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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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Monitoring and research needed to manage the recovery of threatened and endangered Chinook and steelhead in the Sacramento-San Joaquin basin

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In this report, we assess whether existing monitoring activities in the Central Valley are sufficient to determine if biological recovery goals are being met, and make recommendations for monitoring and research that could provide critically-needed information for effective management of Chinook salmon and steelhead beyond simple viability assessments. Assessing population status requires, at a minimum, estimates of abundance on the spawning grounds and the fraction of naturally-spawning fish that are of hatchery origin. We find that such data are generally available for independent populations of Chinook salmon, but are almost entirely unavailable for steelhead populations. Effective monitoring of steelhead run sizes at the population scale is needed urgently.

Effective management of listed salmonids requires more information than simply whether populations and ESUs are achieving viability targets. We anticipate that managers will need information on the response of salmonid populations to regional climate change, the use of freshwater habitat, mechanisms and magnitude of mortality in freshwater and the ocean, age- and stock-specific harvest rates, trends in effective population size and genetic diversity within and among populations, the effects of hatchery operations on naturally-spawning populations, how to go about reintroducing fish to reconnected or restored habitats, and the factors controlling and the implications of variable life history tactics of steelhead. We discuss why these information gaps need to be filled, and offer some suggestions on promising approaches to filling them. Finally, we recommend that new and existing data should be made accessible to researchers and managers through a central data portal that can aggregate information from the many existing databases.

1 Background

A key contribution of science to recovery planning is to ensure that recovery plans specify adequate monitoring of species status (Clark et al., 2002). Lindley et al. (in press.) laid out viability criteria for populations and evolutionarily significant units (ESUs) in the Central Valley recovery domain. Populations are assumed to be viable if they satisfy criteria relating to population size, trends in abundance, incidence of catastrophic disturbance, and hatchery impacts. ESUs are assumed to be viable if enough viable are distributed throughout the ESU. Monitoring ESU viability depends on monitoring the viability of populations. The first part of this report discusses the monitoring needed to determine if populations are satisfying viability criteria. Successful recovery of salmonid ESUs, however, will require more detailed information than that needed to merely assess their viability. In the second part of this report, we discuss the kinds of monitoring and research that are needed to guide recovery and management of Central Valley salmonids listed under the Endangered Species Act.

2 Monitoring for viability

Criteria for assessing the viability of threatened and endangered Chinook and steelhead in the Sacramento-San Joaquin basin are presented and discussed in Lindley et al. (in press.), and the populations, population groups, and ESUs to which they are to be applied are described by Lindley et al. (2004) and Lindley et al. (2006). The criteria and associated data requirement are summarized in Tables 1 and 2 (reproduced from Lindley et al. (in press.)). The criteria in Table 1 were modeled after IUCN (1994) as modified for Pacific salmon by Allendorf et al. (1997), and are designed for use with the data that are practical to collect, rather than the data that one might like to have for the purpose. Accordingly, use of the criteria imposes only modest requirements for monitoring: the abundance of returning adults, and the percentage of hatchery fish among the returning adults. High accuracy in these estimates may not be required, if the population clearly is not near the threshold values that separate risk categories. It is also important to note that abundance estimates need to correspond to specific populations. For example, if a simple weir count is to be used, the weir must be below the spawning grounds of a single population.

2.1 Existing monitoring programs

Existing monitoring programs for listed *Oncorhynchus* in the Central Valley are comprehensively described by Pipal (2005), and monitoring programs for all Central Valley *Oncorhynchus* are described by Low (2005); the programs are described only briefly here.

2.1.1 Spring-run Chinook salmon

Estimates of adult returns are routinely made on all Central Valley streams with extant independent populations of listed Chinook salmon, as well as on some streams with historically dependent populations. These data are available from CDFG's Grand Tab database[1], which is produced annually as part of the ocean salmon fishery assessment.

Various methods are used to estimate adult returns, including counts at ladders and weirs, snorkel surveys, and carcass surveys (Pipal, 2005; Low, 2005). Generally, estimates of adult returns in the Central Valley are given without confidence intervals or standard errors, so the accuracy of the estimates is uncertain and the statistical power of trend detection tests is unknown. A joint CDFG-NMFS review (CDFG and NMFS, 2001) noted that "The accuracy and variance of most Central Valley escapement estimates are currently unknown and may not be sufficient to meet management

[1]Grand Tab can be obtained from Robert Kano, Wildlife and Habitat Data Analysis Branch, CDFG, Sacramento, CA. or from http://www.delta.dfg.ca.gov/AFRP/

Table 1: Criteria for assessing the level of risk of extinction for populations of Pacific salmonids. Overall risk is determined by the highest risk score for any category. Reproduced from Lindley et al. (in press.) based on Allendorf et al. (1997).

	Risk of Extinction		
Criterion	High	Moderate	Low
Extinction risk from PVA	$>$ 20% within 20 years	$>$ 5% within 100 years	$<$ 5% within 100 years
	– or any ONE of –	– or any ONE of –	– or ALL of –
Population size[a]	$N_e \leq 50$	$50 < N_e \leq 500$	$N_e > 500$
	–or–	–or–	–or–
	$N \leq 250$	$250 < N \leq 2500$	$N > 2500$
Population decline	Precipitous decline[b]	Chronic decline or depression[c]	No decline apparent or probable
Catastrophe, rate and effect[d]	Order of magnitude decline within one generation	Smaller but significant decline[e]	not apparent
Hatchery influence[f]	High	Moderate	Low

[a] Census size N can be used if direct estimates of effective size N_e are not available, assuming $N_e/N = 0.2$.
[b] Decline within last two generations to annual run size $\leq$ 500 spawners, or run size $>$ 500 but declining at $\geq$ 10% per year. Historically small but stable population not included.
[c] Run size has declined to $\leq$ 500, but now stable.
[d] Catastrophes occuring within the last 10 years.
[e] Decline $<$ 90% but biologically significant.
[f] See Figure 1 of Lindley et al. (in press) for assessing hatchery impacts.

Table 2: Estimation methods and data requirements for population metrics. S_t denotes the number of spawners in year t; g is mean generation time, which we take as 3 years for California salmon.

Metric	Estimator	Data	Criterion
$\hat{S}_t$	$\sum_{i=t-g+1}^{t} S_i/g$	$\geq$ 3 years spawning run estimates	Population decline
N_e	$N \times 0.2$ or other	varies	Population size
N	$\hat{S}_t \times g$	$\geq$ 3 years spawning run estimates	Population size
Population growth rate (% per year)	slope of $\log(S_t)$ v. time $\times 100$	10 years S_t	Population decline
c	$100 \times (1 - \min(N_{t+g}/N_t))$	time series of N	Catastrophe
h	average fraction of natural spawners of hatchery origin	mean of 1-4 generations	Hatchery influence

needs, ...” However, as noted above, use of Table 1 does not necessarily require that abundance estimates be highly accurate (although standard errors for abundance estimates would be extremely useful).

In response to the need to review and improve escapement monitoring programs in the Central Valley, the CALFED Ecosystem Restoration Program approved funding in 2005 to develop a comprehensive Central Valley Chinook Salmon Escapement Monitoring Plan[2]. From January 2007 through June 2008, a project team consisting of a biostatistician, biologist, and database expert, will evaluate existing monitoring programs and make recommendations for new or revised programs, in coordination with the Central Valley Salmonid Escapement Project Work Team. The Plan is intended to improve monitoring programs for winter-run Chinook salmon and spring-run Chinook salmon, and make the data more relevant to recovery planning for these stocks. The Plan will include the design of a consistent, integrated database and data reporting and communication system for Central Valley salmon escapement monitoring data.

Currently, all spring-run Chinook salmon produced at Feather River Hatchery are marked with adipose fin clips and coded-wire tags, so that tracking the percentage of hatchery fish among spawning adults is relatively straightforward in principal. Available information indicates that the spring-run Chinook salmon population in the Feather River is clearly dominated by hatchery-origin fish. One serious complication arises from the fact that early run timing (a defining characteristic of spring Chinook salmon) appears in the progeny of FRH fall-run Chinook salmon. This raises the possibility that unmarked, early-running Chinook salmon from the FRH could stray to natural populations, where they would be difficult to detect. Ideally, all hatchery fish, or at least a constant fraction of every release group, would be marked in some way so that statistically defensible estimates of their straying rates into natural populations could be made.

Although the rugged terrain typically surrounding spring-run Chinook salmon holding and spawning habitat makes estimating the number or returning adults difficult, existing programs seem generally satisfactory for the narrow purpose of assessing population viability using Table 1. Further valuable information comes from monitoring programs for emigrating juveniles. Except for Clear Creek and the Feather River, current spring-run Chinook salmon populations fall either well below or well above the risk criteria for hatchery influence, so for the narrow purpose of applying Table 1 the accuracy of the estimates of hatchery influence for these populations is sufficient.

2.1.2 Winter-run Chinook salmon

Abundance estimates are generated from carcass surveys conducted in the area most heavily used for spawning by winter-run Chinook salmon, and by expanding counts of winter-run Chinook salmon made at Red Bluff Diversion Dam as the last portion of the run ascends seasonally-operated fish ladders. Resource managers use the carcass-based estimates for management purposes. The accuracy and precision of the mark-recapture estimates is uncertain, largely due to uncertainties surrounding how well the survey method meets the assumptions of the Jolly-Seber model used to estimate abundance. However, recent population estimates are much greater than the criterion for low risk in Table 1, and there is no apparent or probable population decline. At current abundance levels, estimates have sufficient accuracy and precision for assessing extinction risk using Table 1. For assessing the effectiveness of restoration actions, however, more accurate estimates may be needed.

In terms of Table 1, the hatchery influence criterion is more critical for winter-run Chinook salmon than the population criteria, since the rising proportion of hatchery fish among returning adults threatens to shift the population from low to moderate risk of extinction (Lindley et al., in press.). If the status of the winter-run Chinook salmon population is downgraded due to hatchery influence, the accuracy of the estimates of hatchery influence may become contentious. Bias may arise if hatchery fish differ from naturally-spawned fish in their distribution within the river, size or sex ratio. This possibility, and its effect on the estimate of hatchery contribution to natural spawning, should be examined.

2.1.3 Steelhead

In contrast to the existing monitoring programs for Central Valley Chinook salmon salmon, steelhead monitoring is insufficient to evaluate populations with respect to the criteria in Table 1, except for streams where hatchery operations likely satisfy the high risk criterion for hatchery effects (Lindley et al., in press.). Unfortunately, such information as does exist indicates sharp declines in abundance over the least half-century (McEwan, 2001). There are reasons for the dearth of data on anadromous steelhead. Steelhead spawn in the winter, when conditions for monitoring are difficult, and although many steelhead die after spawning, their carcasses are not concentrated near the spawning areas. There is also the difficulty of distinguishing resident and anadromous forms, because resident fish in the tail waters of dams that release cool water though the summer can attain the size of typical anadromous fish, and juveniles migrating downstream may not continue to the ocean. Moreover, the effectiveness of screw traps declines for larger fish, and many juvenile steelhead are large enough that they may be able to avoid the traps.

Given that the anadromous component of the ESU is critical for its long-term persistence, as made clear by the discussion of anadromous and resident *O. mykiss* in Travis et al. (2004), monitoring of the anadromous form should be substantially increased. Populations of *O. mykiss* in Central Valley streams with hatcheries are at high risk of extinction because of the high proportion of hatchery fish among naturally spawning fish (Lindley et al., in press.). More accurate estimates of adult returns will not change this assessment. Accordingly, priority should go to monitoring steelhead populations in streams without hatcheries that have the potential to support significant populations. These are likely often the same streams that support spring-run Chinook salmon, which suggests that efficiency could be maximized by employing methods capable of counting both Chinook salmon and steelhead. However, basic distributional data are needed to guide future monitoring efforts.

Traps at dams on some of these streams apparently have been effective for monitoring steelhead in the past (e.g., Figure 1). An automatic counting system such as the Vaki RiverWatcher or DIDSON sonar could be used in place of a trap, to avoid stress associated with trapping, and resistance board weirs might be used

[2] The proposal to CALFED is available online at `http://www.delta.dfg.ca.gov/erp/docs/2005grants/Central_Valley_Salmon_Esc_CMP_DA_Proposal.pdf`

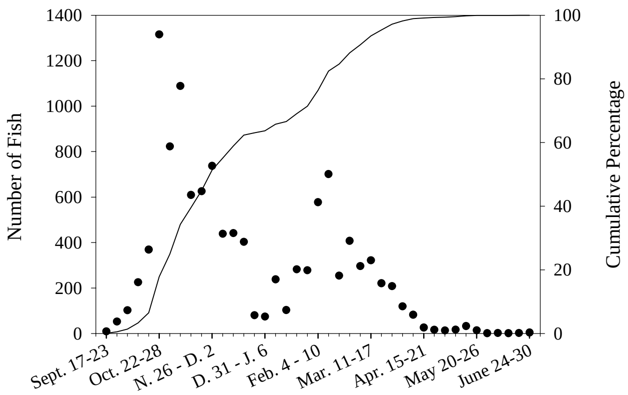

Figure 1: Total number of steelhead observed passing Clough Dam on Mill Creek, 1953-63. Data from Van Woert (1964). On average, 1,160 fish passed the dam each year. Harvey (1995), cited in Pipal (2005), reported that 34 steelhead were observed passing the dam in 1993-94, along with 76 spring Chinook.

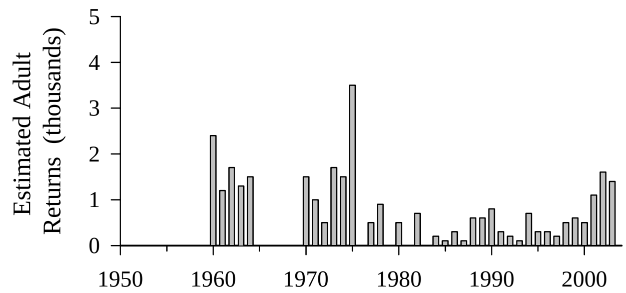

Figure 2: Estimated numbers of adult spring-run Chinook salmon returning to Mill Creek. Data from Van Woert (1964) and the CDFG GrandTab data base. For purposes of the tables, the population is the sum of the returns over a generation, i.e., 3 to 4 years.

instead of dams. Such monitoring will produce partial counts, because some fish will likely bypass the traps during high flows. These partial counts would need to exceed criteria for low extinction risk before the population could be determined to be at low risk. The same facilities could be used to obtain more accurate estimates of returning spring-run Chinook salmon.

In response to the need to develop monitoring programs for Central Valley steelhead, the CALFED Ecosystem Restoration Program approved funding in 2005 to develop a comprehensive Central Valley Steelhead Monitoring Plan[3]. From January 2007 through June 2008, a project team consisting of a biostatistician, biologist, and database expert, will design the comprehensive long-term monitoring program, in coordination with the Central Valley Steelhead Project Work Team. The plan will include the design of a consistent, integrated database and data reporting and communication system. We recommend that serious consideration be given to monitoring returning steelhead adults at weirs or traps on streams that do not have steelhead hatcheries.

3 Research and monitoring to assist management

In this section we provide recommendations regarding research that seems particularly important for improving the scientific basis for management and recovery. At the outset, however, we emphasize the close connection between monitoring and research in the context of adaptive management. The essence of adaptive management is treating management as experimental, so that monitoring provides the experimental results, and is part of science as well as part of management (Peterman et al., 1977; Halbert, 1993; Williams, 1999). Roni (2005) provides a recent review of monitoring and evaluation principles, including adaptive management, as applied to restoration of salmonid-bearing watersheds.

We emphasize that the data required for risk assessment (Table 1) are only a subset of the data required for effective management of the populations and recovery planning. Data on spring-run Chinook salmon in Mill Creek (Figure 2) illustrate this point.

Spring-run Chinook salmon in Mill Creek are monitored by redd counts, a not particularly precise method for estimating run sizes. From the data, however, it seems clear that the population has been over 2,500 in recent years, and over the last decade is not decreasing (note that for the genetic considerations underlying the population-size criterion, the population includes the adult returns for each year of a generation, which lasts 3 to 4 years; see the legend for Table 2). Because there is no reason to expect a significant hatchery influence, the population can be assigned to the low risk category, despite the considerable uncertainty in the abundance estimates.

For management, however, better data seem needed, as shown by the following example. Spring-run Chinook salmon in Mill Creek were monitored at a dam below the spawning grounds from 1954-63 (Van Woert, 1964), and the resulting information on the temporal distribution of the migration indicates that diversions for irrigation probably hinder late-arriving fish, especially in dry years (Figure 3). Better monitoring than now occurs would be required to confirm this, and to allow an assessment of the benefit to the population that might result from, say, pumping water from the Sacramento River to replace the water currently diverted from the creek a few miles upstream from the confluence. Put differently, abundance data by themselves say little about what might be done to improve conditions for the population. Similarly, although uncertain abundance estimates may be all that is needed to assess the viability of a population using Table 1, more accurate estimates may be needed to test hypotheses regarding the importance of various factors in regulating populations.

In the following subsections, we outline what we believe to be the major questions that need to be addressed in order to effectively manage salmon and steelhead in the Central Valley.

3.1 Climate change and temperature tolerance

Regional climate change (driven by global warming) is a critical issue for Chinook salmon and steelhead in the Central Valley (Lindley et al., in press.), and better information on future water temperatures and on the temperature tolerance of Chinook salmon and steelhead will be important for developing realistic recovery plans. This will require improved understanding at several levels: how temperature and precipitation will change at regional scales; how

[3] The proposal is available online at `http://www.delta.dfg.ca.gov/erp/docs/2005grants/Central_Valley_Steelhead_CMP_DA_Proposal.pdf`

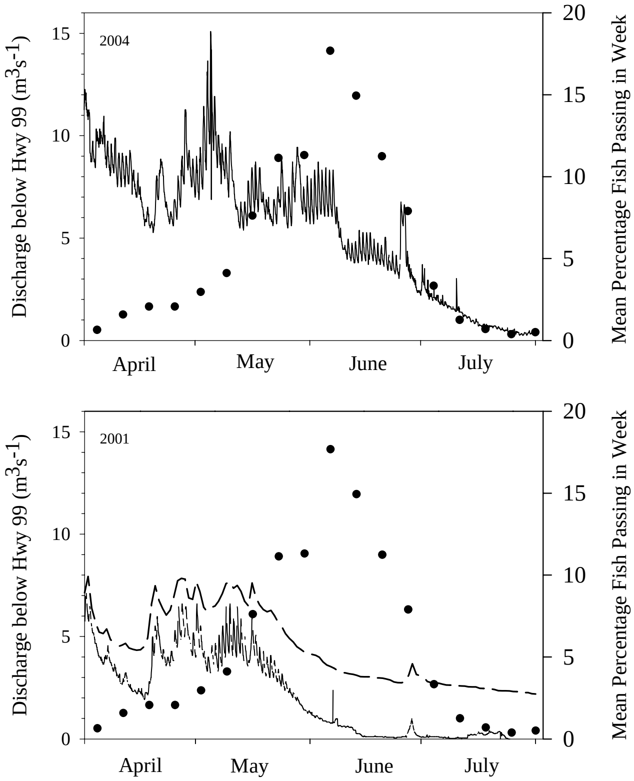

Figure 3: Temporal distribution of adult spring-run Chinook salmon migration for 1954-64 (circles), and discharge in Mill Creek at the DWR gage, downstream from diversions (solid line), and at the USGS gage, upstream from the diversions, 2001 and 2004. Migration data from Van Woert (1964). Copied from Williams (2006).

these regional-scale changes will alter conditions at the scales relevant to individuals and populations; and how individuals and populations will respond to these changes. Recent work has shown that the hierarchical structure linking large-scale climate variation to individual organisms must be understood in order to predict how organisms will respond to climate change (Gilman et al., 2006).

Several climatological studies dealing with warming and subsequent alterations to the hydrologic regime in the Central Valley have been published recently (Wilson, 2003; Dettinger et al., 2004; Hayhoe et al., 2004; Peterson et al., 2005), and we expect that more will be forthcoming. However, more focused efforts will be needed to translate the results of such studies to estimates of actual stream temperatures, which while strongly related to air temperature (Mohseni et al., 1998), are moderated by evapotranspiration, hill shading, groundwater inputs, and hyporheic exchange.

Temperature is a critical determinant of the shifting habitat mosaic (Hauer et al., 2003) that moves in time and space as river temperature isopleths migrate upstream to higher elevations in the spring/summer and downstream to the valley floor in the autumn/winter. For spring-run Chinook salmon the seasonal pattern of temperature is particularly critical. The adults enter in the spring and move to high elevations to avoid the lethal summer temperatures at lower elevations. In the autumn, temperature isopleths move downstream and the adults spread throughout the habitat to spawn. The eggs emerge and the fry move out of the system or seek temperature refugia prior to the next temperature cycle (Lindley et al., 2004).

To understand how climate change and restoration activities will affect this shifting habitat mosaic, salmon ecologist stress a landscape perspective that emphasizes the connectivity of riparian systems to associated terrestrial and aquatic ecosystems (Wissmar and Bisson, 2003). In particular, the hydrological and geological mechanisms controlling stream habitats and the fish responses to the conditions are important. In the Central Valley the seasonal patterns of precipitation and temperature determine snow accumulation and rainfall patterns which are then filtered through the surface and subsurface water exchanges to produce flow and temperature patterns in the salmon habitats. How fish respond to changes in flow and temperature over their critical life stages will determine their ability to respond and adapt to climate change.

While much information is available on the life-stage-specific temperature ranges of Chinook salmon and steelhead (McCullough, 1999) little is known about the specific responses of Central Valley species to temperature. Anecdotal evidence suggests that some species of Central Valley salmonids are heat tolerant: "The high temperature tolerance of San Joaquin River fall run salmon, which survived temperatures of 80° F, inspired interest in introducing those salmon into the warm rivers of the eastern and southern United States" (Ron Yoshiyama, public communication). The full suite of life-stage and species need not be investigated, but rather it may be sufficient to examine those life stages most vulnerable to warming. For winter-run Chinook salmon, which spawn in summer, the embryonic life stage is at greatest risk from warming. Slater (1963) found in laboratory studies that winter-run Chinook salmon eggs and alevins had almost complete mortality by the time water temperatures reached 17.4°C. For spring-run Chinook salmon, the most vulnerable stages are adults holding over the summer in streams, and the gametes that they contain, although spawners, eggs and fry may also be vulnerable into early fall. For steelhead, and for yearling spring-run Chinook salmon, older juveniles are also subject to high summer temperatures. Some juvenile spring-run Chinook salmon and steelhead may encounter stressfully warm water as they migrate through the the lower rivers and Delta in late spring. It may be possible to learn more about the effects of high temperatures under natural conditions by monitoring expression of heat shock proteins (e.g., Viant et al., 2003), viability of gametes, and mortality.

3.2 Use of freshwater habitat

Large numbers of winter-run Chinook salmon fry migrate past the Red Bluff Diversion Dam in late summer and fall (Gaines and Martin, 2002), but little is known about their survival or use of the habitat downstream from the dam. Studying small fish in large rivers is difficult, and it is not obvious how best to proceed, but some combination of exploratory and hypothesis-based research seems in order. A salient question is whether restoring more natural conditions in the Sacramento River upstream from Colusa (the meanderbelt concept) would benefit juvenile winter-run Chinook salmon.

Juvenile spring-run Chinook salmon in Butte Creek have access to a remnant of overbank habitat in the Butte Sinks and the Sutter Bypass, which may help explain the relatively high productivity of this population (Williams, 2006). This hypothesis should be explored, building on earlier Department of Fish and Game studies, because if confirmed it would provide support for the idea of increasing access to the Yolo Bypass for fish moving down the Sacramento River. Microstructural and microchemical analyses of otoliths from returning adults may be a reasonable approach.

The spatial and temporal distribution of fish from various listed ESUs in the Delta is not well known, particularly since the size criteria used to assign juvenile fish to runs are not highly accurate (Hedgecock et al., 2001). How juvenile salmon and steelhead use Delta habitats is also poorly understood, in spite of the long history of sampling in the Delta. This limits the effectiveness of habitat restoration in the Delta. Several management issues of immediate concern involve the effects of water operations on listed runs and whether operations need to be modified to avoid harm to the runs. Better understanding of the spatial and temporal patterns of habitat use by the various runs should allow more effective strategies to balance disruption of water operations and harm to the runs. Such information could be obtained by genetic analysis of tissue samples collected during regular monitoring of juveniles, as well as by more focused studies. To the extent that fish from listed ESUs are sacrificed, it seems appropriate to obtain as much information as is practicable from them; physiologically-based measures of condition, discussed by Williams (2006), should be considered for this purpose.

3.3 Juvenile migration and survival

Low survival of juvenile Chinook salmon during freshwater migration is widely believed to be a serious problem. This belief is based on the propensity of hatchery releases made in San Francisco Bay to yield much higher contribution rates to ocean fisheries than are observed for releases made near the hatchery, at least for the Feather River Hatchery, and on the recognition that river habitats have been highly altered. To date, there has never been a serious attempt to measure the survival of fish migrating down the Sacramento River or to identify locations of unusually high mortality, as has been done for many years on the Columbia River (e.g., Williams et al., 2001; Skalski et al., 2002).

CALFED has funded a collaboration between UC Davis and NOAA to estimate migration and survival patterns of late fall-run Chinook salmon and steelhead smolts as they move from Battle Creek to the ocean in 2007-09. These stocks were selected for logistical reasons, including being large enough to carry the ultrasonic transmitters used by the study, and availability of large numbers of fish. Other agencies will be tagging fish and releasing them in the Delta (USFWS) or Bay (USACOE) in coordinated studies. This study should provide new insights into the magnitude, location and perhaps mechanisms of mortality of salmonids as they migrate through the Sacramento River, Delta and Bay. As tag technology advances and tags become ever smaller, this study design should become feasible for spring-run Chinook salmon and winter-run Chinook salmon.

3.4 Population genetics

Genetic analyses have provided substantial new information about Central Valley Chinook (Banks et al., 2000; Hedgecock et al., 2001; Williamson and May, 2003), and more information will be forthcoming as improved methods for genetic analysis develop. Routine monitoring with population genetics tools can allow detection of population bottlenecks (Garcia and Williamson, 2001), estimation of effective population size (Waples, 2004), and introgression (Aurelle et al., 2002; Cordes et al., 2006). However, the utility of these methods will depend in large part of the availability of tissue samples from which DNA can be extracted. We suggest that fin samples be routinely taken when fish are handled, and sent to the CDFG Salmonid Tissue Archive. Examples of fish that should be routinely sampled would include: fish used for gamete production in hatcheries, migrating juveniles, resident *O. mykiss*, especially where both resident and anadromous forms occur, and fish used in attempts to initiate new runs.

3.5 Harvest

The harvest of listed Central Valley Chinook has generated little controversy in recent years, because populations have been stable or increasing. It seems likely that good ocean conditions have contributed substantially to this state of affairs, however, and harvest may come under greater scrutiny when ocean conditions change (see the current situation regarding Klamath River fall Chinook for a preview of what may happen when fishery management goals in the Central Valley cannot be easily achieved[4]). Harvest affects not only the number of returning adults but also their age structure, and the effects on age structure may be long-lasting (Williams, 2006). It can be anticipated that models will be used to assess the effects of harvest on populations and their viability (Newman and Lindley, 2006), in terms of effects on age structure as well as abundance. To support these assessments, appropriate sampling needs to occur both in the fisheries and on the spawning grounds.

Existing monitoring of ocean harvest provides estimates of total chinook landings and fishing effort stratified by month and catch area. Direct estimates of stock- and age-specific harvest are routinely available only for hatchery coded-wire tagged release groups, and the harvest rates on these CWT groups are used as a proxy measure of the harvest rates on their natural stock counterparts. These hatchery and natural stock counterparts may or may not be different in ways that would effect ocean harvest rates, but in any event the approach is limited to instances in which there is a suitable hatchery/natural counterpart (e.g. Livingston Stone Hatchery/natural born Sacramento River winter Chinook), and is not applicable otherwise (e.g. Central Valley spring Chinook).

Genetic stock identification (GSI) techniques have advanced significantly in recent years. When coupled with the coast-wide microsatellite database for Chinook salmon recently developed by the Pacific Salmon Commission, GSI analysis of fishery harvests should provide a substantial increase in the information available for stock-specific impact assessment and management, particularly for those stocks that do not have a CWT counterpart (although not all listed Central Valley populations are identifiable to river of origin). GSI assessments in themselves, however, do not provide the corresponding age information for the harvests, which is essential for fishery management and population dynamics modeling purposes. Therefore, existing monitoring of the harvest should be expanded to include not only the collection and processing of tissue for the purpose of stock identification, but also the collection and processing of scales or otoliths for the purpose of aging. This data together with stock- and age-specific freshwater harvest and escapement data will enable the estimation of stock-age-specific ocean harvest rates (stratified by month and catch area), maturation rates, and freshwater harvest rates. These estimates in turn provide the foundation for fishery and population viability modeling. We

[4] A Google search on "Klamath fishery controversy" on 23 January 2007 yielded 51,300 pages that will give the interested reader a sense of what to expect.

note that CDFG has recently begun routine aging of many Chinook salmon runs in the Central Valley[5]

The temporal distributions of adult freshwater migrations makes it easier to avoid harvest of listed ESUs in the freshwater fishery than in the ocean fishery, but analysis of tissue samples collected at appropriate times would serve as a check, and also provide information on the tails of the temporal distributions of the adult migrations of listed ESUs. Better monitoring of freshwater harvest is needed for effective management of fall-run Chinook salmon, and tissue samples could be collected as an adjunct to such monitoring.

3.6 Ocean climate influence

It is now generally recognized that ocean conditions can have strong effects on salmon populations, and better understanding of these effects is important for assessing the effectiveness of recovery efforts. Ocean conditions for salmon are the subject of a growing literature, but Central Valley salmon enter a unique ocean environment, the Gulf of the Farallones, and seem to respond differently to ocean conditions than do salmon farther north (MacFarlane et al., 2005; Williams, 2006). Moreover, ocean conditions probably affect winter-run Chinook salmon and spring-run differently, since most spring-run Chinook salmon enter the ocean as subyearlings in late spring, but winter-run Chinook salmon enter the ocean at larger size, in the winter or early spring. Accordingly, although studies elsewhere may provide useful information, direct assessment of the effects of ocean conditions on Central Valley ESUs seems necessary.

Studies of juvenile fall-run Chinook salmon in the Gulf of the Farallones, such as (MacFarlane et al., 2005), probably are applicable to spring-run Chinook salmon, and should be continued. Capturing juvenile winter-run Chinook salmon in the ocean does not seem feasible, even if it were desirable, and studying the otolith microstructure and microchemistry of winter-run Chinook salmon sampled during carcass counts or taken at the hatchery may offer the best opportunity for assessing year to year differences in growth during early ocean residency. Less intensive microstructural analyses of spring-run Chinook salmon may be in order, to confirm that most juveniles follow a life history pattern similar to that of fall-run Chinook salmon.

3.7 Hatchery influence

There is a broad range of concern regarding the effects of hatchery culture on salmonids (Utter, 1998; Waples, 1999), and issues at either end of the range are most relevant for Chinook salmon in the Central Valley. Regarding winter-run Chinook salmon, the concern is whether negative effects of culture in conservation hatcheries such as the Livingston Stone Hatchery outweigh the demographic benefits. More generally, work is needed on the dynamics of hatchery impacts and recovery from these impacts: the theoretical studies done to date (Goodman, 2005) examine steady-state solutions. Also, more empirical information is needed on the strength of domestication selection in the hatchery, the fitness consequences of this selection, and the strength of natural selection in counteracting domestication selection, in order to better identify the safe limits of hatchery impacts.

3.8 Estimating spawning run sizes

Despite their widespread use in the Central Valley, models to estimate in-river spawning escapement based on mark-recapture carcass survey data require a number of assumptions which may not be met in the surveys. A principal assumption of mark-recapture surveys is that the marked animals will distribute randomly among the population during the interval before the recapture sampling. This assumption is often violated for carcasses, with differing consequences on the final escapement estimate depending on the size of the run, the area sampled, and the degree to which random resampling designs are used. Another assumption in carcass mark-recapture sampling is that all fish are either available for marking or are available for recapture sampling. This assumption is likely not met in large streams with deep pools. In these areas, some carcasses may be unavailable to sampling by field crews. This may result in under or over-estimation of the actual run size as it represents an unsampled portion of the run. Research is needed to better understand the degree to which these problems may occur in carcass surveys, the effect that these violations of assumptions have on estimates, and analytical and field strategies to reduce bias.

Data should be gathered on the age and size distributions of returning adults, as well as their numbers. Data on size distributions are important for estimating fecundity, which should be taken into account in estimating the reproductive potential of a given year-class of adults, and data on age are important for assessing the effects of harvest, and more generally are needed for the age-structured population models that could be used in improved harvest and viability models. These data could be obtained during carcass surveys by measuring lengths and collecting otoliths from subsamples of fish. Otoliths could also be used for microstructure analysis to elucidate juvenile life histories, as described above. Scales might also be used to collect age information on adults, but would provide much less information on juvenile life histories.

3.9 Estimating juvenile production

Juvenile production estimates, in combination with adult return data, allow for the effects of ocean and freshwater conditions to be teased apart. Such information is extremely valuable for understanding whether habitat restoration is effective and whether ocean climate anomalies are driving abundance trends. Estimating juvenile abundance is challenging, due to problems of operating sampling gear in highly variable flows, estimating the efficiency, or capture probability, of the gear, identifying juveniles to ESU or population, and accounting for the importance of juvenile age. Advances in all of these areas are needed.

3.10 Life history of *O. mykiss*

As a species, *O. mykiss* exhibit great variation in their tendency to migrate, ranging from non-migratory (resident trout) to strongly migratory (anadromous steelhead moving from rivers to the subarctic Pacific). It is now well understood that these two forms represent two distinct life history strategies of the same taxonomic species. In some river systems, it appears that the two forms maintain separate populations; in others there is evidence that they comprise a single interbreeding population where one form can give

[5] The proposal for this project can be found online at `http://www.delta.dfg.ca.gov/erp/docs/2005grants/Cohort_Reconstruction_DA_Proposal.pdf`.

rise to the other (Zimmerman and Reeves, 2000). This type of population is said to be "polymorphic" in its life history.

In California, steelhead and resident rainbow trout are often sympatric within stream reaches accessible from the ocean. Resident and anadromous fish could either be two components of a polymorphic and panmictic population, or they might be largely separate breeding populations. In the Central Valley, there is limited evidence that at least some populations are polymorphic (Titus (2000), as cited in McEwan (2001)). How we should think about and manage *O. mykiss* populations depends on the prevalence migratory polymorphism. If it is common, then it is nonsensical to manage one of the morphs without reference to the other, because polymorphic populations should have ecological, demographic and evolutionary properties quite distinct from strictly anadromous or resident populations.

To answer the question of whether steelhead and resident rainbow trout comprise a single interbreeding population, one must determine if the two forms are reproductively isolated from one another. Reproductive isolation may occur through differences in spawning times, differences in spawning habitat, or assortative mating. A particularly attractive approach to this question is based on the ratio of strontium (Sr) to calcium (Ca) within the otolith to identify the migration history of individuals and whether that individual had a resident trout or anadromous steelhead mother. Rainbow trout that have migrated to the ocean retain a Sr/Ca signature in their otoliths. Similarly, a rainbow trout that has a steelhead mother, regardless of its own migratory history, also retains an ocean Sr/Ca signature in the primordia of its otoliths due to the fact that the egg from which it arose was formed while its mother was in the ocean. If anadromous and resident *O. mykiss* interbreed rarely, then this should be detectable as differences in the frequency of neutral genetic markers between the two populations (but such differences will not arise with even limited reproductive exchange).

We suspect that there has been a significant shift in the frequency of resident and anadromous life histories in *O. mykiss* in the Central Valley (Lindley et al., in press.), and this likely has important conservation consequences. A CalFed-funded project[6] at UCSC, NOAA and CDFG is examining the role that river regulation may have in driving these shifts, but further work is needed in documenting the distribution of life history types throughout the range, identifying the factors driving this shift, assessing the degree to which it is reversible, and evaluating the consequences for population and evolutionary dynamics.

3.11 Reintroductions

When previously blocked or degraded habitat is restored and made accessible to anadromous fish, how exactly should salmonids be reintroduced to habitats? A number of critical decisions will need to be made when new habitats are made accessible, including method of reintroduction (natural colonization, transplanting of natural fish, outplanting of hatchery fish), source population of founding stock, and methods to limit access by undesired populations, species or stocks. These decisions in turn hinge upon complex genetic, demographic and ecological processes and principles. The Southwest Fisheries Science Center is undertaking a literature review to develop a decision analysis tool to guide future reintroductions.

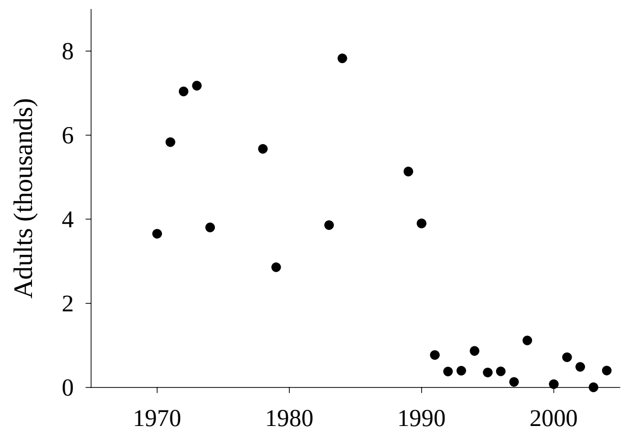

Figure 4: Number of spring Chinook returning to the Sacramento River above the Red Bluff Diversion Dam, as reported in the Grand Tab data base. The decrease after 1990 reflects changes in criteria for assigning fish to runs, not an actual population change.

A related effort is needed to evaluate the prospects for various fish passage technologies that might be employed to allow anadromous fish to move past currently impassable barriers. In concert with this effort, habitat and potential passage opportunities above rim dams in major tributaries of the Central Valley should be assessed.

3.12 Data Management

A good deal of data exist on Central Valley Chinook, steelhead, and their environments, from monitoring programs described by Pipal (2005) and Low (2005), and from other sources. Data are useful to the extent that they are used, however, and by and large the existing data are under used because they are not easily obtained. Worse, some of the data are misleading. Data management is difficult and expensive, but the cost of neglecting data is likely to be greater. Here are some recommendations:

1. Document the the strengths and weaknesses of existing datasets. The quality of existing datasets is highly variable, and sometimes not well documented, although Pipal (2005) provides good preliminary descriptions of many of them. For example, DFG maintains an Excel file, Grand Tab, with historical information on returns of Chinook to Central Valley streams. An apparent decline in returns of spring-run to the upper Sacramento River (above the Red Bluff Diversion Dam) after 1990 reflects a change in the criteria used to allocate fish to runs at the RBDD ladder, rather than an actual change in the population (Williams, 2006). Such problems with existing datasets need to be described before the people who know about them retire, and the descriptions need to be easily available to users of the data. This data about data is called metadata, and using metadata standards is an important step towards making comparisons among datasets feasible.

2. Develop a common portal for basic data on Central Valley salmon and steelhead and related environmental variables, using a common format and data retrieval protocols. A significant number of databases directly connected with ongoing monitoring programs exists for Central Valley fish and habitats. However, the coordination of these databases is weak, in part because the databases

[6] Proposal is available online at `https://solicitation.calwater.ca.gov/solicitations/2004.01/reports/public_proposal_compilation?proposal_id=0140`

were developed independently by programs and agencies for specific unrelated purposes. For example, CALFISH (http://www.calfish.org/DesktopDefault.aspx) provides information on fish migrations and trends, the IEP Data Vault points to the Bay Delta and Tributaries (BDAT) Project data on http://bdat.ca.gov/ and the California Data Exchange (CDE; http://cdec.water.ca.gov) provides information on flows, storage and snow pack. The CALFISH and BDAT databases share some common variables but neither contains water data available at the CDE database and none of these sites has temperature information. Further, they use different data formats, data retrieval protocols, and have different temporal and spatial coverage.

Coordination of essentially independent databases with unique purposes is a major technical and organizational undertaking. However, the Pacific Northwest faces similar challenges and has developed the Northwest Environmental Data Network (NED) (http://www.nwcouncil.org/ned/Default.asp), a cooperative effort to improve collection, management and sharing of environmental data and information. The objective of the NED Portal is to direct scientific and resource management users of data to a consistent source of environmental geospatial and tabular data and metadata. In like fashion, Central Valley and related databases should be coordinated through a common data portal so that data and its metadata can be obtained in a common format using a common retrieval protocol.

3. Develop a portal for graphical data presentation. Analysis and synthesis are necessary to convert data into information. Although researchers and some others need data in numerical form, graphical presentations of data are more useful for most purposes. For example, as part of the Environmental Water Account program, DWR prepares graphics synthesizing data on fish and flow for the weekly conference calls of the Data Assessment Team. Other such graphics, designed to present up-to-date information on particular topics or to meet the needs of particular audiences, should be made available. As an example that might be emulated in the Central Valley, the DART data site (http://www.cbr.washington.edu) synthesizes data on fish, climate, and river conditions from various monitoring programs and provides graphical and textual information on historical, current, and forecasted fish migrations and trends. In general, if monitoring data are not worth presenting in graphical formats on a regular basis, probably they are not worth collecting. With modern graphical programs, creating such graphics and keeping them up to date would not be difficult.

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