Considerations on the Use of Fish Survival Indices as a Tool to Develop Fish and Wildlife Standards in the Sacramento - San Joaquin Delta

Testimony Presented on Behalf of Delta Wetlands to the California State Water Resources Control Board

July 14, 1994

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Introduction

The use of fish survival indices has been suggested as a potential tool to formulate water quality standards for the Sacramento - San Joaquin Delta (Delta). During the State Water Resources Control Board (SWRCB) Hearings on Interim Water Quality Standards for the Delta in 1992, the U.S. Fish and Wildlife Service (USFWS) proposed the use of fish survival indices for application in the Delta. In January 1994, the Environmental Protection Agency (EPA) proposed salmon smolt survival indices as a viable tool to protect fish migration in the Delta (EPA 1994).

Fish survival indices could be a useful tool toward developing fish and wildlife standards in the Delta if those indices are based on empirical data reflective of "real-world" conditions. They may be particularly valuable because they could effectively predict fish survival under future Delta conditions. However, as is the case with scientific experiments, it is critically important to ensure that the fish survival indices (developed from experiments) are reasonably representative of how Delta conditions would be expected to affect fish in a natural setting. In other words, a reasonable rationale has to be presented to support the justification for extrapolating results of experiments to the real world. This paper provides some biological insights into why the USFWS and EPA suggested use of the indices has potential, but is presently limited for application to the Delta. Some suggestions on how to develop more effective fish survival indices and analytical tools are presented.

The USFWS Salmon Model

The fish survival indices suggested by the USFWS and EPA for use in the Delta were derived from extensive in-Delta testing conducted by releasing marked/tagged juvenile hatchery chinook salmon at various locations, times, and conditions in the Delta. Data developed from these investigations have proven to be very valuable in improving our understanding of how certain Delta conditions could influence young hatchery salmon survival during passage through the lower river and Delta.

The USFWS developed the salmon model based on survival indices from coded-wire tagged (CWT) juvenile hatchery fall-run chinook salmon released during April, May, and June at several Delta sites and subsequently recovered near Chipps Island in a trawl. The model uses the water temperature measured at Freeport, the fraction of water diverted off the Sacramento River at Walnut Grove, and total exports of the SWP and CVP in the south Delta to estimate fish survival. From 1978 through recent years, the USFWS has released groups of CWT juvenile hatchery salmon at three locations: Sacramento, Courtland (just downstream of Steamboat Slough), and at Ryde. Survival indices for each of these groups were based on trawl recoveries of young salmon near Chipps Island and, to some extent, on survival estimates generated for later life phases. After the USFWS calculated survival indices, they performed multiple linear regressions on the indices and south Delta export rates and water temperatures. The intent of their study was to develop juvenile salmon survival indices for three potential migratory pathways of young salmon presumably enroute from freshwater to the marine environment:

- **Reach 1** Sacramento to Walnut Grove
- **Reach 2** Walnut Grove to Chipps Island via the Mokelumne River and lower San Joaquin River systems (i.e., the central Delta), and
- **Reach 3** Walnut Grove to Chipps Island via the Sacramento River downstream of Walnut Grove.

In recent years, many scientists have critiqued the USFWS salmon model and the associated assumptions used in application of the model. For example, some individuals have pointed out that the USFWS technique to adjust predicted survival is probably not appropriate (the USFWS adjusted all survival indices by dividing the "raw data"by 1.8 to keep all indices from exceeding 1.0 (i.e., 100 percent survival). Other individuals have critiqued the model on its lack of statistical significance or misapplication or inappropriate use of statistical methods. Still other scientists have pointed out the confounding influence of water temperature in the USFWS model results. In most cases, the net result of past critiques has been the recommendation of reviewers to avoid direct application of the model as suggested by USFWS.

Alternatively, the considerations presented in this paper provide biological insights into how the fish survival indices may ultimately have merit and the biological rationale on why the existing salmon model is limited for potential application to formulate standards for the Delta. Basic information concerning parr-smolt transformation in young salmon has increased in recent years and current understanding and ideas can be applied to our working knowledge of young salmon behavior.

In developing the salmon survival indices, the USFWS presented numerous explicit assumptions to support application of the salmon model to the Delta. In addition, there are also numerous implicit assumptions not presented by the USFWS which are inherent with any application of the salmon model. Prior critiques by other scientists have addressed the appropriateness or inappropriateness of the assumptions. Therefore, the discussion given here will not repeats those efforts.

The focus of this paper is on one extremely important and broad-reaching assumption given by the USFWS which has profound influence on the SWRCB's evaluation of fish and wildlife standards for the Delta. I believe this particular assumption is the most important facet of the salmon model to consider for potential application of fish survival indices in the Delta. The USFWS assumption is:

> *"All juvenile hatchery fall-run chinook salmon used in the Delta survival experiments were assumed to behave as wild fall-run smolts."* (Kjelson et al. 1989)

If this far-reaching assumption is accepted as valid, it could have considerable influence on the SWRCB's ultimate decisions regarding fish and wildlife standards for the Delta.

Ramifications of the Hatchery/Wild Fish Assumption

The USFWS conducted tests using hatchery fish as surrogates for wild fish. As a result, their results suggest that wild fish would survive at various levels depending on Delta conditions present at the time wild fish may migrate through the Delta. Although the hatchery-surrogate-fish assumption has been adopted by the USFWS for the experiments conducted in past years, our technical understanding of this major issue has increased tremendously in recent years. Past justification for using this assumption has essentially been: "It's the best we can do at the present time." However, we are now at a point in time where we can significantly improve upon this assumption. Our scientific understanding of young salmon physiology, morphology, and behavior has increased considerably to the point where we can now seriously examine the validity of the hatchery/wild fish assumption. The scientific literature on the physiology of smolting is now extensive (Hoar 1988). There are numerous techniques now available to assess the validity of the USFWS's assumption but those validity tests have not yet been conducted. If the assumption is valid, it would add more credibility to the USFWS salmon model. Alternatively, if it is not valid, that knowledge would allow for the opportunity to re-examine past fish survival experiments in a new light, alter future experimental design for Delta fish survival experiments, and ultimately provide for a more substantiative basis of Delta fish and wildlife standards using fish survival indices. Clearly, this hypothesis has to be tested to avoid the risk of implementing standards which may not measurably benefit fish or, alternatively, result in worse conditions for fish.

The Biological Significance of What Constitutes a "Smolt" Salmon

Throughout the variety of Bay/Delta SWRCB Hearings in recent years, the term "smolt" salmon is used freely and interchangeably with juvenile salmon regardless of known salmon life stage or physiological development or salmon behavior. In many (and perhaps most) instances, a more appropriate biologically descriptive term would have been either young salmon, juvenile salmon, parr salmon, or pre-smolt. In some cases, the term should have actually been "fry" salmon. Because the criteria for assumed fish behavior in the USFWS tests is critically important to most of the underlying assumptions in predicting what happens to young salmon as they migrate through the Delta, the premise of what constitutes a true smolt salmon is described in this manuscript. This presents the basis for how the existing salmon model and fish survival indices were developed and why the model's present application is limited for developing fish and wildlife standards in the Delta.

Young chinook salmon may migrate downstream from upper river reaches into the Delta as pre-smolts (fry and parr) and as smolts. Young salmon which have not undergone the physiological process of smoltification are not adapted to make the transition from freshwater to the marine environment whereas smolts can easily make that transition. If what is loosely referred to as a "smolt" is actually not yet a smolt, serious erroneous conclusions would almost certainly occur in interpreting results of investigations designed on the wrong premise (discussed in following sections). Zaugg (1989) noted that poor adult recoveries of chinook salmon have been noted from releases of underyearling chinook showing no increase in a gill enzyme (used as a measure of smoltification) prior to release, as well as slow migration rates. If test fish used by the USFWS in Delta survival tests were not truly smolts, the USFWS premise concerning hatchery juvenile/wild smolt behavior would have serious consequences in resultant interpretation of their study results.

EPA (1994) describes a smolt as "... a salmon in the process of acclimating to a change from a fresh water environment to a salt water environment. This occurs when young salmon migrate downstream through the Delta to the ocean.". Although this definition is accurate, it is simplistic because there are complex morphological, physiological, and behavioral changes associated with the transformation of parr salmon to smolt salmon. These changes have a major influence on how young salmon may, or may not, interact with Delta conditions. The significance of what constitutes a smolt salmon has a substantial bearing on Delta water management issues. If pre-smolts are released instead of smolts, their low success rates may be mainly a result of using test fish that are not biologically ready to leave freshwater. And most importantly, if the test fish are subjected to test conditions which do not resemble any conditions which wild smolts may be exposed to during their natural migration to the ocean, the test results cannot be extrapolated to represent what would be expected to happen to wild smolts. Following sections are intended to elucidate the complexities and issues associated with the early life phases of young salmon.

Downstream Migration of Young Salmon

The many variables and interactions between variables associated with the migratory behavior of young salmon are complex and not well understood (Kreeger and McNeil 1992). Abiotic factors which may have primary influence on young salmon migration include photoperiod/date, water temperature, and flow. Other abiotic or biotic factors which may affect migration include barometric pressure, turbidity, flooding, rainfall, wind, species, stock (e.g., fall-run or spring-run), life history stage, degree of smoltification, parental origin (e.g., hatchery or wild), size of juveniles, location (e.g. distance from the ocean), food availability, etc. (Burgner 1991, as cited by Kreeger and McNeil 1992). The specific timing of natural smolt migration depends on the physiological state of the fish.

A review of the scientific literature on the topic by Kreeger and McNeil (1992) provides valuable insight into migratory characteristics of young salmonids. The time and speed of juvenile salmon migration are associated with age and size of the fish as well as with time. Older and larger smolts tend to migrate faster as compared to younger and smaller smolts. Early migrating smolts tend to migrate more slowly than late migrating smolts. Temperature is an important factor affecting smoltification - warmer temperatures can stimulate smoltification up to a threshold where smoltification is inhibited (Kreeger and McNeil 1992). Temperature influences the onset of smoltification through growth and regulates the magnitude and duration of the smolting process (Burgner 1991, as cited by Kreeger and

McNeil 1992). The downstream migration of young salmon may be passive or active and primarily occurs at night (Northcote 1984, as cited by Kreeger and McNeil 1992).

After reviewing numerous investigations on young salmon migration, Kreeger and McNeil (1992) suggest that the time of year when young salmon are released in the investigations is an important explanatory variable which would account for variation in migration timing (i.e., earlier releases result in slower migration rates as compared to salmon released later in the year). Their rationale for this observed behavioral phenomenon is that variations in migratory rates may be accounted for because the salmon were in different physiological states. Some researchers believe that smoltification can increase rapidly as fish migrate downstream toward the ocean which results in increased downstream migration speed with time (Zaugg 1989). Changing physiological state of the fish is a contributing factor for explaining seasonal patterns in migration rate. The Columbia Basin Fish and Wildlife Authority provides the following explanation for the importance of timing associated with smolt migration: "The physiological condition of smolts changes over the time they are migrating. Travel time determines whether the smolts arrive at the estuary during the "biological window", so they can successfully survive the transition to salt water." (CBFWA 1991).

The salmon model used by the USFWS provides estimated travel times for test "smolts" to migrate various distances in the lower river and along various Delta pathways (Kjelson et al. 1989). The migratory intervals given provide a strong indication that the hatchery test fish used were probably not true smolts at the time of release because the intervals appear too long as compared to those expected based on smolt migration research conducted elsewhere. These data also do not correspond to other data on migratory rates of Sacramento River chinook. On May 13, 1985, 66,000 coded-wire chinook salmon were released from Coleman National Fish Hatchery on the upper Sacramento River; the majority of these fish reached Chipps Island in eight days after traveling a distance of 246 miles (Myshak 1985). In contrast, the USFWS estimates that it takes all of their test "smolt" salmon twelve days to migrate from Sacramento to Chipps Island, a considerably shorter distance (Kjelson et al. 1989).

Numerous investigations have shown a correlation between young anadromous salmonid downstream migration and gill Na-K-ATPase activity. Measurement of gill ATPase activity has been demonstrated to be a useful and quantitative test to determine the optimum release date of salmonids from hatcheries (Adams et al. 1975). For example, measurement of gill ATPase is a powerful tool in determining the exact temperature at which parr-smolt transformation is depressed in steelhead trout (Adams et al. 1975). Zaugg (1989) believes that stage of smolt development as measured by gill Na-K-ATPase activity may be related to migratory behavior and survival in underyearling chinook salmon.

Salmon researchers have used a variety of alternative techniques to measure smoltification such as external appearance (e.g., body silvering and dorsal fin margin marking) (Kasahara et al. 1989) and gill Na-K-ATPase activity (Zaugg 1989). Chrisp and Bjornn (1978) describe numerous analytical tools to assess the transformation of parr to smolt and seaward migration for anadromous salmonids. These include such measurable indices as external appearance characteristics, coefficient of condition, NaK-stimulated ATPase activity, saltwater tolerance, and migratory behavior. To my knowledge, none of these techniques have been seriously attempted or used in the course of evaluating fish survival through the Delta. I am not aware of any attempts to accurately measure pre-release smolt development for those fish released as assumed smolts in the Delta fish survival experiments. Techniques to do so are readily available. Some measures that have been successfully used to describe and monitor physiological smolt development which would very probably have a high degree of application to the Delta and Central Valley rivers and streams are:

- Changes in condition factor during juvenile growth and development.
- Changes in gill Na-K ATPase activity
- Seawater tolerance changes as smoltification develops.

Salmon Growth, Water Temperature, and Delta Management

Growth rate of juvenile salmon in freshwater influences the age at which juveniles enter the ocean. With low water temperatures in upper river reaches, growth of rearing fry may be less than optimal causing a delay in time of outmigration through the Delta. After evaluating 13 years of data on Atlantic salmon smolts, Emolaev (1989) found that the initiation of migration was determined by "the rate of warming of the river, not by the absolute temperature of the water." (Emolaev 1989, as cited by Kreeger and McNeil 1992). In some rivers and streams in the Central Valley, the potential may exist to purposefully accelerate young salmon smoltification, downstream migration, and adaptability to seawater. Kasahara et al. (1989) found that accelerating growth of young masu salmon hastened the onset of smolting development and seawater adaptability.

If certain water management actions are implemented in the Delta (under the auspices of providing protection to salmon smolts), those measures may not be effective because juvenile salmon may not respond as anticipated to those measures because they may not be physiologically prepared to migrate. Because of the relationship between water temperatures in the upper river, the associated growth rates of young salmon, and their resultant outmigration timing through the Delta, the SWRCB should consider the potential effects of utilizing the planned temperature control structure on Shasta Dam to accelerate smolt migration timing through the Delta. For example, during the late winter and early spring, water temperatures in the upper river are sub-optimal for salmon growth. A potential management strategy could be to purposefully withdraw water at certain locations in the reservoir to provide better water temperature conditions for rearing salmon in reaches downstream of the dam.

The Effects of Transportation on Young Salmon with Implications on the Formulation of Fish and Wildlife Standards in the Delta

Young fall-run chinook salmon used by the USFWS to conduct the Delta fish survival experiments were obtained from various Central Valley fish hatcheries. These hatchery fish were loaded onto hatchery trucks filled with cold water, transported considerable distances down to various locations within the lower river system or Delta, and dumped into the receiving waters over periods ranging from April 28 to June 24 between years. Although I have not reviewed all the hatchery fish transport records, it is my understanding that the fish used in the experiments were different salmon stocks, were always dumped into river water substantially warmer than the water inside the transport trucks, were dumped into the river during daylight hours, and were not allowed to acclimate to the receiving water conditions prior to liberation into the wild. Because the USFWS assumed that these hatchery fish would behave and respond in a similar manner as wild fish migrating through the Delta, it is very important to closely examine any factors which may reasonably be expected to result in differences between what actually occurs and what is expected to occur in a natural setting.

Stress Effects

Severe physiological stress can be a consequence of transportation and transplantation of anadromous salmonids (Specker and Schreck 1980). Schreck et al. (1989) summarize the serious nature of the effects of transportation on salmonids:

> *"Primary and secondary physiological stress response factors undergo major reactions consequent to handling and transportation procedures (Maule et al. 1988). Physiological reactions such as the elevation in circulating levels of cortisol initiate a cascade of events that appears to hinder essential performance characteristics of juvenile salmonids including disease resistance (Maule et al. 1989), seawater osmoregulatory ability (Redding and Schreck 1983), and rate of outmigration (Specker and Schreck 1980)."* (Schreck et al. (1989)

It is a certainty that young chinook salmon used in the Delta survival tests for development of the USFWS salmon model underwent significant stress by the time of release into Sacramento River or Delta waters. To my knowledge, there was no monitoring of the degree of stress in those test fish (e.g., measurements of elevated concentrations of cortisol at the time of unloading of trucked fish). Schreck et al. (1989) found that fish not given adequate time to recover from transport stress were less capable than unstressed fish of surviving in the wild. These researchers suspected that the phenomenon of reduced relative fitness in the fish released immediately upon arrival was attributable to a general energy drain resulting from the handling and hauling stress. They therefore recommended that salmon be allowed a recovery period of more than 24 hours after transportation before they are liberated in the wild.

Temperature Effects

A review of the temperature data measured at the time of release of young salmon in the Delta fish survival experiments reveals that, in many instances, fish were released into receiving waters under conditions known to be hostile for young salmon. My experience has shown that, under these circumstances, fish mortality directly attributable to the effects of thermal shock could be substantial for some of the high temperatures present in the receiving waters. Coutant (1973) provides evidence that thermally shocked juvenile chinook are selectively preyed upon by predators. It is also evident from the data that the different groups of salmon released at different locations in a similar period during a survival test were subjected to different water temperatures. Releasing test fish from a cold water environment into warm water could potentially decrease gill Na-K ATPase activity. Zaugg et al. (1972) observed a decrease in gill Na-K ATPase activity when steelhead were transferred from cold water to warm water. In most studies of this nature, it would be normal to hold a representative group of fish at the release location after the main large group of fish had been released to monitor any latent mortality attributable to factors such as temperature or stress. These "control" fish would be monitored for several days and latent mortalities would be recorded. Using a simplistic example, if 10,000 test fish were released for an experiment, 100 fish could be held as "controls" at the release site and monitored over several days. If, after several days, 10 control fish died, it could be assumed that there was a 10 percent mortality attributable to factors such as hauling stress or temperature. The numbers of test fish released would then be adjusted for that 10 percent mortality to reflect the fact that 9,000 fish, instead of 10,000 fish were used in the experiment. The USFWS does not describe any such procedures or corrections employed during the Delta fish survival experiments.

Effects of Time of Day

The principal downstream migration period of young wild chinook salmon occurs at night. If any tests are conducted to simulate conditions for wild fish based on releasing hatchery fish into the river, those tests should be conducted at night. It is known that releasing hatchery fish directly into the river during daylight hours can result in substantial mortality attributable to predatory fish and piscivorous birds. These circumstances would not be reflective of conditions wild fish would be exposed to during their natural migration. It is my understanding that most, if not all, of the Delta fish survival experiments were performed by releasing the hatchery test fish directly into the river during daylight hours.

Monitoring Smolt Migration and Smoltification

California Department of Fish and Game's (DFG) "Central Valley Salmon and Steelhead Restoration and Enhancement Plan" contains several recommended studies and monitoring activities. In the section of their plan titled "Studies and Evaluations", they state:

"There still remains many gaps in our knowledge of our salmon and steelhead

resources and how best to restore, enhance, and manage for future generations. Continued monitoring of those fishery populations, including their utilization and their life history needs, is essential to our management efforts." (Reynolds et al. 1990)

Clearly this is the case for the outmigration phase of Central Valley salmon stocks. However, the acquisition, compilation, and dissemination of practical information on the Central Valley salmon has plagued efforts toward effective restoration actions. The University of California at Davis recently sponsored a workshop on Central Valley Chinook salmon because of a need to improve our working knowledge of Central Valley salmon stocks. The following is extracted from the meeting announcement for that workshop to illustrate the problem.

> "*Communication among scientists working on Central Valley chinook salmon is poor, largely because there is no established forum. The annual meetings of the California-Nevada Chapter of the American Fisheries Society might serve as such a forum, but in practice do not. The lack of effective communication is slowing the development of knowledge needed for effective management of Central Valley chinook salmon; experiences are not widely shared among workers in different parts of the river system, management needs are not being communicated effectively to academic scientists, and new scientific developments are not being communicated effectively to biologists in management positions.*"

The University of California workshop was an important first phase in this effort; more detailed workshops on the topic should be pursued in the near future. My opinion is that it would be particularly valuable to solicit expertise acquired in other anadromous salmonid-bearing regions (e.g., Pacific Northwest).

Some of the most important questions to elucidate the uncertainty associated with evaluating the survival of young salmon through the Delta lie in the degree of development of smolting and seawater adaptability, and the downstream migratory behavior in fish utilized in Delta survival experiments. Downstream migration of Central Valley chinook may be passive or active. Passive migration is associated with dispersal or displacement of fry or parr salmon (pre-smolts) from upstream rearing areas to lower river reaches. Based on a wide variety of research, the migratory behavior exhibited by fry and parr salmon suggests that it is typified by a search for more hospitable environments (Kreeger and McNeil 1992). Active downstream migration is associated with the physiological, morphological, and behavioral changes attributable to smoltification. The USFWS has assumed, in their Delta experiments, that the test fish used would behave in a similar manner to wild smolts which have undergone the physiological, morphological, and behavioral changes. This signifies that the fish are purposefully migrating toward the ocean and are physiologically able to adapt to saltwater, as compared to juvenile salmon which may not be ready to migrate to saltwater.

Life history strategies in chinook salmon show a considerably higher degree of complexity and variation than in other species of Pacific salmonids. The recognition of two major categories of juvenile life history strategies, ocean-type and stream-type, is an example of this variation. No where else throughout the geographic range of chinook salmon is this variation in life history and plasticity in adaptation of the species expressed so broadly as in the stocks inhabiting the streams of the Central Valley in California. This is evidenced by the fact that all freshwater life stages of chinook salmon may be found in one or more Central Valley streams year round (VES 1994).

The high degree of variation in life history exhibited by Central Valley chinook salmon is a function of the differences among the four main seasonal races, fall, late-fall, winter, and spring runs. But there is considerable variation within these races for traits such as spawn timing, juvenile riverine residency, and outmigration timing. A considerable data base is being amassed on adult run timing and the timing of the juvenile outmigration of many of the Central Valley salmon stocks and some data are currently being developed on the environmental cues affecting emigration. Very little specific information from these stocks has been developed on the critical underlying physiological processes responsible for motivating the seaward migration of young salmon (VES 1994). This information is critically necessary to formulate actions for salmon restoration in the Central Valley to ensure adequate survival through the Delta. Information on underlying smolt physiology developed to compliment concurrent data collection on juvenile emigration timing and environmental cues affecting emigration would allow for meaningful management recommendations to benefit salmon.

The Significance of the Natural Distribution of Downstream Migrant Salmon

The USFWS has assumed that downstream migrating salmon are distributed uniformly with flow as the fish enter the northern portion of the Delta. I have designed and conducted monitoring programs in the Sacramento River which indicate that downstream migrating chinook salmon appear to be distributed uniformly across the river channel at night in the upper portion of the water column. The USFWS assumption is given in their description of the salmon model:

> *"The proportion of juvenile salmon entering Reach 2 was defined as the fraction of the Sacramento River flow diverted into the central Delta via the Delta Cross Channel and Georgiana Slough."* (Kjelson et al. 1990)

It is my understanding that recent tests at the Delta Cross Channel and Georgiana Slough have revealed conflicting results which indicate that the fish/flow uniformity assumption may not be valid. Based on his investigations of young chinook salmon downstream migration in the Columbia River, Zaugg (1989) suggests that more completely smolted fish move away from the nearshore areas into faster flowing water. Although some limited sampling has been performed in the general vicinity of the Delta Cross Channel which provided some useful information on lateral and vertical distribution of downstream migrant salmon (e.g., Schaffter 1980), our understanding of natural fish distribution is poor. Accurate determination of the natural lateral distribution of young downstream migrant salmon ultimately will be necessary to design fish protective measures or facilities at that location. Moreover, this information will be required to determine if the USFWS uniform distribution assumption is valid.

At this time, we do not know if wild fish behave in the manner assumed. We also do not know if the hatchery fish utilized over the years for the Delta survival experiments were distributed uniformly immediately following release. For example, it is entirely possible that the hatchery fish remain oriented toward the same bank of the river on which they were released for considerable distances downstream of their release location. This knowledge will allow for better interpretation of past USFWS data and improve the experimental design of future fish survival investigations. The techniques to acquire this information are available.

Because of the importance and resultant ramifications of these data on Delta water management and salmon restoration measures, such a comprehensive monitoring program should be initiated. This knowledge is essential to formulate and implement management actions to increase fish survival.

Technological Improvements in Fishery Resource Investigations

There have been relatively recent improvements in the technology associated with conducting detailed fishery resource investigations. New methods, equipment, and sampling devices have been developed to acquire better scientific information on fishery resources. Application of these techniques to Central Valley fisheries research and monitoring activities could vastly improve our working knowledge of fish early life history characteristics and the measures necessary to increase the resources. As just one example, I have begun to utilize passive integrated transponders in some of my field investigations. A passive integrated transponders (PIT tags) is a miniature electronic device in a glass capsule about the size of a grain of rice. Generally fish greater than 55-60 mm fork length can be tagged. The estimated life of the biologically inert tag is more than 50 years. The tag requires no energy source of its own, but is energized by a tag detector. Once implanted in the fish, the tag can be read instantly without anesthesia when the fish (in or out of the water) passes in front of the detector. The tag has a particular advantage over other tagging techniques (e.g., CWT) in that the fish does not have to be sacrificed to obtain the tag codes. This can be especially valuable for investigations on endangered fish species such as the winter-run chinook salmon. Each tag is programmed with a ten-digit alphanumeric code which allows for the creation of 34 billion codes and subsequent identification of individual fish. Fish possessing the tag may be recaptured at various locations and times in the river system, have data collected and the fish released unharmed. The use of PIT tag technology has been successfully used to assess behavior and survival of Columbia River salmon (Johnson 1988). I have recently used the technology on two Central Valley rivers with encouraging results. It is highly probable that wider usage of PIT tags in Central Valley rivers and streams will ultimately greatly expand our working knowledge of the survival and behavior of Central Valley anadromous salmonids. Stansell (1992) provides a description of new technologies being evaluated for monitoring smolts such as advanced underwater imaging techniques, laser light capable of rapidly scanning or screening a cross-section of water, and advanced hydroacoustic techniques.

Conclusions and Recommendations

- There is substantial scientific basis to believe that the USFWS assumption that tests using hatchery fish in Delta survival experiments would be reflective of effects on wild fish is not valid. Because of numerous major biological factors which are believed to have influenced past Delta experiments, the results are limited in application as fish survival indices for Delta fish and wildlife standards.

- Our working knowledge of the physiology, morphology, and behavior of early life phases of chinook salmon has advanced considerably since the original USFWS fish survival experiments in the Delta were initiated. This working knowledge will greatly assist in reassessing USFWS previous test results and allow for significant modification of future experimental designs and protocols in Delta fish survival experiments.

- Fishery resource agencies in California should be encouraged to acquire, assess, and incorporate the wealth of published research findings on migrational characteristics of young salmon conducted in other regions (e.g., Pacific Northwest) to improve the understanding of young salmon migration in Central Valley rivers and streams.

- Periodic technical workshops in California should be held among scientists to develop and disseminate timely information (e.g., ongoing research/unpublished research findings) to improve our working knowledge on the early life phases of salmon in the Central Valley. Expertise on the topic should be solicited from regions outside of California (e.g., the Pacific Northwest).

- In all future forums of the Delta Hearings and Workshops, a more accurate descriptive terminology associated with the early life phases of young salmon should be provided. The term "smolt" should not be used unless it is reasonably certain that this characterization is an accurate depiction of that specific salmon life phase and its associated physiological, morphological, and behavioral characteristics.

- Analytical tools such as measurements of plasma cortisol and gill Na-K ATPase in chinook salmon used in Delta survival tests should be used in future Delta evaluations to assist in predicting relative fitness of transported salmon used in fish survival experiments.

- Chinook salmon used for Delta fish survival experiments should be acclimated within in-river holding areas at least 24 hours prior to release to reduce stress and resultant mortality.

- Control groups of fish used in Delta fish survival tests should be held for several days at the release locations to monitor post-release performance. This information would help ascertain any adverse factors or conditions which may confound study results (e.g., mortality attributable to stress in transport and release, disease, lethal effects of water temperatures, etc.). These data would also be invaluable in adjusting actual numbers of fish released to correct for latent mortalities

- Fish survival experiments conducted in the Delta should be performed by conducting the release of test fish at night to allow for a better simulation of wild salmon natural behavior patterns. In-as-much-as possible, fish recapture tests should be performed at night to avoid problems with sampling gear bias (avoidance) and allow for the development of empirical data more reflective of wild fish behavior.

- The potential to use the planned Shasta Dam temperature control device to accelerate growth of Sacramento River chinook and hasten the onset of smolting development and seawater adaptability should be evaluated as an "adaptive standard".

- A routine (e.g.,every 2 weeks) sampling program should be initiated at Central Valley salmon hatcheries to determine time of smoltification for the various Central Valley hatchery stocks. These data will allow for better interpretation of past Delta fish survival experiments, improve the experimental design of future fish survival experiments, and improve on our working knowledge to increase Central Valley salmon stocks. In addition, this type of information would probably help to maximize survival of hatchery stocks by determining the appropriate stage of smolt development at release (Zaugg 1989).

- The natural diel, temporal, and lateral distribution of young salmon passing the vicinity of the Delta Cross Channel and Georgiana Slough should be empirically evaluated. Early life history information is needed not just for fall-run chinook salmon but also for late-fall run, winter-run, spring-run chinook, steelhead, and other species. There is a high probability that results of this effort can be utilized to ultimately minimize entrainment of fish into the interior Delta during certain times of the year when survival may be reduced.

- As part of "informational standards" design and initiate regular monitoring programs on Central Valley rivers and streams to develop the necessary data on salmon early life history. The monitoring programs should be designed to quantify detailed information on young salmon physiology, morphology, and behavior. The monitoring programs should also be design to test hypotheses of assumed fish behavior for fish used in Delta survival experiments.

- Encourage fishery resource researchers in California to employ new technological developments into research programs in the Central Valley (e.g., downstream migrant trapping, PIT tagging).

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