*North American Journal of Fisheries Management* 14:237–261, 1994


# Historical Decline and Current Status of Coho Salmon in California

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*Abstract.*—The southernmost populations of coho salmon *Oncorhynchus kisutch* occur in California where native coho stocks have declined or disappeared from all streams in which they were historically recorded. Coho salmon previously occurred in as many as 582 streams, from the Smith River near the Oregon border to the San Lorenzo River on the central coast. Information on the recent presence or absence of coho salmon was available for only 248 (43%) of those streams. Of these 248 streams, 54% still contained coho salmon and 46% did not. The farther south a stream is located, the more likely it is to have lost its coho salmon population. We estimate that the total number of adult coho salmon entering California streams in 1987–1991 averaged around 31,000 fish per year, with hatchery populations making up 57% of this total. Thus, about 13,000 non-hatchery coho salmon have been spawning in California streams each year since 1987, an estimate that includes naturalized stocks containing about 9,000 fish of recent hatchery ancestry. There are now probably less than 5,000 native coho salmon (with no known hatchery ancestry) spawning in California each year, many of them in populations of less than 100 individuals. Coho populations today are probably less than 6% of what they were in the 1940s, and there has been at least a 70% decline since the 1960s. There is every reason to believe that California coho populations, including hatchery stocks, will continue to decline. The reasons for the decline of coho salmon in California include: stream alterations brought about by poor land-use practices (especially those related to logging and urbanization) and by the effects of periodic floods and drought, the breakdown of genetic integrity of native stocks, introduced diseases, overharvest, and climatic change. We believe that coho salmon in California qualify for listing as a threatened species under state law, and certain populations may qualify for listing as threatened or endangered under federal law.

Populations of anadromous salmonids in the Pacific Northwest, including California, have generally declined in recent years, as indicated by decreased commercial and sport harvests (Lufkin 1991; Nehlsen et al. 1991). Coho salmon *Oncorhynchus kisutch* in particular have shown substantial coastwide decreases (Konkel and McIntyre 1987). In the U.S. Pacific Northwest, coho salmon are now extinct in the eastern half of their former range, and badly depleted over most of the western half (Frissell 1993).

Although less abundant than chinook salmon *O. tshawytscha* in California, coho salmon have been an important component in both commercial and sport fisheries. In the 1980s, California's combined commercial and sport catch averaged 83,000

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TABLE 1.—Commercial landings of chinook and coho salmon in California. Data are from the National Marine Fisheries Service (NMFS 1977–1993).

| | Chinook salmon | | Coho salmon | |
|---|---|---|---|---|
| Year | Landings (pounds) | Total ex-vessel value | Landings (pounds) | Total ex-vessel value |
| 1992 | 1.6 million | $4.4 million | 11,000 | $18,000 |
| 1991 | 3.2 million | $8.3 million | 460,000 | $701,000 |
| 1990 | 4.1 million | $11.4 million | 311,000 | $617,000 |
| 1989 | 5.4 million | $12.9 million | 229,000 | $320,000 |
| 1988 | 14.4 million | $41.2 million | 320,000 | $707,000 |
| 1987 | 9.0 million | $25.1 million | 246,000 | $263,000 |
| 1986 | 7.2 million | $21.0 million | 195,000 | $101,000 |
| 1985 | 4.5 million | $11.6 million | 81,000 | $128,000 |
| 1984 | 2.6 million | $7.3 million | 346,000 | $370,000 |
| 1983 | 2.1 million | $4.4 million | 266,000 | $327,000 |
| 1982 | 7.4 million | $19.0 million | 545,000 | $790,000 |
| 1981 | 5.5 million | | 482,000 | |
| 1980 | 5.6 million | | 300,000 | |
| 1979 | 7.6 million | | 1,200,000 | |
| 1978 | 5.3 million | | 1,300,000 | |
| 1977 | 4.3 million | | 235,000 | |
| 1976 | 4.2 million | | 3,600,000 | |

coho salmon annually, of which 30,200 were in the sport fishery (Sheehan 1991). Commercial landings of coho salmon in California averaged 301,000 lb annually during the 1980s and 1.6 million pounds annually over the period 1976–1979 (Table 1); the harvest in 1992 (11,000 lb) was substantially lower than in previous years. Aside from their economic importance, California coho salmon stocks are of ecological and evolutionary significance because they are the southernmost populations of the species. These stocks undoubtedly have at least some genetic distinctiveness and local adaptation to southern environmental conditions. Hence, they may be important repositories of genetic variation that could promote the species' expansion if large-scale climatic warming of the Pacific Northwest region occurs. The potential economic significance of these southern stocks to future fisheries in more northern areas could be substantial.

There is general agreement among fisheries biologists familiar with coho salmon in California that native coho salmon stocks have declined significantly throughout the state in recent years (Moyle et al. 1989). The exact extent of that decline is unknown, in part because the species is divided into many small populations, few of which are monitored closely. Nehlsen et al. (1991) listed 214 naturally spawning native stocks of anadromous salmonids that are declining. In that listing, California coho salmon populations south of San Francisco Bay were considered to be at high risk of extinction, and populations north of San Francisco Bay were at moderate risk of extinction, except for populations in the Klamath River, which were classified as "of special concern" (declining but in no immediate danger).

Historical estimates of statewide coho salmon abundance are essentially guesses made by fisheries managers, based on limited catch statistics, hatchery records, and personal observations. In the 1940s, there were apparently between 200,000 and 500,000 coho salmon spawning in the state (E. Gerstung, App.).[3] The number decreased to about 100,000 fish in the 1960s (California Advisory Committee on Salmon and Steelhead Trout 1988), with 40,000 in the Eel River alone (U.S. Heritage Conservation and Recreation Service 1980, App.). The statewide total of natural spawning coho salmon during 1984–1985 was estimated at 30,480 fish, compared with a total of about 3,545,000 natural spawners for the North American Pacific Coast (Wahle and Pearson 1987). Unfortunately, there is no way to test the reliability of the earlier estimates, and they are best regarded as accurate only within an order of magnitude.

This paper summarizes the published and unpublished information on the distribution and abundance of coho salmon in California. This summary is the first attempt to assess the current statewide population status of coho salmon by means of a systematic evaluation of available information from a variety of sources. Our intent is to establish a benchmark population estimate that can be compared with future population assessments and to emphasize that much better information is needed to guide management through the next century. We also discuss the probable causes of the decline of coho salmon populations in California.

## Background Information and Methods

### *Life History*

The life history of the coho salmon in California has been well documented by Shapavalov and Taft (1954), Hassler (1987), and Moyle et al. (1989). A comprehensive account of coho salmon biology throughout the species' range is given by Sandercock (1991), and ocean-related aspects are covered by Pearcy (1992). Coho salmon return to their parent streams to spawn after spending 18 months

[3] Citations followed by "App." are given in the Appendix.

or more in the ocean (up to 3 years in Alaska). Jack males may, however, return after one growing season in the ocean (at age 2). In general, the time of freshwater spawning migration occurs progressively later in the year for more southern coho salmon populations, although there are many exceptions to this pattern (Sandercock 1991). In California, the migrations normally occur from October to March, peaking in November–January. Many of the small coastal streams in California are blocked by sand bars at their mouths, and the coho salmon cannot ascend until the sand barriers are breached by high streamflows that follow heavy autumn rains. Coho salmon use a variety of spawning sites, but they characteristically enter small coastal creeks or tributary headwaters of larger rivers.

Optimal habitat for juveniles seems to be deep pools (≥ 1 m) containing logs, rootwads, or boulders in heavily shaded sections of stream. These habitat characteristics are typical of streams in old-growth forests, and for that reason, the decline of coho salmon stocks in California can be tied to the widespread elimination of old-growth forest on the California north coast. Juvenile coho salmon in California typically live in the streams for about 1 year. The juveniles begin to migrate downstream to the ocean during late March and early April, and outmigration usually peaks in mid-May, if conditions are favorable. The immature salmon initially remain in inshore ocean waters close to the parent stream. They gradually move northward, staying over the continental shelf. Coho salmon range widely in the North Pacific, but the movements of California fish are poorly known.

### *Distribution*

Coho salmon spawning populations are distributed on both the Asian and North American coasts of the North Pacific, ranging southward to the Sea of Japan in Asia and into California in North America (Sandercock 1991). Within California, coho salmon spawn in streams from the Oregon border southward to Monterey Bay. The southernmost recorded spawning stream is the San Lorenzo River, Santa Cruz County (Snyder 1908), but coho salmon probably occurred in smaller streams flowing into Monterey Bay and perhaps as far south as the Big Sur River. Presently, the most southern naturally spawning populations are in Scott and Waddell Creeks, several kilometers north of the San Lorenzo River.

Most of the coho salmon caught in the ocean fisheries of California originate in Oregon. Columbia River fish apparently constitute the largest component of the California ocean catch, and northern California coho salmon contribute only about 10% (Baker and Reynolds 1986, App.). Conversely, few fish from California are harvested out of state. Tagging studies indicated that only 6–7% of California native coho salmon stocks and 20% of nonnative stocks (imported from Oregon and Washington and released at California hatcheries) were caught in Oregon and Washington (Jensen 1971). On the Oregon coast, 75% of the coho salmon caught during 1977 had been released from hatcheries (Scarnecchia and Wagner 1980). In California, the percentage of fish caught that were produced in hatcheries may be even higher, given the present low productivity of natural populations.

### *Methods*

Our approach in this survey of California coho salmon stocks was simply to obtain as much information as possible through searches of the published literature, file reports of fisheries agencies, and from mail or telephone interviews with persons involved in coho salmon research and management in the state. Because of the extreme paucity of published data on native coho salmon populations, we relied heavily on unpublished reports and personal communications; these sources (identified by "App." in their citations) are listed after the references in the Appendix. We sought data on the historical distribution of coho salmon populations, as well as more recent information, in order to evaluate the number of those populations that still exist. Recent data, if they existed, were for 1987 or later for almost all streams. Streams for which there were several years of recent data were classified as having coho salmon even if coho salmon were absent in some years. For many of the streams for which current data on coho salmon were lacking, we asked survey respondents to give their opinions as to whether streams with which they were most familiar still contained coho salmon populations as of 1990–1991. The data used in this paper are compiled in Brown and Moyle (1991a, App.).

Because hatchery-raised coho salmon constitute a significant portion of the population in some streams, we classify coho salmon populations as three stock types: (1) native stocks that have few or no hatchery-raised fish in their ancestry; (2) naturalized stocks that included a large proportion of hatchery fish at one time, but are the progeny of naturally spawning fish; and (3) hatchery stocks

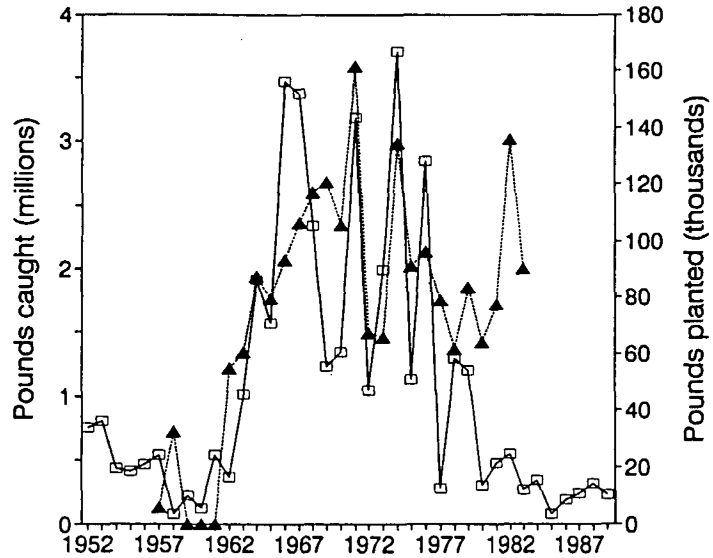


FIGURE 1.—Weight of coho salmon caught in the California commercial troll fishery (open squares; data from California Department of Fish and Game, unpublished records) and pounds of juvenile coho salmon planted each year (solid triangles; data from published hatchery reports).

that include large numbers of hatchery fish every year, usually of nonnative origin, and show little evidence of successful natural reproduction. Many, if not most, of the streams containing stocks that we classify as naturalized may also contain substantial numbers of hatchery strays, as indicated by the greater abundance of coho salmon in streams near hatcheries. For example, the production of coho salmon in Mendocino County centers around the Noyo River, which is stocked with hatchery-raised fish, and the number of coho salmon spawning in county streams declines both to the north and south of the Noyo River (W. Jones, App.). Thus, runs in these streams may be less self-supporting than the limited data indicate.

In attempting to estimate numbers of coho salmon for individual streams, we used procedures that most likely overestimate abundance to avoid exaggerating the extent of population depletion. For our enumeration, we assumed that each stream that historically contained coho salmon or for which there were no data had a basal population of 20 spawners (our "20-fish rule"). For each stream where an estimate of adult populations was available, we used either the estimate itself or 20 fish, whichever was larger. For hatchery populations, we assumed the average population size, based on available data starting in 1981–1982. For streams where hatcheries were located, we included both the average hatchery population and the estimated native or naturalized population.

### Status of Coho Salmon Populations

Most of the coho salmon produced in California waters are harvested there; however, the California commercial catch includes fish produced in streams and hatcheries in both California and Oregon (Hassler 1987). Increases in hatchery production are believed to be the major factor responsible for the increased catches of the 1960s and 1970s; however, the commercial troll catch of coho salmon declined drastically in the late 1970s, despite continued heavy plantings of hatchery fish (Figure 1; Brown and Moyle 1991a, App.). Because counts of adult returns to hatcheries either increased or fluctuated nondirectionally at that time, it is probable that the decline in catch reflected the general decline of California wild populations, as well as decreased production by Oregon stocks. For example, the count of native coho salmon at Benbow Dam on the South Fork Eel River showed a gradual but steady drop from the 1940s until the mid-1970s, when no fish were counted (Brown and Moyle 1991a, App.). In contrast, the hatchery-supported population in the Mad River fluctuated at a low level through the early 1960s, with no evident decline (Brown and Moyle 1991a, App.). A general decline of native

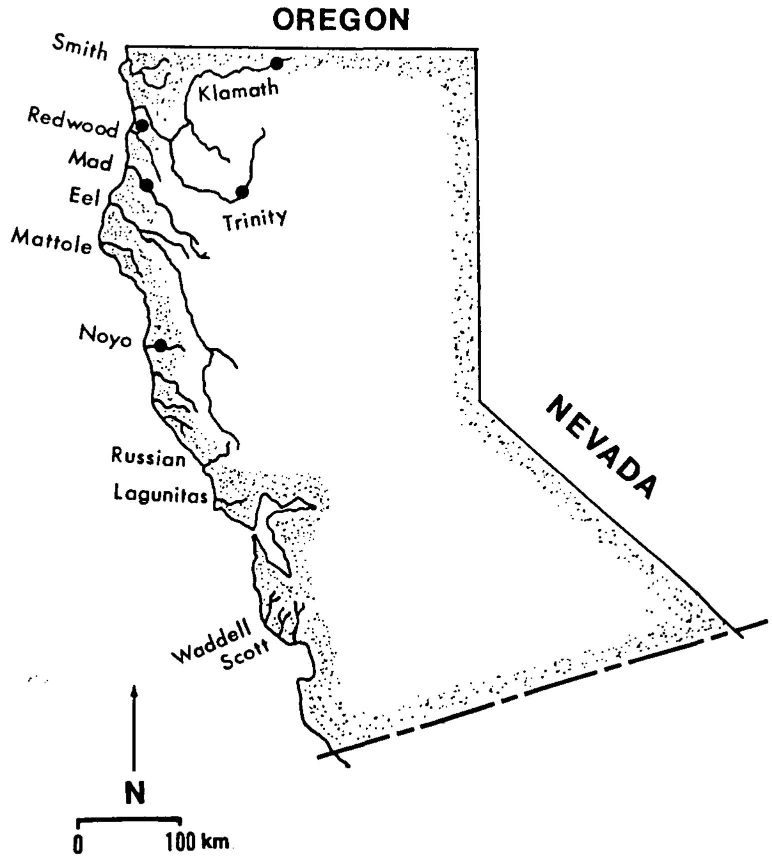


FIGURE 2.—Map of northern California showing major spawning streams of coho salmon. Locations of hatcheries that have produced coho salmon in large numbers are indicated by solid circles.

coho salmon populations has occurred within the entire Oregon Production Area (Washington to northern California) since the mid-1960s (Scarnecchia and Wagner 1980; Nickelson 1986). Furthermore, total coho salmon adult production (including hatchery stocks) in this region has declined abruptly since 1970, in spite of increasingly higher numbers of released hatchery smolts (Nickelson 1986).

### *Hatchery Populations*

Except in the Eel River, coho salmon stocks in the larger rivers of California (Figure 2) are now dominated by hatchery production, and even several small coastal streams receive regular plants of hatchery fish. These hatchery stocks are of diverse origin, but all have included fish derived from outside the river system receiving the plantings and often from outside California. Hatchery stocks have also been used to reestablish extirpated populations or to supplement depleted runs, which may partly explain the overall lack of genetic differentiation among coho salmon from different California streams (Bartley et al. 1992). In the following account, we review the records of the major government hatcheries. In addition, several private hatchery projects have attempted to rebuild local remnant stocks (Miller et al. 1990). The two largest private producers of coho salmon are the Humboldt Fish Action Council and the Monterey Bay Salmon and Steelhead Project, which annually release about 25,000 and 23,000 yearlings, respectively (Miller et al. 1990). In 1989, private projects, together with county and local programs, released more than 266,000 coho salmon yearlings into California waters.

*Klamath River.*—During 1963–1968, adult returns to the Iron Gate Hatchery in the headwaters of the Klamath River never exceeded 500 fish (data in Brown and Moyle 1991a, App.). Following an intensive stocking program begun in 1966 (and continued in 1967 and 1969) with Cascade River (Oregon) fish, adult returns to the hatchery were over 1,000 fish in seven spawning seasons and exceeded 2,200 fish twice, most recently in 1987; numbers typically have ranged between 400 and 1,500 (Hiser 1991). This hatchery run, therefore, is composed basically of an imported stock.

*Trinity River.*—The Trinity River Hatchery successfully established a run of coho salmon that continued to increase in size until recently (Bedell 1991). Prior to 1971, adult returns rarely exceeded 1,000 fish, but have consistently done so since then. Numbers of returning fish, including jacks (males returning after 4–6 months at sea), exceeded 5,000 in 1973 and in 1984–1988. Returns were over 20,000 fish in 1987 and over 10,000 in 1988, but only about 5,000 in 1989 (Bedell 1991) and less than 3,000 in 1990 and 1991 (Ramsden 1993). Like the Iron Gate stock, the Trinity River stock is primarily of nonnative origin. The first significant planting was of Eel River stock in 1964, followed by Cascade River (Oregon) stocks in 1966, 1967, and 1970. Noyo River (California) stock was planted along with Cascade River fish in 1970, and Alsea River (Oregon) stock was planted in 1970. Significant numbers of fish (about 40% of adult escapement) apparently spawned naturally in the Trinity River or in tributaries above the North Fork confluence during 1969 and 1970, mainly in the area between Lewiston Dam and Douglas City (Rogers 1973). Downstream-migrant coho salmon that were not of hatchery origin were captured during 1968 in the Trinity River (Healey 1973), another indication that natural spawning was occurring. The relative contributions of naturalized and hatchery stocks to current production in the Trinity River are unknown.

*Mad River.*—The Mad River Hatchery has been less successful than the Klamath and Trinity facilities in establishing a run of coho salmon (Brown and Moyle 1991a, App.). Adult returns have fluctuated, but have never exceeded 2,000 fish and seldom (2 out of 18 years) exceeded 1,000 fish. The Mad River Hatchery stock has the most diverse heritage of any in California. Planting began in 1970 with Noyo River (California) fish, and there were additional plantings in seven subsequent years. Klamath River fish (derived from Oregon stocks) were planted in 1981, 1982, 1986, and 1987. Trinity River fish (derived from nonnative stocks) were planted in 1971. Additional Oregon stocks were imported from the Trask River (1972), Klaskanine River (1973), Soos River (1978), and Sandy River (1979). Fish from Prairie Creek (Redwood Creek drainage, California) were planted in 1987 and 1989.

*Russian River.*—Warm Springs Hatchery on the Russian River has not established a persistent run of coho salmon since it began planting fish in 1980 (Brown and Moyle 1991a, App.). Adult returns have varied from zero to just under 1,000 fish; the most recent returns have been 170 (1989), 277 (1990), and 162 (1991) (B. Cox, App.). The Warm Springs Hatchery stock is derived from the Iron Gate Hatchery stock (in turn derived from Cascade River, Oregon, stock) and from the Noyo River, Hollow Tree Creek, and Prairie Creek (all California) stocks.

*Noyo River.*—The Noyo River egg-taking station on the South Fork Noyo River began operation in 1962 for the purpose of establishing a supply of California coho salmon eggs to enhance both depleted naturally spawning stocks and hatchery production. The number of coho salmon trapped at the Noyo station varied between 1,500 and 3,000 during 1964–1976 (Brown and Moyle 1991a, App.). The numbers declined during 1977–1986, exceeding 1,500 fish only in 1981. In 1987, about 2,650 adults were trapped (Grass 1990b). However, numbers trapped in subsequent years have been lower: 708 (1988), 1,011 (1989), 145 (1990), 509 (1991), 164 (1992) (S. Poe, App.). Depending on the size of the run, a number of fish are allowed to pass over the dam to spawn naturally—either 10 pairs or 25% of each sex, whichever is fewer, during each week of the spawning season (CDFG 1987, App.). Significant natural spawning also takes place downriver of the station in the South Fork Noyo River and in the tributary Kaas Creek (Nielsen et al. 1991, App.), but the genetic heritage of these spawners is unknown. Since 1964, the river has been routinely planted with yearling fish hatched from Noyo River eggs and raised at various hatcheries. Presently, 150,000 eggs are reserved annually for maintaining the Noyo River run; coho salmon hatched and reared at the Mad River Hatchery are released as yearlings in the Noyo River. The management goal is to maintain a minimum run of 1,500 adults (CDFG 1987, App.). Noyo River stock has also been planted at several hatcheries and in several coastal streams.

*Prairie Creek (tributary of Redwood Creek, Humboldt County).*—Most of the following information was obtained through personal communications with S. Sanders, former manager of the Prairie Creek Hatchery. The Prairie Creek Hatchery did not have facilities to capture returning adult fish until 1972. The run to the hatchery generally exceeded 100 fish and increased to 1,799 fish by 1988; subsequent counts were 682 fish in 1989 and 186 in 1990 (Brown and Moyle 1991a, App.). However, counts for 1988 and later are not strictly comparable with earlier counts because the use of a physical barrier or weir to trap adults was discontinued. Only 154 adults were collected in 1991 because of permit restrictions, but there reportedly were many more fish in the system. Most adults trapped in the hatchery had been previously released as juveniles. In the early 1970s, stray coho salmon from the Columbia River were commonly captured but they are now rare in Prairie Creek. Since 1983, only Prairie Creek stock has been planted, but some nonnative stocks were introduced earlier; those stocks originated from the Soos River (1978) and Sandy River (1979) in Oregon, and the Noyo (1982) and Klamath (1981) Rivers in California (the latter stock imported from the Cascade River, Oregon). Prairie Creek coho salmon have recently tended to return in January–February, which is later than in earlier years (1970s) when imported stocks were heavily used. The Prairie Creek Hatchery was closed in 1992.

*Native Populations*

Little data exist on the status of native coho salmon populations in California, but the available information strongly suggests that native stocks are at very low levels. We present information on adult coho salmon abundances for some major drainages (Table 2) to illustrate the nature of the available data and to convey some impression of historical abundances. Brown and Moyle (1991a, App.) give a more complete listing of streams, including data on juvenile abundances. A brief commentary on coho salmon populations in the various river systems follows.

*Smith River.*—The Smith River drainage (Del Norte County) does not support a large run of coho salmon (Waldvogel 1988, App.). Recent annual counts of adults in a 2.7-km stretch of a small tributary creek have yielded only low numbers (Table 2), but Hallock et al. (1952) seined 60,602 juveniles from the creek in 1951, indicating that it once supported a substantial coho salmon population.

*Klamath–Trinity River.*—In the Klamath River (Del Norte County), coho salmon historically were abundant, but the commercial fishery favored the even more abundant chinook salmon (Snyder 1931); nonetheless, some early harvests of coho salmon were substantial (Table 2). Historical annual spawning escapements for the Klamath River system have been estimated at 15,400–20,000 fish, with 8,000 coming from the Trinity River (USFWS 1979, App.). Presently, Iron Gate and Trinity Hatcheries are considered to be the sources of most Klamath River coho salmon and natural production is minor (Klamath River Fishery Management Council 1991, App.).

Coho salmon have been reported from 113 tributary streams in the combined Klamath–Trinity River system (Brown and Moyle 1991a, App.). Many of the lower tributaries in the Klamath drainage have been degraded by logging and roadbuilding, and their coho salmon runs diminished. For example, surveys in 1989 failed to find coho salmon in Tully and Pine Creeks, and no outmigrants were found in Pecwan Creek, although juveniles were found there in previous years (T. Kisanuki, App.). Some tributary streams in the middle and upper Klamath River still support coho salmon, and these populations may be native because available records do not indicate stocking. Of the larger tributary systems, the Scott River probably holds the largest number of native fish. The Salmon River probably has few, if any, coho salmon (J. West, App.).

In the Trinity River drainage, coho salmon have been reported spawning in the main stem, the South Fork Trinity River, and in the tributaries (Hassler et al. 1991, App.). An estimated 2,098 fish spawned in the main stem below Trinity Hatchery during 1970, but all or most of them probably were hatchery returns (Rogers 1973). Healy (1973) captured naturally spawned downstream-migrant yearlings in the Trinity River, but no juvenile coho salmon were taken in the South Fork Trinity River, which indicates that the native stock there is greatly diminished or gone.

*Redwood Creek.*—Coho salmon were first reported in Redwood Creek (Humboldt County) by Snyder (1908). Juvenile and adults have been seen in the main stem of Redwood Creek, in Prairie Creek (its major tributary), and in several Prairie Creek tributaries. A 1973 survey by the U.S. Bureau of Reclamation estimated 2,000 spawners but reported extensive habitat damage above Redwood National Park, which was attributed to logging (USBLM 1973, App.). The total population in the Redwood Creek system may still number more than 2,000 fish in some years, but most occur in the Prairie Creek drainage and probably originate from the Prairie Creek Hatchery (D. Anderson, App.; S. Sanders, App.).

*Mad River.*—On the Mad River (Humboldt County), numbers of coho salmon passing over

TABLE 2.—Examples of historical and recent abundance data for adult coho salmon in some California rivers.

| Drainage basin and stream | Year(s) | Coho salmon abundance | Source |
|---|---|---|---|
| Smith River | | | |
| West Branch Mill Creek | 1980–1989 | Annual mean = 11 fish (range 2–28) | Waldvogel (1988, App.) |
| Klamath River | | | |
| Lower River | 1919 | 11,162 in gill-net fishery | Snyder (1931) |
| | 1951 | 1,187 in sport catch | Gibbs and Kimsey (1955) |
| | 1954 | 4,000 in sport catch | McCormick (1958, App.) |
| | 1955 | 1,145 in sport catch | Gibbs and Kimsey (1955) |
| Shasta River counting racks[a] | Aug–Nov 1955 | None counted | Coots (1957) |
| | Oct 1957 | 310 counted | Coots (1958a) |
| Klamathon racks[b] | 1923 | Abundant | Bryant (1923) |
| | 1925 | 295 counted | Snyder (1931) |
| | 1956 | None counted | Coots (1958b) |
| Hoopa Valley Reservation | 1988 | 588 in gill-net fishery | Tuss et al. (1989, App.) |
| | 1989 | 525 in gill-net fishery | Kisanuki et al. (1991, App.) |
| Trinity River | | | |
| Main stem, Lewiston | 1958–1963 | Average annual wild escapement = 228 fish (range = 7–583 fish) | Smith and Sharp[c] |
| Main stem, below Trinity Hatchery | 1970 | 2,098 estimated natural spawners | Rogers (1973, App.) |
| Redwood Creek | 1973 | Estimated run of 2,000 | USBLM (1973, App.) |
| | 1990s | Perhaps 2,000+ fish in some years | S. Sanders and D. Anderson (App.) |
| Mad River | 1938–1943 | Annual counts on fishway: 498; 725; 73; 308; 378; 259 | Murphy and Shapovalov (1951) |
| | 1946–1949 | Annual counts on fishway: 415; 510; 515; 512 | Murphy and Shapovalov (1951) |
| Eel River, South Fork (Benbow Dam) | 1938–1949 | Annual counts on fishway: 7,370; 8,629; 11,073; 13,694; 15,037; 13,030; 18,309; 16,731; 14,109; 25,289; 12,872; 7,495 | Murphy and Shapovalov (1951) |
| Noyo River | 1958 | Thousands | Holman and Evans (1964) |
| | 1973 | Estimated 6,000 spawners | USBLM (1973, App.) |
| | 1989–1990 spawning season | Estimated 901–950 spawners | Nielsen et al. (1991, App.) |
| Coastal | | | |
| Ten Mile River | 1973 | Estimated 6,000 spawners | USBLM (1973, App.) |
| | 1989–1990 spawning season | Estimated 31–55 coho, based on carcass count; estimated 80–92 combined coho salmon/chinook salmon/steelhead, based on live fish counts | Nielsen et al. (1991, App.) |
| Big River | 1973 | Estimated 6,000 spawners | USBLM (1973, App.) |
| Gualala River | 1973 | Estimated 4,000 spawners | USBLM (1973, App.) |
| Waddell Creek | 1930–1940 | 120–633 spawners annually | Shapovalov and Taft (1954) |
| | 1990 | 50+ spawners | J. Smith (App.) |
| Scott Creek | 1980s–1990s | 30–40 spawners | J. Smith (App.); D. Streig (App.) |

[a] 282 km upstream from mouth.
[b] 301 km upstream from mouth.
[c] Personal communication, cited in Fredericksen et al. (1980, App.).

Sweasey Dam fluctuated between 0 and 1,000 fish during 1938–1961; in 1962, 3,500 fish passed over the dam, followed by 1,500 in 1963, and less than 500 fish in 1964 (Murphy and Shapovalov 1951; Fredericksen et al. 1980, App.). Counts at the Mad River Hatchery fluctuated in the same range (500–1,000 fish) during 1971–1988. Thus, it appears that overall numbers have remained fairly steady, although the relative contributions of hatchery and native fish to the population are not known.

*Humboldt Bay streams.*—Streams tributary to Humboldt Bay (Humboldt County) historically have been important to the local sport fishery, but estimates of coho salmon abundance are few (Hull et al. 1989, App.). Hallock et al. (1952) seined 8,642 juveniles from Freshwater Creek, 17,671 from Elk River, and 14,243 from Jacoby Creek, which indicates there were substantial populations in those streams. Freshwater Creek has been the focus of population and habitat recovery efforts by the Humboldt Fish Action Council, which began rearing coho salmon and chinook salmon for local population enhancement in the early 1970s (Hull et al. 1989, App.). Total escapement in the Freshwater Creek drainage was estimated at 454 adults in 1986–1987 and 834 in 1987–1988. The entire 1986–1987 run apparently was native fish, but 68% of the 1987–1988 run consisted of hatchery fish (Hull et al. 1989, App.). Initial enhancement efforts used nonnative stocks from the Alsea, Trask, and Sandy Rivers of Oregon; the Skagit, Soos, and Minter Rivers of Washington; and the Trinity, Noyo, and Klamath Rivers of California. We estimate that the Elk River supports an annual run of around 400 native coho salmon, based on recent sporadic surveys of both adults and juveniles (CDFG 1990–1993, App.)

*Eel River.*—The Eel River (Humboldt County) probably supports the largest remaining native populations in California. One estimate places the Eel River run at 40,000 annually (U.S. Heritage Conservation and Recreation Services 1980, App.); however, this figure exceeds a more recent statewide estimate of 33,500 spawners (Sheehan 1991). Presently, coho salmon are known to spawn mainly in the tributaries of the South Fork Eel River. In the main-stem Eel River, coho salmon are known to have spawned in several small tributaries of Outlet Creek as recently as the 1988–1989 season (G. Flosi, App.; W. Jones, App.). Nielsen et al. (1991, App.) conducted surveys on 69 km of Outlet Creek and on 12 of its tributaries during the 1989–1990 season but were unable to find any coho salmon. All but four tributaries had supported coho salmon in the past (Brown and Moyle 1991a, App.). The lower main-stem Eel River apparently is not used as spawning or rearing habitat to any significant degree (Murphy and DeWitt 1951, App.). In the Van Duzen River, juveniles have been captured recently in small numbers from the main river and two small tributaries, Grizzly and Cummings Creeks (Brown and Moyle 1991b, App.).

Tributaries of the South Fork Eel River have been recently surveyed by Nielsen et al. (1991, App.). In the 1989–1990 spawning season, less than 300 adult coho salmon were counted in the system, which probably supports, at best, 1,320 spawners (see next section). Very few juveniles have been present in areas of the South Fork Eel River drainage where there is adequate habitat to support large numbers. Early reports document samples of thousands of juveniles from some streams—4,844 in the Bull Creek system in 1939 (Shapovalov 1940) and 3,000 in 1951 (Hallock et al. 1952); 3,475 in Ten Mile Creek in 1951 and 4,369 in 1952 (Kimsey 1952, 1953); and 1,250 in Dean Creek in 1939 (Shapovalov 1940).

Coho salmon were formerly more widespread in the Eel River drainage. California Department of Fish and Game (CDFG) files contain reports of coho salmon in Indian Creek (main-stem tributary above Outlet Creek) and several tributaries to Tomki Creek. During the 1946–1947 season, 47 coho salmon passed through the Van Arsdale fish facility on the upper main-stem Eel, 315 km from the sea, but they have not been recorded there since (Grass 1990a). The Tomki Creek drainage has been intensively studied since 1986, but no coho salmon have been captured or observed (Steiner Environmental Consultants 1990, App.). There are no recent records of coho salmon in tributaries to the North Fork Eel and Middle Fork Eel Rivers (W. Jones, App.; L. Brown, personal observation), although they were formerly present there.

*Mattole River.*—The coho salmon run in the Mattole River (Humboldt County) is much reduced from historic levels—to less than 800 fish annually. Community-based restoration efforts have been underway for several years, but there is a "good" run in only one out of three years (G. Petersen, App.). Plantings of hatchery fish have not noticeably increased spawner returns, but the program has led to the establishment of populations in tributary streams (Miller et al. 1990). Coho salmon still migrate far up the Mattole River into the South Fork Bear River (Preston 1988–1989, App.), but exact numbers are unknown.

*Mendocino County streams.*—In Mendocino County, juvenile coho salmon were found in 40 of 146 streams recently surveyed (W. Jones, App.). At 71 stations, mean juvenile coho salmon density was 0.41 fish/m$^2$ (range 0.01–1.61 fish/m$^2$). Baker and Reynolds (1986, App.) reported coho salmon in only 21 of 70 major streams surveyed in Mendocino County. Thus, coho salmon appear to be absent or very rare in many of the streams they occupied historically. For example, they have not been recently observed in Usal Creek, which was once used as a source of juvenile coho salmon to plant elsewhere. Numbers of juveniles removed from Usal Creek were 3,963 (1940), 60,510 (1944), 61,133 (1945), 11,455 (1951), and 13,864 (1952)

(Shapovalov 1940, 1945, 1949; Kimsey 1952, 1953). Most recently, Nielsen et al. (1991, App.) found coho salmon populations to be low in all of 82 streams (571 stream kilometers) surveyed in Mendocino County. Only the Noyo River, which is routinely planted with large numbers of fry and smolts, had a population of more than 500 fish. Based on the number of coho salmon carcasses per stream-mile surveyed, the index of abundance for recent spawning seasons for the Noyo River has been 1.69 (1989–1990), 0.92 (1990–1991) and 1.58 (1991–1992) (J. Nielsen, App.)

*Sonoma County streams.*—Coho salmon are present in Salmon Creek, Russian River, Gualala River, and their tributaries. Present numbers in Salmon Creek and the Gualala River are evidently small (B. Cox, App.), although the 1973 spawning population for the Gualala was estimated at 4,000 fish (USBLM 1973, App.). Coho salmon have been reported from the Russian River and 27 tributary streams, but most of the streams no longer have populations (Brown and Moyle 1991a, App.).

*Marin County streams.*—Several coastal streams in Marin County have small coho salmon runs (B. Cox, App.), but there are insufficient historical data to determine trends. Olema Creek and its tributaries are believed to support a run of about 200 native coho salmon, and Redwood Creek has a run of about 75 or more fish (B. Cox, App.). The present population in Lagunitas Creek has been significantly reduced from historical levels (Smith 1986, App.), despite efforts to preserve and enhance the run (Brown and Moyle 1991a, App.). In the early 1900s, special trains brought anglers from the San Francisco Bay area to Lagunitas Creek to fish for coho salmon and steelhead (Smith 1986, App.), and the creek produced a state size record for coho salmon in 1959 (Giddings 1959). The population decline was associated with the construction of Kent and Nicasio Reservoirs, which blocked access to the upper reaches of this system. Annual 1-or 2-d counts of coho salmon in portions of the Lagunitas–San Geronimo Creek system since 1984–1985 have varied, but indicate that the spawning run is generally less than 100 fish (Kelley 1991, App.), despite the stocking of coho salmon juveniles (Noyo River stock) in 1985 (20,040 fish), 1987 (3,888 fish) and 1988 (5,000 fish) (B. Cox, App.). Stream surveys indicate that about 400–500 adults were present in the Lagunitas Creek system (including Olema Creek) during the 1991–1992 spawning season—the highest number seen in the last 7–8 years (B. Cox, App.). Approximately 94–116 coho salmon adults and 41–53 redds were observed during an extensive survey of Lagunitas and San Geronimo Creeks in January 1992 (W. Lifton, App.). An enhancement hatchery that uses local spawners has recently operated on San Geronimo Creek (L. Cronin, App.).

*San Francisco Bay tributaries.*—Within San Francisco Bay, coho salmon runs have been extirpated, or nearly so. Skinner (1962) indicated that prior to human disturbance, most streams with suitable habitat had coho salmon. Spawning migrations were noted in Walnut Creek from the 1950s to the mid-1960s (Leidy 1984). Coho salmon also have been recorded from Corte Madera (San Anselmo) Creek (Fry 1936; Hallock and Fry 1967) and Mill Valley Creek (Hallock and Fry 1967), and juvenile coho salmon were captured in both streams during Leidy's (1984) survey of San Francisco Bay streams. There have been no coho salmon observed in Corte Madera Creek in the last 7–8 years (B. Cox, App.). The threats to any remaining fish are the degradation of habitat and water quality caused by continued urban development.

*Sacramento River drainage.*—Coho salmon occurring in the Sacramento River during recent decades have been regarded as strays (Hallock and Fry 1967; Fry 1973). Hallock and Fry (1967) reported that during 1949–1956 only two coho salmon were seen in the Sacramento River, at the Coleman National Fish Hatchery, and an additional fish was reported there before 1949 (J. Pelnar, App., cited in Hallock and Fry 1967). Older records suggest that coho salmon may once have been more abundant in the Sacramento River. Jordan and Jouy (1881) list a museum specimen from the Sacramento River, and Jordan and Gilbert (1881) describe coho salmon as occurring from the Sacramento River northward. D. S. Jordan also reported a fall run of coho salmon in the Sacramento River (U.S. Commission of Fish and Fisheries 1892). Eigenmann (1890) listed coho salmon as one of the four salmon species occurring in the Sacramento River and stated that runs occurred in that river in the summer and fall. He did not term coho salmon rare as he did pink and chum salmon, which might indicate a higher level of abundance of coho salmon at that time. The lack of more definitive information about the abundance of coho salmon may be due to the difficulty of identification mentioned by Eigenmann (1890), as well as a general lack of interest in coho salmon compared with the much more abundant chinook salmon. For example, Snyder (1931) stated that coho salmon occurred in large numbers in the

Klamath River, although up to that time statistics on coho salmon had been recorded only for the year 1919.

In 1956–1958 the CDFG attempted to reestablish coho salmon in the Sacramento River. In 1956, 43,025 yearlings were released into Mill Creek (Tehama County), followed by 53,505 yearlings in 1957, and 48,000 in 1958 (Hallock and Fry 1967; Fry 1973). These fish were of Lewis River (Washington) stock. The returning adults scattered throughout the drainage, with the largest concentrations occurring at Battle Creek, where the fish had been raised, and Mill Creek, where they were planted. The fish spawned (Hallock and Fry 1967) but failed to establish a self-sustaining population in Mill Creek. Since then, small numbers of coho salmon have been consistently identified at Nimbus Hatchery (Jochimsen 1971 to 1978c), and they also have been taken in the Feather River (Schlichting 1974; Painter et al. 1977, App.).

*Southern populations.*—Most natural production of coho salmon in the smaller streams south of San Francisco Bay appears to have been lost due to the 1976–1977 drought, which exacerbated the cumulative effects of stream alterations caused by agriculture, logging, and urbanization (D. Streig, App.). Apparently stray fish occasionally reproduce in these small coastal streams (e.g., spawning has occurred in San Gregorio Creek: Coots 1973), and they possibly could establish new populations. The only sustained coho salmon runs in this region are in Waddell and Scott Creeks, and in the San Lorenzo River, which has a hatchery-maintained population. The San Lorenzo River lost its naturally spawning coho salmon population during 1976–1977. However, much or all of that population was the result of stocking from the 1950s through the mid-1970s (J. Smith, App.). Smolts planted from Noyo River, Prairie Creek, and Scott Creek stocks have reestablished coho salmon returns to the system, and fish returning to the river have been trapped and artificially spawned in an effort to establish a resident stock (Brown and Moyle 1991a, App.). The number of adult fish trapped from the river peaked in 1989 at 183 fish. However, this stream has undergone extensive habitat loss and degradation, and it is not known if there is adequate habitat for a self-sustaining population to be established.

The coho salmon runs in Waddell and Scott Creeks (Santa Cruz County) are the most southern of coho salmon populations on the North American Pacific Coast—the closest population is 159 km north (in Redwood Creek, Marin County). Waddell Creek, the site of Shapovalov and Taft's (1954) classic study of coho salmon and steelhead life history, presently maintains a much reduced natural run, although there is still extensive coho salmon rearing habitat present (J. Smith, App.). This stream was heavily planted with juvenile coho salmon in 1929, 1930, and 1933. In the early 1970s there were additional introductions of fish from Washington State (Taylor 1991, App.). Also, a number of imported stocks have been introduced by private aquaculturists in recent years, but records of egg sources were not kept (D. Streig, App.: cited in Bartley et al. 1992). Between 1930 and 1940, the population varied between 120 and 633 spawners (Shapovalov and Taft 1954). The present run is about 50 fish in better years, but much less in poor years (J. Smith, App.); "good" runs occur every third year, most recenty in 1989–1990. Lack of early rainfall in the 1990–1991 spawning season prevented adults from migrating upstream at the usual time, and reproduction was probably very low (J. Smith, App.). There were approximately 65 adults estimated for the 1991–1992 run in Waddell Creek, but at least three probable coho salmon redds were destroyed by scouring following a postspawning storm (Smith 1992a, 1992b, App.). Scott Creek also maintains a natural coho salmon run, which averages 30–40 fish per year, although it probably contains stray fish from nearby Waddell Creek. Scott Creek and its tributary, Big Creek, have been the focus of intensive rehabilitation efforts and may provide the best habitat for coho salmon south of San Francisco Bay (D. Streig and J. Smith, App.). At present there is an enhancement hatchery on Big Creek that uses local spawners (Smith 1992a, App.); however, the number of adult spawners returning to the Scott Creek drainage appears to be extremely low (Marston 1992, App.). The somewhat late run and spawning times (December–February; J. Smith, App.) of coho salmon in Waddell and Scott Creeks indicate adaptations to local conditions that have persisted despite past interbreeding with imported stocks.

## Extent of the Decline

### *Presence or Absence of Coho Salmon Stream Populations*

We classified all streams previously known to have contained coho salmon either as (1) "present," where coho salmon are present, whether natural-spawning or hatchery fish, (2) "absent," where

TABLE 3.—Counts for current presence of coho salmon in California streams known to have historically contained coho populations. Results are listed by county; county classifications are based on the location of the mouth of the stream system. Streams where coho salmon are present some years but not in others are classified as having coho. Streams receiving hatchery plants are not counted as having coho salmon unless adult returns were documented. Corresponding percentages for the categories are given in parentheses.

| Location | System | Number of streams | Coho present | Coho absent | No data |
|---|---|---|---|---|---|
| Del Norte County | Coastal | 9 | 1 (11%) | | 8 (89%) |
| | Smith River | 41 | 2 (5%) | | 39 (95%) |
| | Klamath River | 113 | 21 (18%) | 20 (18%) | 72 (64%) |
| Humboldt County | Coastal | 34 | 7 (21%) | | 27 (79%) |
| | Redwood Creek | 14 | 3 (21%) | | 11 (79%) |
| | Mad River | 23 | 2 (9%) | | 21 (91%) |
| | Eel River | 124 | 34 (27%) | 22 (18%) | 68 (55%) |
| | Mattole River | 38 | 3 (8%) | | 35 (92%) |
| Mendocino County | Coastal | 44 | 13 (30%) | 22 (50%) | 9 (20%) |
| | Ten Mile River | 11 | 7 (64%) | 3 (27%) | 1 (9%) |
| | Noyo River | 13 | 11 (84%) | 1 (8%) | 1 (8%) |
| | Big River | 16 | 11 (69%) | 2 (13%) | 3 (18%) |
| | Navarro River | 19 | 4 (21%) | 4 (21%) | 11 (58%) |
| Sonoma County | Coastal | 10 | 1 (10%) | 1 (10%) | 8 (80%) |
| | Gualala | 11 | 1 (9%) | 1 (9%) | 9 (82%) |
| | Russian River | 32 | 2 (6%) | 22 (69%) | 8 (25%) |
| Marin County | Coastal | 10 | 7 (70%) | | 3 (30%) |
| San Francisco Bay[a] | Coastal | 7 | | 7 (100%) | |
| South of San Francisco Bay | Coastal | 13 | 5 (38%) | 8 (62%) | |
| Total | | 582 | 135 (23%) | 113 (19%) | 334 (58%) |

[a] Includes Sacramento River and other tributaries to the Bay.

coho salmon are known to be very rare or extirpated, or (3) "undetermined," where sufficient information is lacking to evaluate their coho salmon stocks. The time frame for which we consider coho salmon to be present in a stream is from the early 1980s up to 1991. For example, if coho salmon were reported to occur in a stream during that period or if our sources were of the opinion that the fish probably still existed there, we considered that stream to have coho salmon present. We note that this time period includes years prior to the recent 6-year drought (1987–1992); thus, streams that had lost their coho salmon runs by the late 1980s did so for reasons other than, or in addition to, natural drought-related causes. The results of our enumeration are summarized by county in Table 3. County classifications of streams were based on the location of the mouth of the system rather than by individual stream locations.

There are 582 California streams known to have supported coho salmon at some time (a complete listing is given by Brown and Moyle 1991a, App.). That number represents a minimum, because some streams possibly had not been surveyed during the years when they contained coho salmon and were not included in the total. Furthermore, the number of streams with coho salmon undoubtedly fluctuated as climatic conditions changed. Bearing these points in mind, our assessment is as follows. We lack data on the recent status of coho salmon in 57% of the 582 identified coho salmon streams. Of the 248 streams for which we have some idea of recent coho salmon presence or absence, 54% had coho salmon and 46% did not. The amount of data varied between counties; the percentage of streams that could not be classified was greatest in the northern part of the state and lowest in the south. This pattern may be partly owing to the greater number of streams in the north, which are also generally less accessible than those in the south. Differences in management emphasis among fisheries managers also may be a contributing factor. The greatest concern for coho salmon appears to occur in Mendocino County and southward, probably because the smaller river systems in the south historically supported a higher proportion of coho salmon to chinook salmon than did the larger northern systems. Also, in the far south (Sonoma County southward), there is concern for preserving habitat for all species of anadromous fishes in the face of rapid urbanization.

In Del Norte County, on the Oregon border, 73% of the streams lacked information about their coho salmon status. In the Klamath drainage, only about half of the streams for which there was information still had coho salmon; most of the streams without coho salmon were tributaries to the South Fork Trinity River and Salmon River. In all, 45% of the streams in Del Norte County for which there were records no longer contain coho salmon.

In Humboldt County, 70% of the streams were classified as undetermined; if the Eel River drainage is omitted, the percentage increases to 86%. Overall, 31% of Humboldt County streams for which there are recent records are without coho salmon, all in the Eel River system. Of 103 former coho salmon streams in Mendocino County, 24% were undetermined, 45% contained coho salmon, and 31% lacked coho salmon. Thus, 41% of classified streams in Mendocino County evidently have lost their coho salmon stocks. Sonoma County contains 53 streams that historically contained coho salmon. Of those, 47% could not be classified; of the remaining 28 streams, 4 streams (14%) contained coho salmon and 24 (86%) did not. From Marin County southward, only 30 streams historically contained coho salmon, not including Sacramento River tributaries. There were no data for 3 streams, 15 have lost their populations, and 12 streams still are used by coho salmon, at least occasionally. Most of the streams having coho salmon in the region south of San Francisco Bay are very small, support few salmon, and are supplemented by hatchery stocks.

*Estimates of Abundance*

Little quantitative data exist on which to base estimates of coho salmon abundance in California, and we therefore assumed that many streams for which data were lacking still contained coho salmon (our 20-fish rule). In most cases when previous estimates of adult abundances were available for individual streams, they were no greater than our assumed basal estimate of 20 fish per stream. Numbers of coho salmon passing over Sweasey Dam on the Mad River varied between 0 and 1,000 fish during 1938–1961; our estimated number of coho salmon in the system, discounting fish returning to the hatchery, was 460 fish, which fits well within the historic range of values (Table 4). We estimated the population in the Outlet Creek drainage (tributary to the Eel River) to be 240 fish, although in 1989–1990 there was no evidence of spawning there. In the South Fork Eel River drainage, we estimated the Hollow Tree Creek population to be 180, assuming 20 fish per tributary. That number is comparable to the 162 fish counted at the Hollow Tree Creek egg-taking station in 1989–1990 and exceeds the counts for several other years. Also in the South Fork Eel River, our 20-fish rule predicted 140 coho salmon in the Ten Mile Creek drainage when none were seen in the 1989–1990 season. Nielsen et al. (1991, App.) estimated fewer than 100 spawners of all species combined in the coastal Ten Mile River system, for which our estimate was 160 fish. We similarly overestimated population sizes for the Big, Little, Garcia and Gualala Rivers. Cases in which the 20-fish-per-stream rule underestimated the population occurred mainly where there was ongoing hatchery supplementation, as in the Noyo River, tributaries around Humboldt Bay, Scott Creek, and the San Lorenzo River.

In most cases, therefore, our estimates for native and naturalized fish seem to be biased upwards. The degree of overestimation may be substantial because we assumed that all streams for which there were insufficient data still contained coho salmon. Despite the probable overestimation of native and naturalized coho salmon population sizes, those populations overall are at low levels. Furthermore, the recent (1986–1992) drought has reduced some small populations to near extirpation (e.g., in the Eel River system and some Klamath tributaries).

Our total population estimate for coho salmon in California is about 31,000 fish (Table 4). However, hatchery populations contribute over half that number (57%), and natural spawners number only 13,240. Probably the largest concentration of coho salmon with little hatchery influence presently occurs in the South Fork Eel River system, which we estimate to have 1,320 fish (using our 20-fish rule for streams that lacked data). This is probably a substantial overestimate, given the absence of fish from many of the tributaries during the 1989–1990 survey by Nielsen et al. (1991, App.). The actual number probably is lower than 1,320 fish but greater than 300 (roughly the number counted by Nielsen et al. 1991, App.). Similarly, our total estimate of 13,240 native and naturalized coho salmon statewide could easily be overstated by 50% or more. This estimate is further reduced if naturalized (hatchery-influenced) stocks are discounted because of doubts over their long-term sustainability. Thus, native coho salmon stocks in California probably have averaged less than 5,000 fish in recent years (Table 4). Many populations in the smaller drainages number less

TABLE 4.—Estimates of coho salmon abundance in California streams that historically contained coho salmon. Streams that are known or believed to currently support coho salmon, and streams for which we found no data on presence or absence of coho salmon were all assumed to support 20 spawners, unless the available data indicated a larger population. Numbers for hatchery populations are the average population from the 1981–1982 spawning season until the latest season (up to 1990–1991) for which data were available. For streams where hatcheries are located, both hatchery and natural-spawning fish are included. An asterisk (*) indicates a high probability that the natural production is by native fish rather than naturalized fish with hatchery ancestry. An S in the hatchery column indicates streams where it was difficult to classify fish as natural spawning or hatchery produced. Supplementation occurs in these streams, but in the Noyo River most of the production is probably natural, and in Scott Creek (south of San Francisco Bay) only returning naturalized fish are spawned.

| | | | Numbers of fish | | |
|---|---|---|---|---|---|
| Location | System | Number of streams | Native and naturalized | Hatchery | Total |
| Del Norte County | Coastal | 9 | 180* | 0 | 180 |
| | Smith River | 41 | 820* | 0 | 820 |
| | Klamath River | 93 | 1,860 | 16,265[a] | 18,125 |
| Humboldt County | Coastal | 34 | 680* | 0 | 680 |
| | Redwood Creek | 14 | 280 | 525 | 805 |
| | Mad River | 23 | 460 | 366 | 826 |
| | Eel River | 102 | 2,040* | 0 | 2,040 |
| | Mattole River | 38 | 760* | 0 | 760 |
| Mendocino County | Coastal | 22 | 470 | 0 | 470 |
| | Ten Mile River | 8 | 160* | 0 | 160 |
| | Noyo River | 12 | 3,740 | S | 3,740 |
| | Big River | 14 | 280 | 0 | 280 |
| | Navarro River | 15 | 300 | 0 | 300 |
| Sonoma County | Coastal | 9 | 180 | 0 | 180 |
| | Gualala River | 10 | 200 | 0 | 200 |
| | Russian River | 10 | 255 | 332 | 587 |
| Marin County | Coastal | 10 | 435 | 0 | 435 |
| San Francisco Bay[b] | Coastal | 7 | 0 | 0 | 0 |
| South of San Francisco Bay | Coastal | 5 | 140 | S | 140 |
| Total | | 469 | 13,240[c] | 17,488 | 30,728 |
| Percentage of total | | | 43% | 57% | |
| Subtotal for native fish | | | 4,640 | | |
| Subtotal for non-hatchery streams[d] | | | 10,385 | | |

[a] Number includes fish from Iron Gate Hatchery and Trinity Hatchery. Also included are hatchery fish spawning below Trinity Hatchery, based on the assumption that only 60% of returning hatchery fish actually enter the hatchery, with the remainder spawning outside (Rogers 1973).

[b] Includes Sacramento River and other tributaries to the Bay.

[c] Includes 4,640 fish of wild ancestry (35% of nonhatchery fish).

[d] Excludes Prairie Creek and the Klamath, Mad, and Russian Rivers, but not the Noyo River, where fish were difficult to classify.

than 100 fish—probably lower than the population size necessary to preserve genetic integrity of the stock and to ensure its survival against random environmental disasters. The abundance of naturally spawning coho salmon, especially native stocks, clearly is at a low level, and the trends indicate coho salmon numbers are continuing to decline statewide. Coho salmon in California (including hatchery stocks) presently are less than 6% of their abundance during the 1940s and probably have declined at least 70% in numbers since the 1960s.

Naturally spawning coho salmon stocks on the Oregon coast also appear to be numerically depressed. For 1990, the standard index of coho salmon abundance used by the Oregon Department of Fish and Wildlife (ODFW) was the third lowest value recorded in the 41-year observation period (Cooney and Jacobs 1992). The estimated spawning escapement for standard sampling stream segments in 1990 averaged 10 fish/km (the lowest since 1983), compared with the 10-year average since 1981 of 19 fish/km (Cooney and Jacobs 1992). The total stock size of naturally spawning coho salmon in Oregon coastal river and lake basins was estimated at 103,964 fish in 1990, which was 52% of the 200,000-fish spawning escapement goal set by the Pacific Fishery Management Council

(PFMC) (Cooney and Jacobs 1992), and the estimated escapement for 1991 was 109,000 fish, compared with the PFMC goal of 161,000 (L. Osis, App.). However, even these escapement values may seriously overstate the true spawning numbers. Based on a new estimation method (stratified random sampling) employed by ODFW (Jacobs and Cooney 1991), the number of spawners for the Oregon coast was estimated to be closer to 20,000 in 1990 and 33,000 in 1991 (Engelmeyer 1992, App.).

## Causes of the Decline

The causes of coho salmon decline in California are multiple and interacting but can be divided into four broad categories: (1) loss of stream habitat, (2) interactions with hatchery fish, which can produce a loss of genetic integrity, and increases in competition and disease, (3) overexploitation, and (4) climatic factors, such as oceanic conditions and precipitation.

### *Loss of Stream Habitat*

Loss of stream habitat is widely acknowledged as the single biggest cause of declines of anadromous salmonids in general in the Pacific Northwest and of coho salmon in particular (Nehlson et al. 1991; Reeves and Sedell 1992; Wilderness Society 1993). In California, some of the loss of coho salmon habitat has been the result of large dams that eliminate access to upstream spawning areas and reduce flows in downstream areas (e.g., Klamath, Mad, and Russian Rivers). However, most of the habitat loss has been the result of watershed disturbances associated with urbanization, logging, agriculture, mining, and other human activities. Such activities are associated with severe loss of the habitat complexity that is characteristic of productive coho salmon streams (Sandercock 1991), especially reduction in the amount of large woody debris and the sedimentation of spawning and rearing areas.

The loss of coho salmon habitat has been cumulative over at least the past 50 years. By 1956, it was estimated that over 1,600 km of streams in California had been lost as important fish habitat (Fisk et al. 1966). Damage was particularly severe in coastal streams affected by logging. For example, 84 of 167 km of potential coho salmon habitat in the Garcia River (Mendocino County) and 110 of 135 km of habitat in Redwood Creek (Humboldt County) were reported as moderately to severely damaged by ongoing logging practices (Fisk et al. 1966). Habitat damage was attributed to erosion and land slippage that had been exacerbated by the construction of logging roads and skid trails on steep slopes and by the removal of vegetative ground cover. Similarly, a 1973 survey of Ten Mile, Noyo, Big, and Gualala Rivers revealed that potential coho salmon habitat in all those rivers had been negatively affected by logging, road building, grazing, or urbanization (USBLM 1973, App.). A review of the effects of logging on salmonids in California streams indicated that logging severely reduced the number of coho salmon smolts emigrating out of a watershed (Burns 1972). The smolts also emigrated at much smaller sizes than had been noted for unlogged streams, presumably due to stress associated with physical changes in the habitat (Graves and Burns 1970).

### *Interactions with Hatchery Fish*

*Loss of genetic integrity.*—The amount of interbreeding of nonnative hatchery strains and of wild native strains of coho salmon is poorly understood (Steward and Bjorm 1990; Hindar et al. 1991). In California, determination of the amount of interbreeding is particularly difficult because populations of native coho salmon within the state do not appear to be strongly differentiated genetically (Bartley et al. 1992). This pattern is consistent with other regional studies of coho salmon (Hjort and Schreck 1982; Wehrhahn and Powell 1987). However, there is obviously genetic differentiation between coho salmon stocks from different geographical regions, as indicated by protein variation (Utter et al. 1970; Hjort and Schreck 1982; Wehrhahn and Powell 1987; Milner, in press), life history and morphology (Hjort and Schreck 1982; Taylor and McPhail 1985a), differential juvenile survival and growth in seawater (Murray et al. 1993), heritable differences in swimming performance (Taylor and McPhail 1985b), and relative survival in the wild (McIntyre 1984). Genetic differences between coho salmon stocks from different streams also have been observed for agonistic behavior (Rosenau and McPhail 1987), susceptibility to a myxosporean disease (Hemmingsen et al. 1986), transferrin genotype (Utter et al. 1970), and resistance to bacterial kidney disease (Winter et al. 1980). Bartley et al. (1992) observed several differences between California coho salmon and more northern populations in the frequency and occurrence of alleles at several loci, and Milner (in press) was able to differentiate Klamath River coho salmon from coho salmon of more northern regions based on allozyme data. It is likely that the full extent of genetic differentiation among coho salmon populations has yet to be fully determined, given the considerable adaptive variation in traits observed between local stocks of other salmon species (Ricker 1972; Taylor 1991; Clarke et al. 1992).

Nevertheless, genetic studies on coho salmon throughout their range indicate that overall levels of variability are low compared with other Pacific salmon and anadromous trout (Utter et al. 1980; Wehrhahn and Powell 1987; Bartley et al. 1992; Milner, in press). Although we cannot be certain of the reasons for this low variability, reduced genetic variation is a well-recognized consequence of small population sizes (Meffe 1986; Steward and Bjornn 1990). It is clear that coho salmon populations in some geographical areas experienced extreme depletion in the past (Johnson et al. 1991), and many are currently in population bottlenecks, particularly in California.

Bartley et al. (1992) used protein electrophoresis to study the genetic structure of 27 populations of coho salmon from throughout California. Allozyme variation occurred at 23 of 45 loci (51%), but much of the variation was due to rare alleles (frequency <5%) present in only a few samples. Of 39 variant alleles, 27 (69%) occurred at three or fewer locations, and the distribution of these alleles did not follow any particular geographic pattern. The average level of gene flow between California populations (*Nm*) was 1.3 individuals per population per generation; this level is high from an evolutionary perspective but low in terms of the actual number of individuals being exchanged between populations (Bartley et al. 1992). Thus, gene flow among California coho salmon populations is lower than that reported for local populations of British Columbia coho salmon ($Nm = 5.8 \pm 1.2$; Wehrhahn and Powell 1987), but comparable to that for chinook salmon ($Nm = 1.16$) and coastal rainbow trout *Oncorhynchus mykiss* ($Nm \geq 1.7$) in California (Berg and Gall 1988; Bartley and Gall 1990).

Bartley et al. (1992) noted that transplants of different stocks within California may have obscured whatever genetic differentiation formerly existed among them and that, in addition, many streams have been planted with coho salmon from Oregon or Washington stocks. Possible effects of such interbreeding include disruption of locally adapted gene complexes, swamping and homogenization of native gene pools, and transmittal of nonadaptive traits from hatchery stocks to wild (native) stocks. Indirect genetic changes in wild fish are also possible, resulting from the altered environment or from processes, such as genetic drift and inbreeding, that accompany reduced population sizes caused by the presence of hatchery fish (Steward and Bjornn 1990; Krueger and May 1991; Waples 1991). What is definitely known, however, is that the long history of stocking imported coho salmon strains in the lower Columbia River system has essentially resulted in the genetic extinction of native coho salmon runs in that system (Johnson et al. 1991).

The reasons for such extinctions are fairly well understood (Fleming and Gross 1989; Skaala et al. 1990; Steward and Bjornn 1990; Waples 1990a, 1990b, 1991; Waples and Teel 1990). Large differences in genetic structure of native and hatchery stocks can potentially lead to lower survival of subsequent hybrid generations compared with pure wild fish (Steward and Bjornn 1990; Hindar et al. 1991). Even the simple homogenization of local stocks by an influx of genes from hatchery fish may be detrimental in the long run. Such homogenization might reduce between-population genetic diversity and lead to decreased overall productivity and increased vulnerability to local extirpation by unpredictable environmental changes (Waples 1991). Obversely, supplementation with hatchery fish may have positive effects on small wild stocks that already have lost, or will soon lose, much of their genetic variability (Steward and Bjornn 1990). For example, Bartley et al. (1992) noted that, of the two southernmost runs of coho salmon, Waddell Creek fish had the highest level of heterozygosity (0.05, based on 10 individuals) for any California coho salmon population, presumably as the result of interbreeding with imported stocks. In contrast, nearby Scott Creek, which has not been planted with imported stocks, had the lowest heterozygosity (0.0). In the long run, the Waddell Creek population should have a greater probability of survival because the increased heterozygosity should improve its ability to adapt to changing environmental conditions.

Despite these potentially significant genetic consequences of stock supplementation, Steward and Bjornn (1990) concluded that there was as yet no conclusive evidence that hatchery stocks caused actual genetic harm (or benefit) to native populations of Pacific salmonids. However, Skaala et al. (1990) and Hindar et al. (1991) cited examples where there has been introgression of hatchery genotypes into native salmonid stocks, in spite of lower survival or reproductive success of hatchery fish (see also Johnson et al. 1991), and in some instances hatchery (or farmed) fish composed significant fractions of in-river populations (Hindar et al. 1991). The likelihood of detrimental genetic repercussions on native stocks is great enough to have led to explicit recommendations regarding the use of hatchery supplementation in salmonid management in the Pacific Northwest (Steward and Bjornn 1990; Hindar et al. 1991; Waples 1991).

An additional, and largely unexpected, genetic problem has been the hybridization of coho salmon with chinook salmon in the Klamath River as the result of hatchery practices and the crowding together of the two species in limited spawning habitat below a dam (Bartley et al. 1990). The significance of such hybridization is not yet known, but Hedrick et al. (1987) speculate that gene transfer between the species may increase susceptibility of coho salmon to diseases to which they are now resistant.

*Competition with hatchery stocks.*—Introduction of hatchery-raised fish into the natural environment can result in competition between hatchery and native fish. For example, release of hatchery presmolts in Oregon streams reduced the density of native juvenile coho salmon by 40–50%, with a subsequent reduction in adult returns (Miller et al. 1990). Similarly, Nickelson et al. (1986) observed reductions in density of native coho salmon juveniles in streams previously stocked with presmolts, and returning spawners in subsequent years showed a shift toward an earlier spawning time, which is indicative of hatchery fish. There are several possible mechanisms leading to the observed net losses of native juveniles. Juvenile coho salmon are territorial (Shapovalov and Taft 1954), and the larger hatchery fish can displace smaller native fish (Nickelson et al. 1986). Fish with territories have an energetic advantage over those lacking a territory (Puckett and Dill 1985). Hungry fish are less responsive to predators, so mortality at high densities would be higher (Dill and Fraser 1984), especially for displaced native fish. At high densities, growth of coho salmon is depressed through intraspecific competition for resources, and mortality is increased (Fraser 1969). Shapovalov and Taft (1954) noted an inverse correlation between the number of downstream migrants and adult returns, implying that in years when intraspecific competition is low, downstream migrants are better able to survive ocean life. Also, Steward and Bjornn (1990) cited studies showing that survival to adulthood of hatchery-produced coho salmon and other salmon is positively related to their size at release, which further suggests that competition (when it affects juvenile size) can affect production of adults.

Competition among adults for spawning sites can occur. When native stocks are small and hatchery supplementation occurs, hatchery fish may outnumber native fish and monopolize the available spawning habitat. The negative effects of such competition can be magnified when naturally spawning hatchery stocks have lower spawning success than native fish (Fleming and Gross 1992). Hatchery stocks also may produce fewer smolts and returning adults (Steward and Bjornn 1990; Hindar et al. 1991).

*Disease.*—The transmission of diseases from hatchery to native stocks of coho salmon, or even between salmon species (Hedrick et al. 1987), is potentially a serious problem for wild coho salmon. However, the effects of introduced diseases on native stocks are not known. Documented cases of disease introductions in North America from stocked or escaped salmonids are uncommon (Krueger and May 1991). Steward and Bjornn (1990) likewise could find little evidence for the importance of transmission of disease from hatchery to native stocks, primarily because little work has been done, but they concluded that the full impact of disease on supplemented stocks is probably underestimated. The protozoan *Ceratomyxa shasta* occurs in the lower Columbia River, where it has caused large losses in hatcheries, but not elsewhere on the Oregon coast (Johnson et al. 1991); the lower resistance of some coastal stocks to this parasite has been experimentally shown to be heritable (Hemmingsen et al. 1986). Viral hemorrhagic septicemia (VHS) has been reported from hatchery coho salmon in Washington, and there are a number of other virulent diseases that affect salmonids (e.g., bacterial kidney disease, infectious hematopoietic necrosis, herpes virus infections, infectious pancreatic necrosis) with the potential for transmission between hatchery and native stocks (Håstein and Lindstad 1991).

*Overexploitation*

Overfishing is often mentioned as a major factor contributing to the decline of coho salmon, but its effects are poorly known because catches of wild and hatchery fish are rarely separated (Steward and Bjornn 1990). Hatchery production can indirectly cause severe depletion of native stocks by encouraging intensified harvest or natural predation (Hindar et al. 1991). Continued harvest of depleted wild stocks may prevent recovery and reduce genetic variability or increase hybridization rates with hatchery fish. Coho salmon in California are particularly vulnerable to overfishing because most females have a 3-year life span (although small numbers of 4-and 5-year-olds have been observed in Mendocino County spawning streams; J. Nielsen, App.). California coho salmon populations, therefore, lack the resilience to withstand excessive harvest compared with other salmonid species (e.g., chum salmon *Oncorhynchus keta* or chinook salmon) or even some coho salmon stocks in more northern areas (Sandercock 1991), which have significant numbers of spawners returning over a wider range of ages. The southernmost coho salmon populations in Waddell and Scott Creeks each have a 3-year cycle (J. Smith, App.); a strong run occurs only every third year, and decimation of the spawning stock by overharvest during a single year could extirpate either or both of those populations.

*Climatic factors*

*Oceanic conditions.*—The decline of coho salmon in California has probably been exacerbated by natural climatic events. A general warming trend in the northeast Pacific during 1976–1983 coincides with an abrupt drop in production of coho salmon adults within the Oregon Production Area (Washington–northern California coast) and also with elevated sea-surface temperatures and reduced biological productivity in the California Current (Nickelson 1986; Lawson 1993). In addition, El Niño events have made oceanic conditions less favorable for coho salmon survival. The 1982–1983 El Niño was the largest warming event on the North American Pacific Coast in this century, and it had major impacts on primary and secondary productivity and on coho salmon abundance off Oregon and Washington (Pearcy 1992). Coho salmon growth and survival were both affected to an unprecedented degree; perhaps 58% of the predicted number of coho salmon adults off Oregon died during their last year in the ocean (Pearcy 1992). Significant statistical relationships of coho salmon abundance and ocean survival rate with sea-surface temperature and strength of coastal upwelling have been identified for the Oregon Production Area (Scarnecchia 1981; Nickelson 1986; Pearcy 1992). Similarly, there is a positive correlation between upwelling and the survival and early growth of coho salmon off northwest Vancouver Island, British Columbia (Holtby et al. 1990). It has been suggested that upwelling affects coho salmon survival by influencing coastal productivity and by transporting coho salmon smolts offshore to areas where there are lower levels of predation (Nickelson 1986). Upwelling was weak off the Oregon coast during the period 1976–1981, and the winds that drive upwelling off northern California were reduced between 1975 and 1988 (Pearcy 1992). The time of transition between winter downwelling and spring upwelling conditions also may affect smolt survival, and on the Oregon coast this transition time occurred earlier during the years of high coho salmon survival before 1976 than in the low-survival years that followed (Pearcy 1992). It is likely that unfavorable ocean conditions may persist for some time (Ware and Thompson 1991), which increases the importance of improving coho salmon survival rates in freshwater (Lawson 1993).

*Precipitation.*—The droughts of 1976–1977 and 1986–1992 have clearly made conditions worse in many streams, some of which completely dried up. On the other hand, heavy precipitation produces stream scouring that can destroy both redds and stream habitat for coho salmon. The effects of the record 1964 floods on north coast streams can still be seen in the streambeds and in the reduced amount of high-quality habitat (W. Jones, App.), because natural recovery has been occurring very slowly in some drainages (Haskins 1982; Lisle 1982). Coho salmon in California undoubtedly experienced catastrophic natural events in the distant past—perhaps worse than those we report here—but they were not simultaneously confronted with widespread human-related degradation of their spawning streams (e.g., water diversions and increased erosion).

## Management

Most of the problems facing California coho salmon populations have been well recognized for many years. One reason that little has been done to remedy the situation seems to be that historically coho salmon have been of secondary importance to California fisheries. They presently rank below chinook salmon in the commercial fishery and below both chinook salmon and steelhead in the sport fishery. Coho salmon also are a very diffuse resource, using a wide range of streams along the coast. As a result, management efforts have focused on chinook salmon and steelhead, apparently with the assumption that coho salmon would be aided incidentally. Their wide distribution over many small coastal streams and their relatively short life span (3 years) make California coho salmon more vulnerable to severe declines during drought years and, therefore, difficult to manage in a consistent manner. Another problem is that juvenile coho salmon require deep, cold, pool habitats for high survival. Inadequate protection of watersheds from the effects of logging, grazing, and urbanization has resulted in increased water temperatures, the loss of pools through sedimentation, and the removal of large woody debris needed for cover and pool formation. Once these changes have occurred, natural recovery can take many years, and stream rehabilitation projects are expensive and time consuming.

In 1988 the California State Legislature passed the Salmon, Steelhead Trout and Anadromous Fisheries Program Act (originally Senate Bill 2261) that directed the California Department of Fish and Game to double the populations of anadromous species, including coho salmon, by the end of the century. The lack of accurate census data has made it difficult to set specific numerical goals for recovery, but efforts are under way to increase populations as much as possible (T. Curtis, App.). The emphasis of these efforts is on the restoration and improvement of habitat. Hatchery production will continue at current levels, and private cooperative fish-rearing projects will be encouraged where short-term, localized enhancement efforts are appropriate. Specific goals for the years 1992–1996 include (T. Curtis, App.):

(1) an inventory of streams within the historic range of coho salmon to determine the present distribution and abundance of the species and to assess the condition of the habitat;
(2) a set of priorities for the improvement of coho salmon streams on the basis of their potential for improvement;
(3) the identification of streams with the highest potential for restoration and enhancement by the Department of Fish and Game and of streams suitable for restoration and enhancement by private organizations;
(4) a set of priorities for restocking streams affected by droughts to speed recovery of the population;
(5) the funding and completion of habitat restoration projects;
(6) the restocking of coho salmon streams according to priorities and in keeping with the department's genetic stock management policy.

We would add to this outline a strong recommendation that hatchery production be carried out conservatively in order to minimize the negative impacts on native stocks (Steward and Bjornn 1990) and that efforts be made to increase the use of native coho salmon strains in hatcheries. We would also recommend a ban on all fisheries for coho salmon until it can be demonstrated that significant recovery is occurring. Furthermore, the addition of a monitoring component seems necessary, for without a baseline it will be difficult to determine the success or failure of enhancement and restoration efforts. A monitoring program should include: (1) annual population surveys of both juvenile and spawner abundance in selected streams throughout the range of coho salmon, including streams both with and without ongoing management efforts; (2) quick assessments of all historic coho salmon streams in the state at least once every 5 years to rate stream conditions and to determine if juveniles are present; (3) further genetic analysis of all stocks; (4) the marking of all hatchery fish; and (5) evaluation of wild and hatchery populations for the presence of debilitating diseases.

There should be greater coordination between the different agencies and organizations concerned with coho salmon, both within California and elsewhere, in order to prevent duplication of effort and failure. We urge that restoration goals be focused on native coho salmon, and that hatchery stocks not be counted toward whatever numerical goals are set.

Coho salmon statewide qualify for listing as a threatened species under state law, and certain populations may qualify under federal law for threatened or endangered status. The southernmost coho salmon populations in Waddell and Scott Creeks warrant special attention and qualify for federal listing as endangered. These populations are extremely small and could be extirpated even by random demographic processes before a full evaluation of their biological distinctiveness can be made. The severity of the coho salmon decline in California, as well as in Oregon and Washington, has led to the filing (October 1993) of a petition to the National Marine Fisheries Service to list the coho salmon as a threatened species under the federal Endangered Species Act.

## Conclusion

Despite the paucity of detailed quantitative data on coho salmon stocks in California, it is clear from the information available that coho salmon populations statewide have undergone a dramatic decline from historic levels. As a specific local example, the South Fork Eel River historically supported a run of 5,000–25,000 coho salmon (Murphy 1952) but now supports, at best, a run of about 1,300. Our abundance estimates are optimistic because we assumed coho salmon still occur in streams for which there are no current data; it is likely, therefore, that we have underestimated the magnitude of the decline.

The decline of coho salmon in California has resulted from the combination of environmental degradation, climatic and ocean factors, and lack of comprehensive management focused on this species. The absence of solid, long-term data on the status of coho salmon populations is a reflection of this lack of focused management. Of particular concern is the fact that the decline has continued despite substantial hatchery programs to raise coho salmon at five facilities in California and despite several private supplementation projects. Coho salmon, with their 1-year freshwater residency as juveniles, are highly suited for hatchery augmentation of natural populations. The failure of these hatchery programs to halt the decline is strong testimony that more effective management and conservation efforts must be pursued. Indeed, hatchery practices probably have contributed to the decline of native stocks. The situation demands immediate action, using the protection available under state and federal endangered species laws, if necessary. Whether or not coho salmon are formally listed under these laws, every native coho salmon population in California should be treated as a threatened species as part of a statewide restoration effort.

## Acknowledgments

We thank the many interested parties who contributed ideas, observations, manuscripts, and unpublished data. Funding in support of this work was provided by the National Marine Fisheries Service; the Hewlett Foundation, through the Public Service Research and Dissemination Program at the University of California, Davis; and the Mead Foundation.

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## Appendix: Unpublished Documents and Personal Communications

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Cronin, Leo. Trout Unlimited, Corte Madera Lagunitas Creek Restoration, Fairfax, California.

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Flosi, Gary. California Department Fish and Game, Weott, California.

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Kisanuki, Tom. U.S. Fish and Wildlife Service, Arcata, California.

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Nielsen, Jennifer. Hopkins Marine Laboratory, Stanford University, Department of Biological Sciences, Pacific Grove, California.

Osis, Laimons. Oregon Department of Fish and Wildlife, South Beach, Oregon.

Petersen, Gary. The Mattole Restoration Council, Petrolia, California.

Poe, Sidney. California Department of Fish and Game, Yountville, California.

Preston, Larry. California Department of Fish and Game, Eureka, California.

Sanders, Steven. Prairie Creek Fish Hatchery, Orick, California.

Smith, Jerry J. Department of Biology, California State University, San Jose, California.

Streig, Dave. Monterey Bay Salmon and Trout Project, 324 Swanton Road, Davenport, California.

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