16. Monitoring:

How odd it is that anyone should not see that all observation must be for or against some view if it to be of any service. Charles Darwin

Science is the art of not fooling yourself. Richard Feynmann

Programs for monitoring Chinook and steelhead in the Central Valley are extensive (Table 16-1; 16-2) and increasingly coordinated, but they are funded or operated by various agencies for various purposes, and do not yet constitute a well integrated system. Some are required by FERC licenses or other binding agreements; others have less secure funding. Programs that collect data on winter-run, spring-run and steelhead are thoroughly described in Pipal (2005), other programs are described in Low (2005). This chapter briefly reviews existing monitoring programs, and offers both general and specific recommendations and suggestions for improving existing programs.

Existing programs:

Monitoring ocean harvest and adult returns has the longest history, and for many streams estimates of returns extend back to the early 1950s. In the Delta, routine monitoring of juveniles began in the late 1970s and continues with the institutional support of the IEP and the CVPIA. Monitoring juveniles in the rivers was more sporadic until the early 1990s. Various multi-year programs did occur earlier, but consistent funding was not generally available until winter-run Chinook were listed under the ESA and the CVPIA became law in 1992.

<u>Adult returns:</u>

Central Valley rivers are too diverse for a single approach to be appropriate for estimating adult returns in all of them, and various methods are used (Table 16-1). Most Central Valley salmon can reach their spawning grounds without passing a dam, so estimates of adult returns cannot be based on ladder counts. Instead, estimates are usually based on mark-recapture approaches applied to carcasses; spawning reaches are surveyed repeatedly, unmarked carcasses are tagged and tallied, and “recaptures” of previously marked carcasses are also tallied. Estimates of adult returns are then developed, usually using an estimator described by Schaefer (1951) or (and increasingly) by Seber (1982), but sometimes also using a modified Petersen formula. These estimators entail assumptions, for example that all carcasses are equally likely to be found, that are more or less seriously violated in different streams or at different times, and they can give significantly different estimates. For the American River in 1995, for example, the Schaefer and Jolly-Seber estimates were 70,096 and 42,973, respectively (Williams 2001). Compared to weir counts on the Stanislaus River, Jolly-Seber estimates were 18% higher and 24% lower in 2003 and 2004 respectively, while Schaefer estimates were 37% higher and 9% lower. Unfortunately, it has been standard practice not to report confidence intervals for the estimates, although programs are available that can generate them, at least for the Jolly-Seber method.

The carcass surveys typically distinguish fish by length as “grilse,” presumably two years old, or as “adults.” The rationale for this seems more traditional than biological; usually the length criterion for the distinction is around 65 cm, close to the minimum legal length for commercial ocean harvest. More complete information on length distributions is increasingly being collected, although often the information is not reported. Heads are collected from fish that lack adipose fins, and so presumably carry coded-wire tags, but the attention given to this task varies among programs, and often there are not enough workers to carry it out properly when there are many carcasses to handle. Few hatchery fall Chinook are marked in any event, so hatchery and naturally produced fall Chinook are not distinguished.

For smaller rivers with relatively stable flow, resistance board weirs (USFWS 1994) seem to be a practical means of estimating returns accurately. Such a weir equipped with an automatic Vaki infrared scanner, is now in use on the Stanislaus River (SRFG 2004). A Vaki scanner is also being tested at Daguerre Point Dam on the Yuba River. The images from these scanners are often good enough for determining size, sex, and whether fish have adipose fins, and provide precise information on the time at which pass the weir; use of these systems probably will increase. Fish are also counted at Woodbridge Dam on the Mokelumne River, at the Coleman Hatchery weir on Battle Creek, and at the Red Bluff Diversion Dam, when its gates are lowered. Morphometric features to use for distinguishing males and females in video images are discussed by Merz and Merz (2004).

Aerial redds counts are used for estimating adult returns on Mill Creek, where other methods are too difficult, and on the Sacramento River. Snorkel surveys are used on several streams for spring Chinook or for steelhead, but a comparison of estimates from snorkel surveys and from carcass counts on Butte Creek indicated that the snorkel surveys seriously underestimate returns, at least when fish are numerous (P. Ward, CDFG, pers.comm. 2004). Steelhead sometimes survive spawning, and even if they do not they are less likely to die on the spawning grounds than are Chinook, so carcass counts are ineffective for estimating the number of steelhead spawners. Steelhead redds are too small to show effectively on aerial photographs, but surveys by canoe have been used successfully on the American River (Hannon et al. 2003). Resistance board weirs should also be effective for steelhead.

Redds:

CDFG monitors the spatial and temporal distribution of fall-run spawning in the American River and of winter-run and spring-run spawning in the Sacramento, using aerial photography in which redds are visible because undisturbed gravel is darkened by algae. This method is effective only when turbidity is low.

Eggs and alevins:

There are no regular programs for monitoring conditions in redds or the survival of eggs and alevins there, but this has been done in various Central Valley studies (e.g., Vyverberg et al. 1997; Merz et al. 2004). Variables most often measured are permeability, upwelling or downwelling, dissolved oxygen, and temperature. Alternatively, eggs may be planted in baskets or tubes so that eggs and alevins can be recovered at intervals to assess their survival and condition, for example their ability to orient themselves in a slight current in a bucket (Merz et al. 2004). Redd caps have been used to monitor the survival of eggs and alevins in Central Valley streams (e.g., EA 1991), but their use has been less successful where winter flows are more variable (K. Vyverberg, CDFG, pers.comm. 2003).

Juveniles:

Rotary screw traps have become the preferred method for monitoring emigrating juvenile Chinook and steelhead where there is enough current to operate the traps (Table 16-2), although fyke nets are also used on the Merced River. The screw traps consist of conical drums situated between pontoons; angled vanes inside the drum catch the current to make it rotate, and move fish into a holding tank at the back of the trap. Typically, groups of captured fish are marked with dye and released above each trap or set of traps, and the efficiency of the trap(s) is estimated as the percentage that are recaptured; on large rivers, the recapture rate is often under one percent. Snorkel surveys and seines are also used for assessments of habitat use in a few streams. Generally, fish lengths and sometimes weights are recorded for samples of juveniles, although when catches are large only a haphazard subsample is measured.

The IEP has a long-standing program of seine sampling at several dozen specific sites in the lower rivers and around the Delta and the bays (Brandes and McLain 2001; SSJEFRO 2003). Although these data provide a general picture of habitat use through time by juvenile Chinook, only one seine haul is made at each site during each sampling interval, and the sampling variance is too great to provide useful information at finer spatial and temporal scales. Whether the particular sites sampled are representative of areas around them is also questionable (Ch. 11).

The IEP also samples juveniles moving into the Delta by trawling at Sacramento and at Mossdale (rk __) on the San Joaquin River. The effectiveness of this sampling may vary with the season; recent and still unpublished studies at the Delta Cross Channel have demonstrated that older juveniles passing Sacramento in the late fall and early winter migrate mostly at night (Ch. 11), but the trawling is done during the day.

Juveniles moving out of the Delta are sampled by trawling at Chipps Island. The trawl used is intended for smolts, however, and probably is less effective for sampling smaller (<50 mm) Chinook that migrate into the bays, at least in wet years. Besides monitoring the movement of juvenile Chinook and steelhead form the Delta to the bays, the trawl serves as a recovery site for fish marked with coded-wire tags. These are described briefly below, and in more detail in Brandes and McLain (2001). Juveniles are also sampled at the CVP and SWP export facilities in the Delta, as discussed in Ch. 11.

Studies of the survival of juvenile chinook marked with coded wire tags have been a mainstay of work on Central Valley salmon. Coded-wire tags (CWT) are 0.5 or 1 mm lengths of stainless steel wire, marked with a binary code, that can be inserted into the snouts of juvenile salmonids or other fish. The tags are not externally visible, but tagged salmon are marked by removing the adipose fin. Coded wire tags are practical only for marking batches of fish, however, since the number of distinguishable codes is limited. In the Central Valley the batches usually include 50,000 or more fish, so that enough tags can be recovered to provide useful data. Use of CWTs in the Central Valley began in 1969, and continues in studies such as the Vernalis Adaptive Management Plan (VAMP), the Delta Cross-Channel studies, and survival studies in tributaries to the San Joaquin River. A prominent use has been a set of survival studies conducted by the USFWS. The most common procedure has been to release batches of tagged fish at different locations in the river or in the Delta, and to recover marked fish in a trawl fished near Chipps Island and in the ocean fishery. On average roughly ten times as many fish are captured in the ocean fishery as at Chipps Island, but ocean recoveries are estimated from sampling and so include additional sampling error. Brandes and McLain (2001) provide a recent summary of CWT releases and recoveries, and more detail is available in earlier summaries such as Kjelson et al. (1981) and USFWS reports cited in Brandes and McLain (2001). Brandes and McLain (2001) and Baker and Morhardt (2001) provide discussions of the data from somewhat differing points of view, and recent statistical studies of the data are described in Chapter 11 and Appendix B. Coded wire tags have also been used for growth studies (e.g., Kjelson et al 1982), and to mark spring, late-fall and some fall Chinook reared in hatcheries.

Table 15-1: Monitoring for adult Chinook and steelhead. Fall-run (FR), late fall-run (LFR), winter-run (WR), spring-run (SR), steelhead (ST). Data from Alice Low, CDFG.

Monitoring Activity	Variable	Stream	Agency
Carcass Counts	**Adult Returns, FR**	**Sacramento River** **Clear Creek** **Battle Creek** **Butte Creek** **Yuba River** **Feather River** **American River** **Cosumnes River** **Stanislaus River** **Tuolumne River** **Merced River**	**CDFG/USFWS** **CDFG/USFWS** **CDFG** **CDFG** **YCWA/JSA**[1] **DWR/CDFG** **DFG** **CDFG, DWR, TNC** **CDFG** **CDFG** **CDFG**
Snorkel Surveys	**Adult Returns, SR, St**	**Clear Creek**	**USFWS**
	SR, WR, St	**Battle Creek**	**USFWS**
	SR	**Antelope Creek**	**CDFG**
	SR	**Big Chico Creek**	**CDFG**
	SR	**Beegum Creek**	**CDFG**
	SR	**Deer Creek**	**CDFG**
Dam or Weir Counts	**FR, WR**	**Sacramento River**	**USFWS**
	LFR, SR, St	**Battle Creek**	**USFWS**
	FR, ??	**Yuba River**	**CDFG?**
	FR, St	**Mokelumne River**	**EBMUD**
	FR	**Stanislaus River**	**S. P. Cramer & Assoc.**
Redd Surveys	**FR, LFR, SR, St**	**Clear Creek**	**USFWS**
	SR, WR, St	**Battle Creek**	**USFWS**
	SR	**Mill Creek**	**CDFG**
	Spawning Distributions, all runs	**Sacramento River**	**CDFG**
	SR	**Yuba River**	**CDFG**
	FR, St	**American River**	**CDFG**
	FR	**Cosumnes Rivers**	**CDFG, DWR, TNC**
	FR, St	**Mokelumne River**	**EBMUD**
	FR	**Merced River**	**CDFG**
Angler Survey	**Sport Harvest**	**Sacramento River**	**CDFG**
		Yuba River	**CDFG**
		Feather River	**CDFG**
		American River	**CDFG**
		Mokelumne River	**CDFG**
		Stanislaus River	**CDFG**

[1] Funded by Yuba County Water Agency, performed by Jones & Stokes

Table 16-2: Monitoring for juvenile Chinook and steelhead. Data from Alice Low, CDFG.

Monitoring Activity	Variable; Run	Stream	Agency
Snorkel Surveys	**Habitat use; FR, LFR, SR, St**	**Clear Creek**	**USFWS**
	Habitat use, survival; St	**Feather River**	**DWR**
	Habitat use; FR	**Yuba River**	**YCWA/JSA**[2]
	Abundance, habitat use; FR	**Calaveras River**	**USFWS, Fishery Fnd.**
	Presence; FR	**Stanislaus River**	**USFWS/ Fishery Fnd.**
Screw traps	**Emigration; all**	**S.R., RBDD**	**USFWS**
	All	**S. R., GCID**	**CDDFG**
	FR, LFR, SR, St	**Clear Creek**	**USFWS**
	FR, LFR, SR, St	**Battle Creek**	**USFWS**
	SR	**Big Chico Creek**	**CDFG**
	SR	**Mill Creek,**	**CDFG**
	SR	**Deer Creek**	**CDFG**
	SR	**Butte Creek, Chico**	**CDFG**
	All	**Sutter By-Pass**	**CDFG**
	All	**S. R., Knights Lndg**	**CDFG**
	FR, SR?, St	**Feather River**	**DWR**
	FR, ST	**Yuba River**	**CDFG**
	FR, ST	**American River**	**CDFG**
	FR, ST	**Cosumnes River**	**USFWS, Fishery Fnd.**
	FR, ST	**Mokelumne River**	**EBMUD**
	FR	**Calaveras River**	**S. P Cramer Assoc.**
	FR, ST	**Stanislaus River**	**S. P. Cramer Assoc.**
	FR, St	**Tuolumne River**	**CDFG**
	FR	**Merced River**	**CDFG**
Beach seines	**Distribution, emigration; all**	**S. R., S.J. R., Delta, bays**	**USFWS**
	Distribution, abundance; FR	**Cosumnes River**	**TNC**
	; FR, St	**Mokelumne River**	**EBMUD**
	Abundance; FR	**San Joaquin River**	**USFWS**
	Distribution; FR	**Tuolumne River**	**TID**
Trawls	**Emigration; All**	**S. R. at Sacramento**	**USFWS**
	Emigration; FR, St	**S. J. R. at Mossdale**	**CDFG**
	Emigration, Survival; All	**Chipps Island**	**USFWS**
Fyke nets	**Entrainment; FR, St**	**Merced River**	**CDFG**

Recommendations for monitoring:

Given that all natural resources management is experimental, whether deliberately so or not (Hennesey 1994), monitoring should be considered as obtaining the experimental results. Even in the absence of deliberate management experiments intended to test alternative hypotheses about the system being managed, hypotheses can still be tested, provided that there is sufficient variation in the main variables of interest. Year to year variation in precipitation and runoff in

[2] Funded by Yuba County Water Agency, performed by Jones & Stokes.

California makes this generally the case for many factors affecting salmon. From this point of view, monitoring should be approached in terms of what can be learned about the system and its management, and not just in terms of tracking whether targets for variables such as adult returns have been met; in other words, we should think of monitoring as part of science as well as part of management. In any event, monitoring deserves careful attention, in part because it is hard to do well. One aspect is the difficulty of sampling consistently through highly variable field conditions, which requires skill and diligence from boat operators and field crews; a good monitoring program is impossible without good execution. However, a good program also requires a good design, and good data analysis.

Although some basic level of monitoring will be needed for all streams, the nature and intensity of monitoring should vary according to need and the suitability of conditions in the stream for addressing particular questions. Given the inevitable constraints of time and money and the magnitude and variability of the system to be monitored, developing a well designed program is a major challenge. This section presents some generalities about monitoring and suggestions for elements of a monitoring program for Central Valley salmon, and offers some suggestions for evaluating and improving existing programs.

<u>General Recommendations on monitoring:</u>

1. *Monitoring should evaluate the condition of organisms as well as of populations and habitats.* Traditional approaches to monitoring try to measure attributes of populations, especially abundance, and attributes of habitats such as water temperature, discharge, etc. These are necessary, but attention should also be given to measuring attributes of individuals, such as growth rates and aspects of physiological condition such as lipid content. In a study monitoring the environmental effects of off-shore oil production in the Santa Barbara Channel, Osenberg et al. (1994) found that individual-based parameters were more effective at detecting impacts than population-based or physical parameters because they have better statistical properties, and because they provide better evidence of the mechanisms that control populations. Castleberry et al. (1996) urged that individual-based measures of condition and performance be monitored, in addition to population measures, for effective adaptive management of instream habitats. Potential individual-based parameters of salmon include growth rates from otolith

microstructure, measures of lipid content, RNA/DNA ratios, and levels of stress proteins, as well as simpler "condition factors" such as relative weight. These are described in more detail below.

2. *Monitoring should address specific questions.* In most cases, monitoring should be linked to specific hypotheses or management activities. Basic biological monitoring is sometimes justified, however, especially where lack of data inhibits the development of useful hypotheses (Power et al. 1996), but there is a danger that monitoring for "status and trends" can become rote, producing data that are never thoughtfully analyzed or critically evaluated for utility. This danger can best be avoided by making data analyses to address specific questions, as well as exploratory analyses, basic parts of the monitoring program. This will clarify which aspects of the monitoring program are producing useful data, and which are not. As a corollary,

3.. *Data collection and analysis should be closely linked.* Monitoring produces better and more useful data if the person responsible for analyzing the data is closely associated with the data collection. This gives the analyst a better understanding of the strengths and weaknesses of the data, and promotes more careful work by the field crews. If no one is interpreting the data, the need for the monitoring should be reconsidered.

4. *Monitoring programs should try to answer multiple questions.* Just as a good move in chess attacks and defends at the same time, so a good monitoring program should develop new knowledge at the same time that it checks the performance of management actions in light of existing knowledge. By addressing multiple scientific questions, a monitoring program can develop data that allow management questions to be addressed from several points of view. This can be important, because field observations of single variables will seldom provide unambiguous answers; almost always, different conceptual models or "stories" can be invoked to explain observations of a single variable, and the monitoring program should include enough elements to test and multiple stories and rank their plausibility. For example, using PIT tags to monitor the survival of individual smolts passing down the Columbia River has not settled a long-standing dispute about the relation between flow and survival, because decreased flow increases travel-time, and there is evidence that increased travel-time reduces the smolts' energy

reserves and so reduces their viability, even if they survive past the last tag detector (Congleton et al. 2003; NRC 2004).

5. *Monitoring should use up-to-date statistical and graphical methods.* The statistical methods now most commonly used were developed for use on mechanical hand-calculators. Computers have allowed the development of computationally intensive statistical methods that allow more useful information to be developed from monitoring programs (Efron and Tibshirani 1991; Hilborn and Mangel 1997). Bayesian statistics arguably provide a more useful guide to management of natural resources than do the more traditional and familiar frequentist methods (e.g., Hilborn and Ludwig 1993). Very few of the scientists now working on Central Valley salmon are familiar with these newer methods, however, so a deliberate effort should be made to introduce the methods and train people in their application. In any event, more attention should be given to developing estimates of effect size and confidence intervals, rather than tests of whether an observed change is statistically significant (Stewart-Oaten 1996; Steidl et al. 1997; Johnson 1999). As a first step, however, better use should be made of available software for graphical presentation of data; for example, box plots can be a useful way to summarize information about distributions of fish size, etc. Graphical presentation of data is discussed at greater length below.

6. *Monitoring programs should be evaluated by simulations***.** Analyses of simulated data that include realistic amounts of uncertainty can help determine whether a proposed monitoring program will provide useful answers to the questions it is designed to address. For example, Williams (1999) used simulations incorporating reasonable amounts of measurement of sampling error to argue that the Comprehensive Monitoring and Assessment Program (CAMP) set up under the CVPIA is unlikely to meet its objectives. Similarly, Meekan et al. (1998) used simulations to show the effect of measurement errors on the ability of regression analysis to detect the relationship between the size of Atlantic salmon at emergence and two measures of otolith size. Monitoring programs are expensive, and experimental programs such as the Vernalis Adaptive Management Program (VAMP) are very expensive; simulations can be an inexpensive way to avoid costly mistakes in the design of these programs (Hilborn and Mangel 1997), or to assess the results. For example, the estimates of smolt survival through the Delta

developed by the VAMP using hatchery fish marked with coded-wire tags are low (~15-20%), and simple simulations of the salmon life cycle could be used to assess whether it is reasonable to think that these survival estimates are also applicable to naturally-produced smolts; that is, given current estimates of mortality in other life stages, is 15-20% mortality passing through the Delta compatible with existing population data.

7. *Monitoring should be complemented by modeling.* To be useful, monitoring data must be converted into information, and one way to do this is to model the biological processes that are thought to underlie the variables being monitored. In an important sense, modeling is simply a formal way of thinking about the data, and many different kinds of models can be used (Ch. 15). As with statistics, modeling is a rapidly developing field that has been stimulated by the rapid development of computers and computer-based methods. More people with good training in modeling and statistics should be employed or retained by agencies concerned with Central Valley salmon, and training opportunities should be provided for existing staff.

8. *The monitoring program should provide for extra sampling of unusual events* Extra sampling during unusual events or situations, such as the aftermath of floods, can sometimes produce particularly valuable information. By their nature, unusual events are hard to plan for, but funding for contingency sampling can be made part of the monitoring program. The utility of contingency sampling probably depends upon close supervision of the field program.

9. Take sampling bias and uncertainty into account. To an extent that is probably greater than most of us realize, our knowledge of salmon is shaped by the gear that are used to sample them. As discussed earlier, sampling with a mid-water trawl in the 1960s (Sasaki 1966) led to the mistaken conclusion that the timing of the main migration of juvenile chinook had changed, a view that was corrected only when sampling with floating screw traps started in the early 1990s. Similarly, the existence of a gill net fishery in Suisun Bay allowed for recovering a significant number of adult salmon that had been tagged well up the Sacramento River (McCully 1956), demonstrating an aspect of behavior that seems to have faded from the common awareness of Central Valley salmon biologists. The current view regarding the number of fry that migrate into the bays is based on data from the Chipps Island trawl, which was designed for capturing smolt migrants and presumably is not as efficient for capturing smaller fish (see Stevens 1966). Similarly, current data on the timing of winter-run migration into the Delta is based largely on trawling at Sacramento, but if the findings of the recent Delta Cross Channel experiments using hatchery late fall-run smolts (Ch. 11) also apply to winter-run, the trawling occurs when most fish are holding near the margins of the stream, so the trawl data may be misleading. As another example, it is common to sample juvenile salmonids with traps facing upstream, in order to catch fish moving downstream, but this practice may give a distorted picture of fish behavior if it is assumed that most movement is downstream. A study using traps facing downstream as well as upstream, described in Ch. 9, sometimes caught more fish in the downstream-facing trap (Venditti and Garland 1994), presumably because the fish were not actively migrating. Special sampling to assess the relative efficiency and bias of various sampling methods should be conducted, although some uncertainty will always remain. Sampling bias seems inevitable, but at least we can be conscious of it.

10. *Make full use of existing data*. A great many data have been collected by monitoring programs that have not been thoroughly analyzed. For example, the data on salvage of juvenile Chinook and steelhead have not been analyzed for differences among years in size at date (e.g., figure 11-13), which could provide a useful index of growth opportunity or habitat conditions in fresh water. Similarly, length at age data from the coded-wire tag database might be used to generate an index of ocean conditions, and both indices could be related to environmental conditions. Generally, these should be exploratory analyses, intended to generate hypotheses that can be tested with future data. Care should be taken to avoid “data dredging,” which occurs when many variables are screened, some are selected for a model, and then the same data are used to evaluate how well the model fits the data (Freedman 1983; Burnham and Anderson 1998).

One reason that data have gone unexplored is that they have been hard to get. The situation has improved recently, with development of the Calfish data base (www.calfish.org) and a new interface for the data managed by the IEP. Good data management is expensive, however, and more money will need to be allocated to this purpose before the data are fully available.

11. *Assess monitoring programs periodically*. It is natural and appropriate that as interests change, perhaps because older questions have been satisfactorily resolved, efforts will be made to address new questions using data from programs that were not designed to address the new questions. Thus, even if monitoring programs are suitably designed for their original purpose, they may become inadequate as needs change. Moreover, standards of practice evolve, so what may have been an acceptable practice before may no longer be so, and new approaches and technologies may make older methods obsolete or require data not previously collected. Periodic review and assessment of monitoring programs is therefore appropriate, and such a review, with substantial participation by outside reviewers, seems in order for salmon monitoring programs in the Central Valley..

The various recommendations and suggestions offered here should be considered in such a review. It should also take account of the findings of a highly qualified panel (Botkin et al. 2000) that considered the question: "If actions are taken in an attempt to improve the status of salmon (or a specific stock of salmon), what measurements are necessary, feasible, and practical to determine whether the actions are successful?" Many of their comments, or questions, are applicable to assessing other monitoring programs as well. Their list of important considerations is paraphrased and abbreviated below:

<u>Sampling:</u>
Do the sampling sites and methods reasonably represent the area in question and the range of conditions that occur there?
Is the sampling of adequate duration and frequency?
Does the sampling take advantage of replicated actions
Are the sampling methods sufficiently accurate and precise to meet the monitoring objectives?
Are proposed monitoring activities really feasible?
Is the use of new technology proposed, and if so, are backup methods also proposed?

<u>Data Management</u>:
Are data properly checked for errors?
Are data archived securely?
Are archived data readily available?

<u>Analysis and Interpretation:</u>
Are the analytical techniques used appropriate for the data and questions being addressed?

Are alternative hypotheses properly considered?
Is uncertainty properly described and taken into account in analyses of the monitoring data?
Do the analyses identify and assess risks as well as benefits from management alternatives?
Do the analyses identify opportunities for additional learning?

The review should include special studies to assess the relative efficiency and sampling biases of various sampling methods.

Possible Improvements to Existing Programs:

The recommendations given above imply changes in existing monitoring programs, most of which would require time, planning, and additional funding to implement. However, there are some changes that can be made more easily.

Improve statistical practice. Monitoring normally involves observations of samples, and observations almost always include some error, so estimates of variables of interest developed from monitoring data are more or less uncertain. Accordingly, the estimate should include both a point estimate and a measure or estimate of the uncertainty around the point estimate; typically, this is done by reporting standard errors or confidence intervals. Unfortunately, this is not done in many Central Valley monitoring programs, although it was standard practice in the past (e.g., Hatton and Clark 1942), when calculating statistics such as standard errors involved considerable work on hand calculators. Off-the-shelf statistical programs now calculate standard statistics almost instantaneously, and bootstrap methods (Efron and Tibishirani 1991; 1993; Manley 1997) can often be used for unusual statistics as well. Agencies should make training opportunities available for staff who prefer it, and time for independent study available to others.

More attention should also be given to the problem of spurious precision in reporting monitoring results. That is, if an estimate of adult returns is thought to be accurate to within a thousand, then it is spurious precision to give the estimate as, say, 14,351, unless standard errors or confidence intervals are also given. Reporting highly uncertain estimates down to single digits seems to be an unfortunate tradition in the Central Valley.

Present data more effectively. Existing programs could yield additional information with modest additional expense, if more effort were put into displaying the data more effectively. For example, it is common practice to measure the lengths of up to fifty individuals from a seine haul or from the daily or weekly catch of a screw trap, and then to report only means and standard errors or deviations, or means and ranges, or even just means. When figures were created by hand, and statistics were run on mechanical calculators, such a practice was understandable. With modern graphical programs, however, it is simple to create several kinds of figures that emphasize different aspects of the data, and there is no good reason that this should not be standard practice.

Good graphics convey information clearly, just as good writing does. As with writing, there is no single best style for graphics, but Cleveland (1985) provides useful guidance. Unfortunately, many biologists are not trained at making graphs, and the standard of graphical practice among Central Valley salmon biologists is not high, although there are exceptions (e.g., see figures 6-30-32, showing the timing and size distributions of juvenile spring-run and winter-run). Agencies should provide their staffs with training opportunities, and with better graphics programs than Excel.

One positive development for Central Valley monitoring programs has been the development of "project work teams," in which biologists working on various aspects of monitoring Chinook and steelhead meet periodically to discuss problems and developments. These meetings provide a good venue in which to implement the suggestions just made. To some extent this has already happened. For example, a training workshop on the use of software for calculating confidence intervals around escapement estimates was organized for members of the escapement project work team. This kind of activity should be encouraged.

Elements of monitoring programs for salmon:

Potential elements of monitoring programs for Chinook and steelhead are described below. Which should be included in actual monitoring programs depends on the questions at play in each case; that is, this list is intended as a menu, not a recipe.

Adult returns: The number of returning adults is a basic measure of the quality of habitats and of management, so estimates of adult returns are a fundamental objective of a monitoring program. Numbers by themselves are not enough, however, and accuracy is subject to diminishing returns, so decisions regarding the allocation of resources among elements of a monitoring program will always be in order. For example, if the interest is in stock-recruit relationships, or the number of progeny that can be expected from a spawning run, then the real quantity of interest is the number of viable eggs, and uncertainty about the size and fecundity of the enumerated fish limits the useful accuracy of the census, unless information is also collected on fecundity and perhaps on egg size, both of which vary with the size and age of the female (Ch. 7). If adult returns are of interest as a measure of habitat quality, then the useful accuracy of estimates is limited by uncertainty about ocean and inland harvest, including illegal harvest. In general, developing a good allocation of resources in a monitoring program will require careful consideration of the marginal utility of accuracy for the various parameters that are estimated, and the importance of other aspects of the monitoring program such as data management.

Where fish need to pass over existing dams, or where weirs can be operated, as on the Mokelumne and Stanislaus rivers, accurate estimates can be obtained. Elsewhere, the accuracy of the estimates will vary depending upon the resources available for surveys and conditions in the stream. Where fish spawn in remote areas where access is difficult, as on Deer Creek, obtaining accurate estimates may be prohibitively expensive. Estimates of returns on most Central Valley streams are obtained by mark-recapture methods applied to carcasses. As delicately put by JHRC (2001;12) "The accuracy and variance of most Central Valley escapement estimates are currently unknown and may not be sufficient to meet management needs, …" Generally, the accuracy will depend on percentage of carcasses that can be recovered and the extent to which various assumptions of the methods, for example that all carcasses are equally likely to be recovered, are violated in the particular circumstances in which the method is applied. A careful and critical review of the use of mark-recapture methods in the various Central Valley streams is in order, and could make use of the results of particularly intensive surveys that have been done recently on the Feather River (B. Cavallo, CDWR, pers.comm. 2005). This would be a serious project, on the order of a Ph.D. project in statistics. Currently two different methods are commonly used to estimate the total run for carcass survey data, and until it is clearly established which is more appropriate in which circumstances, the best course probably is to use and report both. In any event, estimates of adult returns, like other estimates from monitoring, should include confidence intervals or standard errors. Methods for estimating confidence intervals are available, at least for the Jolly-Seber estimator, and confidence intervals should be reported routinely, along with appropriate caveats if important assumptions of the method may be invalid.

Natural Production: The proportions of adult returns that are naturally and hatchery produced should be estimated for most if not all streams. For this and other purposes, all hatchery fish should be marked, as recommended by NRC (1996). Economical marking that can identify the hatchery of origin and brood year can be accomplished by varying the temperature of water in hatchery trays, creating alternating light and dark bands in the otoliths that serve as a bar-code (Volk et al. 1990; 1994, Fraley and Munk 1997). Otolith thermal marking is a mature technology that is widely used around the North Pacific; the otoliths of more than a billion salmon are now marked annually (E. Volk, WDFW, pers.comm. 2004). Preparing otoliths well enough to read thermal marks is easy enough that they are used for in-season management of mixed-stock fisheries (Hagen et al. 2000). Collecting otoliths from a modest number of carcasses in each stream should allow reasonable estimates of the proportions of hatchery and naturally-produced fish, but enough should be collected to meet some specified objective. For example, on a stream without a hatchery, the objective might be to determine with 80% accuracy whether fewer than 5% of the spawners are hatchery fish.[3] This approach would also produce a collection of otoliths that could be analyzed for other purposes, such as estimating the distributions of length at age for naturally produced fish and determining the juvenile life histories of naturally produced fish that survive to spawn.

Hatchery fish can also be marked by clipping their adipose fins, as is done when fish are marked with coded-wire tags. Clipping fins is relatively inexpensive, so all hatchery fish could be given an external mark by clipping the fins, in addition to the otolith thermal marks. Because the fin clip is used to identify coded-wire tagged fish, however, there is reluctance to clip the fins

[3] Rules of thumb for assessing the condition of listed Chinook and steelhead populations being developed by the Central Valley Technical Recovery Team include the question whether fewer than 5% of spawners are hatchery fish.

of fish without tags. On the other hand, marking all hatchery fish with coded-wire tags would be expensive. A compromise approach is to tag a constant fraction of hatchery fish, so that the proportion of hatchery fish among adult returns can be estimated from the proportion with tags. However, it is hard to see any advantage of constant fractional marking over otolith thermal marking, except that coded-wire tags are a familiar technology to Central Valley salmon biologists. On the other hand, constant fractional marking has the disadvantage of focusing attention and learning on hatchery fish, rather than on naturally produced fish. In monitoring programs for juveniles, for example, the origin of unmarked fish would be difficult and expensive to determine. Hatchery and naturally produced fish can be distinguished by the isotopic composition of their otoliths, since the otoliths of the hatchery fish carry the isotopic composition of the hatchery feed (Weber et al. 2002), and they can be distinguished with about 80% accuracy by the greater regularity in the widths of early increments in hatchery fish (Zhang et al. 1995), but sorting fish by origin using these methods too difficult and expensive for routine use in monitoring, or even in many focused studies. If fish need to be marked for special studies such as the VAMP, clips on other fins could be used.

Size at age, age distribution, life history information: The age distribution of returning adults and size at age should be determined, using otoliths collected for tracking the proportion of hatchery and naturally-produced fish. The sample sizes needed should be determined by experience, but should be large enough to meet defined objectives. Better estimates will be justifiable on streams selected for active adaptive management, and might be omitted altogether for some others, although any otoliths collected could be archived in case a need arises for the data. Although preparing adult otoliths for microstructural analysis is more difficult and time consuming than preparing them for reading thermal marks and age in years, analyses of otolith microstructure from early life can also provide information on the prevalence of different life-history patterns among fish that survive to maturity. Such work is currently in progress for Chinook in the Skagit River in Washington (R. Reisenbichler, USGS, pers.comm. 2005).

Timing and location of spawning, approximate number of redds, and estimates of superimposition: The spatial and temporal distributions of spawning can be determined by repeated aerial surveys in some streams but not in others, depending upon depth and clarity of the water. Ground or boat surveys may be effective for tracking redds where aerial photography fails. Where it is effective, aerial photography also provides a lasting record of conditions in the channel that may prove useful for many purposes. Data on the location and timing of spawning seem useful for developing empirical estimates of the relation between discharge and spawning habitat (Williams 2001b), and significant changes in either distribution should provoke inquiries into causes. Estimates of the extent of superimposition can be developed from aerial photography, but this should be done cautiously since redd size estimated by aerial photography on the American River was about three times larger than redd size measured on the ground (Snider and Vyverberg 1996). If adult returns are estimated by carcass surveys, some information on the timing and spatial distribution of spawning is obtained as a by-product.

Fecundity: Fecundity is a basic biological parameter that deserves more attention (Ch. 7), and can easily be measured at hatcheries. Average fecundity is routinely estimated at hatcheries by dividing an estimate of the total number of eggs taken by the number of females stripped, but the data are of uncertain quality and data on variation in fecundity among individuals are scarce. Collecting data on the fecundity of individual fish is not difficult and should be routine, although proper protocols for selecting females to sample need to be developed and used. Besides providing a check on possible effects of hatchery culture, fecundity data contains information on ocean conditions (Figure 7-10). Fecundity data for naturally-produced fish generally should be obtained on an opportunistic basis to check for consistency with hatchery data, but if there is a specific question to be addressed then deliberate collection of a sample of appropriate size may be in order. Data on egg size should be collected along with egg numbers.

Hyporheic conditions: Salmon begin their lives buried in gravel and probably most die there as well (Ch. 8), but very little information is available on the quality of the hyporheic habitat of Chinook and steelhead in the Central Valley. This is a difficult but important area of inquiry. Components of hyporheic water quality, particularly dissolved oxygen content and temperature, are important variables that can be monitored. Permeability is commonly measured with standpipes, but work in progress indicates that in gravel the standpipes are subject to considerable leakage along the pipe, casting doubt on the validity of the data (Tim Horner, CSUS, pers.comm. 2005), so such data should be treated with caution until this question is clarified. Unfortunately, such data as are available suggest that hyporheic habitat is highly variable in time and space, so direct monitoring of hyporheic conditions may be difficult, and should be supplemented by information inferred from the condition of fish that do emerge. For example, the size of recently emerged juveniles that are captured in screw traps and the percentage of them that have not fully absorbed the yolk sac are easily measured and probably vary with hyporheic conditions. Data on otolith microstructure or aspects of physiological condition or histology of newly emerged fry probably would be more informative but would be more difficult and expensive to obtain. As with length-weight indices of condition, standards for comparison would need to be developed to allow better interpretation of the data.

Emergence, early emigration: The timing of emergence and early emigration is most often monitored in the Central Valley using screw traps, but fyke traps or seines can also be used. Data from seines also provide some measure of populations, but in most larger streams there will so much uncertainty in seine data that they are better regarded as qualitative (none or few, some, many, lots) rather than quantitative. Screw or fyke traps provide more accurate estimates of the numbers of migrants, but on large streams where only a small percentage of migrants are sampled the estimates may still be subject to considerable error, and the traps may be more effective for smaller than for larger fish. Software for calculating confidence intervals around screw trap estimates exists (e.g., Bjorkstedt 2005) and should be used, but these depend on assumptions such as constant capture efficiency over sampling periods (e.g., weeks) that may not be valid. Simulations could clarify the potential errors involved. Sampling with seines or screw traps also allows for collecting subsamples of fish for measures of condition, etc., and sampling with seines or fyke traps near the margins of larger stream may collect fish that avoid screw traps fished farther from shore (Ewing et al. 2001; S. Williamson, USGS, pers.comm., 2005)

Population density: A promising approach for estimating the density of juveniles in rivers has been described by Weber and Fausch (2004). Essentially, the method involves outlining a section of channel with posts set in the stream bed (in their case 6.1 x 30.5 m), and attaching a modified seine that can be raised and dropped on the posts. The seine is raised long enough to allow fish to move into the area, and then dropped, and the number within the enclosure is estimated by depletion sampling with a standard seine. This method should allow better estimates of population density and size distributions than conventional seining.

Habitat use by juveniles: Methods for observing fish and estimating their abundance in smaller streams are well established (Dolloff et al. 1996). The problem is more difficult in larger streams, and when water is turbid, but presence and qualitative estimates of abundance can be determined using seines or other traditional gear. Migration rates and habitat use can also be monitored by marking naturally-produced fish with coded-wire tags and adipose fin clips and recapturing them farther downstream. If many fish of approximately the same size can marked with a particular tag code, as has been done in a project on Butte Creek (Ch. 5), then growth rates can be estimated as well.

Methods from landscape ecology (e.g., Jongman et al. 1987; Ford and Brown 2001) seem appropriate for summarizing the relationships between observations of fish and environmental variables. Often, however, there is a desire to relate observations of fish to habitat features in terms of habitat selection or habitat preference, but doing this well is difficult. Kramer et al. (1997) note that "Studies of habitat selection frequently fail to acknowledge the statistical complexity underlying even simple questions of distribution." Manly et al. (2002) have provided a more secure theoretical basis for studies of resource selection in terms of a "resource selection function," which is "a function such that its value for a resource unit is proportional to the probability of that unit being used ", which seems similar to what a PHABSIM suitability curve is often taken to be. The assumptions of their approach are (Manly et al. 2002:43):

a. the distributions of the measured X variables for the available resource units and the resource selection probability function do not change during the study period;

b. the population of resource units available to the organisms has been correctly identified;

c. the subpopulations of used and unused resource units have been correctly identified;

d. the X variables which actually influence the probability of selection have been correctly identified and measured;

e. organisms have free and equal access to all available resource units; and

f. when studies involve the sampling of resource units, these units are sampled randomly and independently.

People familiar with field studies will realize that some of the assumptions are difficult to meet, but Jones and Tonn (2004) have reported resource selection functions for Arctic grayling.

Other difficulties with studies of habitat selection involve questions of scale. A study of substrate use by various species darters (Welsh and Perry 1998) provides a particularly clear example. One of the darters typically holds on top of submerged boulders, while two others typically hold in the gaps between them. Since gravel often occurs in the gaps, these species are associated with smaller substrate when data are taken using small quadrats, whereas the other species is associated with larger substrate. If larger quadrats are used, this difference disappears, and the selected substrate size of two species seems to increase while it seems to decrease for the other. Cavallo et al. (2003) showed that large scale features strongly affect habitat selection by juvenile steelhead in the Feather River. In short, monitoring that tries to relate distributions of fish to habitat features should be approached with due caution, and with good statistical guidance. Generally such work should be regarded more as research than as monitoring, and should be concentrated in the streams selected for active adaptive management, or that offer good study conditions. Monitoring of habitat use is also appropriate for restoration projects justified by specific hypotheses regarding habitat use, and there is a particular need for information on habitat use by small Chinook in the Delta and in the bays.

Condition: One difficulty with monitoring habitat use is that the presence or abundance of organisms in a habitat is not necessarily a good index of the quality of the habitat (Van Horne 1983; Manley et al. 2002), which may be more reliably inferred from measures of the organisms' condition. Which measures will prove most useful needs to be determined by experience, since this depends in large part on the strength of the response to the environmental variable of interest and on the background variability, and in many cases the data needed to estimate these factors do not yet exist. For example, there are few data on the lipid content of wild juvenile chinook in rivers (Beckman et al. 2000; Congleton et al. 2003). Similarly, there may be various ways to estimate a particular factor such as lipid content with varying costs and information returns, and some experience will be necessary to determine which way makes sense in particular situations (e.g. Weber et al. 2003). Sutton et al. (2000) calculated and compared seven different indices based on length, wet weight, dry weight, or lipid content, for a sample of 284 Atlantic salmon parr. Similar comparisons, using a wider array of variables, would be useful for Central Valley salmon, particularly fall-run Chinook.

Length and wet weight can be determined non-lethally from lightly anesthetized fish, and several measures of condition can be calculated from these measurements. Fulton's Condition Factor K (wet weight/length^3) is perhaps the best known index of condition and has been reported for juvenile Central Valley salmon in some studies (e.g., Snider and Titus 2001; Petrusso and Hayes 2001b). However, K can be misleading for comparing fish of different length, (Cone 1989), and better indices compare individual fish to standardized length-weight relationships for the study population (relative condition Kn; Le Cren 1951) or the species (relative weight W_r; Wege and Anderson 1978). Residuals from standard length-weight relationships can also be used (residualized wet weight; Sutton et al. 2000). Whichever index is used, lengths and weights should also be reported, so that other workers can calculate the other indices. Proper interpretation of these indices as indicators of environmental quality depends on the realization that both environmental and genetic factors affect the weight at length of a particular fish. Ideally, the index should reflect the deviation of the individuals' weights at length from a genetically-determined standard, although in practice probably the best that can be done is to compare the weights to a standard for a species, a population or a sample (Sutton et al. 2000). Given the diversity of life history patterns expressed by salmonids, any such group will be genetically heterogeneous.

More informative indices can be developed if fish are sacrificed and the contributions of water and polar lipids to wet weight are determined. Again, comparisons with relationships standardized to length may be useful, and the same caveats apply as for condition factors based on length and wet weight. Difficulties in comparing the results of different studies that use different indices can be mitigated if authors also publish their basic data. Dry weight and percent water is easier and less expensive to determine than percent lipid, but percent lipid is more biologically meaningful and is simple enough to determine that it seems hard to justify sacrificing fish simply to determine dry weight.

A number of measures of growth and condition that can help address such questions have been applied to chinook salmon and steelhead in the Central Valley, especially in the American River (Castleberry et al. 1991; 1993) and in the bays (MacFarlane and Norton 2002), and others have been applied elsewhere. For example:

Otolith microstructure : Because juvenile salmonids generally form one otolith growth increment each day, with distinctive tightly spaced increments at hatching and first feeding (Bradford and Geen 1987; Campana 1983; Neilsen et al. 1985; Castleberry et al. 1994), the number of otolith increments divided by length provides an index of long-term growth rate (e.g., Figure 3.A-12), and if a length is assumed at formation of the hatching or first feeding mark, the subsequent absolute growth rate can be estimated; simulations indicate that such estimates become usefully accurate by the time juveniles reach 45 to 50 mm (Williams 1995). More accurate estimates can be developed if the length at first feeding is also estimated for each individual from the size of the otolith at the first feeding check (Titus et al. 2004). Increment widths are also closely related to growth rate over extended periods (e.g. 50 days), although not for shorter periods (Bradford and Geen 1987). CDFG has been involved with studies of otolith microstructure for some time and should be reporting results soon (R. Titus, pers. comm. 2004).

RNA/DNA ratios: RNA/DNA ratios provide a measure of short-term growth rates, because the amount of RNA in cells increases during active growth but the amount of DNA is relatively constant (Buckley et al. 1999). A measure of short-term growth rate would be useful for evaluating the utility of specific habitats for juvenile salmon; rapid growth rates would be more powerful evidence of benefit to juvenile salmon than the mere presence of the fish in the habitat. In starved rainbow trout, however, the amount of DNA decreases over time, so that an initial decline the RNA/DNA ratio leveled off, although it stayed below the ratio for fed fish (Weber et al. 2003). In the American River, mean RNA/DNA ratios for juvenile Chinook in the American River rose rapidly with size to about 45 mm, but only slowly thereafter, and some of the variation may have been from the analytical technique used (Castleberry et al. 1993).

Lipids: Lipids are an important source of potential energy that reflects the physiological capacity of fish for growth or activity (Busacker et al. 1990), and lipid levels of juvenile salmonids from hatcheries affect their survival (Peterson 1973, Rondorf et al. 1985). Castleberry et al. (1991; 1993) analyzed lipid levels for juvenile chinook salmon and steelhead from the American River for two similar years (1991 and 1992), and found the levels to correspond with the lower range of levels for fed fish in hatcheries or laboratory experiments. However, few other data are available on lipid levels in naturally produced juvenile salmonids in rivers. Lipids occur in various forms. Castleberry et al. reported data for non-polar lipids, which can be determined by a simple ether extraction technique. Chromatographic analysis allows a more detailed and potentially more informative but also more expensive breakdown of lipids into sterol/wax esters, triacylglycerol, nonesterified fatty acids, cholesterol, and polar lipids (MacFarlane and Norton 1996), and was used in a study of salmon smolts from Chipps Island to the Gulf of the Farallones (MacFarlane and Norton 2002). Weber et al. (2003) describe methods for measuring whole body total lipids, whole body triglycerides, muscle RNA:DNA ratio and muscle protein from the same juvenile *O. mykiss*.

Gill Na^+P^+ATPase activity: Gill sodium, potassium-activated adenosine triphosphatase activity levels have been used as a quantitative measurement of the progress of smolting of migrating salmon in routine monitoring on the Columbia River (Beeman et al. 1991), and have been used elsewhere to clarify patterns in life history trajectories (Ewing 2001). The enzyme is used in the transport of NaCl across the gill epithelium, which is necessary for the survival of salmon smolts in salt water. There is concern that temperature stress may lead to reduced ATPase activity (Zaugg 1981), which could further compromise salmon smolts migrating through the Delta. Assays of the ATPase activity of fish exposed in the laboratory to thermal stress simulating migration through the lower Sacramento River in unfavorable conditions could provide a reference from known conditions. ATPase activities may also be helpful for interpreting monitoring data for larger juveniles migrating down the Sacramento River in late fall and winter, especially if combined with genetic analyses to assign fish to runs. ATPase activity can be sampled non-lethally by taking a small clip from one gill filament (Schrock et al. 1994)

Stress proteins: Exposure to thermal or other stresses induces synthesis of small "heat shock " proteins, particularly members of the hsp 70 family (Morimoto et al. 1990 and 1994; Feige et al. 1996). Although the functions of heat shock proteins continues to be elucidated it is known that some, including the hsp-70 family, function as molecular chaperones that reduce damage to other proteins, and account for acclimation to warmer water (Mosser and Bols 1988). Smolting fall-run chinook salmon are frequently subjected to high water temperatures in the lower Sacramento and San Joaquin rivers. Previous attempts to relate smolt survival to water temperature have used paired releases of coded-wire tagged fish. Although the data have been given competent statistical analysis (Baker et al. 1995, Newman and Rice 2002, Newman 2003) and it is clear that high temperatures reduce survival, considerable uncertainty remains regarding the level at which temperature begins to be a significant problem. Assays of one of these "heat shock" proteins, hsp 70, would provide an independent measure of the temperature stress that fish experience. Hsp 70 synthesis is also induced by other stressors such as various toxins that, like high temperatures, act by altering the biologically effective three-dimensional geometry of proteins. Accordingly, the presence of hsp 70 that cannot be accounted for by temperature stress indicates exposure to such stressors.

Field dissection: Sublethal stresses such as low levels of contaminants commonly induce changes in the color or gross appearance of organs and tissues that can be detected by field necropsy, and protocols have been developed for recording these systematically to obtain a profile of the health of a fish population based on percentages of observed anomalies (Goede and Barton 1990; Foott 1990, Adams et al. 1993).

Stomach Contents: Recently ingested prey provide a measure either of habitat quality, or of the ability of the fish to feed successfully. For example, terrestrial insects in stomachs provide evidence of the importance of riparian vegetation as a source of food. The amount of food in stomachs of recently emerged fry captured in screw (outmigrant) traps could provide evidence about the viability of early-emigrating fry.

Otolith microchemisty: The chemical composition of otoliths, particularly isotopic ratios, provides information about the habitats occupied by fish (e.g., Kennedy et al. 2002). Because of geological gradients along the Central Valley otolith composition can even be used to identify the river from which the fish probably came (Barnett-Johnson et al. in prep), and if hatcheries use feed derived from marine organisms, hatchery fish can be similarly identified (Weber et al. 2002). The cost of otolith microchemistry analyses is decreasing rapidly, so that it may soon be feasible for monitoring programs. The most likely uses of otolith microchemistry in monitoring are to determine whether the female parents of juvenile *O. mykiss* were anadromous (Zimmerman and Reeves 2000), and to estimate the life-stage at which juvenile anadromous fish enter brackish water (Secor 1992).

Genetic markers: Enough genetic markers have been identified to allow Central Valley Chinook to be assigned to runs with good confidence (M. Banks, pers. comm. 2004). Given the importance attached to take of winter-run at the pumps, and the inadequacy of size-at-date criteria for assigning fish at the pumps to runs (Hedgecock 2002), genetically based assignments seem appropriate. They should also be used in monitoring of juveniles elsewhere, at least until better understanding is developed of the migratory behavior of the various runs. As genetic typing develops from a research endeavor to a standard practice, however, laboratories will be needed that can do the analyses on a contract basis, and appropriately trained staff will be need to develop sampling protocols, oversee the laboratory work, and interpret the laboratory results.

Smolt and pre-smolt emigration: Generally the same methods can be used to monitor emigration by larger juveniles as for smaller ones, but with gear such as screw traps the efficiency is higher for smaller fish than for larger ones. Counting fences may be an option for pre-smolt and smolt migrants because the fish are larger and spring flows are less variable than winter flows. Dempson and Stansbury (1991) and Warren and Dempson (1995) describe the use of a counting fence with juvenile Atlantic salmon. Studies or adaptive management that require good estimates of numbers of juveniles should be conducted where good estimates can be obtained.

Survival in lower rivers and Delta: Much effort has gone into estimating survival in the lower rivers and the Delta by marking fish with coded-wire tags, and relating recoveries to environmental conditions, with significant but somewhat limited results (Ch. 11). A basic problem is that many weak effects, rather than a few strong ones, seem to control survival, at least in the lower Sacramento River (Newman and Rice 2002; Figure 11-17). Unfortunately, as noted above, even where good estimates of survival rates can be obtained, there still may be controversy regarding their meaning. Generally, future coded-wire tag studies should be designed to address specific questions, such as the relative survival of fish in bypasses versus fish in the rivers, or take place in the context of an experimental design such as the VAMP or the Delta Cross Channel studies. The increased straying rate of fish used in such studies should be taken in to account in assessing the costs and benefits of the studies, however. Although the actual effects of such increased straying are uncertain, modeling studies such as Lynch and O'Hely (2001) or Goodman (2005) provide a logical framework for analyzing the issue.