juvenile Pacific herring fed extensively on newly hatched larvae of their own species when the two occurred together and suggested that such cannibalism could add considerably to the mortality of herring in early life. Sub-adult and adult herring in schools appear to be one of the major fodder animals of the sea, providing food for salmon, sharks, and lingcod (Ophiodon elongatus), as well as for waterfowl, sea lions, and whales (Hart 1973).

The larval nematode Anisakis sp. (herring worm) is a stable part of the parasitic fauna of herring (Hauck and May 1977). The importance of Anisakis larvae as a public health problem became known when they were found to cause gastric granulomata (herring worm disease) in man -- first reported in the United States in 1975. Hauck (1977) stated that the presence of Anisakis makes human consumption of brined or cold smoked Pacific herring a potential health hazard.

ENVIRONMENTAL FACTORS

Alderdice and Hourston (1985) concluded from numerous studies that the Pacific herring and its embryonic and larval stages are essentially euryplastic. Behavioral attributes of the adult spawner in selecting the spawning site, and compensatory mechanisms in the egg and embryo for variations in the incubation environment, apparently combine to determine the probability of hatching success; thereafter, larval survival depends largely on timing in relation to predation and food supply. Lasker (1985) pointed out the need to discover what environmental conditions cause a clupeoid year class to succeed or fail.

Temperature and Salinity

The Pacific herring generally lives at water temperatures of 0-10^{o}C throughout its distribution during the maturation and spawning of adults, incubation of eggs, and hatching of larvae (Alderdice and Hourston 1985). For North American stocks these events tend to occur in the upper half of the temperature range; usually 8-10^{o}C for California waters (Miller and Schmidtke 1956; Eldridge and Kaill 1973). In British Columbia waters, salinities associated with these successive life history events (range, optimum) are 2.6-28.7 ppt and 27-28 ppt for spawning, 4.5-42 ppt and 12-15 ppt for $\geq$ 50% fertilization of eggs, and 4.5-42 ppt and 12-17 ppt for maximum total hatch (Alderdice and Hourston 1985). Within the optimal ranges, maximum incubation success accompanies lower salinities coupled with lower water temperatures or higher salinities with higher temperatures. Early larvae also appear to be euryplastic. Length at hatching, larval growth rate, and growth efficiency on yolk appear to be enhanced at salinities of 13-21 ppt at temperatures of 5.5-12^{o}C (Alderdice and Velson 1978; Duenas 1981). Stevenson (1962) concluded that survival of Pacific herring larvae passively transported into the open waters of the Pacific Ocean might be limited by their inability to tolerate high offshore salinities. Alderdice and Hourston (1985) stated that the salinity tolerance of larvae is influenced significantly by salinity and temperature during egg incubation. At usual incubation conditions in British Columbia waters, the upper boundary of larval tolerance was estimated as 27.5-31 ppt.

When the unusually warm nutrient-depleted water of El Nino occurred in California waters in 1982-83, Pacific herring grew poorly; El Nino also may have affected the distribution of herring stocks during this period (Spratt 1984a,b).

Turbidity and Sedimentation

Boehlert and Morgan (1985) stated that the turbid waters of estuaries and bays used by larval herring as nursery areas may offer survival advantages. In experiments, feeding incidence and intensity of herring larvae were significantly greater at levels of sedimentary suspension of 500 to 1000 mg/l than at the control level (0 mg/l). Feeding decreased at greater concentrations. The suspended sediments may enhance feeding by providing visual contrast of prey items on the small perceptive scale of larvae. Larval residence in turbid environments such as estuaries may serve to reduce predation from larger visual planktivores, while searching ability in the small larval perceptive field is not decreased significantly (Boehlert and Morgan 1985).

Excessive turbidity resulting in settling out of sediments may hinder the spawning and incubation of herring. The spawning female tests the substrate with her genital papilla before depositing eggs, and Stacey and Hourston (1982) stated that sediment on the substrate may inhibit spawning. Alderdice and Hourston (1985) stated that the delivery of oxygen to, and the removal of metabolites from, herring eggs incubating under layered conditions is pertinent to survival -- particularly for occluded eggs in the interior of an egg mass. The authors assumed that substantial movement of water through the interstices between eggs in a mass is required to provide for respiratory exchange. Excess fine sediment settling on egg masses can block the interstices and prohibit adequate circulation of water.

Pollutants

Estuaries, by their nature, are subject to the introduction of many kinds of pollutants. Eggs and larvae are usually the life stages of fish most sensitive to pollutants (Struhsaker et al. 1974). Eldridge et al. (1977) found that sublethal exposure to benzene (0.04-2.1 µl/l), an aromatic component of crude oil, modified the metabolic processes of Pacific herring embryos and larvae. Rice and Harrison (1978) reported that herring embryo mortalities were significant after 180-hour exposures to a copper concentration of 35 µg/l. A survey of six municipal waste discharges along the southern California coast revealed concentrations of copper ranging from 74 to 13,900 µg/l (Mitchell and McDermott 1975).

LITERATURE CITED

Alderdice, D.F., and A.S. Hourston. 1985. Factors influencing development and survival of Pacific herring (Clupea harengus pallasi) eggs and larvae to beginning of exogenous feeding. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):56-68.

Alderdice, D.F., and F.P.J. Velson. 1978. Effects of short term storage of gametes on fertilization of Pacific herring eggs. Helgol. Wiss. Meeresunters. 31:485-498.

Arai, M.N., and D.E. Hay. 1982. Predation by medusae on Pacific herring (Clupea harengus pallasi) larvae. Can. J. Fish. Aquat. Sci. 39(11):1537-1540.

Blaxter, J.H.S. 1962. Herring rearing - IV. Rearing beyond the yolksac stage. Mar. Res. Scot., No. 1. 18 pp.

Blaxter, J.H.S. 1965. The feeding of herring larvae and their ecology in relation to feeding. Calif. Coop. Ocean. Fish. Invest. 10:79-88.

Blaxter, J.H.S. 1985. The herring: a successful species? Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):21-30.

Blaxter, J.H.S., and F.G.T. Holliday. 1963. The behavior and physiology of herring and other clupeids. Adv. Mar. Biol. 1:261-393.

Boehlert, G.W., and J.B. Morgan. 1985. Turbidity enhances feeding abilities of larval Pacific herring, Clupea harengus pallasi. Hydrobiologia 123(2):161-170.

Duenas, C.E. 1981. Influence of incubation salinity and temperature and post-hatching temperature on salinity tolerance of Pacific herring (Clupea harengus pallasi) larvae. M.S. Thesis. University of British Columbia, Vancouver. 82 pp.

Eldridge, M.B. 1977. Factors influencing distribution of fish eggs and larvae over eight 24-hour samplings in Richardson Bay, California. Calif. Fish Game 63(2):101-116.

Eldridge, M.B., and C.F. Bryan. 1972. Larval fish survey of Humboldt Bay, California. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-665:1-8.

Eldridge, M.B., T. Echeverria, and J.A. Whipple. 1977. Energetics of Pacific herring (Clupea harengus pallasi) embryos and larvae exposed to low concentrations of benzene, a monoaromatic component of crude oil. Trans. Am. Fish. Soc. 106(5):452-461.

Eldridge, M.B., and W.M. Kaill. 1973. San Francisco Bay Area's herring resource - a colorful past and a controversial future. Mar. Fish. Rev. 35(11):25-31.

Eschmeyer, W.N., E.S. Herald, and H. Hamman. 1983. A field guide to Pacific coast fishes of North America from the Gulf of Alaska to Baja California. Houghton Mifflin, Boston. 336 pp.

Haegele, C.W., and J.F. Schweigert. 1985. Distribution and characteristics of herring spawning grounds and description of spawning behavior. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):39-55.

Hardwick, J.E. 1973. Biomass estimates of spawning herring, Clupea harengus pallasi, herring eggs, and associated vegetation in Tomales Bay. Calif. Fish Game. 59(1):36-61.

Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Board Can. Bull. 180, Ottawa. 740 pp.

Hauck, A.K. 1977. Occurrence and survival of the larval nematode Anisakis sp. in the flesh of fresh, frozen, brined, and smoked Pacific herring Clupea harengus pallasi. J. Parasitol. 63(3):515-519.

Hauck, A.K., and E.B. May. 1977. Histopathologic alterations associated with Anisakis larvae in Pacific herring from Oregon. J. Wildl. Dis. 13(3):290-293.

Hay, D.E. 1985. Reproductive biology of Pacific herring (Clupea harengus pallasi). Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):111-126.

Hay, D.E., and J. Fulton. 1983. Potential secondary production from herring spawning in the Strait of Georgia. Can. J. Fish. Aquat. Sci. 40(2):109-113.

Hempel, G. 1965. On the importance of larval survival for the population dynamics of marine food fish. Calif. Coop. Ocean. Fish. Invest. 10:13-23.

Hourston, A.S. 1958. Population studies on juvenile herring in Barkley Sound, British Columbia. J. Fish. Res. Board Can. 15(5):909-960.

Hourston, A.S. 1959. Effects of some aspects of environment on the distribution of juvenile herring in Barkley Sound. J. Fish. Res. Board Can. 16(3):283-308.

Hourston, A.S., H. Rosenthal, and N. Stacey. 1977. Observations on spawning behavior of Pacific herring in captivity. Meeresforschung 25: 156-162.

Hourston, A.S., H. Rosenthal, and S. Kerr. 1981. Capacity of juvenile Pacific herring (Clupea harengus pallasi) to feed on larvae of their own species. Can. Tech. Rep. Fish. Aquat. Sci. No. 1044. V + 9 pp.

Lasker, R. 1985. What limits clupeoid production? Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):31-38.

May, R.C. 1974. Larval mortality in marine fishes and the critical period concept. Pages 3-19 in J.H.S. Blaxter, ed. The early life history of fish. Springer-Verlag, Berlin.

Messersmith, J. 1966. Fishes collected in Carquinez Strait in 1961-1962. Pages 57-63 in D.W. Kelley, ed. Ecological studies of the Sacramento-San Joaquin Estuary. Calif. Fish Game Fish Bull. 133. 133 pp.

Miller, D.J., and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game Fish Bull. 157. Sacramento. 249 pp.

Miller, D.J., and J. Schmidtke. 1956. Report on the distribution and abundance of Pacific herring (Clupea pallasi) along the coast of central and southern California. Calif. Fish Game 42:163-187.

Mitchell, F.K., and D.J. McDermott. 1975. Characteristics of municipal wastewater discharges, 1974. Pages 163-165 in S. Calif. Coastal Water Res. Proj. Annu. Rep. 1975.

Outram, D.M. 1951. Observations on the retention and spawning of the

Pacific herring. Prog. Rep. Biol. Stn. Nanaimo and Prince Rupert 87:32-33.

Outram, D.M. 1955. The development of the Pacific herring egg and its use in estimating age of spawn. Fish. Res. Board Can. Gen. Ser. Circ. 40: 11 pp.

Outram, D.M. 1958. The magnitude of herring spawn losses due to bird predation on the west coast of Vancouver Island. Fish. Res. Board Can. Prog. Rep. 111:9-13.

Rabin, D.J., and R.A. Barnhart. 1977. Fecundity of Pacific herring Clupea harengus pallasi, in Humboldt Bay. Calif. Fish Game 63(3):193-196.

Rabin D.J., and R.A. Barnhart. 1986. Population characteristics of Pacific herring, Clupea harengus pallasi, in Humboldt Bay, California. Calif. Fish Game 72(1):4-16.

Reilly, P.N., and T.O. Moore. 1982. Pacific herring, Clupea harengus pallasi, studies in San Francisco Bay, December 1981 to March 1982. Calif. Fish Game Mar. Res. Admin. Rep. 82-8. 43 pp.

Reilly, P.N., and T.O. Moore. 1983. Pacific herring, Clupea harengus pallasi, studies in San Francisco Bay, Monterey Bay, and the Gulf of the Farralones, July 1982 to March 1983. Calif. Fish Game Mar. Res. Admin. Rep. 83-5. 49 pp.

Reilly, P.N., and T.O. Moore. 1984. Pacific herring, Clupea harengus pallasi, studies in San Francisco Bay, Monterey Bay, and the Gulf of the Farralones, May 1983 to March 1984. Calif. Fish Game Mar. Res. Admin. Rep. 84-3. 67 pp.

Reilly, P.N., and T.O. Moore. 1985. Pacific herring, Clupea harengus pallasi, studies in San Francisco Bay and the Gulf of the Farralones, June 1984 to March 1985. Calif. Fish Game Mar. Res. Admin. Rep. 85-4. 73 pp.

Rice, D.W., Jr., and F.L. Harrison. 1978. Copper sensitivity of Pacific herring (Clupea harengus pallasi) during its early life history. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 76(2):347-356.

Samuelson, C.E. 1973. Fishes of south Humboldt Bay, Humboldt County, California. M.S. Thesis. Humboldt State University, Arcata. 94 pp.

Schaefer, M.B. 1937. Notes on the spawning of Pacific herring Clupea pallasi. Copeia 1937(1): 57.

Scofield, W.L. 1952. The Tomales Bay herring fishery. Calif. Fish Game 38(4):499-504.

Sopher, T.R. 1974. A trawl survey of the fishes of Arcata Bay, California. M.S. Thesis. Humboldt State University, Arcata. 103 pp.

Spratt, J.D. 1976. The Pacific herring resource of Tomales and San Francisco Bays: its size and structure. Calif. Fish Game Mar. Res. Tech. Rep. 33. 44 pp.

Spratt, J.D. 1981. Status of the Pacific herring, Clupea harengus pallasi, resource in California 1972 to 1980. Calif. Fish Game Fish Bull. 171. 107 pp.

Spratt, J.D. 1984a. Biomass estimate of Pacific herring, Clupea harengus pallasi, in California from the 1983-84 spawning-ground surveys. Calif. Fish Game Mar. Res. Admin. Rep. 84-2. 29 pp.

Spratt, J.D. 1984b. Biological characteristics of the catch from 1983-84 Pacific herring, Clupea harengus pallasi, roe fishery in California. Calif. Fish Game Mar. Res. Admin. Rep. 84-4. 18 pp.

Stacey, N., and A.S. Hourston. 1982. Spawning and feeding behavior of captive Pacific herring. Can. J. Fish. Aquat. Sci. 39:489-498.

Stevenson, J.C. 1962. Distribution and survival of herring larvae, (Clupea pallasi, Valenciennes), in British Columbia waters. J. Fish. Res. Board Can. 19(5):735-810.

Struhsaker, J.W., M.B. Eldridge, and T. Echeverria. 1974. Effects of benzene (a water soluble component of crude oil) on eggs and larvae of Pacific herring and northern anchovy. Pages 253-284 in F.J. Vernberg and W.B. Vernberg, eds. Pollution and physiology of marine organisms. Academic Press, New York.

Taylor, F.H.C. 1971. Variation in hatching success in Pacific herring Clupea pallasi eggs with water depth, temperature, salinity , and egg mass thickness. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 160:34-41.

Trumble, R.J., and R.D. Humphreys. 1985. Management of Pacific herring (Clupea harengus pallasi) in the eastern Pacific ocean. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):230-244.

Waldvogel, J.B. 1977. Age, maturity and distribution of northern anchovy, Engraulis mordax, in Humboldt Bay, California. M.S. Thesis. Humboldt State University, Arcata. 36 pp.

Wang, J.C.S. 1981. Taxonomy of the early life stages of fishes: fishes of the Sacramento-San Joaquin Estuary and Moss Landing Harbor-Elkhorn Slough, California. Ecological Analysts, Inc., Concord. 168 pp.

Ware, D.M. 1985. Life history characteristics, reproductive value, and resilience of Pacific herring (Clupea harengus pallasi). Can. J. Fish. Aquat. Sci. 42 (Suppl. 1): 127-137.

Wilson, D. 1937. Herring. Pages 16-18 in The commercial fish catch of California for the year 1935. Calif. Fish Game Bur. of Comm. Fish. Bull. No. 49. 170 pp.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 82(11.79)*	2.	3. Recipient's Accession No.

4. Title and Subtitle
Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest)--Pacific Herring

5. Report Date
February 1988

6.

7. Author(s)
Roger A. Barnhart

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
California Cooperative Fishery Research Unit
Humboldt State University
Arcata, CA 95521

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
National Wetlands Research Center
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180

13. Type of Report & Period Covered

14.

15. Supplementary Notes
*U.S. Army Corps of Engineers Report No. TR EL-82-4

16. Abstract (Limit: 200 words)
Species profiles are literature summaries of the taxonomy, morphology, distribution, life history, and environmental requirements of coastal aquatic species. They are prepared to assist in environmental impact assessment. The Pacific herring, Clupea harengus pallasi, spawns in intertidal and subtidal waters of the Pacific coast during the winter-spring season. In California, female herring average about 220 eggs per gram body weight. Herring are fished commercially primarily during the spawning season to obtain herring roe for export to Japan. Herring have a significant ecological role; herring spawn deposits attract many predators, and the abundant herring larvae and juveniles found in estuaries and nearshore waters serve as food for larger sea life. Herring embryos and larvae are fairly plastic regarding temperature and salinity, and survival probably depends largely on extent of predation and food supply. Excessive turbidity hinders the spawning and incubation of herring. Herring embryos, larvae, and juveniles are subject to various pollutants introduced into the estuarine environment.

17. Document Analysis a. Descriptors

Estuaries	Salinity	Contaminants
Fishes	Temperature	Suspended Sediments
Fisheries	Feeding Habits	Growth
Animal Migrations	Life Cycles	

b. Identifiers/Open-Ended Terms
Pacific herring
Clupea harengus pallasi

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	Unclassified	14
	20. Security Class (This Page)	22. Price
	Unclassified	

(See ANSI-Z39.18)

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

TAKE PRIDE *in America*

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
National Wetlands Research Center
NASA-Slidell Computer Complex
1010 Gause Boulevard
Slidell, LA 70458