2. Structure, Viability, and Status of the SONCC Coho Salmon ESU

Much of the plan is drawn from the technical foundations describing the demographic process of species decline and recovery, characteristics of viable salmonid populations, historic structure and function of the ESU, and criteria for SONCC coho salmon viability (e.g., McElhany et al. 2000, Beechie et al. 2003, Williams et al. 2006, Williams et al. 2008). The historic structure and function of the ESU along with the current viability of the ESU provide the biological setting for recovery, and are summarized below.

2.1 Historic Structure and Function of the ESU

Williams et al. (2006) described the population structure of SONCC coho salmon based on the location and amount of potential coho salmon habitat and identified specific populations in the ESU and their demographic characteristics. NMFS considers the approach used, and the outcome of the Williams et al. (2006) analysis, as the best available scientific information on which to base recovery planning. The approach the TRT used was an experimental approach to determining historical abundance. ODFW has concerns that the approach did not accurately reflect what areas were historically used by coho salmon, and as a result has concerns with the criteria that were based on that.

A population is defined as a group of fish of the same species that spawns in a particular location at a particular season and does not interbreed substantially with fish from any other group (McElhany et al. 2000). An integral component for determining the historical population structure for the ESU was estimating the distribution of potential juvenile rearing habitat within each basin. This was accomplished using both historical records and a GIS model. The model used measures of channel gradient, valley width, and mean annual discharge to estimate the potential for a particular stream reach to provide suitable rearing habitat (on a species and life-history basis). This estimated rearing potential is the Intrinsic Potential (IP) of the reach. The IP estimate for each reach was multiplied by its respective reach length, and these values were added together to determine the intrinsic potential-kilometers (IP-km) for the basin. The IP-km is an estimate of the historic rearing habitat carrying capacity, and thus potential habitat carrying capacity for each population in the ESU. A detailed description of the model is provided in Williams et al. (2006), Agrawal et al. (2005), and Burnett et al. (2003).

Basins across the ESU vary greatly in size. Large watersheds, such as the Klamath River watershed, may support multiple populations because they have several large rivers or streams, each supporting unique populations. Small watersheds (e.g., < 4 km of stream) probably did not historically support viable populations, but are not necessarily a part of a larger population. In the development of the historic population structure, Williams et al. (2006) recognized the full range of coho salmon habitat in the SONCC coho salmon ESU. Therefore, each basin would naturally form a separate demographic unit (e.g., population). Since there is a strong tendency for coho salmon to return to their natal stream to spawn (Quinn 1993), the resulting population structure is largely determined by the spatial arrangement of their natal streams, including the structure of freshwater spawning and rearing habitats and migration pathways that allow dispersal among these habitats. Therefore, historical populations are generally based on points of saltwater entry. In addition, spawning groups within a large watershed may comprise multiple

discrete populations if sufficient barriers to effective migration exist within that watershed. Large watersheds have substantial gaps in the distribution of suitable spawning and rearing habitats and watershed-scale heterogeneity in environmental conditions that can limit effective migration and therefore result in discrete populations.

Williams et al. (2006) adopted a population classification system that extends the concept of an "independent population" to consider the place of each population with respect to expected viability-in-isolation and self-recruitment. Viability-in-isolation is assessed as a function of population size using IP-km as a surrogate. Modeling by Nickelson and Lawson (1998) showed that extinction probabilities consistently rose sharply as available habitat decreased below 24 km of high quality habitat. Because 24 km of high quality habitat, on average, equals 34 IP-km, a basin with a minimum of 34 IP-km is designated as an independent population. Self-recruitment reflects the proportion of a population's spawners that are native, and is a function of the size of the population, the size of potential donor populations and the distance between populations.

The IP-km and the self-recruitment data define each population into four types. Except for large basins, independent populations that have 95 percent fidelity (0.95 self-recruitment) are designated as Functionally Independent, while populations that have less than 95 percent fidelity are Potentially Independent. Large subbasins in the Trinity, Eel, Rogue, and Klamath River that have over 200 IP-km are designated as Functionally Independent while basins that have less than 200 IP-km are designated as Potentially Independent. Populations that have at least 5 but less than 34 IP-km are designated as Dependent if they have less than 95 percent fidelity, or Ephemeral if they have more than 95 percent fidelity. Basins with less than 5 IP-km are not recognized as populations. Although Williams et al. (2008) recognized a total of 45 populations in the ESU, subsequent modifications to the IP-km for several populations result in a total of 41 populations (i.e., one independent and three dependent populations are eliminated because their revised IP-km were below 5). These modifications are described in Appendix A. Of the 41 total populations, 30 are independent, 9 are dependent, and 2 are ephemeral. Ephemeral populations were not included in the recovery strategy. The role of each population type in the ESU is as follows:

> *Functionally Independent Populations* are those with a high likelihood of persisting in isolation over a 100-year time scale and are not substantially altered by exchanges of individuals with other populations.
>
> *Potentially Independent Populations* have a high likelihood of persisting in isolation over a 100-year time scale, but are too strongly influenced by immigration from other populations to exhibit independent dynamics.
>
> *Dependent Populations* have a substantial likelihood of going extinct within a 100-year time period in isolation, yet receive sufficient immigration to alter their dynamics and extinction risk, and presumably increase persistence or occupancy.
>
> *Ephemeral Populations* have a substantial likelihood of going extinct within a 100-year time period in isolation, and do not receive sufficient immigration to affect this likelihood. Habitats that support such populations are expected to be occupied only for relatively short periods of time, and rarely at high densities.

With the identified historic population structure of the ESU, the populations were separated into seven diversity strata that likely exhibit genotypic and phenotypic similarity due to exposure to similar environmental conditions or common evolutionary history and the geographical arrangement of the populations (Table 2-1; Williams et al. 2006). A map showing the historic and structure and function of the SONCC ESU is presented below (Figure 2-1).

Table 2-1. Arrangement of historical populations of the Southern Oregon/Northern California Coast coho salmon ESU. Population types are functionally independent (F), potentially independent (P), dependent (D) and, ephemeral (E).

Diversity Stratum	Pop. Type	Population unit	Diversity Stratum	Pop. Type	Population unit
Northern Coastal	F	Elk River	Southern Coastal	F	Humboldt Bay tributaries
	P	Lower Rogue River		F	Low. Eel/Van Duzen rivers
	F	Chetco River		P	Bear River
	P	Winchuck River		F	Mattole River
	E	Hubbard Creek		D	Guthrie Creek
	E	Euchre Creek	Interior – Rogue	F	Illinois River
	D	Brush Creek		F	Mid. Rogue/Applegate rivers
	D	Mussel Creek		F	Upper Rogue River
	D	Hunter Creek	Interior – Klamath	P	Middle Klamath River
	D	Pistol River		F	Upper Klamath River
Central Coastal	F	Smith River		P	Salmon River
	F	Lower Klamath River		F	Scott River
	F	Redwood Creek		F	Shasta River
	P	Maple Creek/Big	Interior – Trinity	F	South Fork Trinity River
	P	Little River		P	Lower Trinity River
	F	Mad River		F	Upper Trinity River
	D	Elk Creek	Interior – Eel River	F	South Fork Eel River
	D	Wilson Creek		P	Mainstem Eel River
	D	Strawberry Creek		P	Mid. Fork Eel River
	D	Norton/Widow White		F	Mid. Mainstem Eel River
				P	Upper Mainstem Eel River

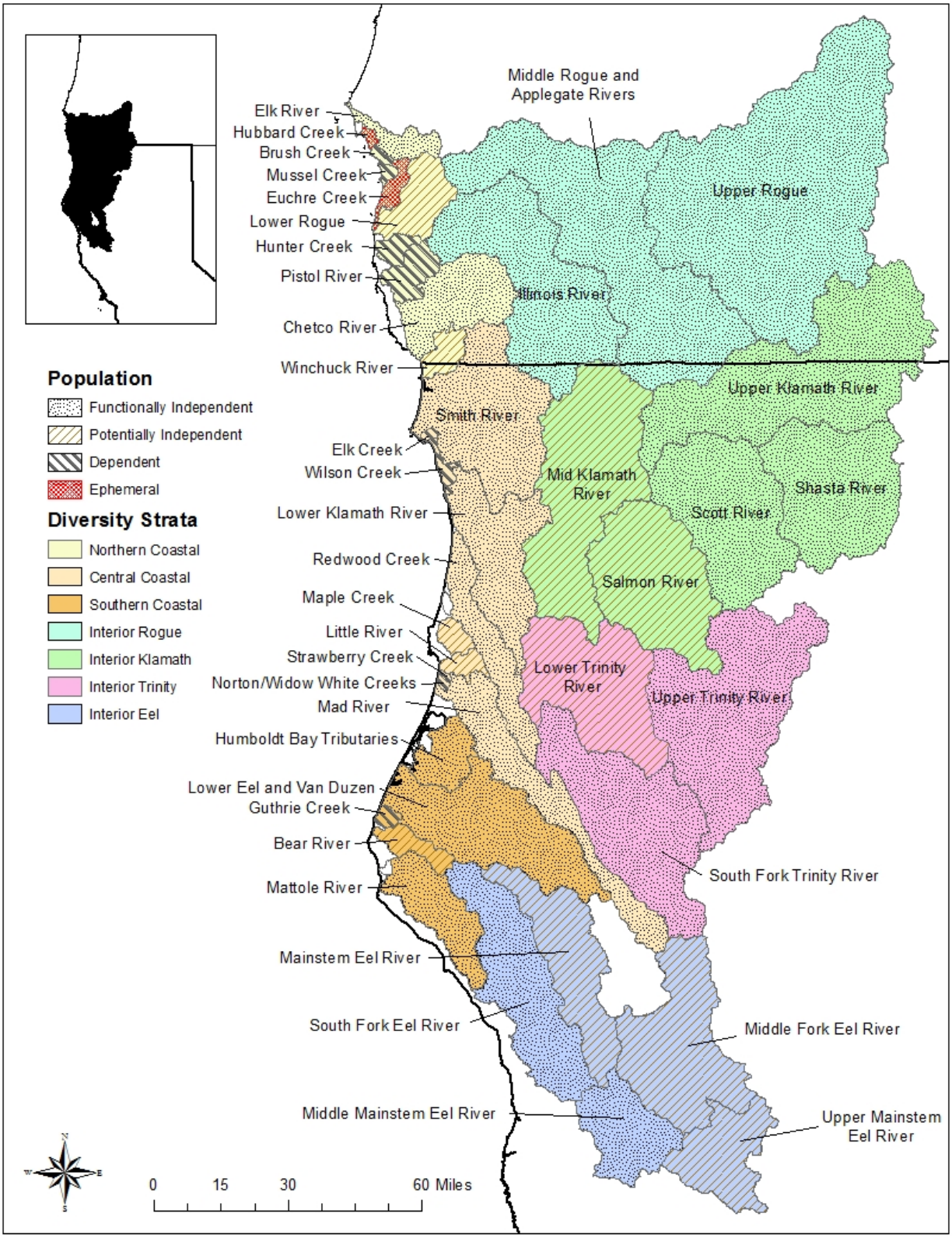

Figure 2-1. Historic population structure of the SONCC coho salmon ESU (Modified from Williams et al. 2006).

2.2 Viability Criteria

Viability criteria are the means by which a viable ESU is defined. Viability criteria are used to develop the delisting criteria described in Section 4.3 of the Recovery Strategy chapter. ODFW expressed concern with the historic population size and viability framework documents that underly these criteria (Williams et al. 2006 and 2008), and their concerns are summarized in Section 1.3.1.

2.2.1 Population

Williams et al. (2008) built on the population structure and the concepts of VSP (McElhany et al. 2000) to establish viability criteria at the population and ESU level. The population viability criteria represent an extension of an approach developed by Allendorf et al. (1997), and include metrics related to population abundance (effective population size), population decline, catastrophic decline, spawner density, hatchery influence, and population viability assessment. Populations that fail to satisfy several viability metrics are likely at greater risk than those that fail to satisfy a single metric. A viable population must have a low extinction risk for all of the population metrics (Table 2-2). For a population to be at moderate risk of extinction, it must meet the moderate risk description for each of the criteria shown in Table 2-2.

Four population categories were identified: Core, Non-Core 1, Non-Core 2, and and Dependent. For delisting, core populations must be at low risk of extinction, non-core 1 populations must be at moderate risk of extinction, and non-core 2 and dependent populations must support immigration from core populations but have no target extinction risk.

Table 2-2. Viability criteria for assessing extinction risk for SONCC coho salmon populations. For a given population, the highest risk score for any category determines the population's overall extinction risk (Williams et al. 2008).

Criterion	**Extinction risk**		
	High	Moderate	Low
	- any One of -	- any One of -	- all of -
Effective population size[a]	$N_e \leq 50$	$50 < N_e < 500$	$N_e \geq 500$
- or -	*- or -*	*- or -*	*- or -*
Population size per generation[b]	Ng ≤ 250	$250 < N_g < 2500$	$N_g \geq 2500$
- or -	*- or -*	*- or -*	*- or -*
Population size per year[c]	*Average* $N_a \leq 83$	*83 < Average* $N_a < 830$	*Average* $N_a \geq 830$[d]
Population decline[e]	Precipitous decline[f]	Chronic decline or depression[g]	No decline apparent or probable
Catastrophic decline	Order of magnitude decline within one generation	Smaller but significant decline[h]	Not apparent
Spawner density (adults/IP km)	$N_a/IP\ km \leq 1$	$1 < N_a/IP\ km \geq 4$*depensation threshold[i]	$N_a/IP\ km \geq$ MRSD[j]
Hatchery influence			Hatchery fraction <5%

Criterion	**Extinction risk**		
			- in addition to above -
Extinction risk from PVA[k]	≥20% within 20 yrs	≥5% within 100 yrs but <20% within 20 yrs	< 5% within 100 yrs[l]

[a] The effective population size (N_e) is the number of breeding individuals in an idealized population that would give rise to the same variance in gene frequency under random genetic drift or the same rate of inbreeding as the population under consideration (Wright 1931). N_e =50 is the number needed to minimize random genetic effects of small population size (Allendorf et al. 1997), and N_e =500 is the number that retains long-term adaptive potential (Allendorf et al. 1997).
[b] The total number spawners per generation (number for all years of generation combined) is N_g.
[c] N_a is the mean annual spawner abundance; the generation time for SONCC coho salmon is approximately three years therefore $N_g = 3\ N_a$.
[d] The required spawner density is always greater than this number.
[e]The population decline criteria require the calculation of two parameters, N_a and the population trend (T). Williams et al. (2008) recommends using the geometric mean of the most recent four generations (i.e., 12 years) to estimate annual population abundance, so N_a is equal to the geometric mean of 12 years of spawner abundance.
[f] Population has declined within the last two generations or is projected to decline within the next two generations (if current trends continue) to annual run size of $N_a \leq 500$ spawners (historically small but stable populations not included) or $N_a > 500$ but declining at a rate of ≥10% per year over the last two-to-four generations.
[g] Annual spawner abundance N_a has declined to ≤500 spawners, but now stable **or** number of adult spawners (N_a) > 500 but continued downward trend is evident.
[h] Annual spawner abundance decline in one generation < 90% but biologically significant (e.g., loss of year class).
[i] Williams et al. (2008) defines this category of risk as "1< N_a/*IP km* < MRSD". The target NMFS has adopted is the depensation threshold multiplied by four. Williams et al. (2008) defines the depensation threshold as 1 spawner per IP km.
[j] MRSD, or minimum required spawner density, is dependent on the amount of IP km of habitat per population. MRSD is the same as the low risk threshold.
[k] "If a credible PVA [Population Viability Analysis] can be constructed, results should be compared to results of the general criteria we propose, and by comparison of the outcomes, potential limitations of either approach identified and examined. A PVA is not required to determine a low-risk designation, but a PVA alone does not supersede the general criteria. For high-risk and moderate-risk determination, a PVA result alone can be used to establish risk level, although we strongly recommend that the PVA results be compared to results of the general criteria we propose. We also caution against using PVA analysis alone to assess population viability (Williams et al. 2008)."
[l] For population to be considered at low-risk of extinction, all criteria must be satisfied (i.e., not just a PVA). A population viability analysis (PVA) can be also included for consideration, but must estimate an extinction risk <5% within 100 years *and* all other criteria must be met. If discrepancies exist between PVA results and other criteria, results need to be thoroughly examined and potential limitations of either approach are carefully identified and examined.

A population is at high risk of extinction if the number of spawners is less than 1 per IP km (depensation threshold) (Table 2-2). All independent populations which aren't extirpated must not be at high risk of extinction, and so their spawner numbers must be greater than the depensation threshold. To provide a reasonable buffer to protect against falling below the threshold, the moderate risk threshold has been identified as the target to be met by non-core 1 populations. The moderate risk threshold is the depensation threshold multiplied by four. Four was chosen as the multiplier based on the following rationale.

Wainwright et al. (2008) chose a value of 0.6 spawners/km to the density at which a population of salmon would be very likely to have significant demographic risks. This was the lowest of four bins the Wainwright et al. (2008) workgroup used to populate a decision support system. Williams et al. (2008) essentially chose this value then divided it by 0.6, which is equivalent to the average ratio of IP km to total km in the SONCC ESU. The resulting value of 1 adult per IP km was deemed to be the threshold for *high risk* of depensation by Williams et al (2008).

Other authors have identified values below which depensation occurs, and these values are typically much higher (Table 2-3). Wainwright et al. (2008) considered a population with value of 4.2 spawners/IP km to have an uncertain probability of incurring depensation, a value similar

to that of Sharr et al. (2000) and Chilcote (1999). Barrowman et al. (2003) note that there is little evidence for depensation in coho salmon, unless fewer than one female per kilometer of river (3.33 spawners/IP km) returned to spawn (Table 2-3). Parameter estimates for the upper 95% confidence interval presented in Barrowman et al. (2003) are given in Table 2-3. According to Sharr et al. (2000), four spawners per IP km would translate into an extinction risk of approximately 10% over four generations (Table 2-3).

Table 2-3 Depensation levels identified by various authors. Results are standardized to IP km.

Reference	**Value below which depensation occurs**
Barrowman et al. (2003) 95% Upper CI Type 2 BH	2.26 spawners/IP km
Barrowman et al. (2003) 95% Upper CI Type 2 LHS	1.6 spawners/IP km
Sharr et al. (2000)	4.2 spawners/IP km
Chilcote (1999)	4.1 spawners/IP km

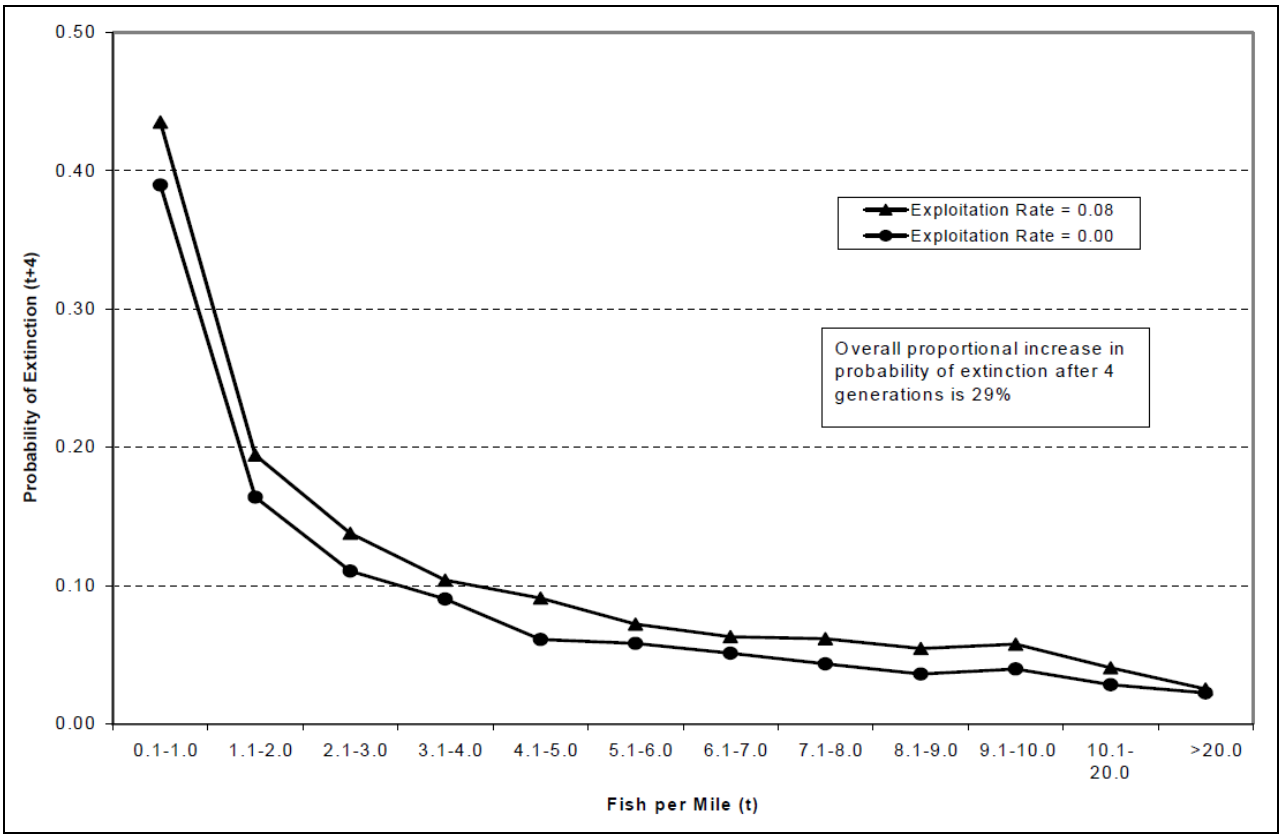

Figure 2-2. Probability of basin level extinction in four generations as a function of spawner density. For fishery exploitation rates of 0.0 and 0.8 in all Oregon coastal basins combined. Figure from Sharr et al. (2000).

2.2.2 ESU

The viability of an ESU depends on several factors, including the number and status of populations, spatial distribution of populations, the characteristics of large-scale catastrophic risk, and the collective diversity of the populations and their habitat (Lindley et al. 2007). In order for the SONCC coho salmon ESU to be viable, every diversity stratum needs at least 50 percent of its independent populations (i.e., Functionally Independent or Potentially Independent) to be viable, and the abundance of these viable independent populations collectively must be at least 50 percent of the total abundance modeled for all of the independent populations in that stratum (Table 2-2). The independent populations that are chosen to meet the population viability criteria are called "core." NMFS' rationale for its choice of core populations is explained in Appendix C. Independent populations which are not core are called "non-core 1" or "non-core 2". Non-core 1 populations must reach at least a moderate risk of extinction. All dependent and non-core 2 populations must exhibit occupancy patterns that indicate sufficient emigration is occurring from the core populations to maintain connectivity within and among diversity strata.

Although not all populations are required to be viable, the ESU viability criteria are intended to ensure representation of the diversity throughout the ESU, buffer the ESU against potential catastrophic risks, and provide sufficient connectivity among populations to maintain long-term demographic and genetic processes. The ESU viability criteria incorporate the principles of representation, redundancy, connectivity, and resiliency. Representation relates to the genetic and life history diversity of the ESU, which is needed to conserve its adaptive capacity. Redundancy addresses the need to have a sufficient number of populations so the ESU can withstand catastrophic events (NMFS 2010). Connectivity refers to the dispersal capacity of populations to maintain long-term demographic and genetic processes. Resiliency is the ability of populations to withstand natural and human-caused stochastic events, and it depends on sufficient abundance and productivity. The overarching goal of these rules was to determine an appropriate number and arrangement of populations that allow populations to track changes in environmental conditions, and therefore be viable at the ESU level (Williams et al. 2008).

Table 2-4. ESU viability criteria for SONCC coho salmon. (Williams et al. 2008).

ESU viability characteristic	Criteria
Representation	1. All diversity strata should be represented by viable populations
Redundancy and Connectivity	2.a. At least fifty percent of historically independent populations in each diversity stratum should be demonstrated to be at low risk of extinction according to the population viability criteria. AND 2.b. Total aggregate abundance of the populations selected to satisfy 2a must meet or exceed 50% of the aggregate viable population abundance predicted for the stratum based on the spawner density 3. All dependent and independent populations not expected to meet low-risk threshold within a stratum should exhibit occupancy indicating sufficient immigration is occurring from the "core populations".

ESU viability characteristic	Criteria
Redundancy and Connectivity	4. The distribution of extant populations, both dependent and independent, needs to maintain connectivity across the stratum as well as with adjacent strata.

Williams et al. 2008 wrote about Criterion 3: "We propose that recovery planners place a high priority on populations that are remnants of historically independent populations **with a minimum standard that most historically independent populations should be at no greater than moderate risk of extinction (i.e., not at high risk) when evaluated as independent populations** [Emphasis added]. This recommendation would require a higher standard for occupancy than just presence of individuals. It should be recognized that these independent populations no longer fulfill their historical role within the ESU, but they can play a critical role in connectivity and have the potential for representing critical components of the evolutionary legacy of the ESU."

To meet this recommendation, we set the delisting criteria for most non-core independent populations at the depensation threshold multiplied by four, which is the minimum number needed for a population to be at moderate (not high) risk of extinction with regard to the spawner density criterion (Table 2-2). These populations were called "non-core 1". "Non-core 2" populations were identified in response to the requirement that "most" (not all) independent populations should be at moderate risk of extinction. For some independent populations, there is little to no documentation of coho salmon presence in the last century, and prospects for recovery to the moderate-risk threshold are low. These populations were made non-core 2 populations, and so had a lower threshold (juvenile occupancy) than if they were non-core 1 populations.

2.3 Current Status of the ESU

In order to determine the current risk of extinction of the SONCC coho salmon ESU, the population viability criteria (Table 2-2) and the concept of Viable Salmonid Populations (VSP) for evaluating populations described by McElhany et al. (2000) are utilized. A viable salmonid population is defined as one that has a negligible risk of extinction over 100 years. Viable salmonid populations are described in terms of four parameters: abundance, population productivity, spatial structure, and diversity. These parameters are predictors of extinction risk, and reflect general biological and ecological processes that are critical to the growth and survival of salmon (McElhany et al. 2000).

Information about population size provides an indication of the type of extinction risk that a population faces. For instance, smaller populations are at a greater risk of extinction than large populations because the processes that affect populations operate differently in small populations than in large populations (McElhany et al. 2000). One risk of low population sizes is depensation. Depensation occurs when populations are reduced to very low densities and per capita growth rates decrease as a result of a variety of mechanisms [e.g., failure to find mates and therefore reduced probability of fertilization, failure to saturate predator populations (Liermann and Hilborn 2001)]. Depensation results in negative feedback that accelerates a decline toward extinction (Williams et al. 2008).

The productivity of a population (i.e., production over the entire life cycle) can reflect conditions (e.g., environmental conditions) that influence the dynamics of a population and determine abundance. In turn, the productivity of a population allows an understanding of the performance of a population across the landscape and habitats in which it exists and its response to those habitats (McElhany et al. 2000). In general, declining productivity equates to declining population abundance. Understanding the spatial structure of a population is important because the population structure can affect evolutionary processes and, therefore, alter the ability of a population to adapt to spatial or temporal changes in the species' environment (McElhany et al. 2000).

Diversity, both genetic and behavioral, is critical to success in a changing environment. Salmonids express variation in a suite of traits, such as anadromy, morphology, fecundity, run timing, spawn timing, juvenile behavior, age at smolting, age at maturity, egg size, developmental rate, ocean distribution patterns, male and female spawning behavior, and physiology and molecular genetic characteristics. The more diverse these traits (or the more these traits are not restricted), the more diverse a population is, and the more likely that individuals, and therefore the species, would survive and reproduce in the face of environmental variation (McElhany et al. 2000). However, when this diversity is reduced due to loss of entire life history strategies or to loss of habitat used by fish exhibiting variation in life history traits, the species is in all probability less able to survive and reproduce given environmental variation.

Because some of the parameters are related or overlap, the evaluation is at times necessarily repetitive. Viable ESUs are defined by some combination of multiple populations, at least some of which exceed "viable" thresholds, and that have appropriate geographic distribution, protection from catastrophic events, and diversity of life histories and other genetic expression. The following subsection provides the evaluation of the risk of extinction for SONCC coho salmon based the four VSP parameters. For information on the status of specific populations, refer to Volume II.

2.3.1 Population Abundance

Quantitative population-level estimates of adult spawner abundance spanning more than 9 years are scarce for SONCC coho salmon. New data since publication of the previous status review (Good et al. 2005) consists of continuation of a few time series of adult abundance, expansion of efforts in coastal basins of Oregon to include SONCC coho salmon populations, and continuation and addition of several "population unit" scale monitoring efforts in California. Other than the Shasta River and Scott River adult counts, reliable current time series of naturally produced adult spawners are not available for the California portion of the SONCC ESU at the "population unit" scale.

Although long-term data on coho salmon abundance are scarce, the available monitoring data indicate that spawner abundance has generally declined for populations in this ESU. The longest existing time series at the population unit scale began in 1994 in the Smith River (Figure 2-3).

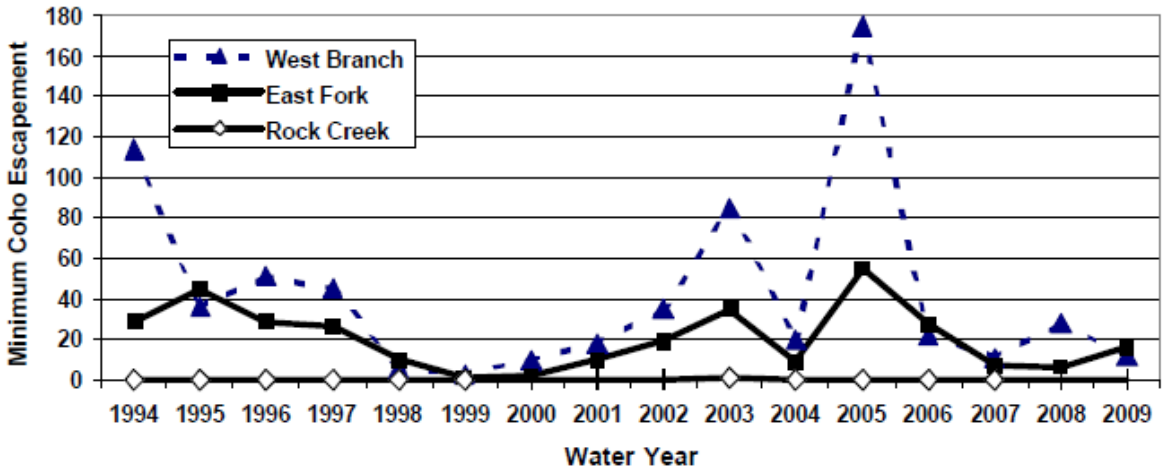

Figure 2-3. Coho salmon minimum escapement estimates for three sites in the Mill Creek watershed of the Smith River basin. Water years 1994 through 1999 (Figure from McLeod and Howard 2010).

The number of adult coho salmon at the video weir on the Shasta River decreased from 2001-2010 (Figure 2-4). Available time series data on the Shasta River show low adult returns, of which two out of three cohorts are considered to be nearly extirpated (Chesney et al. 2009). The Shasta River population has declined in abundance by almost 50 percent from one generation to the next (Williams et al. 2011).

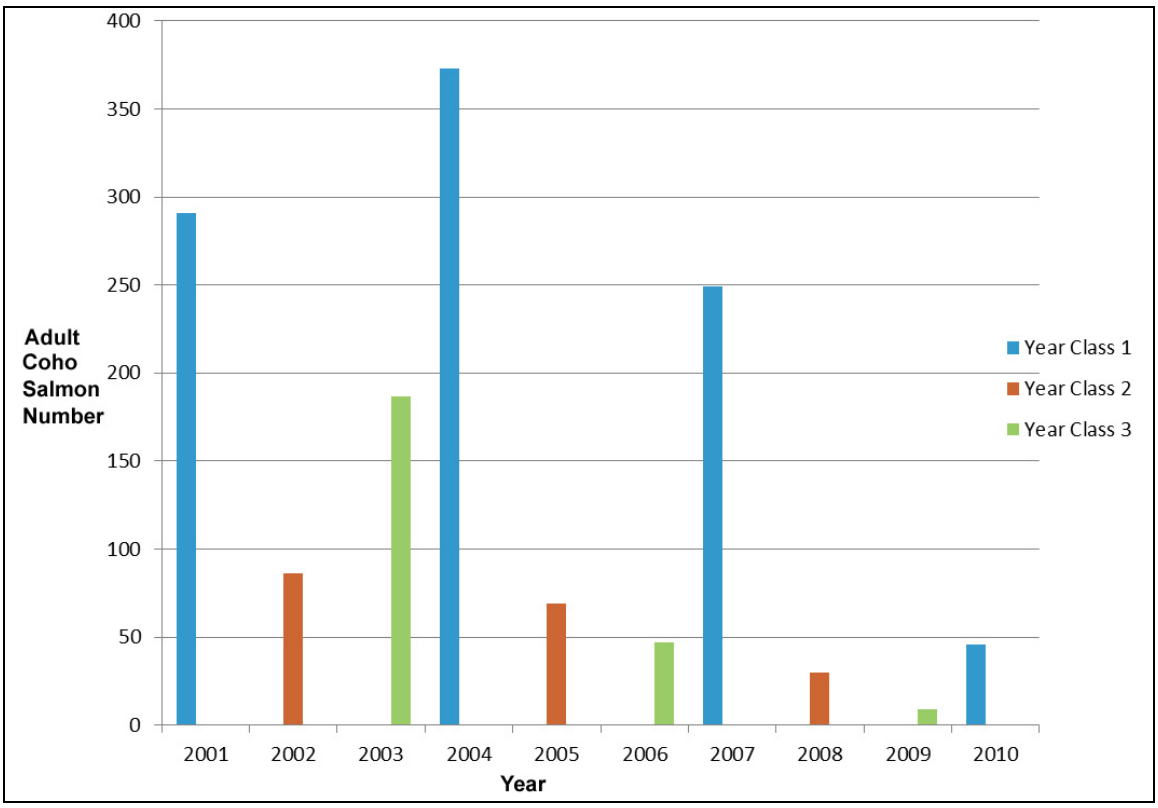

Figure 2-4. Video weir estimates of adult coho salmon in the Shasta River. This is an independent population. Data are for 2001 to 2010. (data from M. Knechtle, California Department of Fish and Game).

Two partial counts from Prairie Creek, a tributary of Redwood Creek, and Freshwater Creek, a tributary of Humboldt Bay show a negative trend (Figure 2-5 and Figure 2-6, respectively). Data from the Rogue River basin also show recent negative trends. Estimates from Huntley Park in the Rogue River basin show a strong return year in 2004, followed by a decline to 2,566 fish in 2009 (Figure 2-7). The Huntley Park seine estimates provide the best overall assessment of naturally produced coho salmon spawner abundance in the basin (Oregon Department of Fish and Wildlife (ODFW) 2005a). Four independent populations contribute to this count (Lower Rogue River, Illinois River, Middle Rogue and Applegate rivers, and Upper Rogue River). The 12 year average estimated wild adult coho salmon in the Rogue River basin between 1998 and 2009 (excluding 2008) is 8,050, which is well below historic abundance. 2008 data were excluded from the average because the extremely low numbers were not consistent with that seen upstream at Gold Ray Dam, suggesting other reasons (sampling issues, data errors, etc.) for the dramatic drop in fish numbers from 2007 to 2008. Based on extrapolations from cannery pack, the Rogue River had an estimated adult coho salmon abundance of 114,000 in the late 1800s (Meengs and Lackey 2005).

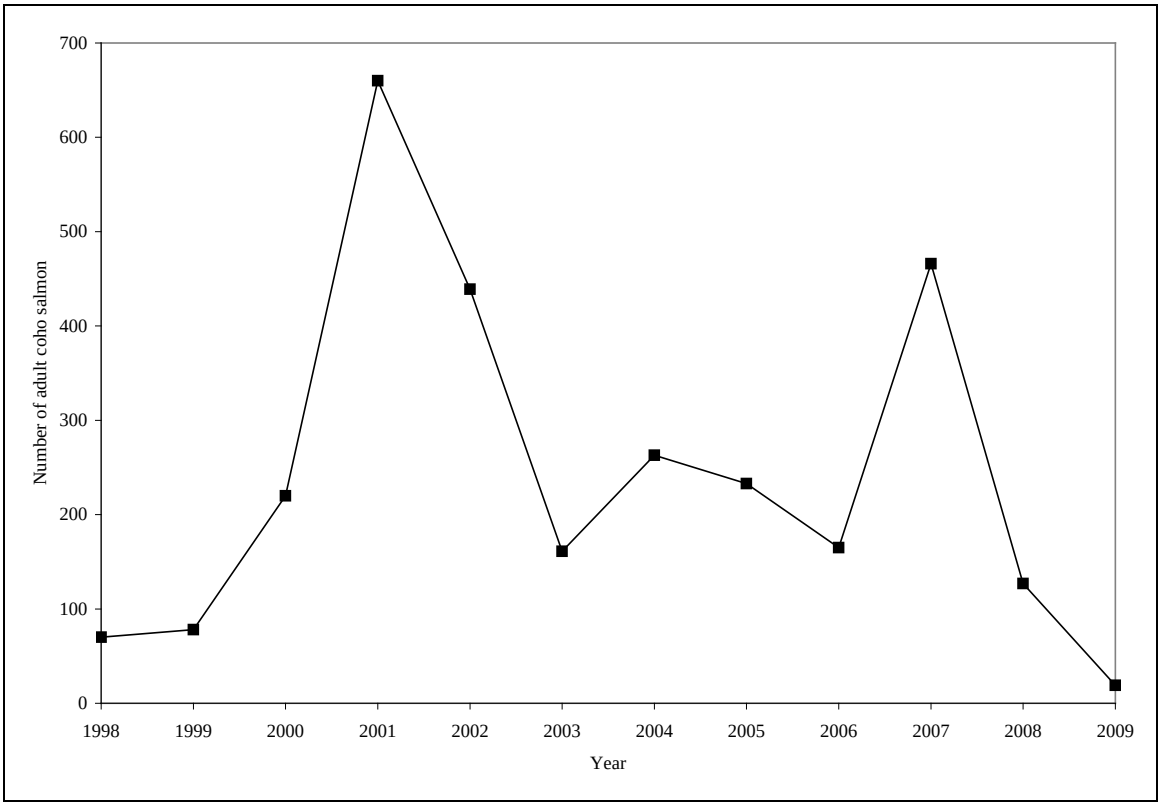

Figure 2-5. Estimate of spawning coho salmon in Prairie Creek. This is a tributary to Redwood Creek (Humboldt County, California). Data are for 1998 to 2009 (Williams et al. 2011).

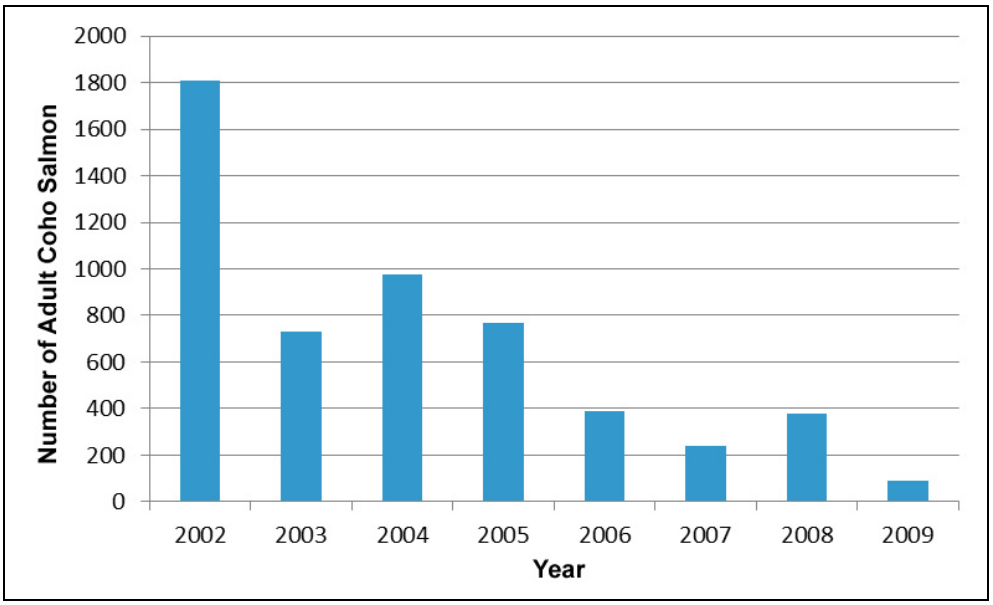

Figure 2-6. Adult coho salmon estimate for Freshwater Creek. This is a tributary to Humboldt Bay. Data are for 2002 to 2009. Data are from Ricker and Anderson (2011).

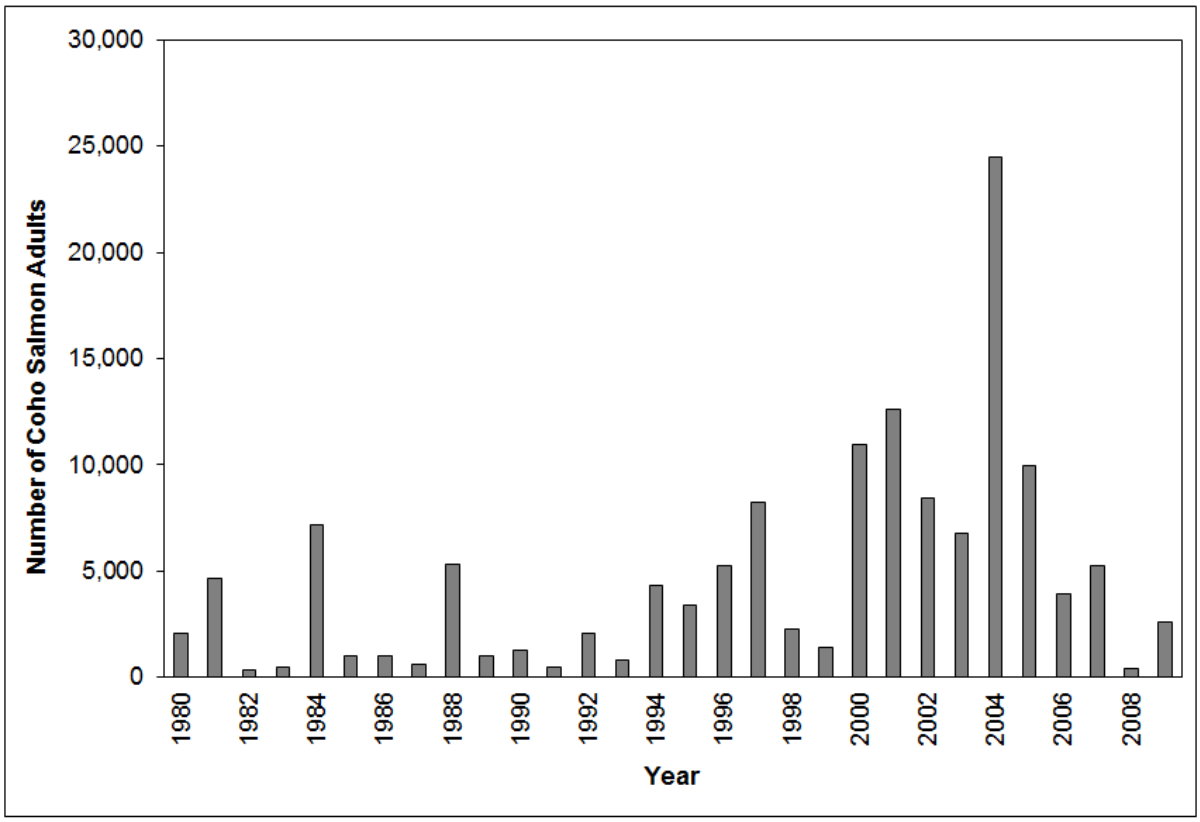

Figure 2-7. Estimated number of wild adult coho salmon in the Rogue River basin. (Huntley Park sampling), 1980 to 2009 (ODFW 2011b).

Though population-level estimates of abundance for most independent populations are lacking, the best available data indicate that none of the seven diversity strata appears to support a single

viable population as defined by in the viability criteria (Table 2-2). In fact, most of the 30 independent populations in the ESU are at high risk of extinction because they are below or likely below their depensation threshold (Table 2-4).

Populations that are below depensation have increased likelihood of being extirpated. Coho salmon spawners in the Eel River watershed, which historically supported significant spawners (e.g., 50,000 to 100,000 per year; Yoshiyama and Moyle 2010), have declined. Yoshiyama and Moyle (2010) concluded that coho salmon populations in the Eel River basin appear to be headed for extirpation by 2025. One of the four independent populations in this basin have already been extirpated (i.e., Middle Fork Eel River; Moyle et al. 2008, Yoshiyama and Moyle 2010) and one population contains critically low numbers (i.e., Upper Mainstem Eel River; with only a total of 7 coho salmon adults counted at the Van Arsdale Fish Station in over six decades; Jahn 2010). Although long term spawner data are not available, both NMFS and CDFG believe the Lower Eel/Van Duzen River, Middle Mainstem Eel and Mainstem Eel River populations are very likely below the depensation threshold, and thus are at a high risk of extinction. The only population in the Eel River basin that is likely to be above its depensation threshold is the South Fork Eel River, which also has significantly declined from historical numbers (Figure 2-8).

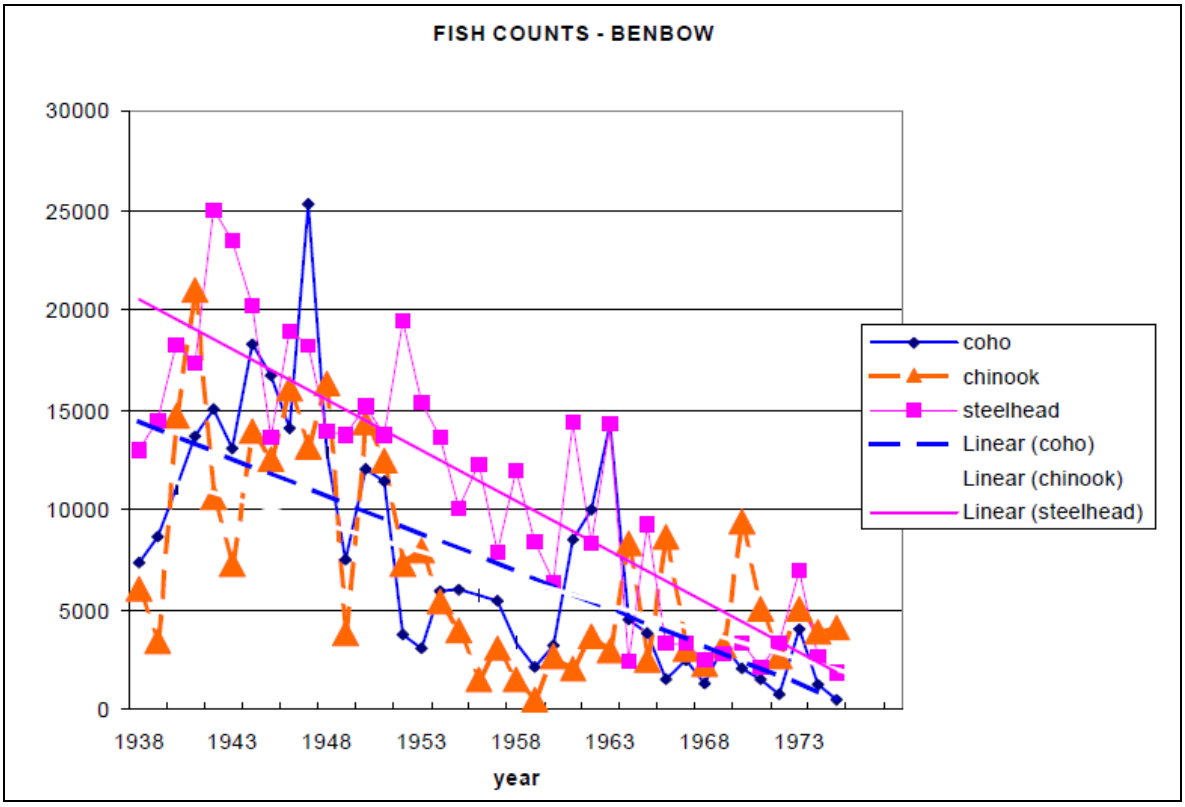

Figure 2-8. Fish counts at Benbow Fish Station, in the South Fork Eel River. Data are from 1938 to 1975. Figure from EPA (1999).

In addition to the Eel River basin, two other independent populations south of the Eel River basin, the Bear River and Mattole River populations, have similar trajectories. The Bear River population is likely extirpated or severely depressed. Despite multiple surveys over the years, no coho salmon have been found in the Bear River watershed (Bliesner et al. 2006, Ricker 2002).

In 1996 and 2000, the California Department of Fish and Game (CDFG) surveyed most tributaries of the Bear River, and did not find any coho salmon (CDFG 2004). In addition, CDFG sampled the mainstem and South Fork Bear River between 2001 and 2003 and found no coho salmon (Jong et al. 2008). In the Mattole River, surveys of live fish and carcasses since 1994 indicate the population is severely depressed and well below the depensation threshold of 250 spawners. Recent spawner surveys in the Mattole River resulted in only 3 and 9 coho salmon for 2009 and 2010, respectively. These low numbers, along with a recent decline since 2005, indicate that the Mattole River population is at a high risk of extinction.

Because the extinction risk of an ESU depends upon the extinction risk of its constituent independent populations (Williams et al. 2008) and the population abundance of most independent populations are below their depensation threshold, the SONCC coho salmon ESU is at high risk of extinction and is not viable.

2.3.2 Productivity

The productivity of a population (i.e., production over the entire life cycle) can reflect conditions (e.g., environmental conditions) that influence the dynamics of a population and determine abundance. In turn, the productivity of a population allows an understanding of the performance of a population across the landscape and habitats in which it exists and its response to those habitats (McElhany et al. 2000). In general, declining productivity equates to declining population abundance. As discussed above in the population abundance section, available data indicates that many populations have declined, which reflects a declining productivity. For instance, the Shasta River population has declined in abundance by almost 50 percent from one generation to the next (Williams et al. 2011 and (Figure 2-4). Two partial counts from Prairie Creek, a tributary of Redwood Creek, and Freshwater Creek, a tributary of Humboldt Bay show a negative trend (Figure 2-5 and Figure 2-6). Data from the Rogue River basin also show recent negative trends. In general, SONCC coho salmon have declined substantially from historic levels. Because productivity appears to be negative for most, if not all SONCC coho salmon populations, this ESU is not currently viable in regard to population productivity.

2.3.3 Spatial Structure

The viability report for the SONCC coho salmon ESU concluded data were insufficient to set specific population spatial structure targets (Williams et al. 2008). In the absence of such targets, McElhany et al. (2000) suggested the following: “As a default, historical spatial processes should be preserved because we assume that the historical population structure was sustainable but we do not know whether a novel spatial structure will be”, where “historical” means “before the recent or severe declines that have been observed in many populations (McElhany et al. 2000).”

An ESU persists in places where it is able to track environmental changes, and becomes extinct if it fails to keep up with the shifting distribution of suitable habitat (Thomas 1994, Williams et al. 2008). If freshwater habitat shrinks due to climate change (Battin et al. 2007) or habitat degradation, certain areas such as inland rivers and streams could become inhospitable to coho salmon, which would change the spatial structure of the SONCC coho salmon ESU, having implications for the risk of species extinction.

Data is inadequate to determine whether the spatial distribution of SONCC coho salmon has changed since 2005. In 2005, Good et al. (2005) noted that they had strong indications that breeding groups have been lost from a significant percentage of streams within their historical range. Relatively low levels of observed presence in historically occupied coho salmon streams (32 to 56 percent from 1986 to 2000) indicate continued low abundance in the California portion of the SONCC coho salmon ESU. The relatively high occupancy rate of historical streams observed in brood year 2001 suggests that much habitat remains accessible to coho salmon (70 FR 37160, June 28, 2005). Brown et al. (1994) found survey information on 115 streams within the SONCC coho salmon ESU, of which 73 (64 percent) still supported coho salmon runs while 42 (36 percent) did not. The streams Brown et al. (1994) identified as lacking coho salmon runs were all tributaries of the Klamath River and Eel River basins. CDFG (2002b) reported a decline in SONCC coho salmon occupancy, with the percent reduction dependent on the data sets used. All the assessments based on fish presence described above were affected by the often poor hydrologic conditions present in the survey years.

Although there is considerable year-to-year variation in estimated occupancy rates, it appears that there has been no dramatic change in the percent of coho salmon streams occupied from the late 1980s and early 1990s to 2000 (Good et al. 2005). However, the number of streams and rivers currently supporting coho salmon in this ESU has been greatly reduced from historical levels, and watershed-specific extirpations of coho salmon have been documented (Brown et al.1994, CDFG 2004, Good et al.2005, Moyle et al. 2008, Yoshiyama and Moyle 2010). In summary, recent information for SONCC coho salmon indicates that their distribution within the ESU has been reduced and fragmented, as evidenced by an increasing number of previously occupied streams from which they are now absent (NMFS 2001). However, extant populations can still be found in all major river basins within the ESU (70 FR 37160; June 28, 2005).

2.3.4 Diversity

The primary factors affecting the genetic and life history diversity of SONCC coho salmon appear to be low population abundance and the influence of hatcheries and out-of-basin introductions. Although the operation of a hatchery tends to increase the abundance of returning adults (70 FR 37160; June 28, 2005), the reproductive success of hatchery-born salmonids spawning in the wild can be less than that of naturally produced fish (Araki et al. 2007a). As a result, the higher the proportion of hatchery-born spawners, the lower the overall productivity of the population, as demonstrated by Chilcote (2003). Williams et al. (2008) considered a population to be at least at a moderate risk of extinction if the contribution of hatchery coho salmon spawning in the wild exceeds 5 percent. Populations have a lower risk of extinction if no or negligible ecological or genetic effects resulting from past or current hatchery operations can be demonstrated. Because the main stocks in the SONCC coho salmon ESU (i.e., Rogue River, Klamath River, and Trinity River) remain heavily influenced by hatcheries and have little natural production in mainstem rivers (Weitkamp et al. 1995; Good et al. 2005), some of these populations are at high risk of extinction relative to the genetic diversity parameter. The extent of hatcheries in the ESU, and a discussion of their effects, is described in Chapter 3. Table 2-5 shows those populations with stress and threat ranks of high (greater than 10 percent and less than 30 percent hatchery-origin adults) and very high (greater than 30 percent hatchery-origin adults).

Table 2-5. Populations with hatchery effects rated as a high or very high stress and threat. Table shows % hatchery spawners, and source.

Population	Stress and Threat Rank	% Hatchery origin adults
Upper Klamath River	Very High	77% from 1996 to 2010; Chesney and Knechtle 2011a 34% at Bogus Creek; Knechtle and Chesney 2011
Shasta River	High	16% in 2001, 2003, 2004; Ackerman and Cramer 2006 23% from 2001 to 2004 and 2007 to 2010; Ackerman et al. 2006 and Chesney and Knechtle 2011b.
Lower Trinity River	Very High	85-97% from 1997 to 2002; CDFG 2009 60-100% from 1998 to 1999; Dutra and Thomas 1999
South Fork Trinity River	Very High	36% in 1985; Jong and Mills 1992.
Upper Trinity River	Very High	97%, USFWS and HVT 1999.

In addition, some populations are extirpated or nearly extirpated (i.e., Middle Fork Eel, Bear River, Upper Mainstem Eel) and some brood years have low abundance or may even be absent in some areas (e.g., Shasta River, Scott River, Mattole River, Mainstem Eel River), which further restricts the diversity present in the ESU. The ESU's current genetic variability and variation in life history likely contribute significantly to long-term risk of extinction. Given the recent trends in abundance across the ESU, the genetic and life history diversity of populations is likely very low and is inadequate to contribute to a viable ESU.

2.3.5 Oregon Assessment

The Oregon Department of Fish and Wildlife assessed the status of the Rogue Coho Species Management Unit (SMU), which includes the Upper Rogue, Middle Rogue, and Illinois River populations (ODFW 2005a) using five interim criteria defined in their Native Fish Conservation Policy. These criteria were designed to identify cases of significant near-term conservation risks. The Rogue Coho SMU was found Not At Risk because all three populations met all six criteria (Table 2-6). The criteria used by ODFW and NFMS to assess the status of the ESU were different, leading to different results. In addition, the NMFS assessment included all populations within the ESU, while the ODFW assessment included the three interior Rogue populations within the Rogue Coho SMU.

Table 2-6 Interim criteria and standards. As defined in the Native Fish Conservation Policy risk assessment of Oregon salmon and steelhead SMUs (ODFW 2005a).

Attribute	Criteria
Existing populations	At least 80% of historical populations are still in existence (i.e., not extinct) *and* not at risk of extinction in the near future.
Habitat use distribution	Naturally produced members of a population occupy at least 50% of the historically-used (pre-development) habitat in at least three of the last five years for at least 80% of existing populations.

Attribute	Criteria
Abundance	Number of naturally-produced fish is greater than 25% of average levels in at least three of the last five years for at least 80% of existing populations.
Productivity	Population replacement rate for at least 80% of existing populations is at least 1.2 naturally-produced adult offspring per parent in three of the last five years when total abundance was less than average returns of naturally produced fish.
Reproductive independence	90% or more of spawners are naturally produced in at least three of the last five years for at least 80% of existing populations.
Hybridization	Hybrization with non-native species is rare or nonexistent in three of the last five years for at least 80% of existing populations.

2.3.6 Summary

Though population-level estimates of abundance for most independent populations are lacking, the best available data indicate that none of the seven diversity strata appears to support a single viable population as defined by the TRT's viability criteria (low extinction risk). Further, 25 out of 30 independent populations are at high risk of extinction and 5 are at moderate risk of extinction (Table 2-7).

Table 2-7. SONCC coho salmon independent populations and their risk of extinction based on number of adults.

Stratum	Independent Populations	Extinction Risk	Population Viability Metric (Williams et al. 2008)
Northern Coastal Basin	Elk River	High	Population likely below depensation threshold[1]
	Lower Rogue River	High	
	Chetco River	High	
	Winchuck River	High	
Interior Rogue River	Illinois River	High	600
	Middle Rogue/Applegate rivers	High	675
	Upper Rogue River	Moderate	800
Central Coastal Basin	Smith River	High	325
	Lower Klamath River	Moderate	205
	Redwood Creek	High	150
	Maple Creek/Big Lagoon	High	40
	Little River	Moderate	35
	Mad River	High	135
Interior Klamath	Middle Klamath River	Moderate	112
	Upper Klamath River	High	425
	Shasta River	High	500
	Scott River	High	450

Stratum	Independent Populations	Extinction Risk	Population Viability Metric (Williams et al. 2008)
	Salmon River	High	115
Interior Trinity	Lower Trinity River	High	112
	South Fork Trinity River	High	242
	Upper Trinity River	High	375
South Coastal Basin	Humboldt Bay tributaries	High	190
	Lower Eel and Van Duzen rivers	High	400
	Bear River	High	50
	Mattole River	High	250
Interior Eel	Mainstem Eel River	High	145
	Middle Mainstem Eel River	High	250
	Upper Mainstem Eel River	High	55
	Middle Fork Eel River	High	75
	South Fork Eel River	Moderate	47

Based on the above discussion of the population viability parameters, and qualitative viability criteria presented in Williams et al. (2008), NMFS concludes that the SONCC coho salmon ESU is currently not viable and is at high risk of extinction.

The precipitous decline in abundance from historical levels and the poor status of population viability metrics in general are the main factors behind the extinction risk faced by SONCC coho salmon. The primary cause of the decline is likely the widespread degradation of habitat, particularly those habitat attributes that support the freshwater rearing life-stages of the species. The demographic response to this impaired habitat has been a reduction in the number of fish and their range, which has made them less resilient to environmental stressors such as poor ocean conditions. The stressors and threats that contribute to the current status of SONCC coho salmon are discussed in Chapter 3.

2.4 Extinction and Recovery Trajectories

Population dynamics are extremely important to consider for recovery of species because the time-to-extinction decreases as the population size decreases (Caughley 1994, Fagan and Holmes 2006). This long standing theoretical prediction and empirically observed phenomenon of small populations (Fagan and Holmes 2006) highlights the importance of keeping currently healthy salmonid populations from reaching low abundance levels. In addition, it adds urgency to recovery efforts for those populations that are depressed.

Small populations are often defined as those having approximately 100 individuals (Treuren et al. 1991; Thomas 1990). For anadromous salmonids, small populations are defined as those that fall near or below the depensation (high risk) threshold. These populations can be affected by multiple forms of stochasticity, not all of which affect large populations (Lande 1993). The fact

that small populations can be affected by multiple forms of stochasticity results in extinction probabilities substantially greater than the extinction probabilities that would occur from of a single form of stochasticity (Melbourne and Hastings 2008). Williams et al. (2008) provides more specific guidance on assessing extinction risk for SONCC coho salmon populations given the state of various population parameters.

There are two broad classes of stochasticity: demographic stochasticity and environmental stochasticity (Caughley 1994). Demographic stochasticity occurs because the birth or death of an individual is a random event (Melbourne and Hastings 2008). Therefore, individuals that are identical in their probability distributions for reproduction or longevity can differ by chance in how many offspring they produce or when they will die (Melbourne and Hastings 2008). Environmental stochasticity occurs because fluctuations in external environmental factors (e.g., ocean condition and precipitation) drive population level fluctuations in birth and death rates (May 1973, Melbourne and Hastings 2008).

Two components of demographic stochasticity, are stochastic sex determination (Engen et al. 2003) and demographic heterogeneity (Kendall and Fox 2003, Melbourne and Hastings 2008). Stochastic sex determination, which can be viewed an extreme form of demographic heterogeneity, occurs because the sex of offspring is randomly determined, which gives rise to a stochastically fluctuating sex ratio in populations (Melbourne and Hastings 2008). Demographic heterogeneity refers to variation in birth or death rates among individuals within a population such as might occur among individuals of different size (Kendall and Fox 2003, Melbourne and Hastings 2008). This contrasts with demographic stochasticity which refers to chance events assuming a fixed value of the birth or death rate of an individual (Roughgarden 1975, Melbourne and Hastings 2008).

Fagan and Holmes (2006) found that the year-to-year rates of decline for a population were larger for smaller values of time-to-extinction, implying that the population dynamics of a species deteriorated as extinction neared. That is, a population size of n individuals within a decade of extinction is less valuable to the persistence than the same population size was earlier (Fagan and Holmes 2006). The findings of Fagan and Holmes (2006) are well supported by those of Frankham (2005), who found very strong evidence that inbreeding and loss of genetic variation contribute to extinction risk and species are impacted by genetic factors before extinction occurs. Similarly, Treuren et al. (1991) found that as a consequence of genetic drift, inbreeding and restricted gene flow, small and isolated populations (>119 individuals) show decreased levels of genetic variation.

If a population is too small, the survival and production of eggs or offspring may suffer because it may be difficult for spawners to find mates (Liermann and Hilborn 2001). Inbreeding, loss of genetic variation, and failure to find mates are all forms of depensatory mechanisms which cause depensation (Liermann and Hilborn 2001). The strict definition of depensation is when the per-capita population growth rate of a population decreases as the density or abundance of the population decreases to low levels (Liermann and Hilborn 2001). This is to be distinguished from the mechanisms that can contribute to depensation (i.e., failure to saturate predators and inbreeding). Even though there has been a lack of empirical evidence of depensation, the lack of evidence should not be interpreted as evidence that depensatory mechanisms are rare or unimportant (Liermann and Hilborn 2001).

Melbourne and Hastings (2008) found that when a population is small, the population could be at much higher risk from undetected demographic variance, even though risk of extinction from environmental stochasticity is typically viewed as being a greater threat to the population. This demographic variance is driven by sex ratio variation (e.g., in 1925, 91% of 295 coho salmon arriving below Copco Dam on the Klamath River were males; Snyder 1931) and demographic heterogeneity that has been mistakenly attributed to environmental stochasticity (Melbourne and Hastings 2008). The increased extinction risk is a consequence of the fact that, for the same overall level of variance in abundance for one generational step, sex ratio stochasticity and demographic heterogeneity give rise to greater variance than environmental stochasticity when population sizes are small and vulnerable (Melbourne and Hastings 2008). Therefore, fisheries managers which oversee small populations must recognize that these populations are likely to be at greater risk of extinction from genetic drift, inbreeding, restricted gene flow, failure to find mates, failure to saturate predators, and other depensatory mechanisms than they are from environmental stochasticity and other exogenous factors.

In the first phase of extinction, population instability occurs with population abundance fluctuating with a higher than normal amplitude (Figure 2-9). Anadromous salmonid populations are known to have large swings in abundance that are usually linked to variations in ocean productivity (Northcote and Atagi 1997; also see Chapter 3). This makes identifying the instability stage difficult for fisheries managers because they rarely have sufficient population abundance data with which to distinguish between population instability and natural population variability. In the decline phase there is a sustained period in which death rates exceed birth rates within one or more populations (Figure 2-9). Depending on the robustness the data and length of the dataset, the decline in the phase may or may not be evident by examining the trend in abundance over time. The collapse phase is characterized by reductions in the number or extent of occurrence. The extent of the occurrence of a species may erode from the edges (i.e., range contraction) or from gaps closer to the center of its range (i.e., fragmentation; Ewers and Didham 2005). In the terminal phase (Figure 2-9), a population is not likely to increase in abundance over any time interval before extinction (Fagan and Holmes 2006). Any increases in abundance are likely to be very short-lived (Fagan and Holmes 2006) and the reproductive success of the population depends on the success of a small number of individuals (Caughley 1994, Fagan and Holmes 2006). The longer a population stays in the small dynamics phase (Figure 2-9), the more likely it will go extinct.

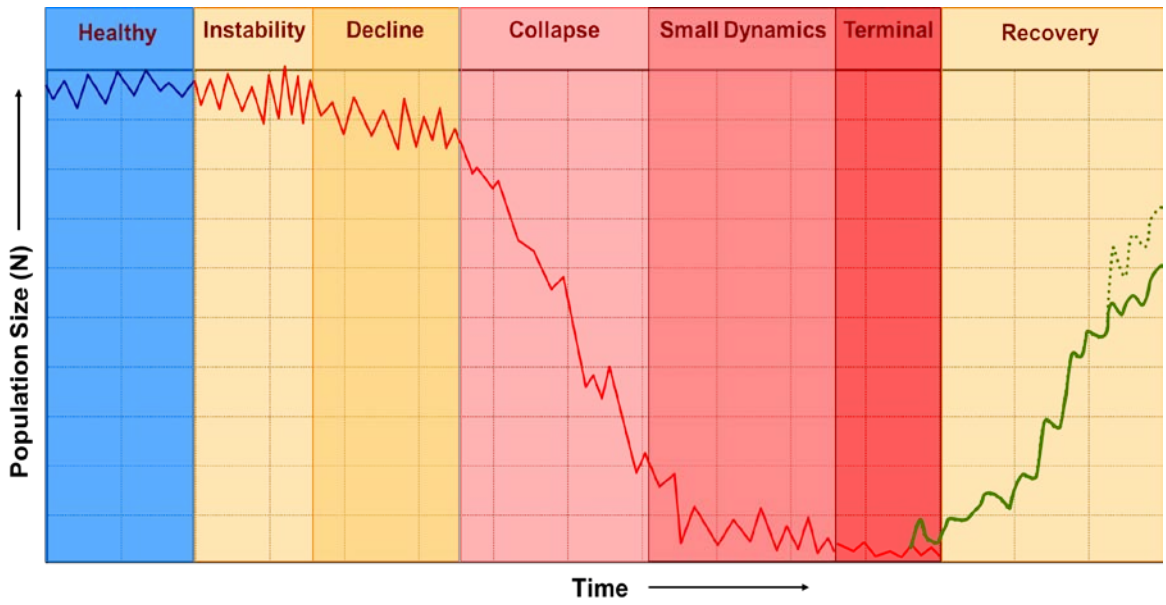

Figure 2-9. Conceptual diagram of the demographic extinction process. Diagram shows the size of a population over time through different stages. In the terminal phase, two possible trajectories for the population are extinction or recovery. Figure adapted from Johnson (2010).

For Snake River coho salmon which were monitored for 20 years preceding their extinction, the population size at which the final decline began (terminal phase) was 404 individuals (Fagan and Holmes 2006). After the population reached 233, there were no increases in the population in subsequent years, with a final population size preceding extinction of 6 individuals (Fagan and Holmes 2006).

In terms of recovery of small populations (those with fewer individuals than the depensation threshold) of anadromous salmonids, it is important to recognize that these populations are subject to both environmental and demographic stochasticity. This is unlike large populations which are, in general, only subject to environmental stochasticity (Lande 1993). Because small populations can be affected by more than one form of stochasticity, they have a much greater probability of extinction than large populations (Lande 1993, Caughley 1994, Melbourne and Hastings 2008). Once a population enters the small population dynamics phase it is equally important, if not more so (Melbourne and Hastings 2008), to recognize and consider that the population is at a substantial risk of extinction resulting from the demographic factors originating from within the population.