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PHASE 1 INTERIM LITERATURE REVIEW FOR SP-F9 EVALUATION OF PROJECT EFFECTS ON NATURAL SALMONID POPULATIONS

Oroville Facilities Relicensing
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INTRODUCTION

The first salmon hatchery (albeit for Atlantic salmon) was constructed in Maine in 1871 (Moring 2000). In 1872 the first egg collecting began on the lower McCloud River (Black 2001) in the Sacramento River drainage and the Battle Creek egg taking station began operation in 1885. The Coleman egg taking station on Battle Creek commenced operation in 1943 by collecting eggs from spring Chinook as part of mitigation package for the construction of Shasta Dam. The Feather River Hatchery began operation in 1967 as mitigation for construction of Oroville Dam. At the same time as hatcheries began operating in California, similar efforts were occurring in the Northwest. The first salmon hatchery in Washington State was built in the 1890s on the Kalama River and by 2001, Washington had about 140 tribal; State and federal hatcheries releasing an estimated 180 million salmon smolts per year along with six to seven million juvenile steelhead (Blankenship, 2002). Oregon and British Columbia also implemented significant salmonid hatchery efforts.

During most of the past 130 years that salmonid hatcheries have been in operation on the west coast, their goals have generally been to produce fish for the commercial, recreational and tribal fisheries or to mitigate for habitat lost due to dams and other perturbations. In actuality production and mitigation goals often overlap and hatcheries have generally been operated as a technological solution to the overall problem of habitat loss due to changes in the amount and timing of streamflows, logging in the watersheds (with its consequent effects on the aquatic system), overfishing, blockages caused by dams and other obstructions, water diversions and the effects of municipal, industrial and agricultural waste discharges to streams and estuaries In recent years, conservation and supplementation hatcheries have come into the salmonid culture lexicon - hatcheries that are designed to be more environmentally benign and may overcome some of the concerns about production and mitigation hatcheries.

During the past two decades in particular there has been increasing evidence that our salmon management programs are not working. The winter run of Chinook salmon in the Central Valley was listed in 1989 and Nehlson, et al. (1991) listed numerous stocks in California and the Pacific Northwest that had been extirpated, or were threatened with extirpation. At the same time we began to learn more about the conservation genetics and could distinguish between runs (see for example, Utter, et a. 1989). The role of hatcheries in fish and ecosystem became of increasing interest.

As DWR developed the study plan for evaluating the effects of the Feather River Hatchery on naturally spawning salmonids, I was requested to examine the available literature regarding hatchery impacts. The original focus of this examination was to determine if the literature could be used to suggest additional study elements/information needs that should be included in the study plan – elements that could be completed within the available time and which would add to our understanding of hatchery impacts. As the study plan evolved, it included a literature review as one of the study elements. One of the other purposes of the literature review was to acquire and read the literature that would be helpful in preparing the final project reports.

In this report I include some observations from a survey of more than 100 published papers as well as some reports not available in the open literature. I do not attempt to duplicate some excellent reviews of this topic that have been conducted in recent years. In fact, I draw heavily from several of these reviews – namely by Campton (1995), Busack and Currens (1995), National Research Council (1996), Grant (1997) Waples (1999) and Orr and Pinikett (2002). Jim Bakke of the Native Fish Society prepared an annotated bibliography on the interactions between hatchery and wild salmonids. This undated bibliography is also quite useful.

These are not all of the reviews on this topic but the ones I found to be most helpful , and the ones I had access to. Jim Lichatowich, Rick Williams and Phil Mundy are preparing a report describing new approaches to hatchery management and the report will contain an extensive literature review. The report, being prepared for Trout Unlimited, is due to be released in January, 2003, thus will be available for inclusion in the hatchery evaluation report.

As with all complex issues, there are advocates for all sides of the issue – ranging from strong hatchery proponents to those stressing the serious environmental consequences of the West coast salmonid hatchery operation. On one hand it appears that from one-half to three-fourths of the Chinook salmon caught in the ocean commercial, recreational and tribal fisheries off Washington , Oregon and California are from hatcheries (Blankenship 2002 and Cramer 1992). On the other hand, Meffe (1991) cited the following reasons why hatchery production of salmonids is ecologically a bad idea and will ultimately fail:

1. *"data demonstrate that hatcheries are not solving the problem – salmon continue to decline despite decades of production,*
2. *hatcheries are costly to run, and divert resources from other efforts, such as habitat restoration,*
3. *hatcheries are not sustainable in the long term, requiring continual input of money and energy,*
4. *hatcheries are a genetically unsound approach to management that can adversely affect wild populations,*
5. *hatchery production leads to increased harvest of wild populations of salmon, and*
6. *hatcheries conceal from the public the truth about the real reason for the salmon decline."*

Both sides of the argument make valid points. Waples (1999) put the controversy in perspective by describing some of the myths and misconceptions about the effects of hatchery production on salmonid populations. He concluded that:

1. *"Hatcheries are intrinsically neither good nor bad – their value can be determined only in the context of clearly defined goals;*
2. *genetic changes in cultured populations can be reduced but not eliminated entirely;*
3. *empirical evidence exists of many adverse effects of hatcheries, but some risks have been overstated;*
4. *monitoring and evaluation programs are important but should not be used as a substitute for developing risk-averse hatchery programs in the first place."*

Waples (1999) further recommended that we need more effort in the areas of goal identification, benefit:cost analysis, data collection and analysis and dealing with uncertainty.

Leading to the myths and misconceptions described by Waples (1999) is the relative paucity of site specific data and from fisheries management practices that make it difficult to sort out direct hatchery impacts from the effects of other factors. For example Hayes and Carmichael (2002) began tagging Chinook salmon destined for the Umatilla River in Oregon and were surprised that many of the returning adults strayed in the Snake River and mixed with threatened Snake River stocks – contributing up to 26% of the escapement. Given the facts that -

- Chinook salmon had been extirpated from the Umatilla River;
- the founding population for the new stock came from adults collected at Bonneville Dam and were of mixed genetic stock;
- the juveniles destined for return as adults to the Umatilla River were reared in different hatcheries with different water supplies – none of which was from the Umatilla River itself;
- and the juveniles were released off site at different locations –

it is not surprising that the fish strayed. In this case well-meaning managers from several agencies (including the Bonneville Power Administration, Oregon Department of Fish and Wildlife, Confederated Tribes of the Umatilla Indian Reservation, US Forest Service and the US Bureau of Reclamation) established a goal of 11,000 returning Chinook salmon with hatchery production used to realize the goal (Boyce 1986). The implementation plan, developed by the tribes and ODFW and extensively reviewed by fish biologists and managers did not include a marking program to establish risks to other salmonid populations associated with achieving the goal for the Umatilla River. This is an example of how fish managers even as late as the 1980s-1990s did not foresee the consequences of an action taken to provide societal benefits, nor did they initially undertake the monitoring needed to assess the risks.

My approach to this literature review is to summarize conclusions from the major reviews cited above. This interim report will be followed in about three months by an annotated bibliography of the technical papers I have collected. (Copies of these papers will be placed in the FERC archives.) It is important to note that the final F9 report will include specific literature references in the individual sections. For example, the extensive work of Quinn and his colleagues (for example Quinn, T. 1997) will be used to put observed straying by fish from the Feather River Hatchery (and other Central Valley hatcheries) in perspective. Finally, I include a short summary of some of the "take-home messages from literature as they apply to the evaluation of the impacts of Feather River Hatchery on naturally spawning salmonids.

From available reviews

Since I don't believe in reinventing wheels, I have based this summary largely on what others have pulled together. As is pointed out in most of the reviews, one has to be careful when applying the results of the literature to each particular situation being evaluated. As will be shown in the summary, however, there are several common themes in all the reviews. For those seriously interested in the issue of hatchery impacts, I recommend that you read the reviews and original literature yourselves. All summaries are abstracts of the original papers and the abstracter provides his or her slant on the topic, if only by selecting which parts of the paper to include.

Robin Waples -1999, *Dispelling some myths about hatcheries*. I found the 1999 review published in Fisheries (a monthly semi-technical journal of the American Fisheries Society) to be quite useful, perhaps because the Fisheries audience is diverse, containing a mix of strong opponents and proponents of hatcheries as well as those that believe properly operated hatcheries will continue to be an integral part of the fisheries managers' tool boxes. (The American Fisheries Society was originally organized around fish culturists.) Following are some of the main messages I took from Waples.

- **Fisheries management and fish hatcheries**. In this opening paragraphs, Waples stated "*because the key issues involve both fish culture and fisheries management, I emphasize hatchery programs rather than hatcheries per se.*" The take home message is that it is not productive to look at an individual hatchery without considering the fisheries management context in which was developed and operated.
- **Hatchery goals**. Hatchery goals need to be clearly identified and programs established to monitor progress towards realizing the goals. Setting goals is not enough, however – goal setting is an iterative process and the original goals need to continuously examined as new data about the effects and benefits of the hatchery program become available.
- **Genetic risks posed by hatcheries**. Genetic changes in hatcheries are associated, in part, with domestication and domestication selection – processes resulting from human efforts to control the environment in which the fish are cultured. Adding one Campton's (1995) factors identified as leading to genetic change, Waples listed the following.

a. Intentional or artificial selection for a desired trait.
b. Selection resulting from non-random broodstock collection procedures
c. Unintentional natural selection that happens in the hatchery environment but might not happen in the wild.
d. Temporary relaxation of selection of selection in the culture phase of selection processes that would occur outside the hatchery.

Hatchery programs may be able to eliminate the effects of the first factor but it will be impossible to completely avoid problems with the last three factors because;

- the hatchery environment is not the same as the wild environment
- hatchery programs dramatically change the mortality profiles of the species cultured – ie hatchery programs are geared to increase egg to smolt survival.

The resulting conclusion is that hatchery programs can reduce genetic risks but can not entirely avoid them. (See also Busack and Currens 1995). This domestication selection can occur in the absence of mortality during the culture phase, if family sizes are equalized or if the broodstock are selected through a random sampling protocol. Although natural selection will occur post release, can not be assumed to eliminate any genetic changes due to domestication selection.

Waples concluded that there is no universal axiom that can be used to develop methods to avoid genetic risks – each situation must be evaluated on a case-by-case basis.

- **Unintended effects of hatcheries on natural populations.** It is not appropriate to conclude, a priori, that hatcheries always have detrimental effects on natural populations. Again the conclusion will have to be based on the information from individual cases and the extent to which the hatchery and natural populstions are isolated will affect the conclusion. Waples identified two incidental risks to hatchery programs.
  a. Straying. Reviewing mostly the literature by Quinn (1993,1997) Waples concluded;
    - The extent to which hatchery and wild fish stray varies widely.
    - Whether hatchery fish stray more than wild is not clear – mainly because of lack to data.
    - The science behind our understanding of homing and straying is poorly understood.
    - Effects of straying on natural populations are a function of the percentages of strays in the affected population, not in the percentage rate at which hatchery fish stray.

  b. Disease transfer. Although several pathogens and diseases are widely present in west coast hatcheries and watersheds, and can cause severe problems to salmonid populations, there is little empirical evidence of widespread transfer of disease and pathogens from hatchery to wild fish. However, there have been relatively few studies to determine if this is a serious problem.

- **Are objections to hatcheries based strictly on theory or do they have ecological basis?** Waples concluded that there is a solid body of empirical data to support most of the concerns about the impacts of hatchery fish on natural populations, but that our understanding is incomplete. Two quotes capture the situation quite well.
    - *a.* As quoted in Waples from Busack and Currens (1995, p77) *"We are unaware of rigorous research designed to detect genetic impacts that has failed to find them."*
    - *b.* From Waples 1999 " *What is lacking is consensus on what constitutes a reasonable approach to this issue given the substantial uncertainty and its potentially major consequences of whatever actions are (or are not) taken."*

- **Fisheries management and hatcheries**. Waples argued that we need to depersonalize the problem and work towards solutions, not assessing blame.

- **The role of monitoring in hatchery management**. Although monitoring and assessment are important components of well-run hatchery program, they are not panaceas. Monitoring data may be slow in coming in (e.g., tag returns from fisheries) and may not have the power to detect subtle, but important population effects.

- **Where to go from here?** My summary of where Waples recommended we go next.

    a. Work with the community of fisheries biologists, fish culturists, conservation biologists and managers to reach general agreement on the role of a hatchery or hatcheries in a basin.
    b. In reaching this agreement examine hatcheries in the traditional benefit:cost approach where benefits to society and population and to the ecosystem are compared to costs to the same components are evaluated to determine if there is a net benefit.
    c. Conduct more research to increase our understanding of hatchery impacts, perhaps with the focus of expanding existing hatchery facilities to expand these research efforts.
    d. Recognize uncertainty and deal with it.

Orr, Gallagher and Penikett, 2002. ***Hatcheries and the protection of wild salmon.*** The authors edited the proceedings of a workshop organized to explore the general topic of hatcheries and the protection of wild salmon. The workshop itself consisted of about 20 presentations on such topics as:

- The setting: Why hatcheries
- Evaluating some stated benefits of hatcheries
- Ecological Issues
- Genetic Issues
- Hatchery Reform: Goals, Data Gaps, Measures of Success

I have taken several points from the Convener's report of the workshop.

- A consensus emerged from the participants that:
    a. *"Hatcheries and other forms of artificial enhancement cannot readily replace damaged or lost freshwater habitat.*
    b. *That we humans can never fully understand the complexities of natural ecological and genetic systems to maintain them artificially.*
    c. *That there can be no substitute for diligent maintenance of:*
        - *High quality natural habitat,*
        - *Healthy freshwater and marine ecosytems,*
        - *Abundant and, naturally reproducing salmon populations with their genetic fitness and diversity intact."*

- There was also general agreement that hatcheries need to be viewed as components of complex ecological and genetic systems and that hatchery evaluations need to focus on the interactions between the hatchery and the systems – not strictly on the numbers of fish released or subsequent returns.
- The marine and freshwater environments have finite but varying carrying capacity, thus carrying capacity needs to be considered in hatchery planning and evaluation.
- The workshop participants identified the following information gaps:
    a. A comprehensive assessment of the role of hatcheries in fish management leading to more defensible hatchery goals.
    b. Use an adaptive management approach to evaluating the impacts of hatchery interventions in fish management.
    c. An examination of the effects of varying ocean survival on salmon populations.
    d. What are genetic impacts?

Sigurd Einum (2001) ***Implications of stocking: Ecological interactions between wild and introduced salmonids.*** Although Einums's article had been published in the Norwegian Journal of Freshwater Research, it was reprinted in the proceeding of the Orr, Gallagher and Penikitt (2002) workshop. Note that this review was based on literature surveys that included migratory populations of trout, charr and Pacific salmon – not just Pacific salmon. The author emphasized several points.

- Why to hatchery and wild fish differ?
    a. Salmonids exhibit high phenotypic plasticity and phenotypes may be changed significantly by the hatchery environment. The feeding regimes, density, substrate, exposure to predators and interactions with conspecifics

are examples of differences between hatchery and wild environments that can lead to changes in behavior.

b. The intensity and direction of selection differs between the two environments. – perhaps most importantly in the differences in survival between eggs and smolts. One outcome of this difference is that less fit genotypes that might not survive in the wild may persist in the hatchery environment.
c. In many of the early hatcheries non-native runs were used as the founding stocks.

- Which characters differ between hatchery and wild salmonids?
    a. In 5 of 9 studies reviewed by Einum, hatchery fish were more aggressive than their wild kin. A meta-analytical approach to the data supported the hypothesis that hatchery fish were generally more aggressive than wild fish.
    b. Hatchery fish exhibited a reduced response to predator risk.
    c. Hatchery fish may have different migratory patterns than wild fish – i.e., changes in migration timing and length of time spent in the ocean.
    d. After release hatchery fish may feed differently than wild fish, although they may adjust to new food sources relatively quickly.
    e. Hatchery fish may be morphologically different than wild fish and morphological traits may be important to breeding success.
- How successful are hatchery fish in the wild?
    a. Growth rates differ between hatchery and wild fish but the direction is not consistent.
    b. Hatchery fish consistently experienced lower overall survival than wild fish.

- How do naturally produced fish respond to hatchery releases?
    a. Since they are generally more aggressive, hatchery fish may replace wild fish. Agressiveness may be compensated by poorer survival of released fish. Initial displacement of wild fish followed by poor survival of hatchery fish could result in lower overall density of fish in the stream.
    b. Hatchery releases of fish ready to emigrate may attract wild fish to join in the movement.
    c. Hatchery releases may attract predators.
    d. Interbreeding may reduce population fitness.
- Conclusions
    a. Although the reports cited may be biased towards the negative effects of stocking, the potential for negative effects must be acknowledged.
    b. Any negative effects of hatcheries may be minimized by:
        - Better broodstock collection and mating protocols.
        - Creating more natural rearing conditions.
        - Employing fish friendly wild-fish release strategies
        - More focus on local broodstocks.

National Research Council (1996). ***Upstream – Salmon and Society in the Pacific Northwest***. In 1992, the NRC formed the Committee for Protection and Management of Pacific Northwest Anadromous Salmon, consisting of 15 scientists with a wide range of technical disciplines. The committee was formed to (in part):

"The committee will review information concerning the seven species of the genus Oncorhynchus *in the Pacific Northwest. The review will focus on the population status, habitat, and environmental requirements of the stocks. It will include analyses of information about their genetics, history, management and production by hatcheries, as well as federal, state, tribal and other management regimes."*

I have included the partial charge because it is very similar to the charge of the salmon-related FERC activities involved in studying the Feather River. For this report, I only reviewed the hatchery related chapter of the report (pp 302-323): however, the book is recommended reading for everyone working on anadromous salmonids in the Feather River studies.

The authors led off with some examples of the increasing importance of hatchery salmonids in Northwest salmon management. Below are a few of these examples, including the citation for the source of the information.

- *By 1987, hatchery-origin fish dominated adult returns to the Columbia River basin, compromising more than 90% of the coho, 70% of the spring Chinook, about 80% of the summer Chinook, more than 50% of the fall Chinook and about 70% of the steelhead (Columbia Basin Fish and Wildlife Authority 1990).*
- *In the Snake River basin, reliance on hatchery propagation of Chinook increased from 0.75 million juveniles released in 1964 to 14.9 million in 1989, but this did not prevent steep declines in numbers of adult returns to the basin (Chapman, et al. 1991).*
- *Hatchery fish make up about one-half of the overall abundance of steelhead trout found from Alaska to California but about 70% of steelhead from Coastal Oregon and Washington and the Columbia River basin (Light 1987).*

The NRC report identified the following areas of concern about the effects of hatchery production on wild fish.

- **Demographic effects**. Large releases of hatchery fish can result in overfishing of natural stocks in mixed stock fisheries. Wild populations can be driven to extinction if their escapement drops below replacement levels.
- **Genetic and evolutionary risks**. The discussion was mainly drawn from Busack and Currens 1995.
    a. Loss of population identity and within-population genetic variability. This risk is increased by collection of non-indigenous broodstock (which was a problem for early hatcheries but not as much now), straying, low effective population size in the hatchery and artificial selection of specific traits (e.g., selection for size and run timing) by hatchery managers.

   b. Domestication can result in a decline in fitness to survive in the wild. Domestication can occur by two pathways – nonrandom selection of broodstock over the spawning period and the responses of fish growing in the non-natural hatchery environment.

- **Behavior**. As shown earlier, hatchery fish are often more aggressive that wild fish but have higher mortality levels. In one study cited (Nickelson et al. 1986) of releases of hatchery coho in a stream containing wild coho juveniles it was shown that:
   a. Larger and more aggressive hatchery releases displaced wild juveniles.
   b. The hatchery releases returned earlier than wild fish and contributed little to the population.
   c. The net result in subsequent years was that fewer juveniles were present in the stream than would have been present had there not been a hatchery intervention.
- **Fish Health** In spite of widespread occurrence of disease in hatcheries, there is little evidence of evidence of transmission of disease from infected wild fish (as reviewed by Steward and Bjorn 1990 – **note that I have not yet been able to obtain a copy of this report.**) The authors noted that there have not been many studies to address this complex problem. They also noted that loss of genetic diversity due to hatchery practices could result in loss of the genes that help salmonids fight infections (see for example Stet and Egbert 1991).
- **Physiology** Post release stresses caused by crowded rearing conditions and handling and transportation often results in high post release mortality and may reduce the fish's immune response. Incomplete smoltification in hatchery fish may result in the fish remaining in the river longer than desired and may compete with wild populations.
- **Ecological Problems** The authors raised the issues of limited carrying capacity, the ability of hatchery fish to survive and be integrated into natural populations and habitats without adversely affecting the natural populations and the loss of carcasses (and their nutrients) on streams.

W. Stewart Grant (1997) ***Genetic effects of straying of non-native hatchery fish into natural populations. Workshop proceedings.*** Several speakers in this 1995 NOAA sponsored workshop provided examples of straying and others addressed the general topic of the genetic effects of straying. NMFS representatives stated that the Agency goal was to limit the number of strays in a stream to less than 5% of the total number of fish present in the stream. On the second day of the session, the organizers assembled a panel to address several questions and reach some general conclusions regarding the effects of straying. Some of the questions (with the answers) and the conclusions are found below.

- **Questions**

1. **What are appropriate parameters to consider in evaluating the effects of straying?**

   a. **Stray rate.** The key straying parameter is proportion of non-native fish successfully spawning in the population.
   b. **Gene flow.** Gene flow only happens when the stray fish become integrated into the population. Stray rate provides an approximate upper limit of gene flow.
   c. **Local population size.** The genetic consequences of straying depend on effective population size more than census size. For salmon, the average population size must be averaged over the entire return period.
   d. **Random genetic drift** The effects of genetic drift are not predictable and can be consequential in small populations. Genetic drift may not be important when the effective population size is greater than 1,000 individuals.
   e. **Inbreeding depression – loss of fitness due to mating of related individuals.** Most important in populations with a small effective size.
   f. Outbreeding depression – loss of fitness due to mating of genetically divergent individuals. Outbreeding depression can occur due to loss of local adaptation or breakdown of favorable gene loci.
2. **What other parameters are important in determining the effects of straying?**
   a. Genetic and life history differences between hatchery and natural populations
   b. Magnitude straying and strength of selection.
   c. Duration of straying.
   d. Number of natural populations affected.
3. **Do short and long-term effects of straying differ?** The answer is yes, with short term effects having either negative or positive effects.
4. **Are the effects of staying likely to be permanent?** The answer is yes.
5. **Can hatchery straying be beneficial to natural populations?** Theoretically, yes by increasing genetic diversity. For well-adapted populations, this increased genetic diversity could be detrimental.
6. **Can the effects of hatchery straying be predicted with any certainty?** No.
7. **What will be the effect of straying at the 5% level?** Although this can not be predicted, the value of a 5% gene flow may be higher than generally occurring between natural populations.
8. **What research should be undertaken to help resolve uncertainties of hatchery straying?**
   a. The relationship between the rate of hatchery straying and the rate at which gene flow occurs.
   b. The nature and extent of outbreeding depression in natural salmon populations.
   c. Rates of straying and gene flow among natural populations.
   d. Selection intensities on whole traits.
   e. Genetic attributes of successful populations.

Craig Busack and Kenneth Currrens (1995). ***Genetic risks and hazards in hatchery operations: Fundamental Concepts and Issues*** Although not a typical review paper, I have included it because it contains one of the original references I found in the fisheries literature to the concepts of genetic risks and hazards in hatchery operations.

- Goal of paper is to acquaint fishery professionals with genetic concepts – concepts that may not be widely known by many professionals.
- Some definitions
  a. A hazard is a potentially adverse consequence of an event or activity. The most commonly cited genetic hazard is a loss of genetic diversity.
  b. A risk is the likelihood of the hazard occurring. Both terms are modified from Smith (1962).
  c. Genetic diversity is all the genetic differences contained with a population or groups of populations.
  d. A population is a group of interbreeding individuals.
- Genetic hazards we should be concerned with:
  a. Extinction, or the complete loss of genetic information. Extinction of a population reduces overall genetic diversity of a species. Until recently extinction has not been associated with hatcheries but broodstock selection, diseases, power failures and ecological interactions between hatchery and wild fish may result in the extinction of some populations.
  b. Loss of within-population variability due to reduction in quantity, variety and combinations of alleles in a population.
  c. Loss of among-population variability is a reduction in the genetic diversity among populations caused by such practices as transfer of genetic material between basins, stocking hatchery fish outside the natural distribution of the species or race and straying.
  d. Domestication is the changes in genetic diversity within the cultured populations or between the cultured population and the population in the wild. Domestication may occur due to intentional selection for some traits, biased sampling in some stage of culture, or unintentional selection during culture.
- In all hazards, theoretical considerations exceed empirical evidence – partly because it is difficult to separate hatchery effects from environmental effects and the lack of science that has been applied to the problem.
- We need more research into the areas of genetic risk including a rigorous treatment of outbreeding depression, domestication selection and the effects of reductions in effective population size.
- In summary they concluded:
  a. There are sound theoretical reasons to expect genetic impacts from hatcheries.
  b. Empirical evidence, albeit sketchy supports the theoretical considerations.
  c. Although more research will shed light on genetic risks, there are likely to real limits to our ability to predict these effects.

d. They recommend that we should begin managing based on the goal of maximizing genetic diversity – mainly because it stresses preservation of fitness.

Don Campton (1995***). Genetic effects of hatchery fish on wild populations of Pacific salmon and steelhead: What do we really know?*** Many of the concerns described in Campton's paper have been mentioned in the above papers. There are several comments from the conclusions that I believe bear considering when approaching an analysis of the effects of hatcheries on wild salmonid populations.

- Many of the perceived and potential genetic effects appear to attributable to fisheries management, either of the hatchery or wild fish.
- Much of problem in distinguishing between management causes and biologic causes is attributable to the relative differences in detecting effects of the two causes. Baseline genetic data prior to the introduction of hatchery fish are seldom available for use in assessing impacts of the hatchery.
- "*there has been a general blurring between fact and speculation, between data and interpretation and between science and values*." This blurring affects our ability to look at the problems objectively and scientifically.
- As proposed by Hilborn (1992), we may have to resolve questions regarding the use of hatcheries in salmonid management in terms of values, Campton also cited the following quote from Scarnecchia (1992) for the need to combine science and value when considering the role of hatcheries in salmon management.

  > *"Salmon resources have been aided and harmed by technology, and managers must carefully assess how current and future technologies will be used to manage salmon. Effective managers must be knowledgeable of fishery science and human values. The science of fishery management is the objective, logical and systematic method of obtaining reliable knowledge about fishery resources. The art in fishery management involves our values, that is, what we judge to good, desirable, and important in the long run."*

- Campton suggested we use the following recommendations (from the International Symposium on Fish Gene Pools, Preservation of Wild Fish Stocks, as summarized by Hindar et al. 1991) when considering supplementing natural salmonid populations with hatchery fish:
  a. Identify genetic resources.
  b. Maintain natural ecosytems.
  c. Avoid selective harvest of natural populations.
  d. Release fish into natural environments with great care.
  e. Provide adequate funding for basic and applied research.
  f. Inform those responsible for management of existing knowledge.

  Campton added an final recommendation

  g. understand, scientifically, the biological consequences of management decisions. He suggested that one of the essential hatchery goals should be to " *integrate scientific research and management into a mutually* *beneficial relationship in order to learn as much as possible about the fish we are propagating and the effects of those fish on natural populations."*

SUMMARY

My interpretation of what the some of published literature tells us about the effects of hatcheries on natural salmonid populations can be summarized by the following. (The order is not significant.)

Hatcheries and fisheries management. We can not consider one without the considering the other. Hatchery managers and their staff grow fish and fishery managers tell them what kind to grow, how many to grow, where to plant them and set harvest targets and regulations. Fish managers determine if the hatchery is to be used for mitigation, supplementation, production or a combination of these purposes.

Hatchery goals. Hatchery goals are generally stated in terms of production or escapement targets and may not be updated as new information comes along. Goals of older hatcheries (i.e., hatcheries older than 10 years) seldom include ecological goals.

Science and hatcheries. In many instances, the early hatchery programs did not include monitoring and research components to help assess genetic and other hatchery impacts. On the other hand hatcheries do provide much of the facilities and raw material needed to conduct large scale studies of the effects of hatchery operation on naturally spawning fish populations.

Hatchery benefits. The literature is not filled with papers lauding the benefits of hatcheries – or at least not the literature I could readily find. On the other hand, most of the Chinook salmon, coho salmon and steelhead rainbow trout caught along the west coast of North America come directly from hatcheries. Defining and maintaining "acceptable" levels of salmonids in these waters will require the collective efforts of fish and fisheries biologists, hatchery managers, economists, sociologists, engineers and restoration biologists. Hatcheries have a long term role in the process of fisheries management and ecosystem science but the role will not be the same as it has been in the past hundred years.

Fitness of hatchery fish. Due to crowded conditions, unnatural feeding regimes, lack of contact with predators and natural stream conditions, hatchery fish are less fit than naturally produced fish. When released they are often larger and more aggressive than wild fish and may displace wild fish and attract predators. In the long run, initial aggressive nature of hatchery fish and their overall lack of fitness can result in depleting natural fish populations. Methods to increase fitness are being explored – methods which in general work towards creating a more "natural" environment in the hatchery.

Empirical versus theoretical data. Given the complexity of the genetic and other issues, the relative newness of concerns in these areas, it is not surprising that many of the concerns are based mainly on theoretical data. The empirical data that are available generally support conclusions from theory; thus fisheries and hatchery managers should take the concerns into consideration during hatchery operation.

Elimination of hatchery impacts. Hatchery impacts can not be completely eliminated but, through proper management, they can be minimized. Proper broodstock selection and mating protocols and release strategies can go a long ways to minimizing impacts

Straying. There appears to be enough natural variation in straying and homing that each hatchery should be evaluated separately through use of a marking program. Marking of hatchery fish should be accompanied by a similar program with wild (natural fish) to provide a comparison. The straying rate is not as important as the percentage of strays in the receiving population. The NMFS recommended maximum of 5% strays in population seems to be a useful goal.

Disease transmission. The relatively limited literature available on transmission of disease from hatchery to wild fish does not indicate that it is a significant problem. On the other hand, there are several diseases and parasites that affect hatchery fish and are found in natural fish as well. Diseases can be acquired by fish in laboratory studies. Clearly more work is needed in this area.

New information that we should be collecting for FERC related studies of the impacts of the FRH on naturally spawning salmonids. Nothing leaps out at this time. As we learn more about straying and genetics, it is clear that sound hatchery management in the future will require more involvement by geneticists.

Mixed stock fisheries. A mixed stock fishery could help isolate some of the impacts of harvest of hatchery fish at the expense of wild stocks. Such a fishery is now present for steelhead but many details need to be worked out for Chinook salmon. In general hatchery and fish managers should constantly aware of changes in fishery conditions and regulations and consider these changes when considering egg take and release numbers.

REFERENCES

Black, M. 2001. Shasta salvage efforts: Coleman National Fish Hatchery on Battle Creek, 1895-1992. pp 177-263 in R. Brown, ed. Volume I, Contributions to the biology of Central Valley salmonids. Fish Bulletin 179, Cal. Dept. Fish and Game, Sacramento, CA. 297pp.

Blankenship, L. 2002. An overview of Washington's hatcheries. Pp 4-5, in Orr, C. and J. Pinkett, eds. Hatcheries and the protection of wild salmon. Simon Fraser University, BC. 131 pages.

Boyce, R. 1986. A comprehensive plan for rehabilitation of anadromous fish stocks to the Umatilla River basin. Final report. Bonneville Power Administration, Portland, OR.

Busack, D. and K. Currens. 1995. Genetic risks and hazards in hatchery operations: Fundamental Concepts and Issues. Pp71-80 in H. Schramm, Jr, and R. Piper, eds. Uses and Effects of Cultured Fishes in Aquatic Systems. Am. Fish. Soc. Symposium 15. AFS, Bethesda, MD.

Chapman, D., A.Girgi, T. Himman, D. Deppert, M. Erho, S. Hays, C.Peven, B. Susumoto and R Klinge. Status of Snake river Chinook Salmon. Report to Pacific Northwest Utilities Conference Committee, Portland, OR.

Cramer, S. 1992. Contributions of Sacramento basin hatcheries to ocean catch and river escapement of fall Chinook salmon. Report to the Calif. Dept. Water Resources. Sacramento, CA. 113pp plus appendices.

Campton, D. 1995. Genetic effects of hatchery fish on wild populations of Pacific salmon and steelhead: What do we really know? Pp 337-353. in H. Schramm, Jr, and R. Piper, eds. Uses and Effects of Cultured Fishes in Aquatic Systems. Am. Fish. Soc. Symposium 15. AFS, Bethesda, MD.

Einum, Sigurd. 2001. Implications of stocking: Ecological interactions between wild and introduced salmonids. Norwegian Jour. Freshwater Research. 75:56-70.

Grant, W. 1997. Genetic effects of straying of non-native hatchery fish into natural populations: proceeding of the workshop. US Dept. of Commerce, NOAA Tech. Memo. NMFS-NWFSC-30, 130 pages.

Hayes, C and R. Carmichael. 2002. Salmon restoration in the Umatilla River: A study of straying and risk containment. Fisheries **27**:10, pp10-19. Bethesda, MD.

Hilborn, R. 1992. Hatcheries and the future of salmon in the Pacific Northwest. Fisheries 17(1):pp5-8, Bethesda, MD.

Hindar, K, N. Ryman and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. Canad. Journ. Aquat. Sci. 48:945:947.

Light, J. 1987. Coastwide abundance of North American steelhead trout. Univ. of Wash., Fish. Res. Inst. Seattle, WA.

Meffe, G. 1992. Techno-Arrogance and halfway technologies: Salmon hatcheries on the Pacific Coast of North America. Conservation Biology **6(**5), pp350-354.

Moring, J. 2000. The creation of the first public salmon hatchery in the United States. Fisheries. 25:7 pp 6-12. Amer. Fish. Soc., Bethesda, MD.

National Research Council. 1996. Upstream – Salmon and Society in the Pacific Northwest. National Academy Press, Washington DC. 452 pages.

Nehlson, W., J. Williams and J. Lichatowich. 1991. Pacific salmon at the crossroads:stocks at risk from California, Oregon, Idaho and Washington. Fisheries 16(2):4-21. Bethesda, MD.

Nickelson, T., M. Solazzi, and S. Johnson. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. Can. J. Fish. and Aquat. Sci. 43:2443-2449.

Orr, C., Gallagher, P. and J. Pinkett. 2002. Hatcheries and the protection of wild salmon. Simon Fraser University, BC. 131 pages.

Quinn, T. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fish. Res. 18:29-44.

Qunn, T. 1997. Homing, straying and colonization. Pp 73-85 in W. Grant, ed, Genetic effects of straying of non-native hatchery fish into natural populations: proceeding of the workshop. US Dept. of Commerce, NOAA Tech. Memo. NMFS-NWFSC-30, 130 pages.

Scarnecchia, D. 1988. Salmon management and the search for values. Canad. Jour. Fish. and Aquatic Sci. 45:2042-2050.

Smith, K. 1962. Environmental hazards. Chapman and Hall, London, UK.

Stet, R and E. Egberts. 1991. The histocompatibility system in teleostean fishes: From multiple histocompatibility loci to major histocompatibility complex. Fish Shellfish Immunol. 1:1, pp1-16.

Steward, C. and T. Bjornn. 1990. Supplementation of salmon and steelhead stocks with hatchery fish: A synthesis of published literature. Part 2. in W. Miller, ed. Analysis of Salmon and Steehead Supplementation, Parts 1-3. Technical Report 90-1 US Dept. of Energy, Bonneville Power Adminsitratin. Portland, OR.

Utter, F., G Milner, G. Sthal, D. Teel. 1989. Genetic population structure of Chinook salmon, Oncorhynchus tshawytscha, in the Pacific Northwest. Fishery Bulletin:87;239-264.

Waples, R. 1996. Dispelling some myths about hatcheries. Fisheries 24(2): 12-21.