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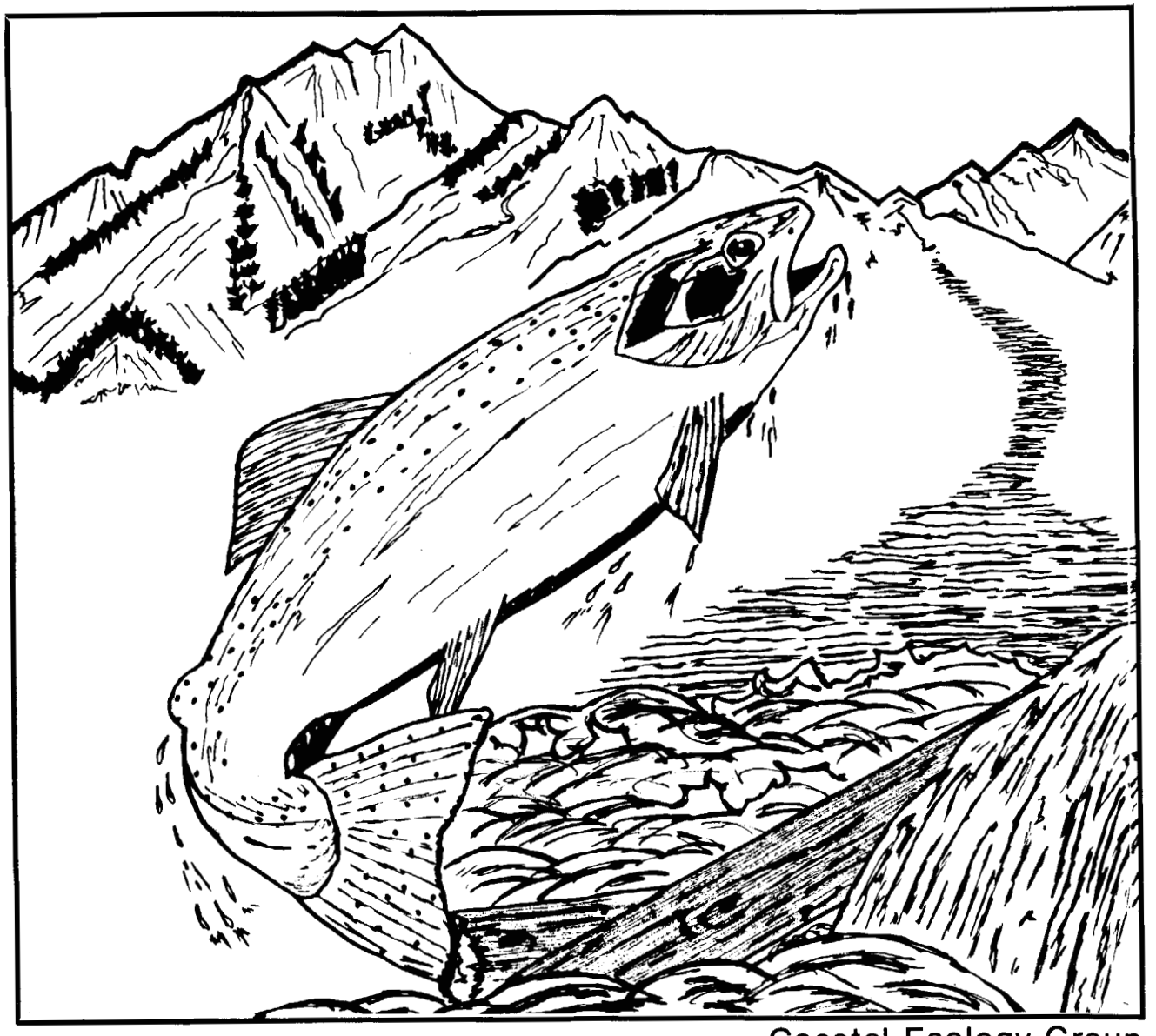
Biological Report 82 (11.60)
June 1986

TR EL-82-4

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

STEELHEAD



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

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

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

STEELHEAD

by

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Performed for

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

and

National Coastal Ecosystems Team
Research and Development
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

This series should 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. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) -- steelhead. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.60). U.S. Army Corps of Engineers, TR EL-82-4. 21 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.

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or

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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
kilometers (km)	0.6214	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	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	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

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

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ACKNOWLEDGMENTS

I thank Dennis P. Lee, California Department of Fish and Game, and Terry D. Roelofs, Humboldt State University, for reviewing the manuscript; Thomas H. Hassler, California Cooperative Fishery Research Unit, for acting as the liaison with the National Coastal Ecosystems Team; and Delores Neher for greatly facilitating the preparation of this report.

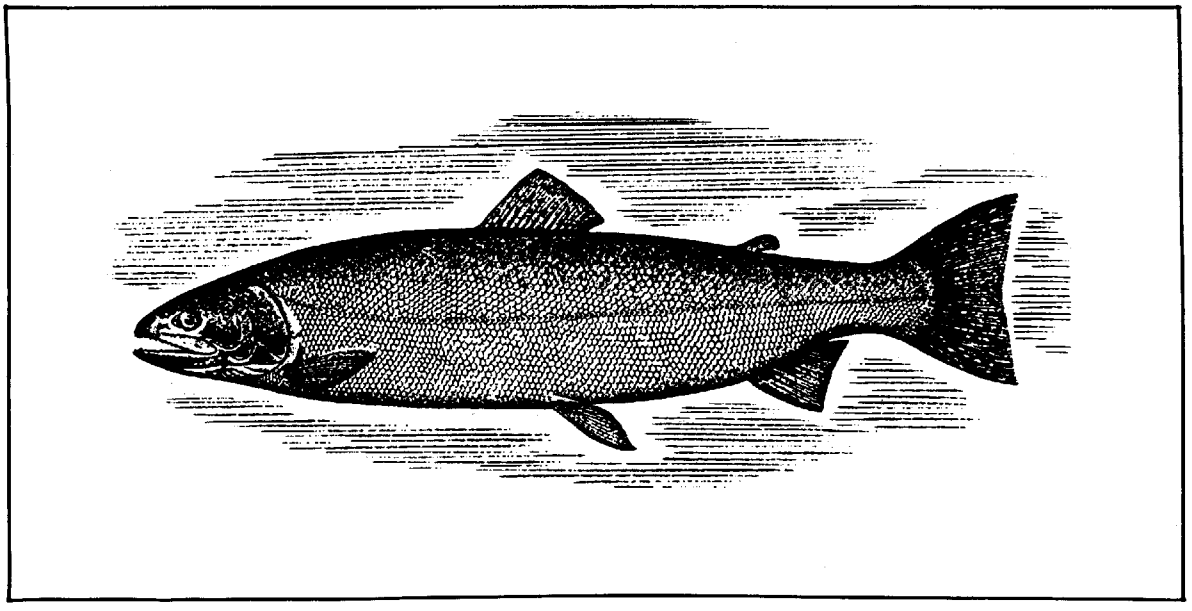

Figure 1. Steelhead.

STEELHEAD

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . . . . *Salmo gairdneri* Richardson
Preferred common name . . . Steelhead (Figure 1)
Other common names . . . . steelhead trout, steelie, half-pounder, ironhead
Class . . . . . Osteichthyes
Order . . . . . Salmoniformes
Family . . . . . Salmonidae

Geographic range: At sea, from northern Baja California to the Bering Sea and Japan. In the Pacific Southwest, steelhead enter coastal streams from the northern California border south to the Ventura River (Figure 2). Adult steelhead have been reported in the Santa Clara and Santa Margarita Rivers in years when winter runoff was high enough to allow upstream migration (Swift 1975). Early in this century steelhead distribution in the Pacific Southwest was more widespread (Figure 3). Steelhead run up the Santa Domingo River in northern Baja California during high runoff in winter (Needham and Gard 1959).

MORPHOLOGY/IDENTIFICATION AIDS

The following descriptions were taken from McConnell and Snyder (1972) and Fry (1973).

At sea, steelhead are steel blue above and bright silver on the sides and belly. Sharply defined black spots are located on back, head, sides, and dorsal and caudal fins. The spots are small and vary in number. After entering freshwater, steelhead gradually take on the

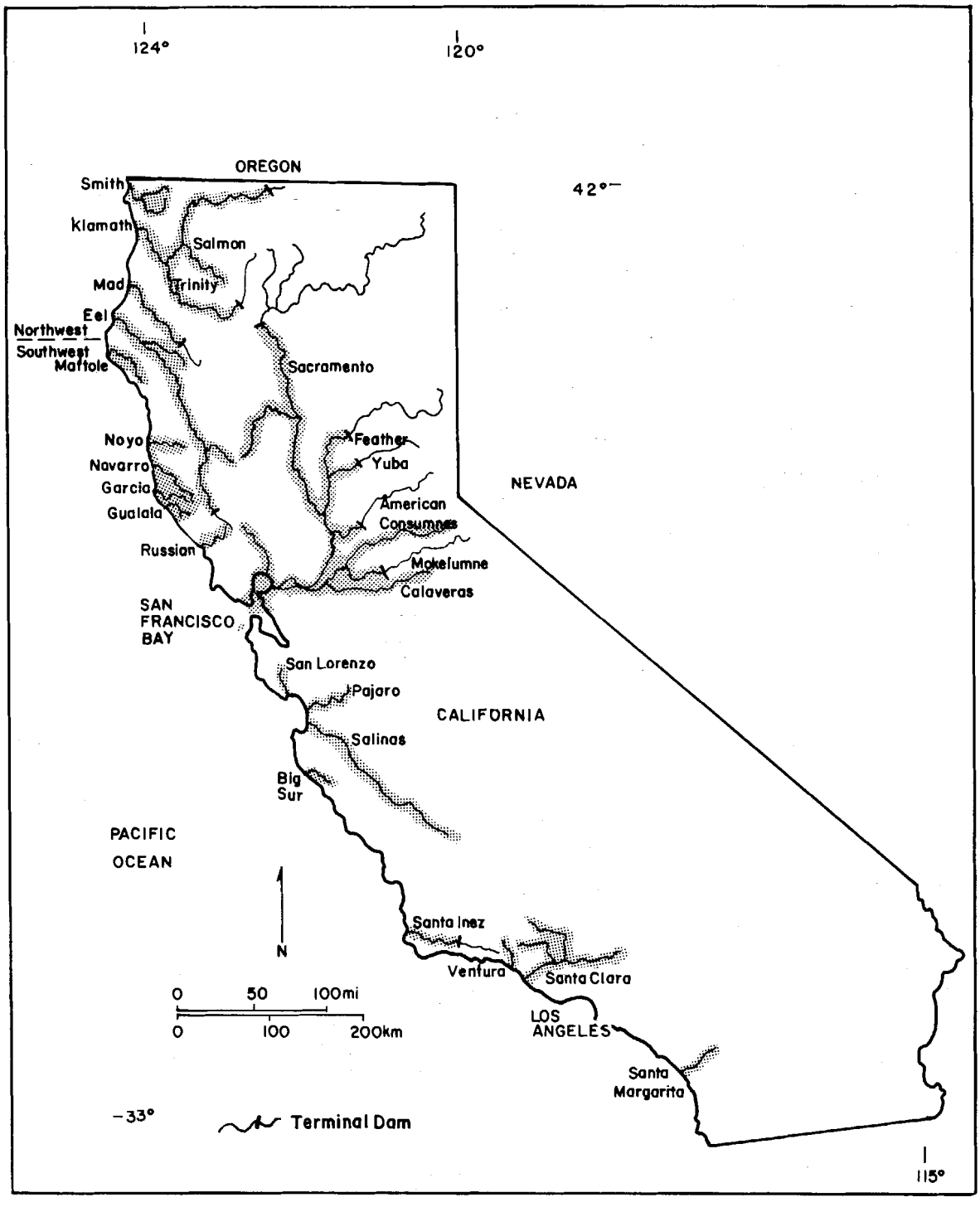

Figure 2. Distribution of steelhead (shaded areas) in Pacific Southwest region streams in 1980's (California Department of Fish and Game, pers. comm.; Moore 1980).

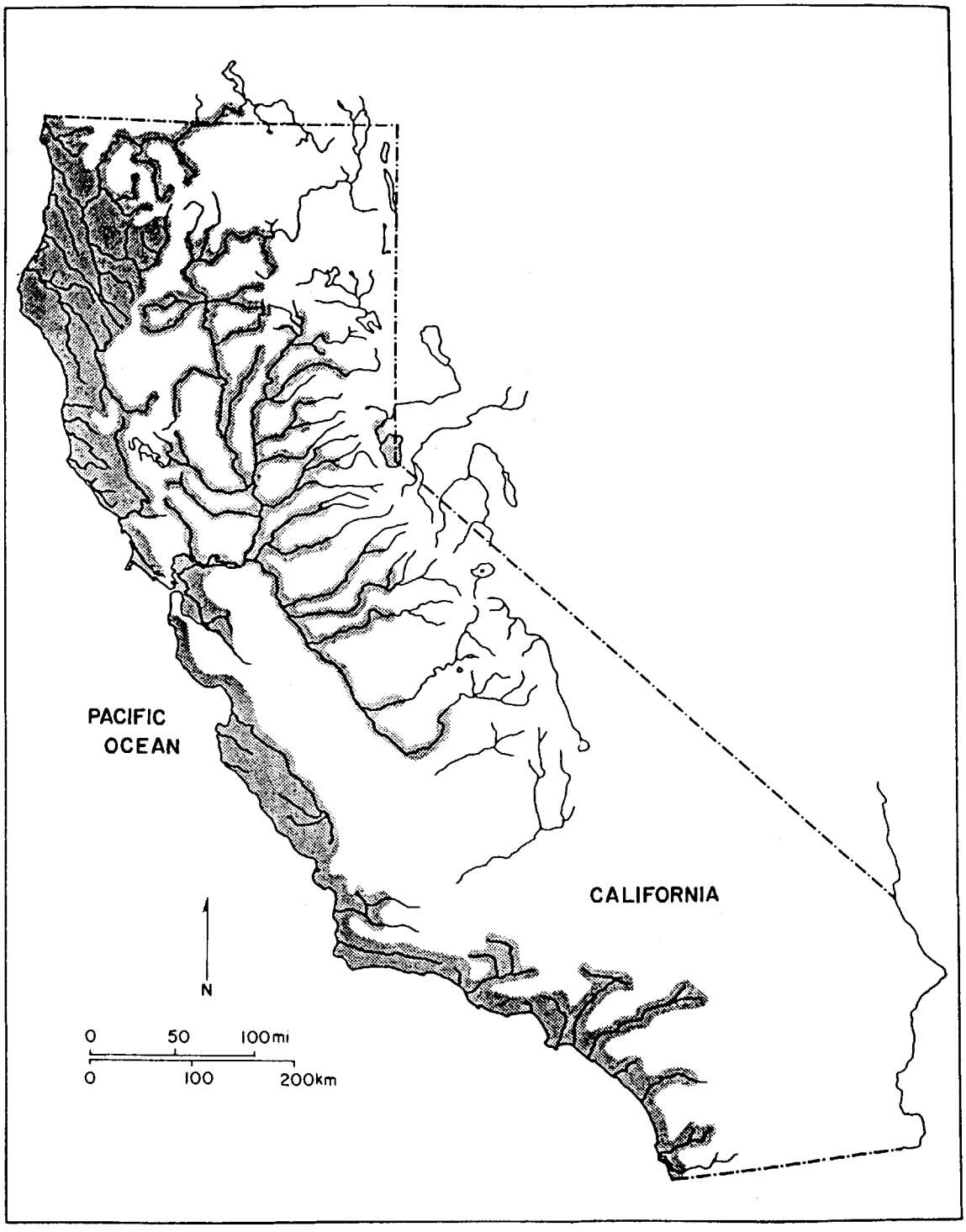

Figure 3.Distribution of steelhead (shaded areas) in the Pacific Southwest region in 1900 (National Council on Gene Resources 1982).

appearance of stream rainbow trout; the back becomes olive green and the sides and belly less silvery. Maturing adults usually develop a broad pink stripe along the lateral line and pink coloration on the operculum. Steelhead lack the red streaks beneath the jaw which characterize the cutthroat trout (Salmo clarki). Juvenile steelhead in streams cannot be distinguished from juvenile resident rainbow trout.

Anal rays 9-12, rarely 13; teeth on tip and shaft of vomer and on tongue; gill rakers on lower limb of first arch range from 17-21; scales in first row above lateral line 115-180; caudal fin shallowly forked; maxillary does not reach past the posterior margin of eye; juvenile parr marks small and oval to nearly round.

Generally adult steelhead in the Pacific Southwest region weigh less than 4.5 kg but some exceed 11 kg.

REASON FOR INCLUSION IN SERIES

The steelhead is the most widespread anadromous sport fish in the Pacific Southwest region, but its abundance has declined since the 1950's because of increased sport fishing intensity and damage to fish habitat through construction of dams, water diversion, road construction, and improper land management practices. In some rivers a steelhead fishery would be nonexistent without hatchery stocks.

In California, attempts are being made to protect wild stocks of steelhead to maintain existing spawning and rearing habitat, to restore or enhance degraded habitat, to use artificial propagation wisely, and to regulate the fishery to provide quality angling (California Department of Fish and Game 1975).

LIFE HISTORY

Steelhead trout spend a portion of their life in the ocean where most of their growth occurs and sexual maturity is attained; then they enter freshwater to spawn. Spawning generally takes place from February to late June. The eggs are laid in pits (redds), dug in the gravel of the stream bottom by the female. Immediately after the eggs are laid and fertilized, they are covered with gravel by the female; the length of their stay in the gravel depends upon water temperature, dissolved oxygen concentration and substrate composition. After the eggs hatch, the young steelhead gradually work their way to the surface of the stream bed. Juveniles usually spend a year or longer in freshwater (length of residence is determined by environmental and genetic factors) and then descend to the ocean.

The steelhead is a strain of rainbow trout that has a strong urge to migrate to the ocean; however, some individuals may remain in a stream, mature, and even spawn without going to sea (Shapovalov and Taft 1954).

The life history of the steelhead trout varies more than that of any other anadromous fish regarding the length of time spent at sea, the length of time spent in freshwater, and the times of emigration from and immigration to freshwater. Unlike salmon, steelhead do not usually die just after spawning.

Steelhead are classified into two races (Withler 1966; Smith 1960, 1969; and Everest 1973): winter steelhead that enter streams between November 1 and April 30, and summer steelhead that enter streams between May 1 and October 30. Portions of both groups may enter freshwater in spring or fall and are then called spring- or fall-run steelhead. In large rivers, such as the Klamath and Sacramento Rivers, steelhead may enter

during most of the year. Winter-run steelhead usually enter freshwater as maturing fish that spawn relatively soon, whereas most summer steelhead enter as immature fish and do not mature and spawn until several months later. In the Pacific Southwest, summer steelhead are not abundant and the runs in many streams consist of less than 100 fish (Roelofs 1983). Degradation of habitat in intermittent streams and susceptibility to angling and predation probably account for the low numbers. The southernmost summer steelhead population is in the Middle Fork Eel River. This river supports the largest run of these fish in the Pacific Southwest--up to 2,000 fish in a good year.

An exception is the "half-pounder" summer steelhead (terminology of Snyder 1925) which has a unique life history described by Kesner and Barnhart (1972) and Everest (1973). Half-pounder runs are confined to a small geographic range encompassing about 120 miles of the southern Oregon and northern California coasts, including the Rogue, Klamath, Mad and Eel Rivers. These small immature steelhead (25-35 cm long) annually enter freshwater from late August to early October, and are the basis of important sport fisheries in the Klamath and Rogue systems. Half-pounders spend only a few months at sea before they return to freshwater and, in contrast to mature steelhead, feed extensively in freshwater. Half-pounders that survive their first upstream migration return to the ocean the following spring and migrate back to freshwater as mature steelhead in the summer and fall. Everest (1973) reported that half-pounders annually comprise about 65% of the summer-run of steelhead on the Rogue River and that 97% of all adult summer steelhead from there make their first upstream migration as half-pounders.

Summer and winter steelhead do not interbreed; they are isolated temporally and spatially (Smith 1969; Everest 1973). Summer steelhead spawn in January and February, whereas winter steelhead spawn in April and May, and summer steelhead spawn in smaller streams or farther upstream. The sex ratio of steelhead trout immigrants is about 1:1 (Shapovalov and Taft 1954; Kesner and Barnhart 1972). Female steelhead contain about 2,000 eggs per kilogram of body weight (Moyle 1976).

Several researchers have concluded that the incidence of steelhead spawning more than once increases from north to south (Bali 1959; Withler 1966; Sheppard 1972). Wide variations in the percent of repeat spawning can be due to genetic factors, habitat quality, fishing intensity, and management practices. Fish that have spawned twice make up 70% to 85% of repeat spawners, whereas those that have spawned three times make up 10% to 25% of all repeat spawners (Forsgren 1979). The few fish that have spawned four times are likely to be females, which have a higher survival rate than males during and following spawning. Spawning males usually each serve more than one female, remain in the stream longer than the females (tagging studies by Jones (1974) indicated nearly two weeks longer), and are exposed to more prolonged physical exertion than the females (Meigs and Pautzke 1941).

Steelhead spawn in cool, clear, well-oxygenated streams with suitable depth, current velocity, and gravel size (Reiser and Bjornn 1979). Measurements made over steelhead redds showed that steelhead spawn at depths of 0.10-1.5 m, current velocities of 23-155 cm/sec, and in gravel of 0.64-12.70 cm in diameter (Smith 1973; Hunter 1973; Bovee 1978; Wesche and Rechard 1980). Intermittent streams are often used by steelhead for spawning (Everest 1973; Kralik and Sowerwine 1977; Carroll 1984). Most of the fry produced emigrate to perennial streams soon after hatching.

The embryology of the steelhead is similar to that of other salmonids (Wales 1941). The number of days required for steelhead eggs to hatch varies from about 19 at an average water temperature of 15 °C to about 80 days at an average of 5 °C. Steelhead fry usually emerge from the gravel 2 to 3 weeks after hatching.

After emergence, steelhead fry (often in small schools) usually live in shallow water along the stream banks. As the fry grow older the schools break up and the individual fish establish territories which they defend. Most steelhead in their first year of life tend to inhabit riffles but some of the larger fish inhabit pools or deeper faster runs. Mortality is high during the first few months after emergence and many investigators have suggested that the relative size of the year class is largely determined at that time (Chapman 1966; McFadden 1969; Burns 1971; Everest and Chapman 1972).

In recent years, habitat degradation has lowered the capacity of many streams to rear steelhead to smolts[1]. For example, excessive sedimentation has reduced food production, pool depth, and cover--all important to juvenile steelhead survival.

Juvenile steelhead feed on a wide variety of aquatic and terrestrial insects. Newly emerged fry sometimes are preyed upon by older juvenile steelhead. Young steelhead moving about trying to find a suitable territory are subject to the highest predation (Shapovalov and Taft 1954; Chapman 1966).

Juvenile steelhead live in freshwater for from 1 to 4 years (usually 2 years in the Pacific Southwest) before becoming smolts and migrating to saltwater. Most of the migrants are 2 years old and 18.6 to 21 cm long (fork length) in the Klamath River (Kesner and Barnhart 1972), or 14 to 21 cm long in Waddell Creek (Shapovalov and Taft 1954). The larger the smolts, the better the survival. Most steelhead smolts enter the sea in March and April.

Steelhead live 1 to 4 years in the ocean (usually 1 or 2 years in the Pacific Southwest). The length of residence in both freshwater and saltwater increases from south to north (Withler 1966). Steelhead grow rapidly in the ocean and their size upon reaching maturity depends primarily on how long they have lived in the ocean. In California, the average length of adult steelhead after 2 years in the ocean is 58 cm (Withler 1966). Immature steelhead trout (half-pounders) increase about 30 mm in length each month from the time they enter the ocean until they return to freshwater (Kesner and Barnhart 1972).

The distribution or migration of steelhead in the ocean is not well defined, particularly in the Pacific Southwest. As judged by tag returns, most steelhead tend to migrate north and south along the Continental Shelf. Steelhead stocks from the Klamath and Rogue Rivers probably mix together in a nearshore ocean staging area along the northern California coast before they migrate upriver (Everest 1973).

THE FISHERY

Commercial fishing for steelhead has been prohibited in the Pacific Southwest since 1924. The species now is managed exclusively as a sport fishery. Most steelhead are caught in rivers rather than in the ocean. The three most important steelhead trout rivers are the Klamath and Eel Rivers in northern California and the Sacramento River which empties into

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[1]Smolt: Term applied to an anadromous juvenile salmonid that is physiologically prepared to adapt to a saltwater existence; steelhead smolts lose their parr marks and become silvery.

San Francisco Bay. The California Department of Fish and Game (1965) in its Fish and Wildlife Plan estimated spawning runs of 221,000 steelhead in the Klamath River and 82,000 steelhead in the Eel River. The Klamath River still has good runs of native steelhead, perhaps approaching 200,000 fish in good years (Barnhart 1975). In the upper Sacramento River from 1953 to 1959, the average run of adult steelhead was 20,590 and consisted of both natural and hatchery-produced fish (Hallock et al. 1961).

In the California Fish and Wildlife Plan (1965), the State's annual spawning stock of steelhead was estimated at 603,000 fish. The Plan also reported that the State contained 8,402 linear miles of steelhead habitat, 31% of which was available to anglers. It was estimated that steelhead anglers fish 304,000 angler-days per year to harvest 122,000 fish (about 0.4 fish per angler-day). Many California streams support a substantial fishery for juvenile steelhead--fish that have not yet migrated to the ocean. These 5- to 8-inch trout are taken in large numbers, mostly during the so-called summer trout season. The fishing pressure for these trout (about 440,000 angler-days annually) exceeds that on adult steelhead (California Department of Fish and Game 1965).

Although adult steelhead do not commonly feed in freshwater, they are readily taken by angling. Bait fishing is popular and effective. Salmon eggs or clusters of roe or night crawlers are drifted through riffles, pools, and especially where a tributary enters a large stream. Spinners and other artificial lures are also used. When streams are low and clear, artificial flies are sometimes effective. Most steelhead fishing is done from the bank or by wading; drifting in boats is popular in larger streams.

The decline of wild, naturally produced steelhead in the spawning runs in the Pacific Southwest region since the 1940's has required an increase in the stocking of hatchery reared steelhead. A total of about 1.9 million yearling steelhead for planting are supplied annually by Coleman National Fish Hatchery on Battle Creek, a tributary to the upper Sacramento River, the Nimbus Fish Hatchery on the American River, the Feather River Hatchery on the Feather River, and the Mokelumne River Hatchery on the Mokelumne River. The goal is to mitigate the loss of steelhead trout in those rivers that has been caused by dams and water diversion.

The average weight of hatchery yearlings at the time of planting (January through May) is about 51 grams (9 fish per pound). At an expected return of about 2% annually, planted steelhead contributed about 38,000 adults to the run in the Sacramento River (Hallock et al. 1961). If steelhead were not stocked, the catch in the Sacramento River would be much smaller. The California Department of Fish and Game operates four hatcheries on the coast that produce about 1.5 million yearling steelhead annually. In addition, trout rearing projects sponsored by the California Department of Fish and Game, private groups, and counties contribute an average of 114,000 yearlings annually (Boydstun 1977a). On the Klamath system, where two of the coast hatcheries are located, hatchery production contributes only an estimated 8% of the run of adults (Boydstun 1977b). California also releases nearly 3 million steelhead fingerlings annually (Jensen 1971).

Fishery regulations are used to help protect declining steelhead stocks from excessive fishing. In California, the daily bag limit is three adult fish. All streams tributary to major coastal rivers and most small coastal streams are closed to angling from mid-November to late April. Special regulations also are sometimes used. For example, a

section of the upper Middle Fork Eel River has been permanently closed to angling to protect the adult summer steelhead trout that concentrate there in summer and fall.

The use of hatchery reared trout to boost populations is not entirely beneficial. Larger runs attract more fishermen, and more fishermen further reduce the abundance of wild stocks. Also, the genetic mixing of hatchery and wild stocks could decrease the advantageous traits in wild stocks. The steelhead trout policy of the California Department of Fish and Game limits artificial propagation and stocking to reduce such interference with natural salmonid stocks; such measures are periodically reviewed to assess their effects on the wild stocks.

The environmental quality of coastal rivers largely governs the level of steelhead production. In the Pacific Southwest, attempts have been made to increase the protection of existing spawning and rearing habitat and to rehabilitate damaged habitat where feasible. California's steelhead trout policy is directed toward three goals: (1) to protect and improve steelhead trout habitat; (2) to develop plans and programs for assessment of habitat conditions and adverse impacts, land use planning, and acquisition of interests in streams threatened with adverse developments; and (3) to study the effects of habitat changes caused by overgrazing, gravel extraction, logging, road construction, urbanization, and water development.

In 1982-84, California spent $900,000 annually on the restoration of salmon and steelhead habitat. A Salmon Restoration Project was developed within the California Conservation Corps in 1980, and by the end of 1983, Corps enrollees removed 7,447 cords of wood and debris from 233 miles of streams used by anadromous fish (Kreb 1984). The Conservation Corps also planted streamside vegetation and constructed fish passage weirs on some streams. In 1981-1983, an additional $1 million was spent annually by California to enhance spawning gravels on the upper Sacramento River and the Shasta and Klamath Rivers, and to construct salmonid rearing ponds (Rawstron and Hashagen 1984). Six Rivers National Forest in northern California during the past 5 years has carried out an extensive program to restore or enhance the spawning and rearing habitats of anadromous fish (Overton et al. 1981; Overton 1984).

ECOLOGICAL ROLE

In freshwater, young steelhead may be sympatric with sculpins, resident rainbow trout, coho salmon (*Oncorhynchus kisutch*), and in some instances other salmonids. Data are lacking on the effects of interaction of juvenile steelhead and resident rainbow trout, largely due to the difficulty in distinguishing between the fish. In the Pacific Southwest, resident rainbow trout are common in streams above barriers to steelhead migration and fry sometimes drift downstream over the barriers. Bjornn (1978) reported that steelhead fry tended to displace juvenile resident trout in the Lemhi River, Idaho. The ecological requirements of the two races are similar.

Coho salmon and steelhead trout are similar in geographical distribution, systematic characteristics, spawning locations, food habits, and the length of time the young spend in freshwater (Milne 1948), although steelhead normally remain in freshwater longer than 1 year. Although both species live in similar habitat in their first year, Hartman (1965) reported that in spring and summer, most steelhead trout live in riffles and most coho salmon live in pools. Several investigators have reported that spatial segregation is

also vertically stratified; coho salmon live near the stream surface and steelhead near the bottom (Hartman 1965; Peterson 1966; Edmundson et al. 1968; Bustard and Narver 1975). Although coho salmon hatch earlier and consequently are larger at first, steelhead fry grow so much faster that by late summer the size difference is small. Interspecific competition is probably not serious because of the initial difference in size, differences in habitat preference, and the difference in age at first emigration to the sea (Fraser 1969). Much the same relation was reported for juvenile chinook salmon (Oncorhynchus tshawytscha) and juvenile steelhead by Chapman and Bjornn (1969).

Native and hatchery-reared steelhead exhibit some competition. Steelhead trout planted at the wrong time or at the wrong size tend to stay in the stream longer than usual and are more competitive with wild fish (Royal 1972). Heavy predation by hatchery-raised steelhead smolts on chinook salmon fry below Coleman National Fish Hatchery on the Sacramento River was reported by Menchen (1981). Wagner (1967) stated that ideally the stream is to serve only as a highway to the sea and not as a postliberation rearing area for hatchery products. Pollard and Bjornn (1973) reported that the stocking of hatchery rainbow trout also caused a localized temporary decrease in the abundance of juvenile steelhead.

In coastal streams, steelhead fry are preyed on by sculpins (Cottus spp.), larger steelhead, and rainbow trout (Shapovalov and Taft 1954); by birds such as the great blue heron (Ardea herodias), belted kingfisher (Ceryle alcyon), American dipper (Cinclus mexicanus), and common mergansers (Mergus merganser); by garter snakes (Thamnophis spp.); and by various mammals (Shapovalov and Taft 1954; Sheppard 1972; Cross 1975). In the ocean, steelhead are eaten by fish and marine mammals but the extent and effect of predation are unknown.

In freshwater, steelhead feed primarily on immature aquatic stages of insects and secondarily on mature terrestrial insects. Ephemeroptera (mayflies), Diptera (true flies), and Trichoptera (caddisflies) are usually the most important taxa in the diet (Shapovalov and Taft 1954; Royal 1972; Fite 1973; Hiss 1984). Juvenile steelhead are somewhat opportunistic, feeding on almost any available insect (Fite 1973). The size of the territory for a single juvenile is determined largely by the availability of food and the size of the fish (Allen 1969). In the ocean, steelhead feed on a variety of organisms including juvenile greenlings (Hexagrammos spp.), squids, and amphipods (LeBrasseur 1966; Manzer 1968).

ENVIRONMENTAL REQUIREMENTS

Temperature

Water temperature affects all metabolic and reproductive activities of fish, including such critical functions as growth, swimming, and the ability to capture and assimilate food (Tebo 1974). Optimum temperature requirements may vary, depending on the season and life stage. A productive steelhead stream should have summer temperatures in the range of 10 to 15 ^{o}C and an upper limit of 20 ^{o}C. Steelhead have difficulty extracting oxygen from water at temperatures much over 21 ^{o}C regardless of the amount of oxygen present (Hooper 1973). Bell (1973) listed the preferred temperatures of young steelhead as 7.2 to 14.5 ^{o}C, the optimum as about 10 ^{o}C, and the upper lethal limit as 23.9 ^{o}C. Bovee (1978), who developed a probability-of-use temperature curve for rearing winter steelhead juveniles, wrote that optimum temperatures ranged from 0 to 24 ^{o}C and peaked at 15 ^{o}C. In studies of the smolting of cultured steelhead

in the spring, Wagner (1974) and Kerstetter and Keeler (1976) reported that low temperatures extend the smolting period and high temperatures shorten it. They reported that smolting ceased rather abruptly when water temperatures increased to 14-18 °C.

During the spawning season a sudden drop in water temperature may cause all salmonid spawning activity to cease (Reiser and Bjornn 1979). Reingold (1968) reported that water temperatures of 2 to 10 °C impaired the viability of eggs and delayed the ripening of adult steelhead held for 51 days in a hatchery pond. Bovee (1978) reported a spawning temperature range for winter steelhead of 4 to 13 °C, and a peak of 8 °C. Bell (1973) indicated that steelhead spawning temperatures are generally from 3.9 to 9.4 °C. The average development time from fertilization to hatching lengthens considerably with decreasing temperature; for rainbow trout it is 19 days at 15 °C, 31 days at 10 °C, and 80 days at 5 °C (Embody 1934). Bovee (1978) gave an incubation temperature range for winter steelhead of 0 to 24 °C and an optimum temperature of about 10 °C.

When water temperatures fall below 4 °C in streams of the Pacific Northwest, juvenile steelhead become inactive and hide in available cover or in the substrate (Chapman and Bjornn 1969; Bustard and Narver 1975). In California's coastal streams, juvenile steelhead remain active year-round and in one small coastal stream, young steelhead grew throughout the winter (Reeves 1979).

The virulence of many fish diseases and the toxicity of most chemicals increase with increasing water temperatures (Lantz 1971). Removal of riparian vegetation can result in marked increases in summer stream temperatures and sometimes in reduced winter temperatures (Brown 1971).

Dissolved Oxygen

Stream-dwelling salmonids require high dissolved oxygen in both the water column and intragravel waters. The swimming performance of juvenile and adult salmon was impaired when the dissolved oxygen concentration was reduced below the air-saturation level (Davis et al. 1963). A sharp decrease in performance was noted at 6.5-7.0 mg/l. Reiser and Bjornn (1979) wrote that the oxygen levels recommended for spawning anadromous fish (at least 80% of saturation, with temporary levels no lower that 5.0 mg/l) should meet the needs of migrating salmonids.

Intragravel dissolved oxygen concentration is positively related to survival of salmonid embryos (Coble 1961; Phillips and Campbell 1962; Silver et al. 1963). Silver et al. (1963), in a controlled laboratory experiment conducted at 9.5 °C, found that steelhead embryos hatched successfully at mean oxygen concentrations as low as 2.6 mg/l but that total mortality occurred at a mean level of 1.6 mg/l. In a field experiment Phillips and Campbell (1962) noted that total mortality of steelhead embryos occurred at mean oxygen concentrations of 7.2 mg/l or less. Although intragravel oxygen levels may appear adequate, the amount of oxygen actually reaching the embryos also depends on the intragravel water velocity (Wickett 1954). The amount of intragravel oxygen available to developing embryos is sometimes reduced by the biochemical oxygen demand of organic material in the gravel bed (Ponce 1974). Even if embryos hatch at low or moderately reduced oxygen levels, the incubation period is extended and the resulting fry are likely to be smaller and weaker than those reared at oxygen concentrations close to saturation (Silver et al. 1963; Shumway et al. 1964). Reiser and Bjornn (1979) concluded that although dissolved oxygen concentrations required for

successful incubation depend on both species and developmental stage, concentrations at or near saturation with no temporary reductions below 5.0 mg/l are generally required by anadromous salmonids.

In salmonid nursery and rearing streams dissolved oxygen concentrations of surface waters are normally near saturation, except in small tributaries with large amounts of debris from logging or other sources or in large, slow-moving streams receiving large amounts of municipal or industrial waste (Reiser and Bjornn 1979). Salmonids function normally at dissolved oxygen concentrations of 7.75 mg/l; exhibit various distress symptoms at 6.00 mg/l; and are often negatively affected at 4.25 mg/l (Davis 1975). Low dissolved oxygen impairs metabolic rate, growth, swimming performance, and overall survival of young salmonids.

Depth

Water depth usually does not prevent migration because adult steelhead normally migrate when stream flows are relatively high. Thompson (1972) wrote that 18 cm is the minimum depth required for successful migration of adult steelhead. The migration of adult salmonids is more commonly hindered by excessive water velocity or obstacles that impede the swimming or jumping of the fish.

Water depth may be important in the selection of redd sites. Shapovalov and Taft (1954) stated that steelhead redds are rarely exposed by falling stream levels. Bovee (1978) showed that steelhead most commonly spawn at depths averaging 36 cm (range, 15-61 cm). The depths of Washington winter steelhead redds ranged from 12 to 70 cm (Hunter 1973). Carroll (1984) measured water depths of 12 to 29 cm over steelhead redds in a Klamath River tributary.

Steelhead tend to occupy the shallow riffle areas of streams, particularly during the first year of life (Hartman 1965). Bovee (1978) presented probability of use curves showing that steelhead fry are most commonly found in water 8 to 36 cm deep, and steelhead juveniles are usually located in water 25 to 50 cm deep. In the Southwest region steelhead streams are annually subjected to low flow conditions due to the extended summer-fall dry season; thus, pool frequency and depth are important. In a 2-year study at Singley Creek, a small coastal stream just south of Cape Mendocino, Cross (1975) found that 67%-96% of young-of-the-year steelhead resided in pools. From June to September, the riffle surface area was reduced 45% while the surface area of pools diminished only 26%. Excessive sediment inputs that fill pools can greatly reduce a stream's capacity to rear steelhead to smolt size.

Water Movement

Steelhead may encounter water velocity barriers during upstream migration, often at falls or culverts. Velocities of 3-4 m/s begin to greatly hinder the swimming ability of steelhead and may retard migration (Reiser and Bjornn 1979). Thompson (1972) outlined methods to calculate minimum and maximum acceptable streamflows for migrating adult steelhead, for specific stream sections.

Bovee (1978) showed that steelhead spawn in areas with water velocities of 30-110 cm/s but that the preferred velocity approximated 60 cm/s. Smith (1973) found that the preferred water velocity for spawning steelhead in Oregon ranged from 40 to 91 cm/s. Steelhead redds were in areas where velocities were 15 to 54 cm/s in a small tributary of the Klamath River (Carroll 1984). Since swimming performance improves with size, large adult steelhead can

establish redds in faster current areas of the stream.

Permeability is defined as the capacity of the gravel to transmit water. Different spawning gravels transmit water at different rates. Several studies have demonstrated that increased intragravel velocities improve the survival of steelhead eggs and fry before emergence and also the condition of fry that emerge (Shumway 1960; Silver 1960; Coble 1961; Silver et al. 1963; Shumway et al. 1964). McNeil and Ahnell (1964) concluded that the streambeds of highly productive spawning streams had gravels with high permeability (24,000 cm/h) and had less than 5% (by volume) sand and silt that passed through a sieve of 0.833 mm mesh.

Sediment

Quantitatively, sediment is the greatest single pollutant in the nation's water (Ritchie 1972). Anderson (1971) reported that sediment production in northern California watersheds increased markedly as a result of poor land management practices and floods. The steelhead's environment can be impaired both by sediment in suspension and by particles deposited as bedload sediment. About 28% of the total spawning area in a once important 16-mile stretch of the upper Trinity River has been lost due to the deposition of sediment (California Resources Agency 1970). Stream channels of northern California markedly aggraded after large flood events during the 1960's and 1970's (Lisle 1982). Channel widening and loss of pool-riffle sequence due to aggradation damaged spawning and rearing habitat of steelhead. The pool-riffle sequence and pool quality in some northern California streams still had not fully recovered by 1980 from a 1964 regional flood (Lisle 1982).

For rearing juvenile steelhead, deposited sediment reduces the carrying capacity of the stream directly by reducing available rearing habitat and indirectly by reducing the production of invertebrate food. Bjornn et al. (1977) found significant reductions in numbers of juvenile steelhead in stream channels where boulders were imbedded in sediment. Crouse et al. (1981), who devised a visual substrate scoring system based on particle size and degree of cobble embedment, reported that fish production was significantly correlated with substrate score. They reported significant decreases in fish production in streams where cobbles were embedded 80%-100% and where sediment (2.0 mm or less) composed 26%-31% (by volume) of the total substrate composition. The authors concluded that rearing habitats of juvenile salmonids in streams, as well as spawning gravels, require protection from excessive quantities of fine sediments.

The size of substrate material has been related by numerous investigators to the standing crops of invertebrates (Sprules 1947; Kimble and Wesche 1975). Pennak and VanGerpen (1947) found that the number of benthic invertebrates decreased in the progression from rubble to bedrock to gravel to sand. Reiser and Bjornn (1979) reported that aquatic insect production was highest in substrate composed largely of coarse gravel (3.2-6.7 cm) and rubble (7.6-30.4 cm).

Suspended sediment occasionally reaches concentrations high enough to directly injure steelhead (3,000 ppm or greater) (Cordone and Kelley 1961). Physiological damage includes the adhesion of silt particles to the chorion of salmonid ova (Cordone and Kelley 1961) and the abrasion, thickening, and fusion of gill filaments (Herbert and Merkens 1961). Sigler et al. (1984) reported that chronic turbidity in streams during emergence and rearing of steelhead affects the numbers and quality of

fish produced. Turbid water also affects recreational angling for steelhead. A study on the Eel River by the California Department of Fish and Game during two winter steelhead seasons showed that 85% of all fishing took place when turbidities had decreased to 30 Jackson Turbidity Units or less; such low levels of turbidity occurred during only one-third of the fishing season (Blake and Goodson 1969).

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REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 82(11.60)*	2.	3. Recipient's Accession No
4. Title and Subtitle Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) -- Steelhead			5. Report Date June 1986
			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 Coastal Ecosystems Team, Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C. 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, TR EL-82-4

16. Abstract (Limit: 200 words)

Species profiles are summaries of the literature on the taxonomy, life history, and environmental requirements of coastal fishes and aquatic invertebrates. They are prepared to assist with environmental impact assessment. The steelhead Salmo gairdneri, an anadromous rainbow trout, supports an important sport fishery in the Pacific Southwest. Although native populations of steelhead have declined, these fish annually enter coastal streams from northern to southern California in years when winter stream flow is high. Steelhead ascend coastal streams from the ocean to spawn in cool, well-oxygenated waters with suitable depth, current velocity, and gravel size. After hatching, steelhead fry emerge from the gravel and begin a freshwater rearing phase that generally extends from 1 to 3 years. Rearing habitat with proper environmental conditions is extremely important to steelhead production. Excessive sedimentation reduces food production, pool depth, and cover--all important to juvenile steelhead survival. Steelhead smolts migrate during spring to saltwater, where most of their growth and sexual maturity is attained in 1 or 2 years. Attempts have increased to protect wild steelhead stocks, to maintain existing spawning and rearing habitat, to restore or enhance degraded habitat where feasible, to use artificial propagation efficiently, and to establish fishing regulations that provide quality angling for steelhead.

17. Document Analysis a. Descriptors

Trout	Salinity	Feeding habits	Growth
Streams	Temperature	Food chains	Oxygen
Fisheries	Sediments	Life cycles	Animal migrations

b. Identifiers/Open-Ended Terms

Steelhead trout
Salmo gairdneri
Spawning requirements
Rearing requirements

c. COSATI Field/Group

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

(See ANSI-Z39.18)

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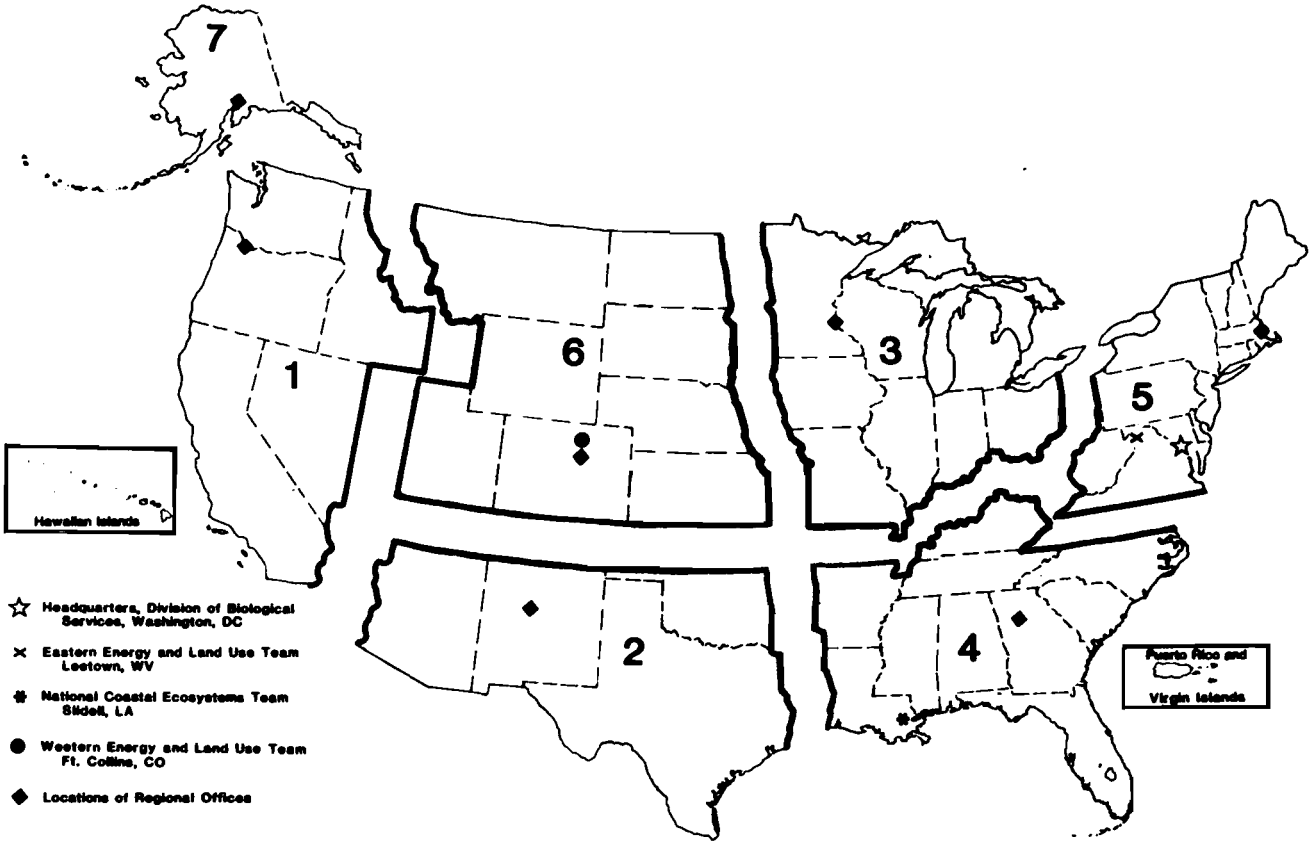

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DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE

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.