13. South-Central California Coast Steelhead Research, Monitoring and Adaptive Management

"The analytic tools to evaluate species health have been greatly developed in recent years. The emergence of extinction theory from population genetics and ecology, the combination of demography and genetics in population viability analysis and the extension of risk analyses into the realm of biological conservation promises to lead us to wiser allocations of effort in the future."

Science and the Endangered Species Act, National Research Council, 1995

13.1 INTRODUCTION

Recovery of SCCCS DPS will require a more complete understanding of the distinctive biology of steelhead within the SCCCS Recovery Planning Area. Additionally, it is important to identify a program for monitoring the status of individual populations and the DPS as a whole, and a plan for tracking and adjusting the recovery actions and recovery strategy over an extended period to optimize the effectiveness of recovery efforts. These research and monitoring activities should run in parallel with the recovery actions identified in Chapters 8 through 12, and are in some cases are dependent upon increasing the number of returning fish. The following sections outline the basic elements of a research, monitoring, and adaptive management program, and identify high priority research and monitoring actions.

13.1.1 South-Central California Steelhead Research

In 2002, NMFS convened a team of scientific specialists, the TRT, to survey existing scientific information on steelhead ecology, and formulate a biological framework for a recovery plan for the SCCCS DPS (Boughton *et al.* 2007b, 2006, Boughton and Goslin 2006, Boughton *et al.* 2005, Boughton and Fish 2003; see also Clemento *et al.* 2009, Girman and Garza 2006).

The current state of knowledge of steelhead ecology is largely descriptive and qualitative. This has led to uncertainties in the viability framework, including the quantitative goals for distribution and abundance of steelhead and the strategy to achieve these goals. In general, the TRT approached uncertainty about recovery goals with a risk-averse, or precautionary, approach, consistent with accepted practices in conservation biology (McElhany *et al.* 2000). The TRT also recognized key uncertainties involved in recovery planning arose from the qualitative nature of the current understanding, and could be improved by a carefully conceived and planned program of scientific research and monitoring. The potential benefits of pursuing such a program are a more effective and more-cost efficient recovery effort for steelhead.

Recovery of the SCCCS DPS will depend upon a quantitative framework addressing annual run size, along with year-to-year variability over the long term; and the quantitative response to specific recovery actions. These are related to the two overarching questions of steelhead recovery in the SCCCS Recovery Planning Area:

- How do we improve the distribution, abundance, and resilience of steelhead trout populations; and

- How much do we need to improve these biological characteristics for steelhead to be considered viable and eligible for delisting?

The following sub-sections focus on the viability criteria developed by the TRT, and a series of related research questions grouped into three areas: enhancing anadromy, clarifying the population structure of *O. mykiss*, and planning for climate change.

13.2 VIABILITY CRITERIA

The viability criteria addresses two levels of biological organization, populations within the SCCCS DPS (*i.e.,* only the anadromous form), and the more encompassing Evolutionarily Significant Unit (ESU), which includes all life history forms. The *O. mykiss* populations in this Recovery Planning Area are composed of both anadromous and non-anadromous fish, but only the non-anadromous form is on the threatened species list, under the DPS provision of the ESA. One of the principal uncertainties is the complicated relationship between the anadromous and non-anadromous (or freshwater-resident) forms of the species. Following convention, the term "steelhead" is used for the anadromous fish, "rainbow trout" for non-anadromous fish, and "*O. mykiss*" when referring to both or either. The goal of the Recovery Plan is to ensure the continued persistence of steelhead in the region over the long term (Boughton *et al.* 2007b), but it is likely that rainbow trout have some role in securing this future, and thus the viability criteria have provisions for both forms of the species.

13.2.1 Population-Level Criteria

The TRT considered *O. mykiss* in the SCCCS Recovery Planning Area to be grouped into demographically independent populations. Generally, each discrete coastal watershed in the region was assumed (based on the species high fidelity to its natal streams) to have historically supported (at least) one demographically independent population of *O. mykiss* (See Appendix A for the definition of an independent population.) If migratory steelhead frequently move from one watershed to another, the one-watershed-one-population assumption may have some important exceptions (*e.g.,* in the small watersheds within the Big Sur Coast and San Luis Obispo Terrace BPGs). Interactions between populations from geographically proximate watersheds could have significant implications for recovery planning, including determining the annual run-size in individual watersheds necessary to constitute a viable population. As noted below several watersheds may support a metapopulation that could be considered as a single viable population for the purposes of meeting the DPS recovery criteria.

The TRT proposed population-level viability criteria for determining whether a demographically-independent population of *O. mykiss* should be considered viable for the purpose of steelhead recovery. The TRT identified two choices for meeting the viability criteria. The first was to meet a set of criteria: an independent population must exhibit a mean annual run size of at least 4,150 steelhead, including during periods of poor ocean conditions (such as occurred from the late 1970s through early 1990s). Additionally, the spawner densities need to meet a minimum density threshold (fish per kilometer of stream channel at some scale), a quantitative criterion yet to be determined. The second choice was to meet a performance-based criterion, demonstrating extinction risk is less than 5% over 100 years. This criterion would use commonly accepted quantitative methods from conservation biology, *i.e.,* demographic data from the population in question.

Extinction risk is very sensitive to both annual run size and year-to-year variability. Due to this sensitivity the performance-based criteria cannot be applied in a meaningful way until run sizes have been monitored for a decade or more, allowing this key quantity to be estimated with reasonable accuracy. In the interim, use of the prescriptive criteria ensures year-to-year variability in run size, whatever its probable magnitude, is unlikely to pose a significant risk to the species. If year-to-year variability turns out to be relatively modest, a mean run size less than 4,150 steelhead would perhaps be sufficient to ensure a low extinction risk. Including the performance-based viability criteria option, provides a mechanism for refining the viability criteria as more is learned over time.

Extinction risk for individual steelhead populations may also be sensitive to the influence of rainbow trout, particularity if the trout tend to stabilize or augment anadromous runs by regularly producing anadromous progeny. This phenomenon is referred to as "life history crossovers," but it is not yet known whether such crossovers occur frequently enough to stabilize steelhead runs. This is another key uncertainty that, if resolved, might allow the run-size criterion of 4,150 spawners per year to be adjusted. In this case, the adjustment would be that some fraction of the 4,150 spawners within a watershed or metapopulation exhibit the anadromous life history, rather than 100%. Additionally, data on the magnitude of natural fluctuations in anadromous run sizes in individual watersheds may identify a smaller mean run size is sufficient for viability in some basins (Williams *et al.* 2011). Until such research is undertaken and revisions made to the viability criteria, the numeric criterion for independent population is set at 4,150 adult spawners per year. This criteria will be reviewed during NMFS's 5-year review of the Recovery Plan, and potentially during the Southwest Fisheries Science Center's 5-year status review update for Pacific salmon and steelhead listed under the ESA.

In the absence of specific information about the role of life history crossovers, the TRT took a precautionary approach (*i.e.,* it was assumed there was not any beneficial effect of crossovers). This meant that the 4,150 spawners per year are composed entirely of the anadromous form of O. mykiss, rather than a mixture of rainbow and steelhead. Nonetheless, the TRT also believed the criteria should cover the possibility that the beneficial effects of crossovers not only exists, but is necessary for viability of the listed species. This led to adoption of additional criteria specifying the anadromous and freshwater resident life history types should both be expressed in populations targeted in this recovery plan for them to be considered viable.

As noted, if rainbow trout progeny crossover does in fact have a beneficial effect on steelhead runs - and its magnitude can be quantified - such knowledge could be used to revise the criteria for anadromous fraction criteria, or it could be incorporated into a performance-based assessment of risk, possibly resulting in different run size and anadromous fraction criteria.

13.2.2 ESU/DPS-Level Criteria

The TRT outlined a set of ESU/DPS-level criteria, which, if met, would indicate that the SCCCS DPS has been successfully recovered. Satisfying the ESU/DPS-level criteria requires a set of *O. mykiss* populations in which:

- ❑ Each population satisfies the population-level criteria described above,
- ❑ The set of populations as a whole satisfies requirements for ecological representation and redundancy, and
- ❑ The set of populations as a whole exhibit all three life history types (fluvial-anadromous, lagoon - anadromous, freshwater resident)

The criteria for representation and redundancy have two purposes:

1. to protect the genetic and ecological diversity that ensures the long-term viability of the species under changing conditions, the set of populations should represent the entire range of ecological and genetic conditions originally present in the ESU/DPS, and

2. to protect against catastrophic loss of entire populations due to disease, wildfires, drought, *etc.*, the set of populations should exhibit redundancy with respect to the range of ecological and genetic conditions originally present in the ESU. This ensures that if, for example, entire populations are lost from a particular ecotype, there will be at least one other population in that ecotype that survives, and can serve as a reservoir of individuals retaining the genetic and phenotypic adaptations necessary for inhabiting that ecotype. Ultimately, such individuals would be necessary for recolonizing all the remaining core watersheds in the ecotype.

The TRT developed criteria for representation and redundancy by grouping the region's populations of *O. mykiss* into biogeographic groups, and specifying a minimum level of redundancy (number of viable populations) within each group. In addition, the TRT recommended that the core populations should inhabit watersheds (with drought-resistant refugia habitat) that are separated from one another by at least 42 miles (if possible), and should exhibit the three previously described life history types.

The biogeographic groups were delineated on the basis of geographic proximity, broadly similar climate, and aspects of physiography that are relevant to the fish (see Table 5 and Figure 5 in Boughton *et al.* 2007b). Summer air temperatures, which strongly influence whether summer stream temperatures are cool enough for the fish, were a key consideration. The most important split was between coastal groups of populations, in which cool mesoclimates are maintained by proximity to the ocean, and interior groups of populations, where cool mesoclimates are primarily confined to mountain ranges, and are maintained by the temperature lapse rate (*i.e.*, the reduction in temperature with increased elevation), moist (transpiration), riparian shading, or by a coastal lagoon (via proximity to the ocean heat sink). As noted in Chapter 2, sparsely shaded higher elevation habitats can also produce higher water temperature conditions; conversely, lower, shaded habitats can produce cooler conditions. Lagoon water temperatures are also influenced by stratification of the water column driven by on and offshore winds.

The criteria for redundancy within each biogeographic group were based on an assessment of catastrophic risks posed by wildfires and debris flows. However, the assessment was based on historical patterns and did not reflect specific climate change drivers for which quantitative data at a regional scale is unavailable, but which could have a large impact on the region as discussed in Chapter 5, South-Central California Coast Steelhead and Climate Change.

The TRT also considered the catastrophic risk posed by drought, but could not incorporate it into the criteria due to insufficient information. The broad spatial extent of the typical drought in the region indicated redundancy was not a suitable strategy for protecting the species from the impacts of drought conditions. Watersheds having potential as drought refugia—stream systems that maintain suitable summer baseflows and water temperatures during severe multi-year droughts – should be identified and protected.

The broad-scale climatic factors that control the distribution of *O. mykiss* in the region appear to be summer air temperatures, annual precipitation, and the severity of winter storms. Winter storms determine the power of high flow events that organize the distribution and extent of in-stream steelhead habitat (see further discussion in Chapter 7, Steelhead Recovery Strategy, section 7.5). All of these factors are likely to undergo a long-term shift as part of CO_2-induced climate change. In addition, the region's frequent wildfires strongly influence the sediment budgets of streams, and thus the distribution of steelhead habitat. The overall wildfire regime is also likely to undergo a shift in response to climate change. The magnitudes of these shifts, and the magnitude of their direct and interaction effects on stream habitat, are not yet clear. A key uncertainty is how to plan for climate change both at the level of the SCCCS Recovery Planning Area and individual watersheds.

13.3 RESEARCH FOCUS: ANADROMY, POPULATION STRUCTURE, AND MONITORING STEELHEAD RECOVERY

Steelhead habitats in the SCCCS Recovery Planning Area maintain a stochastic, dynamic equilibrium. This equilibrium involves dramatic processes such as floods and forest fires that disrupt habitat in the short term but ensure its continued existence over the long term by providing essential habitat features such as instream structure and spawning gravel. Other processes that influence the productivity of freshwater steelhead habitat, such as the severity of warm air temperatures during the dry season or the pattern of high-flow events during the wet season, may affect reproductive success by altering habitat suitability. These ecological constraints are generally understood at a qualitative level, but this level of knowledge is, in some cases, too vague to provide specific guidance for setting goals and designing specific recovery actions. The research program supporting steelhead recovery in this region should focus on quantitative studies that: 1) identify ecological factors promoting both life history types of anadromy; 2) clarify key aspects of population structure; and 3) monitor progress toward recovery. Many of these research activities could be carried out at the life cycle monitoring stations described in the California Coastal Salmonid Population Monitoring Program (Adams *et al.* 2011; see also Table 13-1).

13.3.1 Identify Ecological Factors that Promote Anadromy

The primary focus of this Recovery Plan - to recover and secure the anadromous form of *O. mykiss* - involves restoring ecological conditions that specifically support the population growth and abundance of the anadromous form.

While it is necessary to have migration corridors for steelhead to reach a spawning area, this does not necessarily imply anadromous forms will out-compete the freshwater residents that spawn in the same area. At present it is not clear what ecological conditions specifically promote the sea-going form over the resident form though there are some important clues. These clues present a prime opportunity for research that would lead to more effective recovery actions.

Anadromous females exhibit a large fecundity advantage over their resident counterparts. As shown in Figure 13-1, an adult female's egg production increases exponentially with body length, and adult *O. mykiss* are generally able to attain much larger sizes in the ocean than in freshwater.

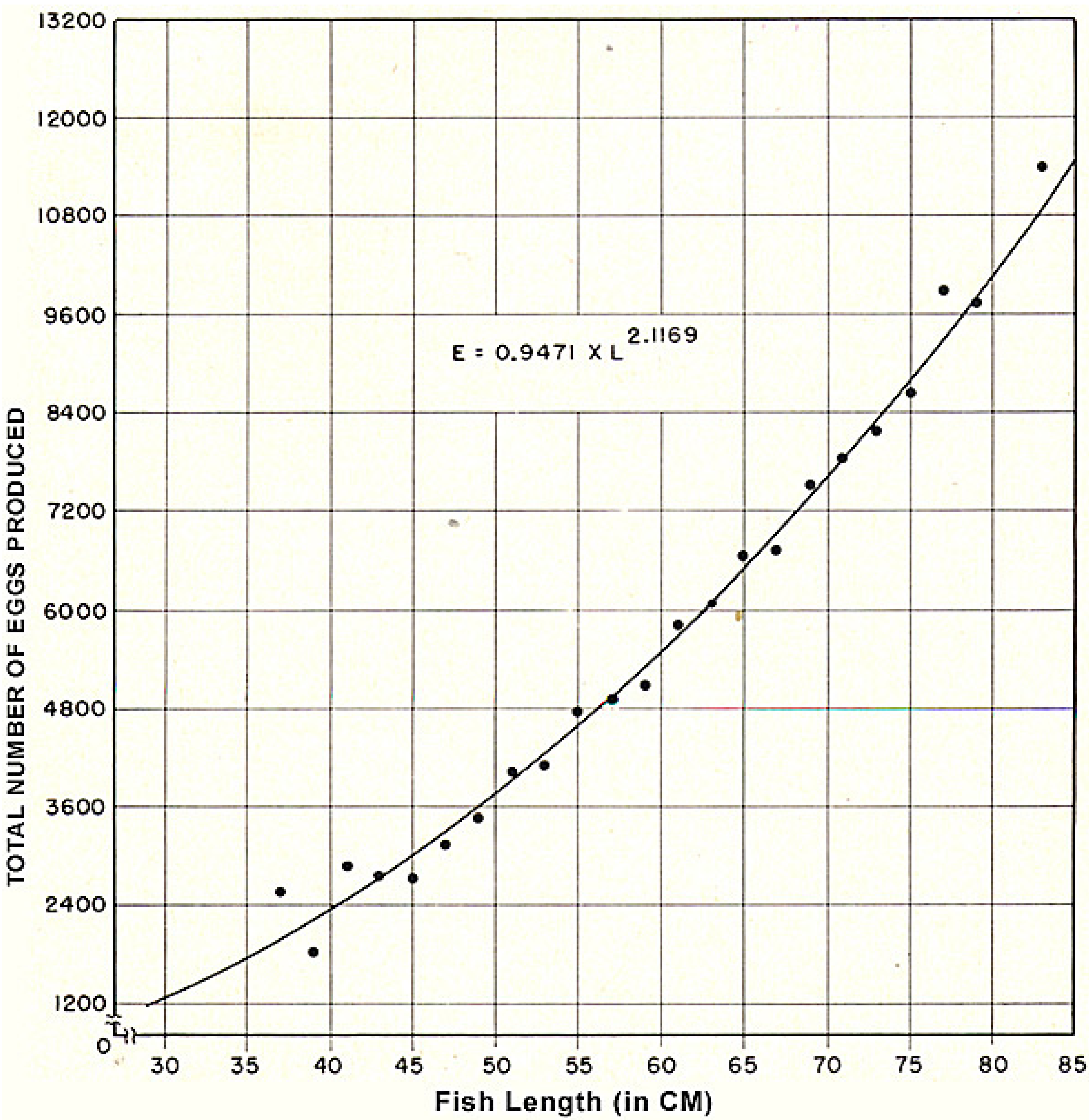

Figure 13-1. Fecundity as a function of body size for female steelhead sampled from Scott Creek in Santa Cruz County. Reproduced from Shapovalov and Taft (1954).

A typical female rainbow trout might attain a length of 35 cm, enabling her to produce 1800 eggs annually, whereas a medium sized steelhead female at 60 cm could produce over 3.5 times that number. This factor alone gives the sea-going form a distinct advantage and, all else being equal (and assuming the two forms do not interbreed to a significant degree), over time the sea-going form should dominate any stream system with migration connectivity to the ocean. The resident forms would become confined to streams which lack migration connectivity to the Pacific Ocean. This pattern has been observed, for example, in the Deschutes River in Oregon (Zimmerman and Reeves 2000).

In South-Central California, three ecological factors could potentially counteract this size advantage so the resident form is sometimes favored in anadromous waters. First, the migration corridor between the ocean and freshwater habitat is often unreliable. Second, mortality may sometimes be much higher in the ocean than in freshwater, counteracting the potential size advantage of sea-going fish. Third, juveniles of the freshwater form may survive better or compete better in freshwater than juveniles of the sea-going form, which could also counteract the natural size/fecundity advantage of the sea-going form. Of these three possibilities, the first two are supported by various lines of evidence, and the third has some suggestive evidence. The need is to move beyond existing evidence to a quantitative understanding of ecological mechanism, so that specific recovery strategies can be linked to desired outcomes.

13.3.2 Reliability of Migration Corridors

Question: What is the relationship between reliability of migration corridors, and anadromous fraction?

Discussion: Migration corridors in this region, particularly in watersheds with deep interior populations, are clearly unreliable under current conditions. It is not clear how reliable they must be for the anadromous form to persist over the long term, nor how to best characterize reliability.

Recommendation: The relationship between flow patterns in managed rivers, the reliability of migration opportunities, and the long term persistence of steelhead runs is likely watershed specific, but could be characterized through the establishment of a long-term monitoring effort that tracks abundance and timing of steelhead runs, and the timing of smolt runs, in specific watersheds of interest. This would provide a framework to inform management actions, for managed flow regimes, to maximize the protection and conservation of the species during critical migration and rearing periods.. However, answers would probably emerge only over the long term, and numerous confounding factors would also need to be taken into account by the monitoring framework.

13.3.3 Steelhead-Promoting Nursery Habitats

Question: What nursery habitats promote rapid growth rates of juveniles (and therefore larger size) at the time smolts emigrate to the ocean?

Discussion: Marine survival varies among salmonids, ranging from 25% to below 1% (Welch *et al.* 2009, Logerwell *et al*. 2003, Peterson and Schwing, 2003, Ward 2000, Ward *et al*. 1989). Improving the marine survival rate of steelhead would be beyond the scope of most management strategies, since steelhead are rarely fished and other sources of ocean mortality are largely uncontrollable. However, mortality rates of many marine fishes are strongly size-dependent. Consistent with this general pattern, young steelhead migrating to the sea tend to survive much better if they have a larger size at ocean entry (Hayes, *et al.* 2008, Bond, 2006, Ward *et al*. 1989). Growth opportunities in freshwater may significantly influence subsequent marine survival.

Figure 13-2, indicates that an outgoing smolt with a fork length of 14 cm has about a 3% chance of surviving to spawn, but a 16.5 cm smolt's chances are at least 3.5 times better (*c.* 10%), and a 22 cm smolt's chances are an order of magnitude better (37%). The mortality effects of size at ocean entry can be of the same order as the fecundity advantages of migrating to the ocean in the first place.

A similar relationship between survival and size at ocean entry was observed by Bond (2006) and Hayes *et al*. (2008) in Scott Creek in Santa Cruz County, which is close to the northern boundary of the SCCCS DPS. Size at ocean entry appears to be at least as important as final spawning size in modulating the relative abundances of the freshwater and ocean-going forms of *O. mykiss.* [1]

[1] Its importance can vary over time, however. Ward (2000) observed that after 1989, marine survival drastically declined in the Keogh River population, and the relationship disappeared between marine survival and size at ocean entry. This was attributed to a change in ocean conditions, and indicates that the survival advantage of being a large smolt varies over time.

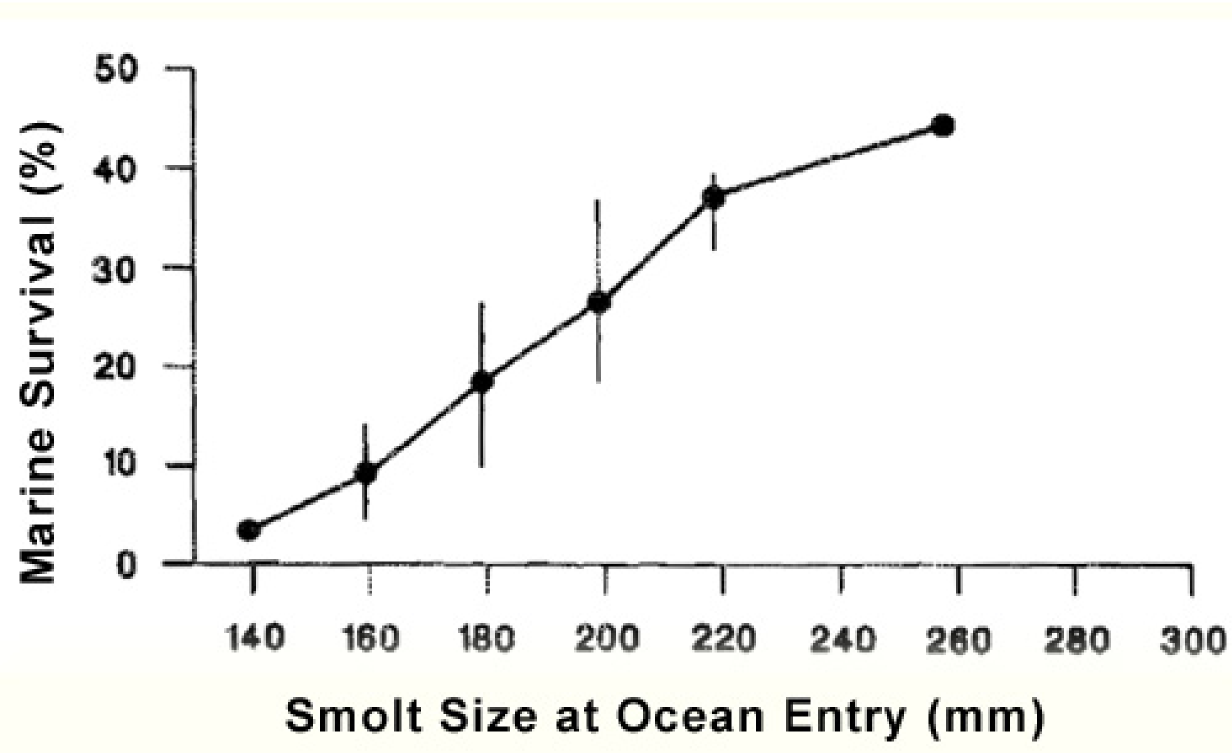

Figure 13-2. Marine survival of steelhead as a function of body size at ocean entry, in the Keogh River steelhead population described by Ward *et al*. (1989). Figure depicts the average survival to spawning of smolts emigrating in years 1977 - 1982.

High quality steelhead nursery habitats might develop where cool-water habitats receive large terrestrial inputs of food items. Terrestrial insects often fall in the water (Harvey *et al*. 2002, Douglas *et al.* 1994), and can provide a significant component of the diet of young steelhead (Rundio 2009, Rundio and Lindley, 2008). The study by Rundio and Lindley (2008) in the Big Sur area found terrestrial insects were sporadic in the diet of *O. mykiss*, but each item had large mass and was highly nutritious for the fish. Habitats with more frequent inputs of terrestrial insects would afford larger growth opportunities.

Additionally, some habitats might produce rapid growth if there is a mechanism to keep juvenile densities low, so that individuals have expanded feeding opportunities. For example, it might be the case that intermittent streams provide expanded feeding opportunities during the wet season, because their seasonal low flows prevents the establishment of a large permanent population of resident rainbow trout.

Finally, this suggests recovery prospects for steelhead runs could be significantly improved by identifying, restoring, and protecting freshwater habitats that produce large smolts, as part of the overall recovery strategy. These areas would qualify as steelhead "nursery habitats," defined as juvenile habitats that produce adult recruits out of proportion to their spatial extent relative to other habitats (Beck *et al*. 2001).

Recommendation: Identification and restoration of steelhead nursery habitats is a prime research opportunity with large potential for enhancing steelhead recovery efforts. Nursery habitats would likely be estuarine or freshwater habitats (including some small on-channel impoundments and/or areas with augmented summer flow) supporting rapid growth of young fish during the first or possibly second year of life, since large body size of migrants at ocean entry substantially improves their subsequent survival in the ocean (Moore 1980, Smith and Li 1983, Smith 1982, Casagrande 2010). The simplest type of study to identify such habitats would be to use mark-recapture techniques to track growth and survival of juveniles as a function of habitat use. A more complete study would also track the consequences for marine survival.

13.3.4 Comparative Evaluation of Seasonal Lagoons

Question: What role do seasonal lagoons play in the life history of steelhead, in particular, to what extent are seasonal lagoons used as nursery areas and promote growth of juveniles prior to emigration to the ocean? What specific ecological factors contribute to lagoon suitability steelhead rearing (survival, growth)? What ecological factors contribute to the persistence of those lagoon features?

Discussion: One type of steelhead nursery habitat is the freshwater lagoons that form in the estuaries of many stream systems during the dry season. In some of these seasonal lagoons, juvenile steelhead can grow very quickly and enter the ocean at larger sizes, where they survive relatively well and contribute disproportionately to returning runs of spawners (Bond, 2006). Smith (1990), however, has observed that some lagoons can be quite vulnerable to rapid degradation in quality, and others may never be suitable, due to local environmental factors that can produce anoxic conditions or poor feeding opportunities. The existing information on the role of lagoons mostly comes from Santa Cruz County, and is focused only on a few systems. As described above, this work suggests that lagoons can comprise steelhead nursery habitat, but can also be vulnerable to various natural and anthropogenic disturbances (Smith, 1990). There is a need to determine which lagoons have the potential to play a positive role in anadromy-targeted recovery efforts.

Seasonal lagoons are a specific kind of estuary and in general, estuaries are highly dynamic interfaces between two other much larger ecosystems: freshwater stream networks on the terrestrial side, and the ocean ecosystem on the marine side. This accounts for estuaries' dynamism, complexity, and sensitivity to external influences, but also for much of their productivity (Hofmann, 2000; Jay *et al.* 2000). Although there appears to be a general unity in function of many of the small estuaries in the region (due to the general similarity of climate, terrestrial watershed conditions, and the raised coast), there is also significant variation due to small differences watershed condition or coastal wind and current patterns *etc*. which can, translate into large differences in the suitability of lagoons as steelhead nursery habitat (Rich and Keller 2013, 2011).

Recommendation: Comparative studies on the environmental controls for productivity and reliability of lagoon habitat (including how to restore it if necessary) would aid in identifying estuaries currently capable of serving as reliable steelhead nursery habitat and estuaries which could be restored to support these habitats in the future. Such studies should focus on factors enabling rapid growth of juvenile steelhead, identification of limiting factors and restoration potential, and factors conferring resiliency against catastrophic failure of habitat quality (anoxia, premature breaching, *etc*.).

13.3.5 Potential Nursery Role of Mainstem Habitats

Question: What role do mainstem habitats play in the life history of steelhead, and in particular, to what extent are they used as nursery areas and promote the growth of juveniles prior to emigration to the ocean as smolts? What specific ecological factors contribute to mainstem quality (survival, growth) for steelhead rearing? What ecological factors contribute to mainstem reliability?

Discussion: There may be other freshwater habitats that support high survival and robust growth of juveniles, and so constitute nursery habitat specifically for the anadromous form of the species. Low-gradient mainstem habitats, such as the mainstems of the Pajaro and Salinas Rivers may also have once supported rapid growth of juveniles, particularly if reaches received enough sunlight to support primary productivity and where artesian flows or other groundwater inputs kept water sufficiently cool in the summer (C. Swift, personal communication). Most mainstem (including riparian) habitats have now been highly altered by agricultural clearing high rates of sediment input, and groundwater pumping, so an effort to determine their potential to contribute to steelhead recovery would require a focused effort. However, lower mainstems with sandy substrates, such as the Pajaro and Salinas Rivers, with naturally low summer flows, and seasonally hydrologically disconnected from upstream spawning and rearing habitat, may have provided limited over-summer rearing opportunities prior to major watershed development (see Snyder 1913).

Recommendation: The potential nursery role of mainstem habitats is much more speculative than the nursery role of lagoons because mainstem habitats were degraded prior to most modern fishery assessments. Initial assessment of the potential nursery role could take the form of 1) empirical study of mainstem habitat use by juvenile steelhead, at broad and fine scales; and 2) water-temperature modeling that accounts for effects of climate, insolation, food availability and groundwater interaction on mainstem water temperatures, especially during the summer. The empirical work would be most useful if it applied mark-recapture techniques to assess growth and survival as a function of habitat use, and in managed rivers, as a function of the flow regime.

13.3.6 Potential Positive Roles of Intermittent Creeks

Question: Do intermittent creeks (*i.e.,* those in which some reaches only flow seasonally), serving as steelhead nursery habitat, positively influence the anadromous fraction of *O. mykiss* populations, or otherwise enhance viability of the anadromous form of the species?

Discussion: Juvenile *O. mykiss* are common in intermittent creeks (Boughton *et al*. 2009), but it is unclear whether these only function as sink habitat (a net drain on productivity) or play a more positive role in population viability. Boughton *et al.* (2009) observed during the early summer in a moderately wet year, densities of young-of-the-year *O. mykiss* were nearly identical in the perennial and intermittent creeks of the Arroyo Seco watershed in Monterey County. Much of the intermittent creeks dried up and killed juveniles later in the summer, and indeed such mortality has been observed in the region for many years (Shapovalov 1944), although it is also common to find scattered residual pools or reaches packed with fish in late summer. For example, Spina *et al.* (2005) observed fish in San Luis Obispo creek moving into sections of the stream network retaining perennial flow as other streams dried out over the summer months. The important issue for recovery purposes is identifying the potential positive, rather than negative, roles of intermittent creeks in sustaining the viability of steelhead populations.

The most obvious positive role is that intermittent creeks provide migration corridors to perennial creeks during the wet season. Perennial reaches often occur in low-order streams upstream of intermittent sections, so the corridor role increases the amount of accessible perennial habitat, and the potential size of the steelhead population.

Boughton *et al*. (2009) found most spawning habitat in the Arroyo Seco system tended to occur in intermittent streams, and argued that hydrologic and geomorphic processes would tend to produce such a pattern in general. This suggests a second positive function of intermittent streams—significantly expanding the amount of spawning habitat beyond what is available in perennial streams—but it also suggests a need for an additional migratory corridor function. In this case, the corridor function is for young-of-the-year to emigrate to perennial reaches before the summer dry season traps and kills them.

It is possible that intermittent streams enable a high-risk, high-reward strategy on the part of young steelhead. Many individuals may be killed during the summer drying season, but those surviving in residual pools may benefit from enhanced growth. One mechanism for enhanced growth may be cannibalism of trapped cohorts. However, the high food demands and small portion that actually result in growth may require that most of the fish would be consumed. Another mechanism for rapid growth may be rapid recolonization of the dried stream channels as flows become re-established with cooler, wet weather in the fall.[2] Such fish would find few competitors, and perhaps even an enhanced opportunity to feed on eggs and fry of the following winter's spawners (Ebersole *et al.* 2006). In this manner, intermittent creeks could serve as steelhead nursery habitat.

In wet years, the seasonal drying may be substantially reduced, increasing summer survival and allowing large pulses of juveniles to be recruited to the subpopulation of adult steelhead in the ocean. Under some scenarios, such as a highly plastic life history strategy (see next section), it is possible such pulses would be the primary mode of production for anadromous individuals, and sustain the anadromous form of the species over the long term.

Recommendation: Intermittent creeks comprise a large proportion of freshwater *O. mykiss* habitat in the region. Despite an obvious negative role in the species ecology, they may have important positive roles as well. These potentially positive roles have the status of hypotheses with general implications for recovery strategies and viability targets, and should be tested.

13.3.7 Spawner Density as an Indicator of Viability

Question: What spawner density (at what spatial and temporal scale) is sufficient to indicate a viable population of steelhead?

Discussion: Answering this question requires one or more robust anadromous populations be carefully characterized (*e.g.*, San Carpoforo and Arroyo de la Cruz Creeks in the San Luis Obispo Terrace BPG). The answer is more useful in the long-term, as an indicator of progress toward recovery, than it is in the short term. The most useful data would be a time-series of observations of spawner density over many years.

Recommendation: Monitor a select number of Core (and potentially non-Core populations) to determine the numbers of spawners using both mainstem and tributary spawning habitats.

13.3.8 Clarify Population Structure

Discussion: Population structure is shaped by the ecological and biological factors that cause fish to naturally group into functional units known as independent populations. Independent populations are defined as "a collection of one or more local breeding units

[2] Fall rains can re-establish flows, but flows may also be re-established by cooler fall weather, which presumably lowers transpiration demands of riparian vegetation, leaving more groundwater to maintain base flows in stream channels.

whose population dynamics or extinction risk over a 100-year time period is not substantially altered by exchanges of individuals with other populations" (McElhany *et al*. 2000). These groups may in some cases be as small as those occurring in individual tributaries, or groups of tributaries within a single watershed (*e.g*., Arroyo Seco within the Salinas River watershed, upstream tributaries with the Carmel River watershed).

If groups of fish regularly exchange individuals, they are members of the same population, whereas if exchange is rare or does not significantly affect population dynamics, they are members of separate populations. This definition of "separateness between, exchanges within" means that the proper context of most management strategies is the independent population: a recovery strategy that directly affects only a portion of a population will soon have significant indirect effects on the rest of the population, but few immediate effects on other independent populations. [3]

The independent population is also the fundamental functional unit for steelhead viability in a biogeographic area. As a result, many of the viability criteria described by Boughton *et al.* (2007b) were defined in terms of population traits such as anadromous fraction and mean spawner abundance over time. The collections of fish to which these criteria should be applied are a function of what is known about the patterns of exchange of fish among breeding biological units. Open questions about such exchange result in uncertainty in application of the criteria.

[3] Over the longer term, a permanent change in population dynamics *would* be expected to extend to other independent populations, due to occasional exchanges of individuals. Occasional exchanges are expected to drive important processes such as gene exchange and recolonization of stream systems following a drought or other causes of local extirpation.

An analysis of a simple quantitative model led Boughton *et al*. (2007b`) to conclude an annual adult abundance of 4,150 fish was necessary for an independent population to be considered viable. But it was unclear, due to questions of exchange patterns, whether the criteria should be applied to:

- ❑ anadromous fish in a particular watershed; or
- ❑ the sum of anadromous fish across several watersheds; or
- ❑ the sum of anadromous and freshwater-resident fish in a particular watershed; or
- ❑ the sum of anadromous and freshwater-resident fish across several watersheds

The answer to these questions of exchange patterns has implications for the scope and scale of recovery efforts. The answers depend on the level of exchange of fish across separate coastal watersheds, and on the level of exchange between the anadromous and resident forms of the species within a particular watershed—termed 'life history crossovers". A life history crossover is a freshwater parent that has anadromous fish among its progeny, and/*or vice versa.*

Questions about life history crossovers and dispersal between watersheds, and the implications for viability criteria are addressed in the following three sections, 13.3.9 through 13.3.11.

13.3.9 Partial Migration and Life History Crossovers

Question 1: What is the mechanism for, and frequency of, life history crossovers in South-Central California?

Question 2: How does crossover affect the persistence of the anadromous form?

Partial migration is the phenomenon in which a population consists of both migratory and resident individuals (Jonsson and Jonsson, 1993), implying the regular or at least occasional occurrence of life history crossovers. A diversity of crossover patterns have been observed in the small number of studies conducted on *O. mykiss* to date. Zimmerman and Reeves (2000) observed no crossovers in resident and anadromous *O. mykiss* of the Deschutes River in Oregon, suggesting two demographically distinct populations. For one natural and eight hatchery populations in California, Donohoe *et al.* (2008) found anadromous females sometimes produced resident progeny, but resident females did not produce anadromous progeny, suggesting a one-way flow of crossovers away from the anadromous form.

The Babine River *O. mykiss* in British Columbia apparently exhibit modest levels of crossover (*c.* 9%) in both directions (Zimmerman and Reeves, 2000), suggesting a single population that is partially subdivided, whereas J. R. Ruzycki (personal communication in Donohoe *et al.* 2008, p. 1072) reports a high level of bi-directional crossover in various tributaries of the Grande Ronde River in Oregon (0% to 33% of anadromous adults were progeny of resident females, and 44% of resident adults were progeny of anadromous females), indicating a fully integrated population where the two life history forms functionally coexist.

This continuum has significant implications for viability criteria. Are the populations in South-Central California fully integrated, or do they avoid interbreeding. Boughton *et al.* (2007b) made recommendations that embodied these two possibilities (actually two endpoints of a continuum). In one scenario, criteria should be specified that would secure the ocean-going fish if they turn out to comprise a demographically independent population. Under the other scenario, criteria should be specified that secure the ocean-going fish if they depend on the resident form.

Answering the first question will take an extended research effort because it necessarily involves multiple populations studied over a number of years. Currently, staff from NOAA's SWFSC and UC Santa Cruz are leading a research effort to better understand life history crossovers in California steelhead. Mangel and Satterthwaite (2008) give an overview of the framework being used. Their hypothesis is that the anadromy/residency life history crossover made by individual *O. mykiss* is cued by the environment, using a mechanism similar to what has been observed in Atlantic salmon (*Salmo salar)*, a better-studied species that also exhibits variation in the timing of the smolting process during life history. Specifically, the hypothesis is that the smolting/residency life history crossover is made by individual fish during a sensitive period some months before the actual process of smolting is observed, and that the cues for the crossover are the fish's size and growth rate during the sensitive period. This might be expected because size and growth in the freshwater habitat integrate information about the quality of that habitat, as well as about the expected survival and fecundity in the marine environment versus the freshwater environment. What is hypothesized is a physiological (and perhaps hormonal) process that processes information from the environment to produce an adaptive life history crossover (see Hayes, *et al*. 2012, 2011, Satterthwaite *et al.* 2012, 2010, 2009).

Though this research is important progress on the anadromy/residency life history crossover phenomenon, it has limitations including a hypothetical framework subject to substantial uncertainties due to the use of a surrogate species from the Atlantic Ocean, and possible genetic constraints. At this time life history crossovers in *O. mykiss* have not been induced by manipulating size, growth rates or any other environmental factor. Also, the existence of a plastic life history strategy does not preclude the possibility of important genetic constraints. Even if the current model is broadly correct, the specific timing of sensitive periods, and the thresholds for the size and growth cues, could vary markedly among populations of steelhead due to genetic differences. The responses to environmental cues would therefore likely have a heritable component, and exhibit local adaptation to specific conditions.

Recommendation: Research on the mechanisms of life history plasticity in *O. mykiss* should be vigorously pursued. A successful recovery effort is unlikely without a better understanding of the functional relationship between resident and anadromous fish. Genetic markers might prove useful for distinguishing resident and anadromous fish in juvenile samples. Current research efforts should yield useful information over time, but these efforts focus on systems outside the SCCCS Recovery Planning Area: Soquel Creek in Santa Cruz County (a coastal redwood forest system near the northern boundary of the SCCC DPS), and the American River near Sacramento, California (a large Central Valley River system). Due to local adaptation of steelhead populations in South-Central California, some of the conclusions from these ongoing studies may not be directly applicable, particularly for the interior populations.

Because of the likelihood of local adaptation, it would be useful to address some related questions about the frequency of life history crossovers and their implications for recovery planning in the SCCCS Recovery Planning Area. In particular:

- Identify environmental factors that specifically promote anadromy (discussed in the previous section). It is clear that the abundance of anadromous fish needs to be increased, and identifying relevant environmental factors would inform this goal. The principal uncertainty is how much the abundance of anadromous fish needs to be increased, a separate question depending on the frequency of life history crossovers and the mechanisms underlying them. This question can be addressed over the longer term as more is learned about the mechanism, and used to refine the viability criteria described by Boughton *et al.* (2007b).

- Estimate the frequency of life history crossovers in the populations of interest, to determine whether it even occurs with any regularity. The most practical method for doing so is by analyzing otolith microchemistry of juvenile *O. mykiss* (see Donohoe *et al.* 2008), but this requires lethal sampling of juveniles. Modest lethal sampling of juveniles (as opposed to adults) may pose only a negligible increase extinction risk, due to the low reproductive potential of juveniles.

- Determine how life history crossover affects the persistence of the anadromous form. This could be done using existing frameworks in population modeling, such as individually-based models or integral projection models. Results from these studies should produce important insights. For example, persistence of anadromous runs could be strongly affected by the difference between complete lack of crossovers and a modest rate, such as 5%. It would be useful to more rigorously evaluate the validity and relevance of these levels of life history crossovers.

13.3.10 Rates of Dispersal Between Watersheds

Question: How common is dispersal of anadromous *O. mykiss* between watersheds, and how does it relate to population structure, especially in small coastal watersheds?

Discussion: Just as life history crossovers may knit resident and anadromous *O. mykiss* into integrated populations, frequent movement of anadromous fish through the ocean to neighboring watersheds may knit neighboring *O. mykiss* into integrated "trans-watershed" populations. If inter-watershed exchange is common, the most effective recovery strategies might be those that emphasize integration of recovery efforts across a set of linked watersheds. If inter-watershed exchange is rare, the most effective strategies would be identifying watersheds with stable conditions to protect small, inherently vulnerable populations.

The places where the implications of the single-watershed versus trans-watershed scenarios are most distinct are those areas along the coast where numerous small coastal watersheds occur in close proximity. In the SCCCS Recovery Planning Area, these areas include the small watersheds along Big Sur Coast BPG in Monterey and northern San Luis Obispo County, and the small watersheds within the northern portion of the San Luis Obispo Terrace BPG, in San Luis Obispo County.

Recommendation: Answering this research question will involve tracking the populations from multiple watersheds, including groupings of small, closely spaced watersheds as well as groupings involving large and small watersheds more spatially dispersed. However, it is not clear at this time what is the most practical and effective way to try to estimate exchange rates in the SCCCS Recovery Planning Area. Genetic and Radio Frequency Identification (RFID) tags and ecological traps may have potential to effectively address this question, particularly in small basins where it is possible to sample a significant fraction (perhaps all) of a given cohort of adults.

13.3.11 Revision of Population Viability Targets

In the framework described by Boughton *et al.* (2007b), the key criteria for establishing population viability was sustaining a long-term mean run size of at least 4,150 anadromous spawners per watershed per year. However, the authors noted that the criteria were precautionary due to scientific uncertainty about key issues, and that better information might allow the criteria to be revised without increasing the risk of extinction. There were three types of information that seemed most likely to lead to useful revisions of the viability criteria:

1. The threshold run size could be revised downward (but also possibly upward in some cases) from 4,150 spawners per year if it was determined that year-to-year variation in run size was modest enough to be consistent with a lower threshold. The necessary information, annual estimates of run size over several decades, would come from the types of monitoring programs described below.

2. Data on the frequency of life history crossovers might justify the 4,150 threshold could include some fraction of adult resident fish, rather than the 100% anadromous fraction currently recommended (*i.e.,* because the resident and anadromous forms are shown to comprise functionally integrated populations). The necessary information would come from successfully implementing the recommendations identified above.

3. Data on inter-basin exchanges might justify that the 4,150 threshold include spawners from neighboring watersheds (*i.e.,* because inter-watershed exchanges is sufficiently high that the fish in neighboring watersheds comprise a single, trans-watershed population). The necessary information would come from successfully implementing the recommendations identified above.

It should be noted that data for item 1 would arise over time as a byproduct of a comprehensive monitoring program, which is necessary to assess risk in any case. The top priority item, however, is probably item 2, since the integration of the resident and anadromous forms is not well understood, but has profound implications for a very diverse set of management issues beyond just revision of recovery criteria.

13.4 MONITORING PROGRESS TOWARD RECOVERY GOALS

Monitoring should be conducted for each BPG, with monitoring initially focused on Core 1 populations. Monitoring involves two different but related activities: status and effectiveness monitoring. Status monitoring is intended to assess the status of a population (or a DPS) as a whole, and to assess its progress toward recovery or further decline toward extinction. It should also be designed to gather data for assessing the viability criteria described by Boughton *et al*. (2007b). Monitoring the annual run size of populations is the most important objective of status monitoring. Effectiveness monitoring is intended to assess the response of populations to specific recovery actions, and thereby develop a better understand of their effectiveness. Effectiveness monitoring will generally be more powerful if it focuses on the specific life stage affected by the recovery actions in particular habitats, and it if compares it to the same life stage in similar unaffected habitats that serve as controls.

As described by Boughton *et al.* (2007b), the general goal of recovery is to establish a diverse and geographically distributed set of populations, each meeting viability criteria over the long term. These viability criteria are expressed in terms of mean annual runs size, persistence over time, spawner density, anadromous fraction, as well as the continued expression of life history diversity, and the spatial structure of the population. Strategies for monitoring these properties are essential for assessing the attainment of recovery goals.

13.4.1 Strategy for Monitoring Steelhead in South-Central California Coast

SCCCS DPS steelhead habitats exhibit characteristics that must be considered in formulating a monitoring plan. These characteristics include differences in geology, climate and hydrology, as well as the fact that other species of anadromous salmonids are absent. The differences in the geology, climate, and hydrology are described in Adams *et al.* 2011, Boughton and Goslin (2006), and Boughton *et al*. (2006). The strategy described below considers these factors, as well as the spatial and temporal distribution of SCCCS DPS. The basic components of the SCCC steelhead monitoring strategy include:

- ❑ Reconnaissance surveys and assessments of steelhead populations;
- ❑ Reconnaissance surveys and assessments of riverine and estuarine habitat conditions;
- ❑ Monitoring stations stratified at both the BPG and population levels, and
- ❑ Life cycle stations (LCS) stratified at both the BPG and population levels

Presently there is no current comprehensive assessment of the condition and distribution of steelhead populations and habitats in South-Central California that use standard population and habitat assessment protocols. However, NMFS and the CDFW have begun to develop a comprehensive coastal salmonid monitoring program and have identified a basic strategy, design, and methods of monitoring California coastal salmonid population (Adams *et al.* 2011).

The monitoring strategy outline includes an, initial assessment both of the *O. mykiss* populations and habitat conditions. Assessments should initially focus on Core 1 populations in each BPG, and ultimately include all populations that are necessary for full recovery of the species. Watershed and assessments and habitat inventory methods should be conducted using the protocol in the California Department of Fish and Wildlife's California Salmonid Stream Habitat Restoration Manual (Flosi *et al*. 2010).

Monitoring (or lifecycle) stations comprised of fixed structure utilizing technologies such as DIDSON cameras are the most effective means of establishing abundance and trends of adult anadromous runs of steelhead and juvenile out migration. Monitoring stations should initially be located in Core 1 populations in each BPG. However, since no trap system will work at 100% efficiency with the flashy winter flows characteristics of coastal watersheds, a mark-recapture system would be needed to determine actual numbers and to correct for trapping inefficiency.

Life cycle monitoring stations (LCS) can be co-located with monitoring stations, but may also be conducted in one or more of the non-Core populations which support smaller but less impacted populations. LCS monitoring efforts provide the foundation for evaluating the relationship of *O. mykiss* habitat use and habitat condition over time.

These efforts should focus on:

- Estimation of marine and freshwater survival;
- Spawning success (spawning ground distribution, redd to adult ratio);
- Juvenile rearing success (over-summering and winter growth); and
- Major life history traits (anadromy/resident relationships, sex ratio, age and size structure, habitat utilization patterns, emigration age and timing, maturation patterns, run-timing, and physiological tolerances)

LCSs could also be used to evaluate nutritional needs, predation, disease, and other environmental factors relevant to assessing the status of individual populations. Where permanent LCSs are not established, temporary stations should be deployed to maximize the development of population information in Core population watersheds.

Table 13-1 lists the preliminary sites where counting stations and LCSs should be established. LCS sites should be sited based on two criteria: their relation to the DPS and whether they are necessary to represent the full range of watershed types for each BPG.

Table 13-1. Potential Locations of South-Central California Coast Steelhead Life Cycle Monitoring Stations (alternative populations are listed in parentheses).*

Life Cycle Monitoring Station	Population	Potential Locations
1	Pajaro River (Uvas, Corralitos, Little Arthur, Llagas, Dos Picachos, Pacheco)	Highway 1 Highway 101 Southern Pacific Trestle Fish Ladder(Uvas/Carnadero) Bloomfield Road Redwood Retreat Road City of Watsonville Fish ladder
2	Salinas River (Arroyo Seco, Nacimiento, San Antonio)	Salinas Diversion Dam Highway 101 (various crossings)
3	Carmel River	Highway 1 Rancho San Carlos Road Sleepy Hallow Crossing
4	Little Sur River	Highway 1 Old Coast Highway Camp Pico Blanco Summer Dam
5	Big Sur River	Highway 1
6	San Carpoforo Creek	Highway 1
7	Arroyo de la Cruz Creek	Highway 1
8	San Simeon Creek	Highway 1 San Simeon Creek Road
9	Santa Rosa Creek	Highway 1 Santa Creek Rosa Road
10	San Luis Obispo Creek	Avila Road Highway 101
11	Pismo Creek	Highway 101 Price Canyon Road Ormonde Road
12	Arroyo Grande Creek	Highway 1 Highway 101 Lopez Drive

* Note: Additional evaluation of these and other locations may identify more suitable locations than those provisionally identified here.

To the maximum extent possible, monitoring the status and trends of steelhead populations should be undertaken simultaneously with restoration efforts. Watersheds where restoration has occurred or is occurring should be considered a high priority for monitoring. Monitoring stations, whether counting or life cycle stations, should serve as a magnet for research efforts.

13.4.2 Monitoring Protocols

Below is a brief summary of potential methods to monitor run-size of steelhead (number of anadromous spawners per year per population). All these methods involve two components:

1. Observed counts for O. *mykiss* that contains information about adult run size; and

2. Some method for estimating the number of unobserved fish.

For the first component, the observed count may actually be the run, but if it is some other life stage, there is a need to collect data to estimate a conversion factor. For example, if redds are counted, it is necessary to estimate redds per female and sex ratio to get an estimate of the full run size (Gallagher and Gallagher 2005).

The second component is necessary because simple observations, or proxies of presence (redd counts), can under- or over-estimate true number of *O. mykiss* depending on observer detection rates. For example, a large population where conditions are unsuitable for visually observations (*i.e.*, highly turbid waters during the winter period) may have detection rates similar to a naturally smaller population in a more pristine watershed with excellent observing conditions. Due to this and other inherent limitations, it is necessary to develop appropriate confidence intervals for population estimates which are based on appropriate and flexible sampling techniques.

Williams *et al*. (2001) provides a comprehensive technical review of applicable protocols which require repeated observations (often only two times) of the same group of fish (see also Rosenberger and Dunham 2005).

13.4.2.1 Counting at Fish Ladders

Fish ladders can provide important opportunities to count upstream migrants, because they can facilitate better estimates of a population when the majority of a run must migrate through the ladder[4] Nonetheless, estimates of abundance at ladders can pose technical challenges for fish detection and counting devises because of the extremely flashy systems characteristic of South-Central California (see discussion below). Counts at ladders, while potentially more accurate than estimates derived from other methods, are only relevant to areas where these structures exist and cannot be used to quantify the portion of the run that spawns below the fish ladder. Depending on the location of the ladder and the amount and type of habitat downstream of the ladder, the spawners below the ladder can be an important component of the run.

13.4.2.2 Redd Counts

Gallagher and Gallagher (2005) have shown that salmon and steelhead runs can be estimated using redd counts. They estimated Chinook salmon, coho salmon and steelhead escapement in several coastal streams in northern California through a stratified index redd method. Escapement estimates were compared with releases of fish above a counting structure. Reduction of counting errors and uncertainty in redd identification, biweekly surveys throughout the spawning period, and the use of redd areas in a stratified index sampling design produced precise, reliable, and cost-effective escapement estimates for Chinook salmon, coho salmon, and steelhead.

This method has considerable promise, but has not been systematically applied in the South-

[4] Assuming the fish passage facilities themselves provide effective and relatively unimpeded fish passage opportunities.

Central California setting, where stream turbidity and channel geomorphology, or repeated disturbance of redds by winter storms, may make redds difficult to detect under certain circumstances. The method has high personnel requirements, because it requires survey reaches are visited biweekly throughout the spawning season. On the other hand, it is simple, requires only modest training in field personnel, and has modest costs (other than the hiring of personnel).

13.4.2.3 Monitoring runs using the DIDSON Acoustic Camera

Dual-frequency identification sonar (DIDSON) is an off-the-shelf device that uses high frequency sound waves to produce near video-quality images of underwater objects. It can potentially be used to identify and count all migrating steelhead at some survey point in a stream system, for the entire spawning season. Its advantages are similar to those of using a weir or ladder to make counts, but has other advantages:

1. There is no need for a weir or other device that impedes flow. The absence of a hardened structure eliminates concerns regarding fouling, destruction by high-flow events, etc.; and

2. A DIDSON device can detect fish in turbid waters (unlike a regular video camera).

These traits make a DIDSON acoustic camera a tool that is well suited for evaluation of steelhead runs in the flashy, turbid conditions typical of most South-Central California streams.

DIDSON has been successfully used to estimate adult salmon escapement in high-abundance rivers in Alaska, Idaho, and British Columbia. In principle it should be suitable for low-abundance creeks, such as those in South-Central California. NOAA's Southwest Fisheries Science Center have evaluated field methods for using the device to monitor steelhead runs in South-Central California streams (Pipal *et al.* 2010).

The principal disadvantages of a DIDSON are:

1. The cost of the device;

2. Deployment constraints for obtaining good images; and

3. The risk of "flashy flows" damaging or destroying the device.

This tool has the potential to solve some of the difficult problems of monitoring steelhead in South-Central California, particularly counting very small numbers of migrants in very turbid waters during and after very flashy high-flow events.

13.4.2.4 Tagging Juveniles and Monitoring Migrants (T-JAMM design)

Steelhead runs can potentially be estimated by tagging juveniles with Radio Frequency Identification (RFID) tags during their freshwater phase, and subsequently monitoring migrants using in-stream tag readers.

The tagging phase use standard block-netting and electro-fishing techniques during the summer low-flow season. Depletion-sampling can be used to estimate juvenile abundances. However, Rosenberger and Dunham (2005) found that capture-recapture methods gave more robust estimates than depletion sampling, and Temple and Pearsons (2006) showed that the customary 24-hour period in capture-recapture sessions can be shortened.

The monitoring phase uses instream tag readers such as those described by Bond *et al.* (2007), Zydlewski *et al.* (2006, 2001), Ibbotson *et al.* (2004). These must be deployed for the duration of the migration season (both outgoing and incoming) each year.

The design has potential for monitoring runs of steelhead when many other methods are problematic. In unpublished simulations, Boughton found the precision of run size estimates is primarily controlled by the number of tagged spawners that ultimately return and get detected. The number required is modest: around 30 to 90 tagged spawners are necessary to obtain 50% confidence intervals that stay below one-third of the estimated of run size. However, with marine survival typically falling between 0.3% and 3%, the required tagging effort would usually be between 3,400 and 45,000 juvenile fish tagged per generation per population. Other issues that should be considered in using implanted tags include:

- mortality/fitness risks;
- permitting requirements;
- total tagging effort necessary to achieve acceptable levels of statistical significance

Reach-sampling allows the entire run to be estimated using fish from a sample of reaches. In the simulations, the number of reaches needed for acceptable precision could be as low as 30-40 under scenarios of high marine survival, with a sampling fraction of around 2% in large watersheds, such as the Arroyo Seco watershed used in the simulations.

Under low marine survival, the necessary sampling fraction was around 10% in the simulations. A side-benefit of this method is that one would obtain good estimates of ocean survival. This is useful because it allows the overall trajectory of steelhead runs to be decomposed into marine and freshwater components. This, in turn, would have greater statistical power for determining if recovery actions on the freshwater side are actually having the desired effect.

NMFS Staff scientist at NOAA's Southwest Fisheries Science Center are currently tagging juveniles and monitoring migrants in a case study of Big Creek steelhead population, a member of the Big Sur Coast BPG within the SCCCS DPS.

13.4.2.5 Sampling Young-of-the-Year Otoliths (YOYO design)

This method is similar to tagging juveniles and monitoring migrants, but instead of tracking the fate of captured juveniles to estimate run size, a fraction of juveniles are collected for otoliths and to evaluate genetic relatedness. From these data, the number of anadromous mothers (and as a byproduct, non-anadromous mothers) for each annual cohort of young-of-the year fish could be estimated. This should be suitable for estimating annual run size, at least of female fish.

This method would dispense with the need to implant RFID tags in fish, and the need to maintain instream tag readers during difficult winter conditions. Field work would consist of collecting juveniles at randomly-sampled stream reaches each summer. However, the method would require the time and expense of otolith analysis, and it would require killing some fraction of the juveniles that are electrofished during the summer field season.

This method is currently not well-developed, but it has promise as a relatively simple and efficient way to estimate run sizes using established and familiar field methods. An unknown variable is the appropriate sample size to obtain a reasonable estimate of the number of anadromous mothers.

13.5 ADAPTIVE MANAGEMENT: LEARNING FROM RECOVERY EFFORTS

Adaptive management is a systematic process that uses scientific methods for monitoring, testing, and adjusting resource management policies, practices, and decisions, based on specifically defined and measurable objectives and goals (Williams *et al.* 2009, Walters 1997, 1996). Adaptive management is predicated on the recognition that natural resource systems are variable, and knowledge of natural resource systems is often uncertain. Further, the response of habitats to restoration and management actions is complex, and frequently difficult to predict with precision. The Recovery Plan provides both overall goals in the form of viability criteria, and suite of DPS-wide watershed specific recovery actions. The viability criteria, however, are provisional, and the recovery actions are couched in broad terms and will be given more specificity on a case-by-case basis as projects are proposed, developed, and subject to environmental and regulatory agency review for permitting purposes, and ultimately assessed for their effectiveness.

The success of an adaptive management program can be enhanced by having stakeholders and scientists engage in developing a shared vision for an indefinitely long future together. The development of a guiding image helps organize an adaptive management program, align interests, and enhance cooperation in a complex process. Focusing on fundamental values, rather than on predetermined means can open up possible alternative solutions; participating in this type of framework, scientists can help construct solutions that may not be self-evident to stakeholders.

Adaptive management can be applied at two basic levels: the overall goals of the recovery effort, or the individual recovery or management actions undertaken in pursuit of overall goals. The research sections above are intended to address the first application. The following discussion is focused on the second application of the concept of adaptive management.

13.5.1 Elements of an Adaptive Management Program

There is no uniformly applicable model for an adaptive management program, and key elements must be identified and tailored to recovery action-specific, site-specific, and impact-specific issues. However, effective adaptive management programs should contain three components: 1) adaptive experimentation by which scientists and others with appropriate expertise, learn about habitat response to recovery or management actions; 2) public education and 3) shared decisions making. Six specific elements associated with adaptive management have been identified (Panel on Adaptive Management for Resource Stewardship 2011):

1st Element: Recovery Action Objectives are Regularly Revisited and Revised. Key recovery action objectives (and related questions) should be regularly reviewed through an iterative process to help stakeholders maintain focus on objectives and develop appropriate revisions. The recovery goals, objectives, and criteria in Chapter 6, Steelhead Recovery Goals, Objectives & Criteria, should provide a basic framework. Additionally, recovery actions identified for each BPG should be a starting point for the adjustment of recovery actions. The mandatory five-year review process can serve as a means of conveying any needed modification to the overall recovery goals, as well as individual recovery actions.

2nd Element: Model(s) of the System Being Managed. Four types of models were identified in the use of adaptive management program to test hypotheses regarding effectiveness of recovery actions (Thomas *et al.*, 2001):

Conceptual Model: Synthesis of current scientific understanding, field observation and professional judgment concerning the species, or ecological system

Diagrammatic model: Explicitly indicates interrelationships between structural components, environmental attributes and ecological processes

Mathematical model: Quantifies relationships by applying coefficients of change, formulae of correlation/causation

Computational Model: Aids in exploring or solving the mathematical relationships by analyzing the formulae on computers.

River systems are generally too complex and unique for controlled, replicated experiments. Conceptual models based on generally recognized scientific principles can provide a useful framework for refining recovery actions and testing their effectiveness. Diagrammatic models such as the one used to characterize the parallel and serial linkages in the steelhead life cycle, can also be used *in lieu* of formal mathematical models to test hypotheses regarding the effectiveness of recovery actions. Mathematical and computational models, themselves have their limitations in the context of an adaptive management program: they are difficult to explain, and require specific assumptions that may be difficult to justify. As noted in the discussion above regarding recovery goals, viability criteria are based on a combination of a synthesis of current scientific information and a simplified model which uses data not specific to the SCCCS Recovery Planning Area. Additional quantifiable data is necessary to refine the viability population and DPS models that form the basis of the provisional recovery goals, objectives and criteria. Modification of the model could result in modification of the priorities assigned to the individual recovery actions in individual populations or BPGs.

3rd Element: A Range of Management Choices. Even when a recovery action objective is agreed upon, uncertainties about the ability of possible recovery or management actions to achieve that objective are common. The range of possible recovery or management choices should be considered at the outset. This evaluation addresses the likelihood of achieving management objectives and the extent each alternative will generate new information or foreclose future choices. A range of recovery actions and management measures should be considered, either through a planning process or the environmental review process prior to permitting the individual recovery action.

4th Element: Monitoring and Evaluation of Outcomes. Gathering and evaluation of data allow for the testing of alternative hypotheses, and are central to improving knowledge of ecological and other systems. Monitoring should focus on significant and measurable indicators of progress toward meeting recovery objectives. Monitoring programs and results should be designed to improve understanding of environmental systems and models, to evaluate the outcomes of recovery actions, and to provide a basis for better decision making. It is critical that "thresholds" for interpreting the monitoring results are identified during the planning of a monitoring program. This element of adaptive management requires a design based upon scientific knowledge and principles. Practical questions include what indicators to monitor, and when and where to monitor. Guidance on a number of these issues is provided in the sections above regarding research and monitoring.

5th Element: A Mechanism for Incorporating Learning Into Future Decisions. This element recognizes the need for means to disseminate information to a wide variety of stake-holders, and a decision process for adjusting various management measures in view of the monitoring findings. Periodic evaluations of the proposed recovery action, the monitoring data and other related information, and decision-making should be an iterative process in which management objectives are regularly revisited and revised accordingly. Public outreach, including Web-based programs, should be actively pursued. Additionally, the mandatory five-year review process can serve as a means of conveying any needed modification to the Recovery Plan, and well as individual recovery actions.

6th Element: A Collaborative Structure for Stakeholder Participation and Learning. This element includes information dissemination to a variety of stakeholders, as well as a proactive program focused on soliciting decision-related inputs from a variety of stakeholder groups. Inevitably, some of the onus for adaptive management goes beyond managers, decision makers, and scientists, and rests upon interest groups and even the general public. NMFS has provided a general framework by which a shared vision can be further developed and pursued for restoring a set of watersheds supporting a network of viable steelhead populations, and providing sustainable ecological services to the human communities of South-Central California (Boughton, 2010a, Tallis *et al*. 2010, Levin *et al*., 2009, Ruckelshaus *et al*. 2008). Such a vision also provides opportunities for the protection and restoration of other native freshwater and riparian species which form an integral part of the ecosystems upon which steelhead depend.