SOUTHERN OREGON-NORTHERN CALIFORNIA COAST COHO SALMON
Oncorhynchus kisutch

Critical Concern. Status Score = 1.7 out of 5.0. Critically vulnerable to extinction as wild fish within next 50-100 years. There has likely been 95% or more decline in numbers since the 1960s in California.

Description: Spawning adult coho salmon are 55-80 cm FL (35-45 cm FL for jacks) and weigh 3-6 kg. Meristic counts are as follows: 9-12 dorsal fin rays, 12-17 anal fin rays, 13-16 pectoral fin rays, 9-11 pelvic fin rays, 121-148 scales in the lateral line and 11-15 branchiostegal rays on either side of the jaw. Gill rakers are rough and widely spaced, with 12-16 on the lower half of the first arch. Spawning adults are dark green on the head and back, maroon on the sides, and grey to black on the belly. Females are paler than males. Spawning males are characterized by a bright red lateral stripe, hooked jaw, and slightly humped back. Both sexes have small black spots on the back, dorsal fin, and upper lobe of the caudal fin. The adipose fin is grey and finely speckled, while the paired fins lack spots. The gums of the lower jaw are grey, except the upper area at the base of the teeth, which is generally white. Parr have 8-12 narrow parr marks centered along the lateral line and are distinguished by the large sickle-shaped anal fin with a white leading edge, bordered on the inside by a black line. Southern Oregon-Northern California Coast coho salmon (SONCC coho) are an Evolutionary Significant Unit (ESU) that can only be distinguished from other coho ESUs by genetic means.

Taxonomic Relationships: Coho salmon are most closely related to Chinook salmon among the six Pacific salmon species (including the cherry salmon, *O. masou*, of Asia) and have hybridized with them in hatcheries (Moyle 2002). Populations in California are the southernmost for the species. As discussed in Moyle (2002), spawning coho salmon demonstrate strong fidelity to natal streams, thus showing some local differentiation, but there is enough movement of fish between streams so that genetically distinct groups occur only over fairly wide areas, separated by natural features that reduce genetic exchange. In California, Punta Gorda (Humboldt County) is the separation point between California's two coho ESUs, the Southern Oregon-Northern California Coast ESU and the Central California Coast ESU. Punta Gorda is not only a prominent feature that affects local ocean currents but it marks the northern end of a long stretch of steep coast line where the streams are too small and precipitous to support coho salmon. The Mattole River at Punta Gorda is home to the southernmost SONCC coho population.

The genetics of coho salmon in California were not well studied until relatively recently (Bucklin et al. 2007, Gilbert-Horvath et al. 2016). The most recent, detailed genetic study of California coho salmon populations, using microsatellite DNA markers, is that of Gilbert-Horvath et al. (2016) who confirmed the validity of the SONCC and CCC coho ESUs. They also discovered that historical widespread planting of coho salmon from non-natal stocks had minimal influence on the genetic integrity of local populations. These results demonstrated that coho from each stream sampled were distinct, yet more closely related to coho from nearby streams than to those in streams further away. Bucklin et al. (2007, p. 40) concluded the following:

> "Our study implicates population fragmentation, genetic drift, and isolation by distance, owing to very low levels of migration, as the major evolutionary forces shaping genetic

diversity within and among extant California coho populations… [Our] resolution of smaller population units suggests that they are experiencing rapid genetic drift, inbreeding, and the associated deleterious effects of inbreeding depression. Accordingly management and rehabilitation of these populations is needed at much smaller scales than current ESU designations."

Life History: The life history of coho salmon in California was first documented in the classic studies in Waddell Creek by Shapovalov and Taft (1954). Coho life history throughout their range is summarized in Sandercock (1991), while Baker and Reynolds (1986), Moyle (2002) and CDFG (2002, 2004, 2015) reviewed their biology in California. Because of the availability of these detailed reviews, our account will be brief and provide references mainly to studies on SONCC populations. A critical element of their biology and conservation is that coho salmon use at least some part of their spawning streams on a year-round basis (Table 1).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult migration	xx								x	xx	XX	XX
Spawning	XX	xx								x	XX	XX
Incubation	XX	XX	xx							x	XX	XX
Alevin/Fry		xx	XX	XX	XX	x						
Juvenile rearing	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Out-migration	x	x	xx	XX	XX	XX	xx					x
Estuary rearing			xx	XX	XX	xx						

Table 1. Timing of use of different life stages of California coho salmon in natal streams. Modified from CDFG (2002) and S. Ricker, CDFW, pers. comm. 2017. X = major use, x = minor use; each 'x' = ca. 2 weeks.

Coho salmon in California return to their natal streams to spawn after spending 6-18 months in the ocean. Typically, some fraction of males, called "jacks," return after one growing season in the ocean (at age two years), but most males and virtually all females return after two growing seasons in the ocean (typically age three). The fairly strict three-year life cycle is reflected in numbers of spawners in many streams, which have highs and lows at three-year intervals. However, the number of jacks in proportion to the number of hooknose (three year old) males in a spawning population is determined in part by their differential growth and survival as juveniles under different freshwater conditions (Watters et al. 2003, Koseki and Fleming 2007). Recent studies indicate that juveniles can emigrate as young-of-year, one year olds, or two year olds, indicating more flexibility in life history than previously perceived for California populations (Gallagher et al. 2012).

Spawning migrations begin after increased stream flows in fall and early winter allow the fish to move into coastal rivers. Upstream migration usually occurs when stream flows are either rising or falling. The timing of their return varies considerably, but in general coho salmon return earlier in the season in more northern areas and in larger river systems. In the Klamath River, SONCC coho salmon run between September and late-December, peaking in October-November. Spawning occurs in November and December (USFWS 1979). In the Eel River, SONCC coho run 4-6 weeks later than in the Klamath River; arrival in the upper reaches peaks in November-December. In smaller coastal streams coho generally return during mid-November through mid-January. In some years, spawning can occur as late as March, especially if stream flows are low or access is limited because of drought. In smaller coastal streams (such as Redwood Creek and Mattole River), the peak coho runs are in late October-November, or are determined by the first rain event afterward, which increases flow sufficiently to break bars at the mouth of estuaries, permitting access to the stream (M. Sparkman, CDFW, pers. comm. 2017). Coho salmon migrate up and spawn mainly in low-gradient streams that flow directly into the ocean or in tributaries of large rivers.

Females choose redd sites where gravel is mixed in size and sufficiently coarse so that it is easy to move by digging and facilitates subsurface flow around the buried embryos. The best redd sites are often at the head of a riffle, just below a pool, where the water changes from a smooth to a turbulent flow, is deep enough to cover the female when she is digging (ca. 20-75 cm), and typically has high intragravel flow. Each female builds a series of redds, moving upstream as she does so, and deposits a few hundred eggs in each. A dominant male accompanies a female during spawning, but one or more subordinate males and jacks also may engage in spawning. Spawning can take about a week to complete, with females depositing 1,400-7,000 eggs; bigger females produce more eggs. Both males and females die after spawning, although the female may guard her redd for up to two weeks (Hassler 1987).

Embryos hatch after 8-12 weeks of incubation, the time depending on both temperature (colder temperatures increase incubation time) and on inherited adaptations to local conditions. Hatchlings (alevins) remain in the gravel for 4-10 weeks, until their yolk sacs have been absorbed. Under optimum conditions, mortality during this period may be as low as 10 percent; but under high scouring flows or heavy siltation, mortality can reach 100 percent. Upon emerging, fry (30-35 mm TL) seek out shallow water, usually along stream margins. In the Klamath River watershed, emergence of fry starts in mid-February and peaks in March and early April (May in the Shasta River), although apparently fry have been found into July (CDFW, unpubl. data, C. Bean, CDFW, pers. comm. 2017). After moving into shallow water, fry form loose aggregations, but as they grow bigger (50-60 mm TL), most parr set up feeding territories. Behavior of parr, however, shows considerable variation (Nielsen 1992a, b). In smaller streams, as parr continue to grow they move into increasingly deeper water until by mid-summer, they are in the deepest pools available, often swimming in small shoals. If temperatures become high enough to be stressful, individuals will seek cool water refuges, usually where cooler subsurface flows upwell through the gravel. In the Klamath River, SONCC juveniles seek cool water refuges at the mouths of tributary streams in early summer but these areas are usually too warm or crowded with other salmonids to support them by late summer (NRC 2004). At least some of these fish, however, may migrate upstream into coldwater tributaries if access is present. Growth rates slow down at this stage, possibly due to lack of food or because the fish reduce feeding as a result of warmer temperatures (see Box 1).

During December-February, winter rains result in increased stream flows and by March, following peak flows, fish again feed heavily on insects and crustaceans and grow rapidly. During winter, refuges from high, turbid flows are required for survival. Typically, these refuges are side channels, complex masses of large woody debris, and small, clear tributaries. A variable, but substantial, portion of coho parr emigrate to stream-estuary ecotones to exploit the rapid growth potential of these habitats (Wallace et al. 2015). Towards the end of March and the beginning of April, juvenile coho begin to migrate downstream and into the ocean, though a small fraction of juvenile coho smolts may emigrate to the ocean in December-February based on limited occurrences in screw trap data (S. Ricker, CDFW, pers. comm. 2017). Outmigration in California streams typically peaks in April if conditions are favorable (B. Spence, NMFS, pers. comm. 2008) although Shapovalov and Taft (1954) found that coho emigration from Waddell Creek peaked in mid-May. Migratory behavior is stimulated by a variety of factors: rising or falling stream flows, size of fish, day length, water temperature, food densities, and dissolved oxygen levels and available rearing habitat. At this point, outmigrants are typically about one year old and are 10-13 cm FL. Larger fish (ca. 20 cm FL) have usually spent two years rearing in the stream. In Prairie Creek (Humboldt Co.), over 20% of emigrating juvenile SONCC coho are two years old (Bell and Duffy 2007), though this proportion can vary widely from year to year. Ransom (2007) found the portion of age-2+ coho to range from 0-30% in Prairie Creek. According to Brakensiek and Hankin (2007), age-2 fish in Prairie Creek were smaller in length during their first year in freshwater than other fish in the same cohort and larger the next year than fish of the subsequent year class. Large numbers of age 2+ coho were observed in 2015 in tributaries to Humboldt Bay, possibly as a result of poor rearing conditions from drought (M. Wallace, CDFW, pers. comm. 2017). Some juveniles also emigrate from streams as young-of-year (Gallagher et al. 2012), and move in small schools of about 10-50 individuals. Parr marks are still prominent in the early migrants, but the later migrants are silvery, having transformed into smolts.

All juveniles leaving streams have to spend some time in estuaries, a habitat that has been underappreciated for its importance in California. Wallace et al. (2015) found estuaries in Humboldt Bay, including those in which no coho spawned, to be a major rearing habitat for juvenile coho. They identified three life history patterns:

- Juveniles aged 1+ that had reared in streams and largely migrated through estuaries in spring.
- Yearling fish that moved in during the first high-flow event of the fall and reared in non-natal estuaries and off-channel habitat during winter and spring.
- Young of year that moved downstream in spring and reared in the main channels of the larger estuaries in summer and fall.

The importance of these findings is that estuarine habitat was used by SONCC coho year-round, and that different ages and sizes of coho used different parts of the estuarine environment in different ways. Juveniles using the estuarine habitats were generally larger at age than those that remained in streams to rear, and fed largely on amphipods, small crustaceans, and shrimp (R. Taylor, R. Taylor Associates, pers. comm. 2016). Young-of-the-year (YOY) found in stream-estuary ecotones exhibited growth rates as high as .7 mm/day, while yearling fish could grow as much as 1.0 mm/day (Wallace et al. 2015). The increased food availability and temperatures, coupled with lower bioenergetic demands in low-gradient habitat, most likely increase growth rates (Wallace et al. 2015).

After entering the ocean, immature salmon initially remain in inshore waters close to parent streams. They gradually move northward, staying over the continental shelf. Coho salmon can range widely in the north Pacific, but movements of California fish are poorly known. Most coho caught off California in ocean fisheries were reared in coastal Oregon streams (natural and hatcheries). In 1990, for instance, 112,600 coho were caught in commercial and recreational ocean fisheries, which may greatly exceed the present production capability of California populations alone (A. Baracco, CDFW, pers. comm. 1994). Oceanic coho tend to school together, with fish from different regions found mixing in the same general areas. Adult coho salmon are primarily piscivores, but shrimp, crabs, and other pelagic invertebrates can be important food in some areas.

Habitat Requirements: This section is based on Moyle (2002) and CDFG (2002, 2004). For a useful tabular summary of coho habitat requirements see CDFG (2004, p. 222). In general, coho salmon respond to multiple habitat cues at any given time. Bioenergetics is the key to understanding why coho juveniles choose a particular combination of habitat characteristics and how habitat affects growth and survival.

Adult coho salmon move upstream in response changes in stream flows caused by fall storms, especially in small streams when water temperatures < 16°C. However, their presence on occasion in the Lower Klamath River as early as mid-September when flows are low and temperatures are high suggests that other cues are important as well. For example, high turbidity may delay migration even if other conditions are optimal.

Spawning sites are typically at the heads of riffles or tails of pools where there are beds of loose gravel (< 15 cm average diameter) and cover nearby, such as a deep pool or undercut bank or log. Coho salmon redds can be excavated in substrates composed of up to 20 percent fine sediment, but spawning success and fry survival generally are best in very clean gravel (<5 percent fines). Spawning depths are 10-54 cm, with water velocities of 0.2-0.8 m sec-1. Optimal temperatures for development of embryos in the gravel are 4.4-13.3°C, although eggs and alevins can be found in 4.4-21.0°C water. Dissolved oxygen levels should be above 8 mg l^{-1} for eggs and above 4 mg l^{-1} for juveniles.

Juveniles are generally most abundant where there are deep (0.5 to 1+ m), well-shaded pools with plenty of overhead cover; highest densities are typically associated with instream cover such as undercut banks or logs and other woody debris in pools or runs. Optimal summer habitat seems to be pools containing rootwads and boulders in heavily shaded sections of stream, although warmer, more open areas may be used if food is abundant.

Juveniles can move to neighboring streams to rear. Non-natal coho rearing has been documented in the Smith, Klamath, Eel, Russian, Salt, and Elk rivers, as well as Redwood, Freshwater, Jacoby, and Salmon Creeks in California (Wallace et al. 2015). Juveniles have been observed rearing in winter and in spring in watersheds where there is a lack of documented coho spawning, raising the point that spatial habitat usage can vary broadly in a region. For example, juvenile coho were documented in Wood Creek, Martin Slough, and Rocky Gulch (streams without spawning coho), indicating that juveniles either migrated over flooded pasturelands or entered Humboldt Bay to reach suitable rearing habitat in adjacent watersheds (Wallace et al. 2015). It is possible that spawning adults were present but not observed during sampling.

In winter, refuge habitat, especially large wood and complex side channels and off-channel habitat such as alcoves are needed to protect juveniles from being washed away by high flow events (Gallagher et al. 2012, and references therein). Bell (2001) found the habitat with highest site fidelity and survival of juveniles consisted of deep mainstem pools with off-channel refuge, such as alcoves, nearby. Preferred water velocities for juveniles are .09-.46 m/sec, depending on habitat (Gallagher et al. 2012). High turbidity is detrimental to emergence, feeding and growth of young coho.

Juvenile coho require cold water during rearing, generally regarded as less than 18-20°C. At the southern edge of their range in the Mattole River watershed, for example, SONCC coho were absent from streams that had maximum weekly maximum temperatures (MWMT) exceeding 18°C, but were consistently found in streams in which temperatures did not exceed MWMT of 16.3°C (Welsh et al. 2001). Stenhouse et al. (2012), based on a literature review, concluded that:

- Optimal temperatures for growth, swimming performance, and disease resistance were

10-15.5°C.

- Suboptimal temperatures were 15.5-20.3°C.
- Temperatures greater than 20.3°C were detrimental or lethal.

In their review, Stenhouse et al. (2012) discounted laboratory studies that showed rapid growth of coho at temperatures higher than 15.5°C, although juveniles have been shown to grow under stream temperatures regularly exceeding 24.5°C, up to 29°C, when conditions are appropriate in the wild (Bisson et al. 1988; Moyle 2002). In the temperature gradient of the Shasta River, where food is essentially unlimited, caged juvenile coho grew much faster at warmer temperatures (MWMTs: 19.1-21.8 °C) than at cold temperatures (MWMTs: 15-16°C) (R. Lusardi, unpubl. data). In contrast, Gallagher et al. (2012) found lowest growth rates in coho in fairly typical oligotrophic forest streams in Mendocino County, when summer temperatures were warmest. In general, optimal conditions for coho (and other fishes) are determined by bioenergetic considerations, not just temperature (Box 1) and are context and watershed specific.

Box 1. Bioenergetics: a key to salmon survival

In the laboratory, most fishes have an 'optimal' temperature range for growth, in which the conversion rate of food to fish flesh is most efficient. For juvenile coho, this range appears to be 12-14°C. The problem is, of course, that stream environments are rarely constant and juvenile coho are often found at higher temperatures. In tributaries to the Mattole River, juvenile SONCC coho were absent from streams where mean weekly maximum temperature exceeded 18°C (Welsh et al. 2001). This suggests that Mattole River fish are persisting mainly where temperatures are close to optimal. Similar observations have been made for SONCC coho in Redwood Creek (Madej et al. 2005). In contrast, Bisson et al. (1988) observed juvenile coho rearing in a Washington stream where maximum weekly temperatures regularly exceeded 20°C and daily maxima sometimes reach 29°C for short periods. This was hypothesized to be possible because (1) coho had essentially unlimited food, (2) there were no competitors or predators present, (3) night-time temperature were cool (often around 12°C) and (4) thermal refuges may have been present (springs, etc.), although there was little evidence of refuge use.

The explanation for this becomes clear if survival and growth of coho is put in terms of an energy budget. Basically, juvenile coho will grow if they ingest more energy than they consume, through activities such as searching for food, avoiding predators, or even resting. Individuals eventually die if they ingest less energy than they use during daily activity. Part of that energetic cost can be increased metabolic rates and stress caused by temperatures higher than optimum. As temperatures increase, so do metabolic rates. In the studies by Bisson et al. (1988), bioenergetic conditions (most likely high availability of food) were adequate to sustain coho at nearly lethal temperatures. A similar phenomenon was documented on the Shasta River in northern California. Here, researchers found that juvenile SONCC coho grew at faster rates under warmer water conditions (~15°-16° C vs. ~19°-22° C), primarily because food resources were extremely abundant (R. Lusardi, pers. comm. 2016). In Mattole River tributaries, where food was not abundant and predators and competitors were common, even moderately high temperatures may be lethal if experienced on a regular basis. The energetic costs of living at higher temperatures are simply more than the fish can sustain.

Distribution:

General. Coho salmon are widely distributed in northern temperate latitudes. In North America, they spawn in coastal streams from California to Alaska. In Asia, they range from northern Japan to the Anadyr River in Russia. In California, they live in streams from Del Norte County on the Oregon border to Santa Cruz County. SONCC coho salmon are found from Cape Blanco in Oregon south to the Mattole River, just north of Punta Gorda. Historically, SONCC coho salmon occupied numerous coastal basins where high quality habitat was located in their lower portions and three large basins where high quality habitat was located both in lower tributaries and in headwaters, while the middle portions of the basins provided little habitat (Williams et al. 2006). In Oregon, south of Cape Blanco, the Rogue River is apparently the only river with a persistent run of coho, although a few coho are observed on occasion in the Chetco and Winchuk rivers and other smaller streams. Most SONCC coho are therefore in California.

NMFS (Williams et al 2006) divided the California populations into five diversity strata, each representing environmentally and ecologically similar regions: Klamath River, Trinity River, Eel River, Central Coastal, and Southern Coastal strata. Among these six strata, the SONCC historically had 14 functionally independent populations, 11 potentially independent populations, and 6 dependent populations (Williams et al 2006). The largest remaining SONCC coho populations in California are in the Klamath, Trinity, Mad, Humboldt Bay, Eel and Mattole drainages, with additional populations in some smaller coastal streams.

Garwood (2012) updated the distribution of California coho salmon of Brown and Moyle (1991) and Brown et al. (1994) through 2004. In sum, 540 historical SONCC coho streams were identified in California, which was a 40% increase from the 325 streams identified by Brown and Moyle (1991). Presence/absence observations from surveys for a subset of these streams found 31% to 62% were still used by coho each year (Garwood 2012). The following is a description of their use of major watersheds in within California.

Smith River and Del Norte County streams. In the Smith River and smaller streams in the region, 53 potential coho salmon streams were identified; 28 were sampled with juveniles detected in 61% (Garwood 2012). However, Mill Creek, tributary to the Smith River estuary, appears to be the principal stream supporting spawners, averaging 54/year (CDFW 2015).

Klamath River. Historically, coho were found throughout much of the ~ 4000 km^2 watershed, spawning and rearing primarily in coldwater tributaries. In the mainstem Klamath, they presumably were present roughly up to the mouth of Spencer Creek, about 350 river km upstream and used all permanent tributaries for which there was access. They were found throughout the watersheds of two major tributaries, the Scott and Shasta Rivers. At the present time, coho use the mainstem Klamath up to Iron Gate Dam, where the Iron Gate Fish Hatchery is located. In the Shasta River, Dwinnell Dam blocks upstream access and coho are absent from several major tributaries due to a lack of instream flow during irrigation season (Little Shasta River and Yreka Creek). Below the dam, the principal tributaries suitable for coho rearing during the summer months are Big Springs Creek and Parks Creek. In both tributaries, but Parks Creek in particular, rearing habitat occurs adjacent to cold water spring inflow. The Scott River watershed is a snowmelt driven system, and the mainstem goes dry during the summer months due to irrigation demands. However, tributaries adjacent to the Marble Mountain Wilderness, located on the west side of the watershed, provide summertime refugia (C. Bean, CDFW, pers. comm. 2017).

In the Trinity River and its forks, coho were once distributed well upstream of Lewiston Dam. Below the dam (about 175 km upstream from the mouth on the Klamath River), they were present in most tributary streams, as well as in the mainstem up to the Trinity Fish Hatchery. Garwood (2102) estimated 184 streams in the Klamath basin below Iron Gate and Trinity dams were historically available to coho salmon spawning and rearing. In 2001-2003, 63 of these streams were sampled (not randomly selected) and coho were found in 65% of them. In the Trinity River, upwards of 90% of the coho are of hatchery origin, so the recent distribution may reflect hatchery production rather than use of the streams by naturally spawned fish (Spence et al. 2005).

Redwood Creek. Redwood Creek and its major tributary Prairie Creek were historically important coho streams, as were their 30 tributaries. Today coho are largely confined to the lower 20 km of the 90 km-long Redwood Creek and tributaries to the lower 20 km, including Prairie Creek, as a result of elevated summer water temperatures higher upstream (Madej et al. 2005). Prairie Creek, however, is an important rearing stream for coho and other salmonids because of its relatively undisturbed nature inside State Park boundaries with intact old-growth forests (Sparkman et al. 2015).

Mad River and Humboldt County streams. The Mad River historically supported coho salmon in its lower reaches, as did the smaller coastal streams in the coastal fog belt, where air and water temperatures were consistently cool. Coho apparently ascended the Mad River to either Bug or Wilson creeks, just below a relatively steep area on the main river ("the roughs"), a distance of about 80 km. They have been reported in recent years in some of the larger tributaries (e.g., Lindsay Creek). There are 62 potential coho streams, of which 29 were sampled in 2001-03; 62% contained coho (Garwood 2012). Freshwater Creek and Elk River and their tributaries seem to be particularly important coho streams in the region.

Eel River. In the 9500 km^2 Eel River system, coho formerly ascended the mainstem, the South, Middle, and North forks, 69 tributaries of the South Fork Eel, and the Van Duzen River. They are currently absent from the Middle and North fork drainages and from over 40% of the tributaries in which they once existed (Garwood 2012).

Mattole River. The Mattole River (watershed area, 787 km^2) and its 21 larger tributaries presumably all once supported coho salmon but Welsh et al. (2001) found them in 9 of 21 tributaries and largely absent from the mainstem. Garwood (2012) identified 44 potential coho streams in the watershed, of which 27 were sampled in 2001-03; coho were detected in 63%.

As the above summary indicates, SONCC coho salmon were and still are widely distributed in coastal streams from the Oregon border to Punta Gorda, and fairly far inland in the Klamath and Eel rivers. However, the long-term trend has been downward in the number of wild populations, with individual populations becoming more isolated and the overall distribution becoming fragmented. The spawning population in the Klamath basin is increasingly dominated by hatchery fish (Quinones et al. 2013). Of 541 coastal and tributary streams that historically held SONCC coho salmon, coho have been lost from at least 38% of them, assuming the study of Garwood (2012) involves unbiased sampling of the streams in 2001-03. Spence et al. (2005) found that the number of California streams containing SONCC coho salmon probably changed little in the period 1987-2001; over the 15 yr period occupancy rate varied from 55 % to 67% with no trends. The effects of the on-going drought have yet to be fully evaluated but the effects are likely to be strongly negative, pushing numbers even lower.

Trends in Abundance:

Overview. Very rough estimates indicate that the number of coho salmon returning to streams in the SONCC region 50-60 years ago was somewhere between 100,000 to 300,000 spawners (or more) per year (Brown et al. 1994), using several hundred streams for spawning and rearing. This suggests a long-term decline in excess of 95% in population size and a decline in number of streams used annually on the order of 40-50%.

Since the statewide assessment of coho status in the 1980s (Brown et al. 1994), SONCC coho salmon have remained in low numbers and have probably declined further. Monitoring is inadequate to say that populations have definitely decreased, but they certainly have not increased significantly. According to CDFG (2004) "...declines appear to have occurred prior to the late 1980s and the data do not support a significant decline in the distribution between the late 1980s and the present (p. 2.2)". Nevertheless, they recognize that the severe declines in habitat quality indicate that "…coho salmon populations …of this ESU will likely become endangered in the foreseeable future in the absence of protection and management required by the CESA (p 2.2)." Similarly, Bucklin et al. (2007) suggested that most SONCC coho populations are in decline from which recovery will be difficult.

Garwood (2012) summarized survey results that indicated there were 542 streams in California with historical use by SONCC coho; non-random sampling of a subset of these streams indicates somewhere between 30 and 60% of the streams supported coho in each year in 2001-03. How this relates to populations of naturally produced coho at present is not certain, especially given the effects of severe drought during 2012-2016. Reductions in streamflow and higher water temperatures in many habitats due to the ongoing drought and other anthropogenic effects have likely decreased juvenile over-summer survival. These drought impacts, coupled with poor ocean conditions, likely depressed SONCC coho populations, but the magnitude of these effects will likely not be known for at least another few years when three-year old adults return to spawn.

Historical abundance. Historical estimates of statewide coho salmon abundance were essentially best guesses made by fisheries managers, based on limited catch statistics, hatchery records, and personal observations of runs in various streams. Maximum estimates for the number of coho spawning in the state in the 1940s range from 200,000-500,000 to close to 1 million (Calif. Advisory Committee on Salmon and Steelhead Trout 1988). Coho numbers held at about 100,000 spawners statewide 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), and then dropped to a statewide average of around 33,500 during the 1980s (Brown et al. 1994). The reliability of these estimates is uncertain, and so they must be viewed only as "order-of magnitude" approximations, although Brown et al. (1994) attempted to estimate abundance on a stream-by-stream basis. Coho salmon in this ESU, including hatchery stocks, presently seem to be less than 6 percent of their abundance during the 1940s, with probably at least 70 percent decline in numbers since the 1960s. Brown et al. (1994) estimated that the total number of adult coho salmon entering California streams in 1988-90 averaged about 31,000 fish per year, with SONCC coho making up about 80% of the total. However, fish of suspected hatchery origin made up 57 percent of the state total. The hatchery stocks have in their ancestry fish from other river systems and often from outside California, although extra-basin stocks rarely seem to establish permanent populations or contribute to the wild populations (Bucklin et al. 2007).

Klamath River. Klamath River populations presently are largely maintained by Iron Gate hatchery production. About 80% of returning fish are of hatchery origin and a small percentage of these originate from the Trinity River Hatchery, as well as from hatcheries in Oregon and Washington (Chesney 2007). Hatchery returns are highly variable among years

(Chesney 2007). At Iron Gate Hatchery, for example, only 322 coho returned in 2006-2007, and less 100 in 2015 and 2016, although returns of over 2,500 adults have occurred in the past (1,605 fish average (D. Bean, CDFW, pers. comm. 2017). Historical annual total spawning escapements for the Klamath River system have been estimated at 15,400-20,000 fish, with 8,000 for the Trinity River (USFWS 1979). Numbers are presumably much less today, even with hatchery production. Recent returns from the Upper Klamath population unit have dwindled to a few hundred to less than 55 fish to the Iron Gate Hatchery and Bogus Creek, a major tributary, in 2009 and sometimes fall below the high risk abundance level of 425 individuals (CDFW 2014). The Shasta presumably once supported runs of several thousand fish each year, based on the presence of high-quality coldwater habitat in upstream areas. Dwinnell Dam blocks access to some of this habitat, while other habitat has been made unsuitable by agricultural diversions and warm return flows (Jeffres and Moyle 2012). In 2001, CDFG started counting coho salmon coming through a weir on the lower river. Despite considerable difficulties in operating the weir, especially during high water, the counts suggest that annual runs are now between 40 and 400 fish per year (Walsh and Hampton 2007, Swales *in prep.*). Improvements to the river's coldwater flows are apparently responsible for increases in survival of juveniles, even during drought years, although many of the returning adults are of hatchery origin (Swales 2016). However, very low numbers of returning coho in the Shasta River in 2014-2015 raise a serious cause for concern (NOAA Fisheries 2016) and highlight the need for research into how the ongoing drought may affect spring-dominated systems and ocean survival.

The Scott River is run-off dominated tributary just south of the Shasta River. Adult returns to this river, monitored since 2007, have been highly variable, from 63 fish in 2008 to 2750 fish in 2013 (NOAA Fisheries 2014). Documentation of hatchery origin coho in the Scott River is very rare (2 to 5 fish over all sampling seasons); in general the returning adults are of wild origin (CDFW unpubl. data).

Trinity River. In the Trinity River over 90% of returning coho are of hatchery origin, indicating natural spawning of wild-origin fish is depressed (Spence et al. 2005). Hatchery returns and 'wild' populations fluctuate more or less in synchrony. The Trinity River Hatchery releases over 500,000 smolts each year, with unknown, but presumably detrimental (density-dependent) effects on wild-produced fish. However, the number of natural origin fish returning to the Trinity River seems to have increased somewhat in recent years (2012, 2013) (Swales 2016). Total numbers of adults returning to the Trinity River watershed are estimated be between 5,000 and 39,000 fish, with considerable year to year variability; the number of adults that are not of hatchery origin is presumably between 500 and 3900 each year, usually on the lower end of this range.

Eel River. Probably the largest concentration of wild SONCC coho (with little or no hatchery influence) is in the South Fork of the Eel River, which has been estimated in recent years to have adult runs ranging between 1,000 and 2,000 fish. The latter number is from 2010/11 (CDFW 2015). Counts at Benbow Dam from 1938-1976, showed numbers to be highly variable but in long-term decline: 7,000-25,000/year in 1940s, 2000-11,000/year in 1950s, 1,200-14,000/year in 1960s, and 500-2,000/year in 1970s. They are apparently now in only small numbers (< 200) in historical habitats in other parts of the Eel watershed, including the Van Duzen River, Mainstem Eel and tributary creeks (NOAA Fisheries 2014); they are absent from most of the watershed.

Mattole River. According to NOAA Fisheries (2014, 29-6): "CDFG estimated an average run size of 8,000 coho salmon in the mid-to late 1950s, and in 1960 the United States

Fish and Wildlife Service (USFWS) estimated an average run size of 2,000 coho salmon and a potential population abundance of 20,000 coho salmon based on habitat characteristics at the time." In 2000, Juvenile coho salmon were noted by Welsh et al. (2001) to be present in just 9 of 21 tributaries of the Mattole River and scarce in the mainstem river. Surveys of adults and redds by the Mattole Salmon Group since 1995 have shown a general decline in spawners since the surveys were initiated. In the winter of 2012-13, there were an estimated 39 coho redds in the entire watershed (Ricker et al. 2014), presumably representing a run of < 100 fish.

Other populations. Populations in other coastal watersheds (such the Smith River and Redwood Creek) are highly variable from year to year but represent important source populations, especially in Prairie Creek (Redwood Creek, Table 2).

Redwood Creek adults	Chinook salmon		Coho salmon		Steelhead	
Year	Redd estimate	DIDSON estimate	Redd estimate	DIDSON estimate	Redd estimate	DIDSON estimate
2009-10	520	2438	382	373	436	560
2010-11	1566	*768*	1148	*322*	172	695
2011-12	1732	1455	1080	803	100	267
2012-13	1880	3401	810	747	810	1331
2013-14	1926	3487	1410	2175	164	787
2014-15	2126	x	594	x	670	x
2015-16	1480	*1839*	412	*144*	566	*203*
Delisting Target		3450		3000		6000

Table 2. Redwood Creek redd estimates and DIDSON camera estimates. From Ricker, S., Lindke, K., and C. Anderson 2014 Fig. 9, pg. 18.

Overall. Presently, there are likely less than 5,000 wild coho salmon (no hatchery influence) spawning in the SONCC region of California each year, but this number should vary with cohort and with variation in survival in both stream and ocean. In their 2016 status review, NOAA Fisheries found that of the seven major independent populations within the ESU, none supported viable populations according to the recovery plan (NOAA Fisheries 2016). In fact, only the populations of the Little, Klamath, Scott, Upper Trinity, South Fork Eel, and Humboldt Bay watersheds have moderate extinction risks based on spawner density estimates (NOAA Fisheries 2016). Many of these fish are in populations of less than 100 individuals, below the minimum population size required to preserve stock genetic diversity and to buffer populations from natural environmental disasters. The small populations also present major difficulties for conducting a census of fish numbers; a large effort is required to obtain estimates that are still of marginal reliability (Gallagher and Wright 2007, NOAA Fisheries 2014).

There is every reason to think that SONCC coho populations are not secure, even though hard data on numbers, especially in recent years, are hard to come by in most watersheds. Most available data comes from redd counts and some spawner surveys that mostly cover the last fifteen years and are not comprehensive (NOAA Fisheries 2016). Recent efforts to standardize methods among survey crews has provided some continuity and consistency in sampling across agencies, tribes, and other cooperators, which should help to improve reliability of abundance estimates in the future and coordinate recovery efforts (J. Garwood, CDFW, pers. comm. 2016). What evidence there is makes it seems likely that in most years, total SONCC adult coho spawners in California are somewhere between 3,000 and 10,000 wild fish, excluding the hatchery-dominated numbers from the Trinity River. The actual numbers are imprecise, but SONCC coho salmon are certainly at a small fraction of historical numbers, are likely decreasing, and are highly vulnerable to continued environmental change. To make matters worse, these fish are mostly in small isolated populations that show evidence of genetic and demographic problems that are likely to lead to extinction (Bucklin et al. 2007).

Factors Affecting Status: The general reasons for the decline of coho salmon in California are many and well known (Brown et al. 1994, NOAA Fisheries 2014); they include (1) poor land-use practices that degrade streams, especially those related to logging and agriculture, (2) dams and diversions, (3) urbanization, and (4) overharvest in combination with natural cycles of floods and droughts and ocean productivity, and, in addition, climate change. NOAA Fisheries (2014) identified multiple factors limiting SONCC coho populations, covering virtually every means by which humans damage streams and fish populations. CDFG (2002, 2004) provided extensive discussion of these factors and how they affect coho populations. Although all salmon are affected by the above factors, their effects on coho are likely to be particularly severe because virtually all females are three years old. Therefore, a major flood or severe drought, in conjunction with one of the above human-caused factors, can eliminate one or more year classes from a stream. There is good evidence that this has already happened repeatedly in coastal drainages, where the decline of coho is linked to poor stream and watershed management and legacy impacts from logging practices. This problem has been exacerbated by the rapid growth of marijuana cultivation in recent years, which removes water from small coho streams, damages stream channels, and introduces fertilizers and other pollutants. In addition, the long-term impact of dams of denying access to upstream areas and altering downstream habitats is still a problem. Clearly, existing regulatory mechanisms, such as forest practice rules, water agreements, streambed alteration agreements, and state and federal Endangered Species Act take prohibitions have been inadequate to protect SONCC coho. The relationship of people with landscapes containing coho salmon needs to be changed on a large scale to prevent extirpation from California.

Here we briefly discuss: (1) dams, (2) diversions, (3) logging, (4) grazing, (5) agriculture, (6) mining, (7) estuarine alteration, (8) alien species, (9) harvest, and (10) hatcheries.

Dams. Dams have two major general impacts on coho salmon: they deny or reduce access to upstream areas and they alter habitat below the dams. In the SONCC area, there are major dams on the Rogue (Oregon), Klamath, Shasta, Trinity, and Eel Rivers (CDFG 2004). All of the California dams have cut off access to upstream spawning and rearing habitat, which CDFG (2002) estimates to be 311 km of stream, mostly (175 km) above Lewiston Dam on the Trinity River alone. Likewise, Dwinnell Dam on the Shasta River cuts off access to approximately 22% of the historical coldwater habitat upstream and the reservoir prevents cold water from reaching downstream areas where it is critically needed (NMFS 2007). As in the Shasta River, rivers downstream of dams are typically unsuitable for coho spawning and rearing because of reduced flows, altered flow regimes, increased temperatures, embedded gravel, and other problems. The main function of the mainstem rivers is reduced to providing passage for upstream and downstream migrating fish, although some rearing of juveniles may occur where there are ‘cool pools’ of upwelling or tributary water. Decreased habitat connectivity in the form of dams, levees, diversions, tide gates, and other obstructions can reduce winter growth and survival of coho juveniles and may potentially reduce life history diversity and expression (Wallace et al. 2015).

There are literally hundreds of diversions on SONCC coho streams, which cumulatively reduce flows and increase temperatures. If diverted water is used for flood irrigation of pasture, much of it can return to the river at high temperatures and often polluted with nutrients. The problem with diversions is particularly acute during summer when flows are naturally low and temperatures are stressful to salmonids, especially in dry years. In the Shasta River, the combined effects of diversions are to turn what was once the coldest (in summer) large tributary to Klamath River into one that is largely too warm for most salmonids. However, acquisition of a key parcel that includes a portion of Big Springs Creek by The Nature Conservancy (TNC) in 2009, and consequent reductions of surface water diversion on their property, has resulted in an increase in available coldwater habitat (Jeffres 2009). Other tributaries (e.g., Little Shasta River) dry up in their lower reaches from diversions. Conditions in the Scott River are similar in that much of the water is diverted for agriculture and pasture; when irrigation season begins in the summer, streamflows drop and water quality becomes unsuitable for juvenile coho salmon (NMFS 2007). However, some tributaries upstream of diversions still support coho populations. During recent years, the mainstem goes dry because of diversions and groundwater pumping, as do the lower reaches of most of its tributaries.

Logging. Logging is one of the principal uses of both public and private land in the range of SONCC coho. It is most likely the single largest cause of coho decline overall because it began in the 19th century with the logging of key coho watersheds at lower elevations and then gradually moved upslope and inland. In SONCC coho streams, there were essentially two waves of damaging logging. The first involved logging the original old-growth forests, with complete disregard for watershed and salmon effects. Streams were largely regarded as convenient ways to float or drag logs to accessible locations (often behind a mill dam) so splash dams and log drives down larger rivers were commonplace. These dams were temporary dams constructed to back up water to float logs and then to wash them downstream when a dam was deliberately breached. The damming was usually preceded by channel clearing to allow unobstructed washing of logs to the mills, usually on or near the estuaries. This practice essentially scoured coho habitat and deprived fish of essential cover in the form of fallen trees (large woody debris). The second wave of damage was the result of post-World War II logging practices that reversed partial stream recovery from past damage. Unrestricted logging using trucks and other heavy equipment caused massive erosion and removed riparian vegetation and woody debris from channels. Over time, stream temperatures increased, pools filled with silt and gravel, stream channels became altered, and water quality declined. SONCC coho streams still suffer from this double legacy of harmful logging; streams are still suffering and the coho are disappearing from them as a consequence. For many years, fisheries agencies continued the practice of "debris" removal on the assumption that debris jams prevented upstream migrations of spawning fish. These legacy effects still compromise the ability of many streams to support large numbers of coho salmon.

While logging today is much more regulated than in the past (at least since the 1970s), it is still having multiple, cumulative effects on coho streams. Removal of trees reduces shade, increases water temperatures, and reduces the amount of large woody debris that falls into the streams, which provide critical habitat for rearing salmonids. An even more detrimental effect of logging is the creation of thousands of miles of temporary roads, which create large-scale instability of soils on the steep slopes that characterize coastal northern California. The result has been the erosion of huge quantities of sediment into streams, burying coho habitat. Sediment deposition and channel alteration was particularly severe as the result of the large floods of 1955 and 1964, from which the SONCC salmon basins have still not recovered. Forest practice rules are now much more stringent and restoration projects (eliminating roads etc.) are common, but the continued low populations of SONCC coho indicate that the rules (and enforcement) are still not strong enough to make up for past transgressions, nor are habitat restoration projects on a large enough scale.

Many of the streams containing SONCC coho salmon are impaired under the Clean Water Act because of high sediment loads, although low dissolved oxygen, and high water temperatures and nutrients (e.g., in the Klamath River) may also lead to impaired status. Many of the streams have Total Maximum Daily Load standards that are supposed to be met under section 303(d) of the Clean Water Act, but rarely are. High sediment loads in streams is a common legacy of past logging, road building, and other activities in SONCC coho streams.

Grazing. Grazing practices have had less of an impact on SONCC coho than on more southern populations, but are nevertheless a factor in preventing recovery. Many areas that were historically forested have been turned into pasture or grazing lands, so water flowing into the streams tends to be warmer and flashier in flow and there is less wood available to create cover for the fish. In the Shasta River, especially Big Springs Creek, cattle not only historically trampled banks but also grazed on aquatic plants in the water itself, especially in winter when the spring water was warmer than the air. This problem was largely alleviated after TNC acquired Big Springs Ranch and fenced out cattle. See estuarine alteration for a discussion of conversion of estuarine marshland into pasture for dairy cows.

Agriculture. Historically, agriculture, aside from grazing and pasture, had a minor influence on SONCC coho populations because most streams flowed through forested lands, although diversion of water for agriculture from the Klamath Basin in Oregon may have had indirect effects on coho through decreasing water quantity and quality. In recent years, marijuana cultivation on private and public forest lands has increased dramatically, resulting in the alteration of coho rearing streams, as well as their dewatering for irrigation (Bauer et al. 2015). While much of this activity is illegal or quasi-legal, its rapid increase in recent years has made enforcement of water rights and stream alteration rules overwhelmingly difficult. Impacts on coho populations are not known but can only be harmful to already stressed populations.

Mining. As in the case of logging, historical placer mining in SONCC rivers has had strong legacy effects. Long reaches of the mainstem Scott River, for example, are now lined with piles of rocky spoils from the large dredges that turned over the landscape in the 19th century. These reaches are largely too warm and shallow to support coho during the summer months today. Similar effects can be seen on other SONCC streams such as the Trinity River. Unfortunately, the rise in the price of gold in recent decades saw a resurgence of instream mining, mostly though the use of small gasoline-powered vacuum dredges. This activity disturbs fish, turns over streambeds, and reduces water clarity when juvenile coho are most stressed because of natural conditions (e.g., warmer temperatures). Fortunately, instream dredging was banned by CDFW in 2016 after a seven-year moratorium.

Estuarine alteration. Perhaps the least appreciated crucial habitat for juvenile salmonids, including coho salmon, is the estuary or lagoon at the river mouth (Wallace et al. 2015). Juvenile coho rear in an estuary for varying lengths of time and most are resident for a few weeks to over a year as they adjust to the shift from fresh to salt water. Consequently, estuaries with abundant food and cover can significantly improve survival rates of out-migrating juveniles. Unfortunately, most estuaries in the SONCC coho region are degraded to some degree. The largest, such as those on the Eel and Mad rivers, have large sections that are diked and drained, with comparatively little habitat remaining for coho rearing. Much of the diking and draining of estuarine habitat has been done to create pasture for livestock.

Alien species. Non-native predators are mainly a problem for coho salmon in the Eel River and off-channel habitats in Humboldt Bay tributaries, where the out-migrants have to pass through large stretches of river containing Sacramento pikeminnow (*Ptychocheilus grandis),* introduced in the 1980s. The effects of pikeminnow predation on coho are not known.

Harvest. Both legal and illegal harvest have had important effects on coho populations in the past, although until 1950s record keeping was poor and in the early cannery records for the Klamath River coho were often not distinguished from Chinook salmon. Between 1952 and 1992, about 40,000 fish were caught per year in the commercial fishery (high =362,000) and about 10,000 per year (high 69,000) in the sport fishery. The ocean commercial fishery for coho salmon was halted in 1993 and the ocean sport fishery in 1994 and 1995, despite the fact they are mixed stock fisheries with many of the fish coming from Oregon hatcheries and streams. Sport fishing is now not allowed in streams as a result of listing of SONCC coho as threatened under the federal Endangered Species Act. Small numbers are undoubtedly caught and released in both commercial and sport fisheries for other species. Overall, fisheries are having only a minor impact on coho populations today and the closure of fisheries has presumably helped to protect the dwindling California populations.

Hatcheries. Coho are/have been produced in a number of California hatcheries in the SONCC coho region: Rowdy Creek (Smith River), Iron Gate (Klamath River), Trinity (Trinity River), Mad River, and a number of small cooperatively-run hatcheries, although the Rowdy Creek and Mad River hatcheries are no longer in operation. There is also a large hatchery on the Rogue River, Oregon. The largest hatchery is on the Trinity River, which began production in 1963. It has a production goal of 500,000 volitionally released smolts per year, which it usually meets. The other hatcheries combined produce or produced about 200,000 smolts per year. It is significant that hatchery production has failed to halt the decline of SONCC coho salmon spawners or the decline in the fishery. Estimated survival of hatchery-produced smolts from Iron Gate Hatchery is 1.5%, with a range of 0.3 to 3.5% (Chesney 2007). Iron Gate Hatchery completed a hatchery genetics management plan in 2014 to help them move from mitigation to recovery operations, and a plan is currently being developed at the Trinity River Hatchery as well (NOAA Fisheries 2016). All SONCC coho released from these hatcheries are coded-wire tagged to allow for identification, monitoring, and management. According to DFG (2002), 80-90% the coho spawning below Trinity Dam are of hatchery origin, and roughly 1000-2000 fish return to the hatcheries each year (CDFG 2002). The fish produced in these hatcheries have origins from mixed stocks of California, Oregon, and Washington. Until there is evidence to the contrary, it must be assumed that hatchery coho salmon are having a negative effect on native wild coho salmon by competing with them for resources at all stages of their life history (Nielsen 1994). In the Trinity River, it appears that wild SONCC coho have been completely replaced by hatchery fish. The hatchery fish are nevertheless considered part of the ESU because non-native strains of coho ceased being used by the 1970s and all fish spawned at the present time are of Trinity River origin (Spence et al. 2005). If present trends continue, the only coho left in the Klamath-Trinity system will be hatchery origin fish in declining numbers (Quinones et al. 2012).

Factor	Rating	Explanation
Major dams	High	Reduced habitat, inadequate releases.
Agriculture	High	Irrigation diversions in many streams reduce flows, especially from marijuana cultivation.
Grazing	Medium	Chronic stream bank alteration.
Rural /residential development	Low	
Urbanization	Low	Urban areas mostly small in CA.
Instream mining	Medium	Dredging ban reduces risk; past mining has altered habitats.
Mining	Low	Hardrock mining limited; could become problem on Smith River.
Transportation	Medium	Roads create sediment and erosion.
Logging	Medium	A chronic problem related to roads and other impacts; legacy affects a major issue.
Fire	Low	Can cause siltation of coho streams, loss of shade to cool water.
Estuary alteration	High	Most estuaries highly altered with reduced rearing habitat and connectivity among habitats.
Recreation	Low	Boating, rafting.
Harvest	Medium	Mostly protected; some inadvertent ocean mortality and poaching.
Hatcheries	Critical	Hatchery-origin fish increasingly dominate populations.
Alien species	Low	Few aliens in coho watersheds.

Table 6. Major anthropogenic factors limiting, or potentially limiting, viability of populations of SONCC coho salmon in California. Factors were rated on a five-level ordinal scale where a factor rated “critical” could push a species to extinction in 3 generations or 10 years, whichever is less; a factor rated “high” could push the species to extinction in 10 generations or 50 years, whichever is less; a factor rated “medium” is unlikely to drive a species to extinction by itself but contributes to increased extinction risk; a factor rated “low” may reduce populations but extinction is unlikely as a result. Certainty of these judgments is high. See methods for explanation.

Effects of Climate Change: Moyle et al. (2013) rated SONCC coho as “critically vulnerable” to climate change, indicating it could drive them to extinction. This is a result of populations being low, stream flows being greatly reduced, and watersheds being highly damaged. Predicted effects on coho habitat include increases in stream temperatures, increased variability in flows (including greatly reduced summer flows), and changed ocean conditions increasing variability in productivity. Increased frequency of wild fires may increase erosion, sedimentation, and remove riparian habitat and large woody debris input into streams, thus reducing shading of already warming streams. These on-going changes are being superimposed on the other threats to coho, increasing the likelihood of rapid extirpation as time passes without dramatic action to protect and enhance habitats. As the linkages between climate change and more frequent and prolonged drought become clearer, there is evidence that the combined effects will increase temperatures and reduce streamflow and survival of SONCC coho. During the recent drought, record low precipitation coupled with several of the warmest years on record combined for a “hot drought,” which likely significantly exacerbated general drought impacts. Unfavorable oceanographic conditions related to El Nino and the overarching background conditions of

Pacific Decadal Oscillation in temperature in the Northeast Pacific likely also reduced ocean survival of coho even further. Despite numerous and ongoing recovery efforts statewide to address instream habitat, poor productivity in the ocean is likely to reduce abundance in the short-term (NOAA Fisheries 2016).

Status Score = 1.7 out of 5.0. Critical Concern. Critically Vulnerable to extinction as wild fish within next 50-100 years (Table 2). This score is conservative, given the apparent rapid declines of most populations and the probable 95% or more decline in numbers from 50-60 years ago. Garwood (2012) lists 542 potential SONCC coho streams, with an "occupancy rate" of 62%, meaning at least one detection over a three year period in a non-random sampling of streams; it is uncertain what this analysis means, given the general indications of continued long-term decline and/or high variability in numbers in the larger streams. SONCC coho are listed as threatened by both state and federal governments (NOAA Fisheries 2016).

Metric	Score	Justification
Area occupied	4	Populations in Eel, Klamath, Mattole, and other watersheds.
Estimated adult abundance	2	Most populations are isolated and function independently and are < 100 fish. There are < 5,000 returning wild adults each year.
Intervention dependence	2	All populations require continuous intervention to persist.
Tolerance	1	Coho are among the most sensitive of salmonids to environmental conditions.
Genetic risk	1	See Bucklin et al. (2007).
Climate change	1	Rated critically vulnerable in Moyle et al. (2013).
Anthropogenic threats	1	1 Critical, 3 High factors.
Average	1.7	12/7.
Certainty (1-4)	4	Well-studied populations.

Table 2. Metrics for determining the status of SONCC coho salmon, where 1 is a major negative factor contributing to status, 5 is a factor with no or positive effects on status, and 2-4 are intermediate values. Certainty of these judgments is high. See methods for explanation.

Management Recommendations: Literally hundreds of management actions on hundreds of individual streams throughout the range of SONCC coho are needed to prevent its eventual extinction. This is recognized in the recovery plans of CDFW (2015) and NOAA Fisheries (2014). Over the last several years, state, federal, and county governments have come together to undertake habitat improvements to create off-channel pools, woody debris, alcoves, and beaver dams across the SONCC coho range in California. The Yurok, Karuk, and Hoopa Tribes have also partnered to restore off-channel habitat on the Klamath and Trinity Rivers to support coho and other salmonids. These individual actions must be taken, however, in the context of a broader conservation strategy, on which we focus here.

To stop the decline of coho salmon, spawning and rearing streams must be protected and restored, and connectivity to those habitats that allows for expression of life history diversity must be restored at the watershed scale. Improving conditions for coho salmon is a difficult task because it means modifying logging, farming, and road construction activities in dozens of watersheds and implementing habitat restoration plans along hundreds of miles of streams. In many streams it means that major restoration projects must be funded, completed, and monitored. Keeping sport and commercial fisheries closed or greatly restricted is also a necessity. Given the large scale of problems facing coho salmon, innovative approaches to stream restoration must be tried, working with landowners, timber companies, and gravel miners and capitalizing on voluntary forbearance by citizens in some watersheds such as the Mattole, where local and state partnerships are providing water storage tanks to residents to reduce diversions in the summer and fall (R. Taylor, R. Taylor Associates, pers. comm. 2016). CDFG (W) reports (2002, 2004, 2012) provide many recommendations for improving management, but they are probably insufficient without further changes in public attitudes towards conservation and large increases in funding for restoration of streams, changing forest practice rules, and other major actions. The federal recovery plan for SONCC coho salmon lists projects that should be undertaken to prevent further declines and help bolster SONCC coho numbers; some broad-scale recommendations are listed below:

1. Eliminate or greatly reduce all *production* hatchery programs in order to protect the remaining wild stocks. There is growing evidence that genetically based domestication can occur in a single generation of hatchery rearing (e.g., Christie et al. 2016). Hatchery fish, even with low survival rates in the wild, can compete with, dominate, and interbreed with wild fish, reducing fitness of offspring and eventually creating genetically uniform populations (Chilcote 2011). Careful breeding programs using naturally spawned fish as hatchery stock, can reduce these problems but probably only temporarily. Klamath dam removal may eliminate the source water for the Iron Gate Hatchery and render that facility and its operations ineffective (CDFW 2014). While the current hatchery operates as a mitigation hatchery, it will gradually shift operations to an “integrated type” program, which supports conservation and recovery of coho under the new Hatchery Genetics Management Plan by allowing the environment to drive adaptation of a combined hatchery- and wild- population. This program has an annual production target of 75,000 yearling coho, which consists of juveniles that are 20-50% of natural origin. Whether or not this program can sustain coho populations in the long run is problematical. A grand experiment to see if the effects of hatchery production can be reversed would be to shut down the Iron Gate Hatchery for 5 coho generations (15 years) and then carefully monitor the origins of all fish spawning in tributaries to the Klamath River. New genomic techniques allow for much more sophisticated monitoring at lower cost than current tagging and genetic monitoring programs.

2. Maintain/develop intensive, long-term monitoring programs on the least disturbed streams containing SONCC coho such as Blue Creek, Prairie Creek, and South Fork Eel, as well as some highly disturbed streams, in order to be able to distinguish among causes of coho population fluctuations such as ocean conditions and drought. CDFW is currently monitoring degraded tributaries to Humboldt Bay, and this program should be replicated where possible. Monitoring in these watersheds concurrently would allow population trends to be followed and provide focus for restoration efforts. With impending large changes to the Klamath River, monitoring should be implemented to help assess habitat conditions and coho usage of the nearly 112 km of habitat in the Upper Klamath Population Unit before, during, and after dam removal.

3. Improve over-wintering and off-channel habitat in important coho producing streams to increase survival in fresh water, including greatly increasing the amount of large wood in stream channels (Gallagher et al. 2012).

4. Remove dams on the Klamath River to increase coldwater habitat for coho. Dam removal is slated to be completed by 2020. Consider removing dams on other coho rivers as

well (e.g., Shasta, Mad).

5. Work with landowners on the Scott and Shasta Rivers to improve thermal habitat.

6. Use environmental DNA techniques to sample all 542 streams considered by Garwood (2012) to potentially offer coho suitable habitat. Sample a random selection of these streams to confirm DNA results over three years. Use this information to focus restoration on clusters of streams with consistent coho use.

7. Develop and implement strategies for increasing life history diversity, to get away from the strict three year life cycle model. For example, increase numbers of smolts that leave after two years in freshwater or find ways to increase numbers of jack males. Habitat restoration in estuaries, such as Humboldt Bay, that increase connectivity between stream-estuary ecotones and neighboring watersheds can play a role in potentially increasing life history diversity and expression (Wallace et al. 2015).

8. Design and implement emergency rearing facilities to increase juvenile coho survival during periods of drought or during significant restoration activities. Such facilities should focus on creating as 'natural' an environment as possible.

9. Set aside funds to regain control over illegal marijuana grow sites and their water usage. This is currently being addressed in the California State Legislature with several bills introduced.

While these actions are necessary, most will not realize marked improvement in coho abundance for some time. The species is likely to become endangered in the near future (NOAA Fisheries 2016) without concerted and broad scale efforts to restore their habitat and increase their survival dramatically. The large-scale habitat restoration program necessary to avoid this fate for coho will require hugely increased effort involving increased funding, considerable interagency cooperation, and development of an extensive monitoring program. The challenges of managing such a diffuse resource as coho salmon are considerable, but if the population declines are not reversed soon, all coho salmon are likely to disappear from California.

New References:

Baracco, A. 1994. Pers. comm. CDFW Fishery Biologist, Napa, CA.

Bean, C. 2017. Pers. comm. CDFW Environmental Scientist, Region 1.

Garwood, J. 2016. Pers. comm. CDFW Environmental Scientist, Smith River, CA.

Ricker, S. 2017. Pers. comm. CDFW Coastal Monitoring Program Coordinator, Region 1.

Sparkman, M. 2017. Pers. comm. CDFW Environmental Scientist (Aquatic), Northern Region.

Spence, B. 2008. Pers. comm. NMFS Landscape Ecologist, Southwest Fisheries Science Center.

Taylor, R. 2016. Pers. comm. Principal, Ross Taylor Associates.

Wallace, M. 2017. Pers. comm. CDFW Senior Environmental Scientist, Arcata, CA.

Adams, P. et al. 2007. "Coho salmon are native south of San Francisco Bay: a reexamination of North American coho salmon's southern range limit." *Fisheries* 32:441-451.

Adams, P. et al. 2011. "California coastal salmonid population monitoring: strategy, design, and methods." California Department of Fish and Game, Fish Bulletin 180: 81pp.

Auer, S., et al. 2015. "Impacts of surface water diversions for marijuana cultivation on aquatic habitat in four northwestern California watersheds: a pilot project." *PLoS One* 10(3) e0120016.doi:10.1371/journal.pone.012006.

Bell, E. (2001). "Survival, growth and movement of juvenile coho salmon (*Oncorhynchus kisutch*) over-wintering in alcoves, backwaters, and main channel pools in Prairie Creek, California." Humboldt State University, Arcata, CA.

Bisson, P., Nielsen, J. and J. Ward. 1988. "Summer production of coho salmon stocked in Mount St. Helens streams 3–6 years after the 1980 eruption." *Transactions of the American Fisheries Society*, 117(4): 322-335.

Brakensiek, K. and D. Hankin. 2007. "Estimating overwinter survival of juvenile coho salmon in a northern California stream: accounting for effects of passive integrated transponder tagging mortality and size-dependent survival." *Transactions of the American Fisheries Society*, *136*(5): 1423–1437.

Bucklin, C., Banks, M. and D. Hedgecock. 2007. "Assessing genetic diversity of protected coho salmon (*Oncorhynchus kisutch*) populations in California." *Canadian Journal of Fisheries and Aquatic Sciences* 64(1): 30-42.

CDFW. 2014. "Hatchery and Genetic Management Plan for Iron Gate Hatchery Coho Salmon." Report prepared for PacifiCorps. 163pp.

CDFW. 2015. "Recovery Strategy for California Coho Salmon: Progress Report 2004 – 2012." *Report to Fish and Game Commission*. 296pp. Web: http://www.fgc.ca.gov/public/reports/FGC_Coho_Report_2015.pdf. Accessed 3/9/2016.

Chesney, D. 2007. "California Department of Fish and Game Klamath River Project Recovery of Fall-run Chinook and Coho Salmon at Iron Gate Hatchery, 2007." 22pp. Yreka, CA. Web: http://cahatcheryreview.com/wp-content/uploads/2012/08/IGH-2007-Final-Report.pdf. Accessed 2/2/2017.

Chilcote, M., Goodson, K. and M. Falcy. 2011. "Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish." *Canadian Journal of Fisheries and Aquatic Sciences*. 68(3): 511-522.

Christie, M. et al. 2016. "A single generation of domestication heritably alters the expression of hundreds of genes." *Nature Communications* 7:10676 doi: 10.1038/ncomms10676.

Gallagher, S., Thompson, S. and D. Wright. 2012. “Identifying factors limiting coho salmon to inform stream restoration in coastal Northern California.” *California Fish and Game* 98: 185-210.

Garwood, J. 2012. “Historic and recent occurrence of coho salmon in California streams within the Southern Oregon/Northern California Evolutionarily Significant Unit.” California Department of Fish and Game, Fisheries Branch Administrative Report No. 2012-03. Web: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=56769. Accessed 3/3/2016.

Gilbert-Horvath, et al. 2016. “Hierarchical Phylogeographic Structure of Coho Salmon in California.” *Transactions of the American Fisheries Society* 145(5): 1122-1138.

Hamilton, J. et al. 2005. “Distribution of Anadromous Fishes in the Upper Klamath River Watershed Prior to Hydropower Dams - A Synthesis of the Historical Evidence.” *Fisheries* 30(4):10-20.

Jeffres, C. and P. Moyle. 2012. “When good fish make bad decisions: Coho Salmon in an ecological trap.” *North American Journal of Fisheries Management* 32:87-92. Web: http://dx.doi.org/10.1080/02755947.2012.661389. Accessed 3/16/2016.

McLeod, R., and C. Howard. 2010. “Mill Creek Fisheries Monitoring Program, Final Report, Del Norte County, California.” 84 p. *California Department of Fish and Game*.

NMFS. 2014. “Southern Oregon Northern California Coast Coho Salmon Recovery Plan.” Web: http://www.westcoast.fisheries.noaa.gov/protected_species/salmon_steelhead/recovery_planning_and_implementation/southern_oregon_northern_california_coast/SONCC_recovery_plan.html. Accessed 6/10/2016.

NMFS. 2016. “5-Year Review: Summary & Evaluation of Southern Oregon/Northern California Coat Coho Salmon.” Arcata, CA. 70pp. Web: http://www.westcoast.fisheries.noaa.gov/publications/status_reviews/salmon_steelhead/2016/2016_soncc_coho.pdf. Accessed 10 June 2016.

Quinones, R. 2014. “Potential Factors Affecting Survival Differ by Run-Timing and Location: Linear Mixed-Effects Models of Pacific Salmonids (*Oncorhynchus* spp.) in the Klamath River, California.” *PLoS ONE* 9(5): e98392. doi:10.1371/journal.pone.0098392.

Ransom, B. 2007. “Extended freshwater rearing of juvenile Coho salmon (Oncorhynchus kisutch) in Northern California streams.” Master’s thesis, presented to Humboldt State University, Arcata, CA. Web: http://humboldt-dspace.calstate.edu/handle/2148/298. Accessed 3/5/2017.

Ricker, S., Lindke, K., and C. Anderson. 2014. “Results of regional ground surveys and estimates of total salmonid redd construction in Redwood Creek, Humboldt County, California, 2013.”

Ricker, S., Lindke, K. and C. Thompson. 2014. "California Coastal Monitoring Program Annual Report: Results of regional spawning ground surveys and estimates of total salmonid redd construction in Mattole River, Humboldt and Mendocino Counties California, 2012." California Department of Fish and Wildlife. Arcata, CA. 32 pp. Web: http://www.mattolesalmon.org/wp-content/uploads/2015/01/MSG_Spawner_FinalReport_2012-2013.pdf. Accessed 3/3/2016.

Sparkman, M. et al. 2015. "Prairie Creek Monitoring Project, 2014 Season: a report to the Fisheries Restoration Grants Program (Project No. P1210321)." California Department of Fish and Wildlife. Web: https://www.coopunits.org/California/Research/. Accessed 3/2/2016.

Spence, B. et al. 2005. "Historical occurrence of coho salmon in streams of the Central California Coast Coho Salmon Evolutionarily Significant Unit." NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-383. 89 pp. Web: https://swfsc.noaa.gov/publications/FED/00768.pdf. Accessed 3/10/2016.

Swales, S. 2017. Pers. comm. CDFW Senior Environmental Scientist (Specialist), Fisheries Branch, Sacramento, CA.

Wallace, M. et al. 2015. "Importance of the stream-estuary ecotone to juvenile coho salmon (*Oncorhynchus kisutch*) in Humboldt Bay." *California Fish and Game* 101:241-266.

Yurok Tribal Fisheries Program. 2013. "Juvenile Coho Salmon Use of Constructed Off-Channel Habitats in two Lower Klamath River Tributaries: McGarvey Creek and Terwer Creek." 13pp. Web: www.yuroktribe.org/departments/fisheries/documents/LKlam_CohoResponse_2013.pdf. Accessed 6/13/2016.