INDEPENDENT MULTIDISCIPLINARY SCIENCE TEAM (IMST)

State of Oregon

John Buckhouse
Wayne Elmore
Stan Gregory
Kathleen Kavanagh
James Lichatowich
Logan Norris, Chair
William Pearcy

February 6, 2001

The Honorable John A. Kitzhaber
Governor of Oregon
State Capitol
Salem OR 97310

The Honorable Gene Derfler
Oregon Senate President
State Capitol
Salem OR 97310

The Honorable Mark Simmons
Oregon House Speaker
State Capitol
Salem OR 97310

Enclosed is Technical Report 2001-1 of the IMST on artificial propagation of salmonids to accomplish the goals of the Oregon Plan for Salmon and Watersheds. It is the fourth report of the IMST on this subject, and should be seen as identifying the scientific basis by which artificial propagation can be used to help accomplish the goals of the Oregon Plan.

There are two fundamental changes identified in this report:

- Develop an overarching policy and complementary strategic plan for artificial propagation that is consistent with the goals of the Oregon Plan. Fundamental to this is adoption of a "landscape perspective" for artificial propagation that:

  - o manages individual hatcheries as part of the productive system of the basin in which they reside,
  - o manages aggregations of hatcheries as part of the larger landscape in which they exist and complementary to the structure of the metapopulation of wild fish in that landscape,
  - o reflects the changing conditions and carrying capacity of freshwater, estuarine and ocean conditions,
  - o has a multigenerational time perspective, and
  - o meshes with other aspects of fish management such as harvest, and land management as it influences the quality of habitat for production of wild fish.

Modify as needed the Oregon Administrative Rules and the management strategies and tactics to implement and carryout the policy and strategic plan for artificial propagation called for above.

These changes will be challenging to make, but based on our interactions with ODFW staff, we feel confident of their ability to do so if the appropriate policy framework and resources are provided for it.

We conclude after nearly three years of study and four technical reports that artificial propagation can help accomplish the goals of the Oregon Plan, and we feel the scientific direction we provide in our reports can help make this a reality.

Sincerely Yours,

Logan A. Norris
Chair, Independent Multidisciplinary Science Team

Enclosure

cc: IMST
Ken Messerle, Chair, Committee on Natural Resources, Agriculture, Salmon & Water
Bob Jensen, Chair, House Committee on Stream Restoration & Species Recovery
ODFW Commissioners
Kay Brown, ODFW
Roy Hemmingway, Manager, Oregon Plan

The Scientific Basis for Artificial Propagation in the Recovery of Wild Anadromous Salmonids in Oregon

Technical Report 2001-1

A report of the Independent Multidisciplinary Science Team, Oregon Plan for Salmon and Watersheds

January 11, 2001

Members of IMST
Logan Norris, Team Chair, Department of Forest Science, Oregon State University
John Buckhouse, Department of Rangeland Resources, Oregon State University
Wayne Elmore, Bureau of Land Management, US Dept. of Interior
Stanley Gregory, Department of Fisheries and Wildlife, Oregon State University
Kathleen Kavanagh, Department of Forest Resources, University of Idaho
James Lichatowich, Alder Fork Consulting
William Pearcy, College of Oceanic and Atmospheric Sciences, Oregon State University

Citation: Independent Multidisciplinary Science Team. 2001. The scientific basis for artificial propagation in the recovery of wild anadromous salmonids in Oregon. Technical Report 2001-1 to the Oregon Plan for Salmon and Watersheds. Oregon Watershed Enhancement Board Office. Salem, Oregon

Acknowledgments

The IMST would like to thank Cathleen Rose for her contributions to writing and producing this report. We are grateful to Glenda Serpa for her administrative support in the production of the report. We also thank Suzie Peck and Cynthia Taylor for their assistance. Finally, we are grateful to three technical reviewers, Mark Chilcote, Kathryn Kostow, and Trent Stickell, for providing helpful comments on this report.

Table of Contents

PREFACE

The Independent Multidisciplinary Science Team (IMST) developed the following conceptual scientific framework for the recovery of depressed stocks of wild salmonids in Oregon. It was developed originally as we evaluated Oregon's forest practices. Since then, it has been expanded to cover all land uses and fish management. Although not testable in a practical sense, we believe this conceptual framework is consistent with generally accepted scientific theory.

Conceptual Scientific Framework

The recovery of wild salmonids in Oregon depends on many factors, including ocean conditions, the availability of quality freshwater and estuarine habitats, the management of fish harvest and the adequacy of natural and artificial propagation. Freshwater habitat extends across all the lands of the State, and includes lands in urban areas and lands devoted to agriculture, forestry, and other uses. Estuaries provide a transition between fresh water and the ocean, and are a critical part of the habitat of wild anadromous salmonids. The ocean on which salmonids depend extends well beyond Oregon and is subject to fluctuations in productivity that markedly affect adult recruitment. Fish propagation and fish harvest are critical activities in which humans are directly involved with anadromous fish. The IMST is evaluating the science behind the management practices and policies that affect all of these freshwater and estuarine habitats and the management of fish and fisheries.

We have subdivided the work to focus on major types of land use (forestry, agriculture, and urban land uses) and fish management (artificial propagation and harvest). The land use subdivisions correspond to the different policy frameworks within which these lands are managed. Although the policies differ, these land uses interface and intermingle, and the aquatic environments on which the fish depend traverse and link them all; therefore, the boundaries we make in our reports are artificial.

Concepts

IMST is conducting its analysis of land use practices and fish management within a framework made up of the following three fundamental concepts:

1. ***Wild salmonids are a natural part of the ecosystem of the Pacific Northwest, and they have co-evolved with it.*** The contemporary geological landscape of the Pacific Northwest was established with the formation of the major river/stream basins of the region, approximately two to five million years ago. The modern salmonids of the region largely developed from that time (Lichatowich 1999). The abundance of these species at the time of Euro-American migration to Oregon is a reflection of more than 10,000 years of adaptation to the post-glacial environment and 4,000 to 5,000 years of adaptation to contemporary climatic and forest patterns. There is some indirect evidence from anthropological studies that salmon in Oregon's coastal streams may not have reached the high levels of abundance that the first Euro-Americans saw until about 1,000 to 2,000 years ago (Matson and Coupland 1995). The point is that the salmonid stocks of today co-evolved with the environment over a relatively long period compared with the length of time since Euro-Americans entered this landscape.

2. High quality habitat for wild salmonids was the result of naturally occurring processes that operated across the landscape and over time. These same processes occur today, but humans have altered their extent, frequency, and to some degree, their nature. Humans will continue to exert a dominant force on the terrestrial, freshwater, and estuarine landscape of the Pacific Northwest, but current ecosystems need to better reflect the range of historic conditions.

3. The environment and habitat of these species is dynamic, not static. At any given location, there were periods of time when habitat conditions were better and times when habitat conditions were worse. At any given time, there were locations where habitat was better and locations where it was worse. Over time, the location of better habitat shifted, both in fresh water and the ocean.

   Fresh water and estuarine salmonid habitat in the Pacific Northwest has been a continuously shifting mosaic of disturbed and undisturbed habitats. One of the legacies of salmonid evolution in a highly fluctuating environment is the ability to colonize and adapt to new or recovered habitat.

   The ocean habitat also fluctuates and is dynamic, changing over several time scales. There are inter-decadal variations in climate called regimes (as well as shorter term variations) that affect the ocean productivity for salmonids. One regime that resulted in a shift from favorable to unfavorable ocean conditions, especially for coho salmon, occurred in 1977. Some believe that we are entering a more favorable regime that began with the 1998 La Nina. However, it is important to realize that full recovery of salmonid populations is a long-term process. A major assumption is that improved conditions of freshwater and estuarine habitat are buffers to poor ocean conditions. Without improvement of the condition of these habitats, the return to poor ocean conditions in the future will be more devastating to salmonids than what was experienced in the early 1990s (Lawson 1993).

These concepts apply regardless of the land use or fish management strategy and are the basis for the evaluations in this report.

Operation of the Concepts in Salmonids

Wild salmonid stocks historically accommodated changes in their environment through a combination of three strategies**.** ***Long-term adaptation*** produced the highly varied life history forms of these species, providing the genetic diversity needed to accommodate a wide range of changing conditions. ***High fish abundance distributed in multiple locations (stocks)*** increased the likelihood that metapopulations and their gene pools would survive. ***Occupation of refugia*** (higher quality habitat) provided the base for recolonization of poor habitat as conditions improved over time.

History

Since the mid 1850s, the rate and extent to which habitat conditions changed has sometimes exceeded the ability of these species to adapt; therefore, stock abundance currently is greatly reduced. Although refugia exist (at a reduced level) today, population levels of wild salmonid stocks are seriously depressed because of other factors (ocean conditions, fisheries and hatchery management, land-use patterns and practices) that limit habitat productivity and the rate and extent to which recolonization can occur. In addition, some harvest and hatchery practices have diminished the genetic diversity of salmonids, limiting their ability to cope with climate fluctuations. It is the combination of these factors and their cumulative effects since 1850 that have produced the depressed stocks of today.

The historic range of ecological conditions and the diversity of salmonid stocks in the Pacific Northwest are important because they provide a framework for developing policy and management plans for the future. The persistence and performance of salmonids under historic ecological conditions is evidence that these habitats were compatible with salmon reproduction and survival. Prior to European settlement of the western United States, artificial propagation was not practiced, yet the level of harvest by Native Americans may have reached the levels of peak harvests by Euro-Americans (Beiningen 1976; Schalk 1986).

Conclusions

Land uses and fish management strategies resulting in non-historical ecological conditions may support productive salmonid populations, but the evidence for recovery of wild salmonids under these circumstances is neither extensive nor compelling. Recovery of wild salmonids also requires fish management (artificial propagation and harvest) strategies that are consistent with the goals of recovery and are compatible with the condition of the terrestrial and ocean landscape within which they operate.

Therefore, we conclude that:

- the goal of land use management and policy should be to emulate (not duplicate) natural processes within their historic range.
- the goal of fish management and policy should be to produce and take fish in a manner that is consistent with the condition of the environment and how it changes with time.
- the recovery of wild salmonid stocks is an iterative and a long-term process. Just as policy and management have changed in the past they will continue to change in the future, guided by what we learn from science and from experience.

EXECUTIVE SUMMARY

Artificial propagation has been a prominent part of the management of salmonids in Oregon since the late 1800s, and we expect this will continue to be true because hatcheries can have an important role to play in the recovery of wild stocks of anadromous salmonids in Oregon. Today, the state of Oregon operates 34 hatcheries plus satellite facilities, which released 74 million salmon and trout in 1995 (ODFW 1998). ODFW also works with the Clatsop Economic Development Commission in the operation of the Youngs Bay facility and with the Port of Newport in the operation of the Yaquina Hatchery, which releases 150,000 fall chinook annually. ODFW oversees fish cultural activities at 25 sites for the Salmon Trout Enhancement Program (STEP) (ODFW 1998). In addition there are two federal hatcheries that operate in the state: Eagle Creek in the Clackamas watershed and Warm Springs in the Deschutes watershed.

The Oregon Plan for Salmon and Watersheds (Oregon Plan) identified hatcheries as a factor limiting the recovery of wild salmonids (Oregon Plan 1997). While the factors for decline are specific to Oregon coast natural (OCN) coho salmon, they are believed to be broadly applicable to other anadromous salmonids as well.

Oregon uses artificial propagation to achieve several different management purposes: Mitigation, Harvest Augmentation, Supplementation, Restoration, Conservation, and the STEP Hatchbox Program. Hatcheries are also seen as one element of a broad strategy for the recovery of depressed stocks in the Oregon Plan. We describe here the scientific basis on which artificial propagation can be a positive force in the Oregon Plan. Our approach to this topic is broad and strategic, and our findings and conclusions are at this same level of resolution. There is a lot of variation in hatchery programs and the circumstances within which they operate; therefore, there are likely to be some exceptions to our findings and conclusions. These should be viewed simply as exceptions to findings and conclusions that have broad applicability.

The IMST study of artificial propagation began in 1998, and was divided into three phases.

- Phase I addressed the consistency of hatchery measures in the Oregon Plan with the findings on salmon hatcheries reported in three scientific review panels. The results of Phase I are in a Technical Report released in 1998 (IMST 1998).

- Phase II of the IMST study of artificial propagation was a scientific evaluation of the audit of Oregon's coastal and Willamette hatchery programs conducted in 1999 (ODFW 1999a). The results of the scientific evaluation are in an October 25, 2000, letter report to ODFW[1].

- Phase III focuses on the scientific basis for the artificial propagation of anadromous salmonids, and how the artificial propagation programs of the State can be scientifically consistent with the recovery of wild salmonids in Oregon. This document is the Technical Report on Phase III of the IMST study of artificial propagation. The conclusions we reach in this report are based on information in this report and on what we learned in three other IMST reports dealing with various aspects of artificial propagation (IMST 1998; IMST 2000; letter report to ODFW[2]).

---

[1] October 25, 2000 letter to Kay Brown, ODFW
[2] October 25, 2000 letter to Kay Brown, ODFW

Science Questions - There are a great many science questions that could be part of this project. The two broad questions we selected for study are critical to accomplishing the mission of the Oregon Plan. Each question contains sub-elements in which more specific issues are addressed.

1. **What is the scientific basis for the artificial propagation of anadromous salmonids?** To answer the first science question, we evaluate the scientific basis for the key management assumptions associated with artificial propagation. Following are the five assumptions we tested and our findings for each of them:

   Assumption 1. Higher survival in the egg to smolt life stage in the hatchery results in a net increase in adult ocean recruits. Ocean recruits are the total of hatchery and wild fish.

   This assumption was subdivided to consider egg to smolt survival separately from smolt to adult survival.

   The IMST finds that the hatchery environment does give a survival advantage from the egg to smolt stage compared to survival for the same life stages for naturally produced fish, and the monitoring of egg to smolt survival in hatcheries appears to be adequate.

   In mitigation and augmentation hatchery programs, the IMST finds that post-release survival rates for hatchery fish are often lower than the survival rates of wild fish. However, we also find that under most conditions, smolt to adult survival of artificially propagated fish is sufficient to provide an increase in adults for the fishery. We caution however that current monitoring is not adequate to verify that the combination of artificial propagation and production by wild fish is greater than would occur from natural production alone.

   In supplementation and conservation hatchery programs, the IMST finds that under some conditions, smolt to adult survival of artificially propagated fish is sufficient to provide a net increase in the number of naturally spawning adults, but this may not be resulting in increased natural production in subsequent generations.

   With respect to the STEP Hatchbox program, the IMST finds that there is no basis on which to judge whether the program provides a net increase in ocean recruits. Monitoring and evaluation of the hatchbox program is inadequate. However, the hatchbox program does appear to have value as an educational tool.

   Assumption 2. Hatchery production can mitigate for wild fish production lost due to human activities in a watershed.

   The IMST finds that Oregon's hatchery mitigation programs have met with some success; however, many mitigation goals only specify the numbers of juveniles to be released. This does not allow assessment of whether hatchery programs are maintaining the premitigation, naturally-produced supply of adult fish to the fishery. Most mitigation goals do not take into consideration the productive capacity of the system or fluctuations in climate and ocean conditions.

Assumption 3. Hatchery operations retain behavioral, physiological, and genetic characteristics that facilitate hatchery adult returns. This assumption was subdivided to consider domestication separately from genetic management.

The IMST finds that domestication does occur, and it is not necessarily inconsequential, resulting in decreased survival of hatchery fish after they are released from the hatchery. The IMST also finds that mate selection in the hatchery can have major detrimental consequences on the characteristics of the hatchery population, post-release performance of hatchery fish, and the performance of the wild fish if the two interact.

Assumption 4. Interactions between hatchery and wild fish do not negatively impact the survival of wild fish.

The IMST finds that this is not a uniformly valid assumption. Interactions between hatchery and wild fish at the adult and juvenile stages may pose real risks of detrimental impacts to wild populations. The occurrence and magnitude of the risks depend on the circumstances. Unfortunately, due to insufficient monitoring, we do not know enough about effects outside the hatchery to determine the impact of interactions on the fitness of wild fish.

Assumption 5. Augmentation and supplementation hatcheries add to existing natural production without replacing it.

The IMST finds that supplementation can increase the level of natural spawners over the numbers that would have been present without supplementation. It remains to be documented that an increased level of spawning activity translates into sustainable higher levels of natural production, especially in those cases where the factor(s) limiting natural production has not been corrected. Unless supplementation programs are carefully implemented, there is a risk that artificial production could replace natural production.

The IMST also finds that augmentation hatcheries have contributed to the catch of salmon and steelhead in Oregon. In general, however, the natural and artificial production in watersheds that employ augmentation hatcheries have been so poorly monitored that we cannot tell whether they replaced natural production or added to it. There are cases where the evidence suggests that replacement of natural production with hatchery production has occurred (Hilborn and Eggers 2000).

2. Scientifically, how could Oregon's artificial propagation program be consistent with the recovery of wild salmonids in Oregon?

The IMST finds that Oregon's artificial propagation program could be consistent with the recovery of wild salmonids if it has an overarching and strategic plan and policy that incorporated recommendations from recent scientific panels and a landscape perspective. The landscape perspective means a management perspective that includes a larger spatial scale, a longer time horizon and that integrates information about the condition of freshwater and marine systems, predation and other aspects of fish management such as harvest and hatchery management.

Conclusions and Recommendations

Based on these findings, the IMST reaches the following conclusions and makes the following recommendations:

Conclusion 1: ODFW lacks an overarching policy/framework for hatchery management.

Recommendation 1. ODFW should develop a comprehensive plan/cohesive policy for hatchery management.

Artificial propagation, the largest single program devoted to fish management in ODFW, needs a single coherent set of goals, policies, and Administrative Rules. This policy should provide:

- Specific management objectives.
- Strategic guidelines for the entire hatchery program and for the management of individual hatcheries.
- A link between hatchery objectives and management objectives.
- A link between hatchery management and the Oregon Plan.
- Strategies for mitigation of fish lost to the fisheries that include a combination of artificial propagation, habitat improvements, harvest management, and other appropriate strategies.

Recommendation 2. ODFW should adopt and incorporate the recommendations of the independent science panels into statewide comprehensive policy.

This would:

- Minimize the adverse affects of hatcheries on natural populations.
- Adequately evaluate hatchery programs.
- Link supplementation programs with habitat improvements.
- Include genetic considerations in hatchery programs.
- Eliminate stock transfers and introductions of non-native species.
- Incorporate more experimental approaches into their artificial propagation program.

Recommendation 3. ODFW should tie the operation of hatcheries to explicit, measurable management objectives.

The performance measures that track the achievement of these objectives should include a quantitative measure that relates directly to management purposes. This will provide a technically sound basis for policy and management decisions.

Recommendation 4. ODFW should implement the recommendations made in IMST's Workshop on Conservation Hatcheries and Supplementation in the assessment and revision of supplementation programs.

Conclusion 2: Many of Oregon's hatchery programs fall closer to the hatchery-specific approach than to the landscape approach*. *Current management strategies do not provide a cohesive approach to manage hatcheries from a landscape perspective.

Recommendation 5. ODFW should incorporate the landscape perspective into hatchery management.

The shift towards a landscape perspective for hatchery management should include consideration of the following:

- The stream and ocean environment into which the hatchery fish are released, the effects of hatchery fish on other species, and the effects of hatchery fish on wild populations of the same and other species.
- Natural fluctuations in climate and habitat conditions in freshwater and the ocean.
- Metapopulation structure and dynamics and the role of a specific hatchery to emulate a core or a satellite population within the metapopulation.
- System wide measures of performance that include a hatchery(s) as part of the watershed need to be utilized.

Recommendation 6. ODFW should initially give priority for change from the hatchery-specific to the landscape perspective consistent with the direction of this report to coastal and Lower Columbia system hatchery programs.

Recommendation 7. ODFW should support and participate in collaborative research efforts to determine the consequences of interactions between hatchery and wild fish.

Few studies have tracked the effects of interactions between hatchery and wild fish on the long-term survival of wild populations. Studies to resolve the consequences of differences between hatchery and wild fish are long and difficult to accomplish. There are many potentially valuable collaborators in this effort.

Recommendation 8. The IMST should convene a workshop to clarify the state of knowledge on the differences between hatchery and wild fish and the implications to supplementation programs and the fitness of naturally spawning populations.

Conclusion 3. Current monitoring and evaluation of hatchery programs is inadequate.

Recommendation 9. ODFW should strengthen the monitoring and evaluation of hatchery programs.

All artificial propagation programs need to monitor what occurs after fish are released from the hatchery, including smolt to adult survival, effects on wild fish of the target species, and effects on non-target species. Monitoring needs to be done at the watershed and individual hatchery levels to produce different types of information to accomplish hatchery-specific and landscape management goals.

Specifically this recommendation includes but is not limited to:

- **Monitoring smolt to adult survival for hatchery and wild fish on a watershed basis.**
- **Monitoring smolt to adult survival at each individual hatchery program.**
- **Monitoring fry to adult survival in the STEP hatchbox program.**
- **Determining the effects of interactions between hatchery and wild fish outside the hatchery.**
- **Placing monitoring data in an accessible, user-friendly database**.

Recommendation 10. ODFW should establish an explicit process for adaptive management that makes effective use of the results from monitoring programs.

Monitoring and evaluation are essential to adaptive management. However, determining the extent of monitoring and evaluation programs is a dilemma because, while they are very valuable, they require the allocation of scarce financial and human resources. The following approach helps determine what needs to be done, given that there is a limit to the amount of monitoring and evaluation that can be done:

a. Describe artificial propagation programs at the hatchery and at the landscape level in measurable management objectives that are meaningful within the context of the Oregon Plan.
b. Establish the variables that can be measured and will be used to represent the management objectives.
c. Measure and evaluate the variables with an intensity that will allow evaluation of the degree to which the management objectives are being attained, within some established level of certainty.

INTRODUCTION

Artificial propagation has been a prominent part of the management of salmonids in Oregon since the late 1800s, and we expect this will continue to be true because hatcheries have an important role to play in the recovery of wild stocks of anadromous salmonids in Oregon. Hatcheries and reviews of hatchery programs have been controversial and are likely to continue to “enjoy” this distinction, in part because of the inherent complexity of the subject and the fact that the Oregon Department of Fish and Wildlife (ODFW) must operate the hatchery program within a large number of constraints. These constraints include policy agreements with other states, with independent Tribes, with federal agencies; an array of specific mitigation agreements, to address the sometimes-conflicting interests of sport and commercial fishermen and the conservation community; and, in some cases, federal laws such as the Endangered Species Act.

Today, the state of Oregon operates 34 hatcheries plus satellite facilities (see Appendix C for a map of the locations of these facilities). These hatcheries released 74 million salmon and trout in 1995 (ODFW 1998). In addition, ODFW works with the Clatsop Economic Development Commission in the operation of the Youngs Bay facility and with the Port of Newport in the operation of the Yaquina Hatchery, which releases 150,000 fall chinook annually. ODFW oversees fish cultural activities at 25 sites for the Salmon Trout Enhancement Program (STEP) (ODFW 1998). In addition, two federal hatcheries operate in the state: Eagle Creek in the Clackamas watershed and Warm Springs in the Deschutes watershed.

Initially, the principles of animal husbandry and agricultural production were applied to increase the numbers of fish to compensate for lost habitat and to enhance opportunities for harvest. In the early years, the belief was that hatcheries could operate independently from the ecosystem of which they were a part. With the deepening crises of depression of salmon stocks, we increasingly understand that hatcheries and other forms of artificial propagation must operate in harmony with the entire system. In the future, it will be important to manage artificial and natural production in Oregon's rivers so that they complement one another (Lichatowich and McIntyre 1987).

Undisturbed rivers, especially larger river systems, have the capacity to incubate more eggs from wild spawners than could possibly be incubated in a hatchery. The size of the early runs of salmon suggests the incubation and rearing capacity of many streams was enormous. The cost of trying to replace all of the natural capacity with artificial propagation would be prohibitive even if the physical conditions such as water quality and quantity could be met. So, the rational goal of using hatcheries is to increase total production, not replace existing natural production. In addition, for species listed under the Endangered Species Act, delisting can occur only after the recovery of naturally reproducing populations (NMFS 1993). Therefore, for full recovery, these populations need to become self-sustaining.

The Oregon Plan for Salmon and Watersheds (Oregon Plan) identified hatcheries as a factor limiting the recovery of wild salmonids (Oregon Plan 1997). While the factors for decline were identified specific to Oregon coast natural (OCN) coho salmon, we believe they are broadly applicable to other anadromous salmonids as well. Among the factors specific to artificial propagation are the following, from the Oregon Plan (1997):

Factor V. Loss of genetic adaptation of wild populations from interbreeding with genetically dissimilar, less fit hatchery fish.

This is felt to result in the loss or reduction in such locally important adaptations as run timing, emergence timing, movement patterns within basins, timing of smoltification, and migratory patterns in the ocean. The Oregon Plan placed emphasis on the interbreeding that occurred due to the straying of hatchery fish into natural spawning areas.
The Oregon Plan identifies three biological objectives relevant to Factor V. They are to:

(1) "reduce the genetic risk to wild populations by reducing the percentage of hatchery fish to less than 10% of the total population spawning in the wild." The Oregon Plan proposes to accomplish this objective through:

- The use of volunteers to (among other things) assist in spawning surveys to document the ratio of wild to hatchery fish.
- Fully implement the ODFW Wild Fish Management Policy.
- Reduce coastal hatchery releases from 6.4 million in 1990 to 2.3 million by 1998.

(2) "clearly describe the purpose and conduct of all coastal hatchery programs." The Oregon Plan proposes to accomplish this objective through:

- Development of management guidelines, including genetic guidelines, for each hatchery program.

(3) "facilitate differentiation of hatchery fish from wild fish on spawning grounds." The Oregon Plan proposes to accomplish this objective through:

- Marking of all hatchery coho salmon.

Factor VI. Competition with hatchery-reared fish

The Oregon Plan identifies competition for food and cover between wild fish and hatchery released smolts (which may be larger in size) as potentially detrimental to wild fish and therefore to their recovery. The Oregon Plan notes that the magnitude of this effect is uncertain at any one location or in aggregate across the range of basins used by OCN coho salmon.

The Oregon Plan identifies the following biological objective to deal with Factor VI: "reduce the potential for competition between juvenile hatchery and wild coho by decreasing the number of hatchery fish released." This would be accomplished by:

- Reducing coastal hatchery releases from 6.4 million to 2.3 million by 1998.
- Development of management objectives, including genetic guidelines.

Factor VII. Low-density reproductive failure of wild populations

At extremely low densities, spawning populations of wild fish may fail to sustain themselves due to inability to find a mate, inbreeding depression, and other unknown depensatory factors.
The biological objective of the Oregon Plan, relevant to Factor VII is to: "evaluate the potential and effectiveness of using hatchery production to rebuild or restore critically

depressed wild populations of coastal coho salmon." This objective is to be accomplished through:

- The use of volunteers to implement habitat restoration activities and the collection of wild broodstock.
- Utilization of hatcheries to rebuild wild runs.

It is clear that the Oregon Plan both recognizes artificial propagation as one of several factors contributing to the decline of wild salmonids and relies on hatcheries to be part of the solution. The measures proposed for accomplishment of the biological objectives associated with mitigation of these factors of decline are key parts of the State's program of artificial propagation.

One of the challenges for ODFW is how to optimize across the varied and sometimes conflicting interests while actively working to meet the goals of the Oregon Plan. How this can be done is a matter of policy and not science. Therefore, we describe the scientific basis on which artificial propagation can be a positive force in the Oregon Plan, leaving the challenging policy issues of how to implement the science in this complex policy arena to those with responsibility for doing so. Our approach to this topic is broad and strategic, and our findings and conclusions are at this same level of resolution. There is a lot of variation in hatchery programs and the circumstances within which they operate, therefore there are likely to be some exceptions to our findings and conclusions. These should be viewed simply as specific exceptions to broadly applicable findings and conclusions. The conclusions we reach in this report are based on information in this report and on what we learned in three other IMST reports dealing with various aspects of artificial propagation (IMST 1998; IMST 2000a; letter report to ODFW[3]).

Resource Materials

There is an abundance of technical and scientific information on artificial propagation, harvest, and other aspects of fisheries management of anadromous salmonids. There have been several major reviews of hatcheries in recent years, and the findings from these provide a rich source of information (Appendix A includes the text of the recommendations from these science panels). Since 1994, there have been three independent reviews of artificial propagation in general, a review of artificial propagation by the Northwest Power Planning Council (NWPPC), two reviews of artificial propagation in the Columbia River system, a review of artificial propagation in Puget Sound and Coastal Washington, and an IMST report on a scientific workshop about conservation hatcheries and supplementation. All eight of these reports, listed below, are based on the technical and scientific literature of what is known about artificial propagation:

- National Fish Hatchery Review Panel (1994): "Report of the National Fish Hatchery Review Panel"
- Independent Scientific Group (1996): "Return to the River: Restoration of Salmonid Fishes in the Columbia River Ecosystem"
- National Research Council (1996): "Upstream: Salmon and Society in the Pacific Northwest"

[3] October 25, 2000 letter to Kay Brown, ODFW

- Scientific Review Team (1998): "Review of Artificial Production of Anadromous and Resident Fish in the Columbia River Basin"
- National Marine Fisheries Service (1999a): "Biological Opinion on Artificial Propagation in the Columbia River Basin – Incidental Take of Listed Salmon and Steelhead from Federal and Non-Federal Hatchery Programs that Collect, Rear, and Release Unlisted Fish Species"
- Northwest Power Planning Council (1999): "Artificial Production Review"
- Hatchery Scientific Review Group (2000): "Scientific Framework for Artificial Propagation of Salmon and Steelhead"
- Independent Multidisciplinary Science Team (2000): "Conservation Hatcheries and Supplementation Strategies for Recovery of Wild Stocks of Salmonids: Report of a Workshop"

The IMST determined that these reviews are technically sound and accurately reflect the details of the abundant literature in these areas. For this reason, in this report, we do not reevaluate and cite the majority of the scientific literature. Our approach instead is usually to refer to the major review papers and reports, citing specific papers only when needed for emphasis.

These other reviews have generally focused on whether or not hatchery programs have met their goals. Our approach is different, focusing on the scientific validity of the assumptions we believe are inherent in artificial propagation programs. We reviewed these assumptions in a public meeting with ODFW, and based on the discussion modified some assumptions, dropped others, and added an assumption suggested by the Department.

The challenge is to synthesize from all of this technical information the fundamental scientific concepts that make artificial propagation a complementary part of a whole system that includes freshwater, estuarine, and ocean habitat and sport and commercial harvest. This integration and complementarity is critical to accomplishing the goals of the Oregon Plan. Oregon is fortunate that ODFW is staffed with technically competent and dedicated people who are capable of developing programs and measures that are consistent with these scientific concepts and implementing them in ways that can accomplish the mission of the Oregon Plan. Our purpose in this report is to provide ODFW and the Fish and Wildlife Commission broad scientific guidelines within which they can develop hatchery policies and management activities that are relevant to the Oregon Plan.

History of the IMST Project on Artificial Propagation

The IMST initiated a project to study artificial propagation in 1998. The goal of our work is to determine how artificial propagation could be scientifically compatible with accomplishing the mission of the Oregon Plan. This study was divided into three phases.

- Phase I addressed the consistency of hatchery measures in the Oregon Plan with findings on salmon hatcheries from three scientific review panels. The results of Phase I are in a Technical Report released in 1998 (IMST 1998).

- Phase II of the IMST study of artificial propagation was a scientific evaluation of the audit of Oregon's coastal and Willamette hatchery programs conducted in 1999 (ODFW 1999a). The results of the scientific evaluation are in an October 25, 2000, letter report to ODFW[4].

- Phase III focuses on the scientific basis for the artificial propagation of anadromous salmonids and how the artificial propagation programs of the State can be scientifically consistent with the recovery of wild salmonids in Oregon. This document (IMST Technical report 2001-1) is the Technical Report on Phase III of the IMST study of artificial propagation.

Context and Scope of this Report

Hatcheries can play an important role in salmon management and recovery, but the historic vision for hatcheries was inadequate. We seek to provide a scientifically sound contemporary vision for them in this report. The scope of this Technical Report is artificial propagation of anadromous salmonids in Oregon. All artificial propagation objectives are addressed, including mitigation, harvest augmentation, supplementation, restoration, and conservation strategies, as they are part of the operations of conventional hatcheries. In addition, the hatchbox strategies used in the STEP program are included in this report. While this report does not explicitly address non-anadromous salmonids or other species of fish, the fundamental concepts in this report are broadly applicable to them.

This report is strategic not tactical, focusing on broad scientific issues and concepts. It emphasizes conditions and functions that go well beyond the specific activities and operations inside of the hatchery. It is not a review of each of the individual policies, Administrative Rules or Measures in the Oregon Plan, or of individual hatcheries. Such an effort is beyond the scope of what can be accomplished by the IMST. In some cases, we focus on specific policies, rules, or measures, but this is done primarily to illustrate examples. Lack of inclusion of a specific rule or measure does not imply either approval or rejection of it by IMST.

The scientific direction provided by this report can guide ODFW (working with other panels of experts as needed) in formulating policy, Administrative Rules and Measures for the Oregon Plan that are needed as part of accomplishing the recovery of depressed stocks of wild salmonids.

Science Questions

There are a great many science questions that could be part of this project. From these, we selected two broad questions, which IMST considers to be most important in accomplishing the mission of the Oregon Plan. These questions contain sub-elements in which more specific issues are addressed. We list the two broad questions here to provide direction in reading the balance of this report. Specifically:

1. What is the scientific basis for the artificial propagation of anadromous salmonids?

2. Scientifically, how could Oregon's artificial propagation program be consistent with the recovery of wild salmonids in Oregon?

[4] October 25, 2000 letter to Kay Brown, ODFW

Organization of This Report

This is a long and complex report, reflecting the breadth and complexity of the issues involved. It is divided into eight sections, including appendices. The following explanation of its organization is to help readers direct their attention to the elements that are of greatest interest.

Preface

The preface outlines a conceptual scientific framework for the recovery of wild salmonids.

Introduction

The introduction provides the history, context and scope of the report, and identifies the major science questions addressed in the report.

Background

This is a brief history of Oregon's hatchery program and the role of hatcheries in salmonid management and conservation. It describes harvest augmentation, mitigation, and restoration, which are the conventional objectives of hatchery programs. It also describes the newer objectives of supplementation and conservation, and the STEP hatchbox program. There is a brief description of the concept of managing hatcheries from a landscape perspective. We also address the question of differences between hatchery and wild fish and if these differences are important. There is also a brief statement on the status of hatchery related policies and Administrative Rules. A more detailed listing of those policies and rules is presented in Appendix B.

Science Questions

This section provides the analysis and answers to the two science questions.

Conclusions and Implications For Policy

This section draws major conclusions from the answers to the science questions and addresses them in the context of their implications for policy. This section is at the interface between science and policy. It is meant to help those addressing policy to do so in ways that are as consistent as possible with what is known from science.

Recommendations

These are the specific recommendations of the IMST.

Literature Cited

Appendices

Appendix A: Recommendations for Artificial Propagation from Other Scientific Reviews.
Appendix B: Summary of Policies Regarding the Artificial Propagation of Fishes in Oregon.
Appendix C: Map of Locations of State Hatcheries in Oregon.

BACKGROUND

Brief History of Hatcheries in Oregon's Coastal Rivers

The first Pacific salmon hatchery was established by Spencer Baird, the U.S. Fish Commissioner, in the Sacramento Basin in 1872. Five years later, he responded to a request from a group of cannery operators in Oregon and Washington and helped them build and operate a hatchery on the Clackamas River (Hayden 1930). In that same year (1877), in an effort to enhance his salmon canning operation, R. D. Hume built a hatchery on Indian Creek, a tributary to the Lower Rogue River. By 1900, many of Oregon's major coastal watersheds had operating hatcheries. Hatchery production rapidly increased and, in 1905, 23 million fry and fingerling salmon and steelhead were released into Oregon's coastal watersheds (Cobb 1930) (Figure 1).

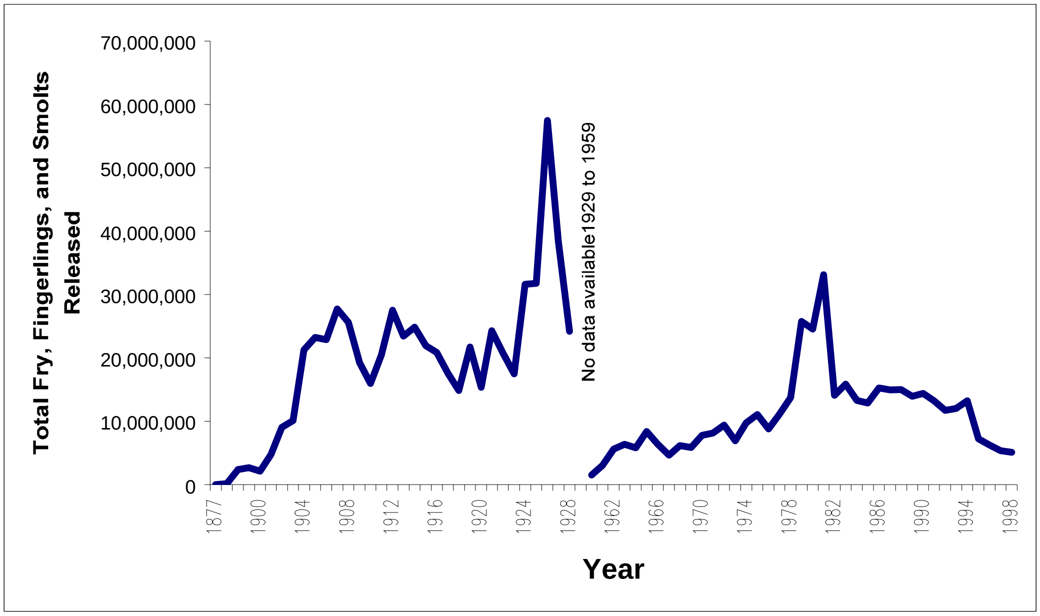


Figure 1: Total of salmon fry, fingerlings, and smolts released into Oregon coastal streams, 1877-1928 and 1960-1998. (Sources: 1877-1928, Cobb 1930; 1960-1998, available from StreamNet at http://www.streamnet.org/online_ data.html).

The early decades of artificial propagation were characterized by claims of success; however, there was no monitoring or evaluation to document the actual contribution hatcheries made to total production (Lichatowich 1999). It is now generally accepted that prior to about 1960, few salmon fry survived after release from hatcheries (CBFWA 1990). By the 1960s, research initiated in the 1930s began to produce more nutritious diets, better disease treatments and improved hatchery practices. These advances in hatchery technology and science combined with productive ocean conditions in the 1950s to the 1970s dramatically increased smolt to adult survival of artificially propagated salmon. By the mid-1970s, this led to coho salmon harvests that were approaching and even exceeding historical harvest levels and most of the fish caught were of hatchery origin. During the period of high fish abundance and favorable ocean conditions in the 1960s and 1970s, harvest rates were high, frequently over 70 to 80 percent. Unfortunately, this catch level overharvested wild coho salmon and, along with habitat degradation, contributed to their decline (Figure 2). As climatic conditions shifted to a less favorable regime in 1977, ocean survival of all coho salmon declined (Figure 2).

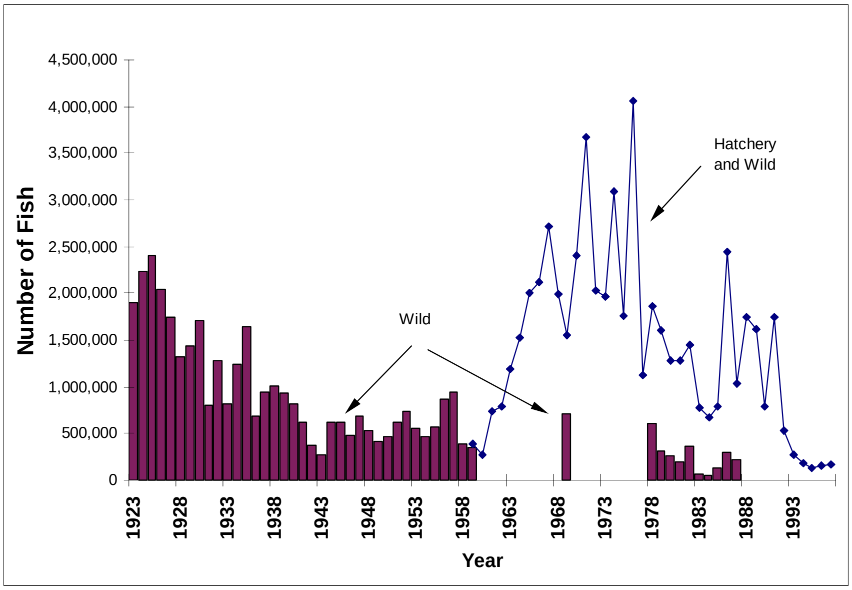


Figure 2: Harvest of coho salmon in the Oregon Production Index partitioned into wild and hatchery fish. Solid bars are catch of wild coho salmon. All coho are assumed wild before 1960. Data sources: OPI harvest 1923-1970, ODFW unpubl. data; 1971-1991, PFMC (1992). Harvest of wild coho salmon 1959 and 1969, ODFW (1982); 1978-1987, L. Borgerson, ODFW, pers. Comm. (Taken from Lichatowich 1997).

These factors (changes in ocean conditions and freshwater and estuarine habitat, artificial propagation, and overharvest) set the stage for the listing of coho salmon under the Federal Endangered Species Act in 1998. This sequence of events prompted biologists to ask questions about the impact of hatcheries on wild salmon (e.g., Caliprice 1969; Chilcote et al. 1986; Reisenbichler and Phelps 1989; Hindar et al. 1991; Bowles 1995; Flagg et al. 1995).

Questioning of hatcheries is not new; it dates back to the first use of artificial propagation in salmon management (Lichatowich 1999). Because of this history and the way hatchery programs responded or failed to respond to criticism, artificial propagation (along with habitat degradation, overharvest, and other factors) is considered part of the problem by many biologists, yet at the same time it is also considered part of the solution (Oregon Plan 1997; NWPPC 1999).

Hatchery technology has made dramatic improvements over the last 120 years, but most of those improvements have been in hatchery operations (NWPPC 1999), i.e., activities inside the confines of the hatchery. For example, over the last century, hatchery design improved, nutritional value of feeds increased, better treatments for diseases were developed, geneticists improved animal husbandry practices, and tagging technology has enhanced monitoring of survival and contribution to fisheries. Comparatively, little effort has been directed toward the behavior of hatchery fish outside the hatchery and their impact on wild fish. Campton (1995) argues that the concern over the effects of hatcheries has to be partitioned into two sources: effects caused by factors intrinsic to the operation of hatcheries (such as domestication, disease management, and nutrition) and effects caused by fish management decisions (such as stock transfers, selective breeding, and the impact of fisheries on mixed hatchery and wild stocks). Most of the hatchery problems solved in the past 120 years deal with factors intrinsic to hatchery operations. Domestication and its consequences is an exception. It has received inadequate attention.

Traditionally, fish hatcheries have often been operated as though they were independent of the ecosystem. Part of the reason for this approach is the complex and difficult demands placed on hatcheries. Artificial propagation programs actually have dual and possibly contradictory missions. They must: 1) produce fish that survive in the highly controlled hatchery environment, and at the same time, 2) produce fish that can also survive in the natural environment outside the hatchery.

Most artificial propagation programs have focused on the first mission, producing fish well adapted to survival inside the hatchery. Where this focus has led to domestication of the hatchery stock, it can lead to reduced survival after release from the hatchery (Campton 1995). Less information is available on the survival of fish after release from the hatchery. Evidence for this comes from ODFW's hatchery audit (ODFW 1999a). Of the 51 hatchery programs audited, 41 were evaluated by the number of juveniles released. Only nine hatchery programs were evaluated by the number of adult salmon produced. Thus, performance monitoring focused mainly on factors inside the confines of the hatchery. For most of the programs audited, what happened after the fish were released was not reported. The failure to report survival to the adult and the recruitment of artificially propagated fish is difficult to understand because some of these data are available in other reports prepared by ODFW staff. This suggests a weak linkage between the hatchery program and the management objectives it is expected to meet. The audit did not cover the use of artificial propagation by the STEP program.

Objectives of Artificial Propagation

Oregon uses artificial propagation to achieve several different management objectives:

- **Mitigation.** The mitigation hatchery attempts to maintain the supply fish to the fishery that would otherwise have been lost because of habitat degradation or blocked access to natural spawning areas. Most of the hatcheries built in the 20th century are for mitigation purposes (NRC 1996). Mitigation hatcheries are usually the product of formal, legal agreements tied to specific development activities such as dams. For instance, on the Oregon coast, Cole Rivers Hatchery (Rogue River) was constructed to mitigate for habitat removed from anadromous salmonid production by operation of the Lost Creek Dam. Most of the hatcheries in the Columbia River Basin mitigate for the construction and operation of the dams used for hydroelectric power generation, irrigation, flood control, and navigation.

- **Harvest Augmentation.** This type of hatchery program seeks to increase sport and/or commercial harvest opportunities by releasing artificially propagated salmon smolts. Harvest augmentation is probably the oldest use of artificial propagation. Many of Oregon's coastal hatcheries are of this type. The Nehalem Hatchery is one example. Harvest augmentation is being proposed again in new and innovative programs in the Columbia River. In some cases, the programs are designed to provide a specific fishery in a specific location that minimizes interaction with wild populations. The Young's Bay program in the lower Columbia River is a current example of a harvest augmentation program.

- **Supplementation.** The term supplementation has been used to describe such a wide range of propagation and enhancement activities that the National Research Council recommended dropping the use of the word (NRC 1996). However, when restricted to a narrow set of activities, supplementation can be a useful term. The generally accepted definition of supplementation was developed by the Regional Assessment of Supplementation Project (RASP): *"Supplementation is the use of artificial propagation in the attempt to maintain or increase natural production while maintaining the long-term fitness of the target population, and keeping the ecological and genetic impacts on non-target populations within specified biological limits"* (RASP 1992). RASP (1992) concluded this definition of supplementation imposes several constraints on the use of hatchery fish:

1) The objective is to increase natural production. That implies habitat is of sufficient quantity and quality to sustain natural production.
2) The population being supplemented must retain its long-term fitness.
3) Allowable ecological and genetic impacts on non-target populations must be specified ahead of time. These constraints imply that extensive monitoring programs will accompany attempts to supplement natural production. The hatchery programs in the Grande Ronde and Imnaha Rivers are examples of supplementation programs. The IMST recently conducted a workshop on conservation hatcheries and supplementation, which produced several useful recommendations (IMST 2000a). The assumption with supplementation programs is that at some point, the other factors affecting wild fish survival will be addressed, and the supplementation program will not be needed indefinitely. Supplementation is not a proven methodology and is currently undergoing large scale testing in the Columbia Basin.

- **Restoration.** This type of hatchery program attempts to reestablish salmon or steelhead populations in habitat from which they were extirpated. In contrast, supplementation attempts to increase the abundance of an existing, but depleted population. Both supplementation and restoration programs have the same end objective, but they start from a different place. In Oregon, the hatchery program in the Umatilla River is an example of a restoration program.

- **Conservation.** The listing or potential listing of several species/stocks of salmon and steelhead under the Endangered Species Act has generated the newest purpose for artificial propagation. The goal of a conservation hatchery is the preservation of a gene pool while other recovery efforts are conducted. The concept of a conservation hatchery is new and its scope and constraints are still being developed. In the Columbia River and Puget Sound, hatchery programs with conservation objectives are using new technology such as captive broodstocks on a large scale. Captive broodstock programs attempt to circumvent natural smolt-to-adult mortality by keeping the salmon in the hatchery throughout their entire life cycle.

  Conservation hatcheries may play an important role in preventing extinction, but the concept is still evolving, is experimental, and is not a proven methodology. Conservation hatcheries should be used with caution and adequate levels of monitoring against which management objectives can be quantitatively evaluated. The assumption is that at some point the factors affecting wild fish survival will be addressed, and the captive broodstock program will no longer be needed.

- **STEP Hatchbox Program**. The use of streamside incubators to hatch salmon eggs is a form of artificial propagation used by Oregon's Salmon Trout Enhancement Program. The STEP program, started in 1981, has the goal of restoring native salmon and trout stocks to historic levels of abundance (Solazzi et al. 1999). However, the program's objectives appear to have evolved more towards public education instead of restoration of stocks. In this program, volunteers raise eggs in hatchboxes and release unfed fry into streams. A 1999 review of the STEP hatchbox program (Solazzi et al. 1999) noted that hatchboxes are only utilized under certain conditions, most likely in streams in which the target species was historically present, but is no longer present in the system. When hatchbox releases are made in streams in which there are existing populations, it is only when the local population is extremely depressed and there is sufficient habitat to support the additional fry.

Managing Hatcheries from a Landscape Perspective

A broader, landscape approach to hatchery management would be consistent with strategies 6.e and 7.c of the Oregon Plan. In addition, it would be consistent with several recent recommendations contained in the literature on salmon management and recovery of depleted populations.

In our report on Oregon's forest practices (IMST 1999), we recommended that the policies, operational guidelines, and rules governing forest management broaden their emphasis on individual actions and sites to include a landscape perspective. This recommendation is equally relevant to fisheries management in general, including the management of artificial propagation programs of all types. There have been many recommendations for fisheries and streams to be addressed from a landscape perspective (Schlosser 1991; Grossman 1995; Reeves et al. 1995; ISG 1996; NRC 1996). The Oregon Plan also approaches salmon recovery from a landscape perspective, integrating actions across broad spatial and temporal scales. Hatchery management needs to shift from the narrow, hatchery-specific focus to a broader landscape perspective because hatcheries are part of the landscape and cannot be separated from it.

The landscape perspective will require a broader geographical and a longer temporal perspective in the planning and operation of hatcheries than has generally been the case up to now. At a minimum, attributes of the entire watershed and its assemblage of native fishes must be considered in the management of hatcheries. Long-term changes in ocean conditions that affect salmon survival should also be factored into hatchery operations. The need for a broader approach to management was recently recognized in the proceedings of an international symposium on sustainable salmon management:

> "While most of the existing institutions have adequately fulfilled their stated mandates, the current status of salmon and steelhead populations and their associated habitats suggests that the existing *institutional management structures* do not adequately respond to the challenges we are currently facing. One need only look at the precipitous and widespread declines of salmon populations in the Pacific region to conclude that, together, the institutions responsible for their management have failed to protect them.
>
> …. recent challenges underscore the need for a new, science-based approach to the management of Pacific salmonids and the ecosystems upon which both fish and humans

depend. The ecosystem approach provides a framework for meeting these challenges." (Knudsen et al. 2000)

In addition, the National Research Council (NRC) recommended:

"Decision-making about uses of hatcheries should occur within the larger context of the region where the watersheds are located and should include a focus on the whole watershed, rather than only the fish." (NRC 1996)

Following a review of the artificial propagation program for the Columbia River Basin, the Northwest Power Planning Council adopted ten policies to guide the management of hatcheries (NWPPC 1999). Five of those policies include a landscape perspective:

1. The manner and use of artificial propagation must be considered in the context of the environment in which it will be used.
2. Hatcheries must be operated in a manner that recognizes that they exist within ecological systems whose behavior is constrained by larger scale, basin, regional and global factors.
3. Decisions on the use of the artificial production tool need to be made in the context of deciding on fish and wildlife goals, objectives and strategies at the subbasin and province levels.
4. A diversity of life history types and species needs to be maintained in order to sustain a system of populations in the face of environmental variation.
5. Naturally selected populations should provide the model for successful artificially reared populations, in regard to population structure, mating protocol, behavior, growth, morphology, nutrient cycling and other biological characteristics.

Hatchery management strategies span a continuum bounded by strategies that are hatchery-specific and strategies that have a landscape perspective (Figure 3). It is likely that no individual hatchery falls entirely in the hatchery-specific or landscape end of the continuum.

Our current review and the preparation of two previous reports lead us to conclude that many of Oregon's hatchery programs fall closer to the hatchery-specific than to the landscape approach. According to ODFW's hatchery audit (ODFW 1999a), performance monitoring focuses on hatchery production objectives (eggs taken, smolts released, etc.) with little emphasis on meeting larger management objectives or objectives of the Oregon Plan. The newer hatchery programs in the Columbia Basin appear to be exceptions to this generalization. Their planning documents and monitoring reports suggest they are closer to the landscape end of the management continuum.

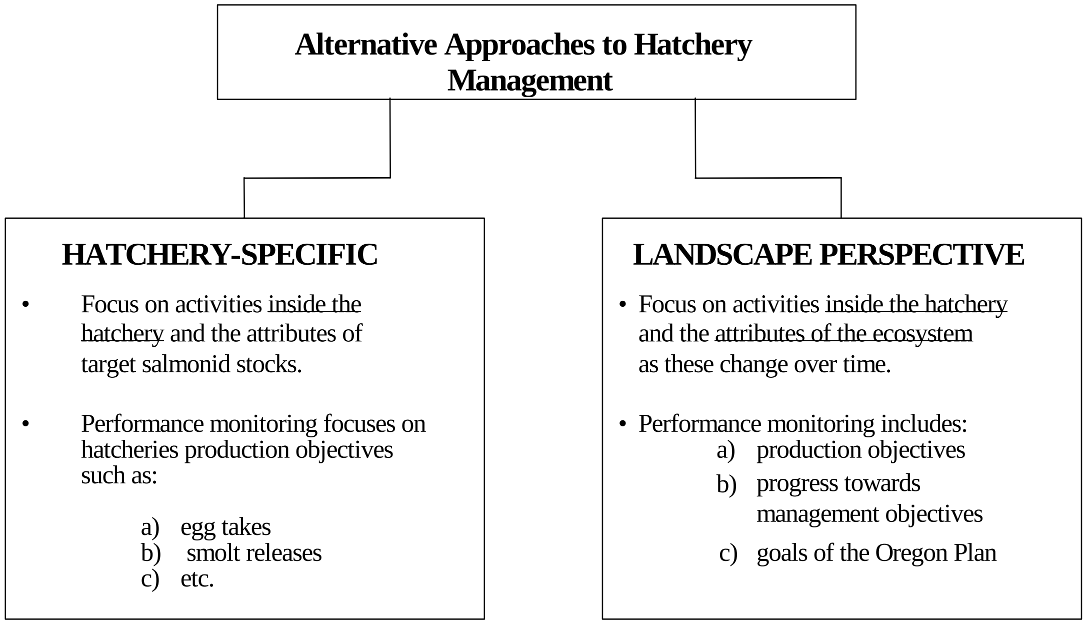


Figure 3: Two approaches for managing Oregon's hatcheries.

The landscape approach incorporates a broader spatial and temporal perspective. It incorporates the hatchery-specific focus, but also gives equal weight to ensuring hatchery operations are consistent with the attributes of the ecosystem. Performance monitoring includes an equal emphasis on hatchery production and management objectives (survival to adult, catch contribution, hatchery-wild interactions, etc).

Figure 4 shows one way that the landscape perspective might be used to set priorities for artificial propagation. In this example, the probability of extinction of coho stocks across all the coastal watersheds is examined and the pattern used to shift emphasis in hatchery programs. Thus, hatcheries in the north and south coast might have different management objectives leading to different operational strategies. In the north coastal watersheds where the coho populations have the highest risk of extinction, the focus of hatchery management is on controlling negative ecological and genetic interactions between natural and artificially propagated fish, the maintenance or enhancement of life history diversity, the use of local broodstocks to support rebuilding of native populations, and harvest systems that minimize the catch of wild fish. On the south coast, harvest augmentation accompanied by appropriate risk analysis to reduce negative impacts on wild populations and maintain historical spawning distributions is emphasized. Other landscape level factors that might shift priorities in hatchery management include long-term climate regimes, changes in habitat in response to land use, and large-scale natural disasters.

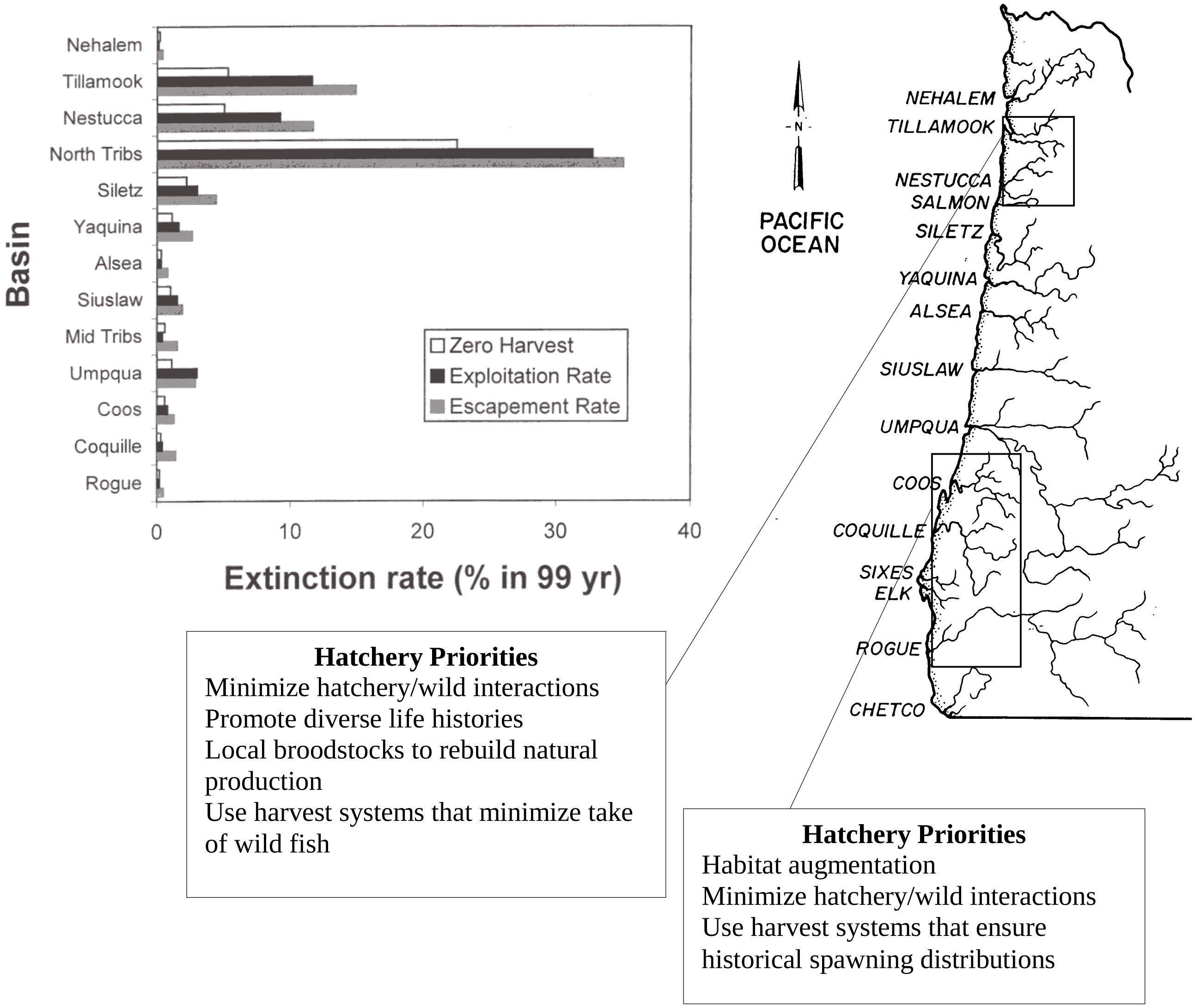


Figure 4: Estimates of risks of extinction of coastal coho salmon (ODFW and NMFS 1998). Exploitation rate refers to management strategies in Amendment 13. Escapement rate refers to management of a specific number of returning spawners under Amendment 11. Insets suggest priorities for artificial propagation in the designated areas. (Adapted from IMST 2000b)

We conclude that the hatchery-specific approach is not consistent with the recovery of listed salmonids and the goals of the Oregon Plan, and we believe that ODFW should shift the management of its hatcheries closer to the landscape perspective. It appears that efforts to begin the process of shifting hatchery management to a landscape perspective are underway within the Department. The IMST was shown several ODFW documents, including draft Hatchery and Genetic Management Plans that appear to be steps in the right direction. These efforts need to be conducted within the framework of an overarching policy and statewide guidelines. Background information and guidelines for implementing the landscape perspective are located in the answer to science question 2.

Alternative Approaches to Broodstock Management

We have described two generalized approaches to the management of Oregon's hatcheries, the hatchery-specific and the landscape approaches. The latter was judged more consistent with the goals of the Oregon Plan. Within the landscape approach, there are two generalized ways that hatcheries can manage their broodstocks to achieve management objectives (Figure 5). Hatchery broodstocks may be managed to produce life history types that have no spatial or temporal overlap with wild salmonids in the same watershed or to produce fish that mimic the wild stock.

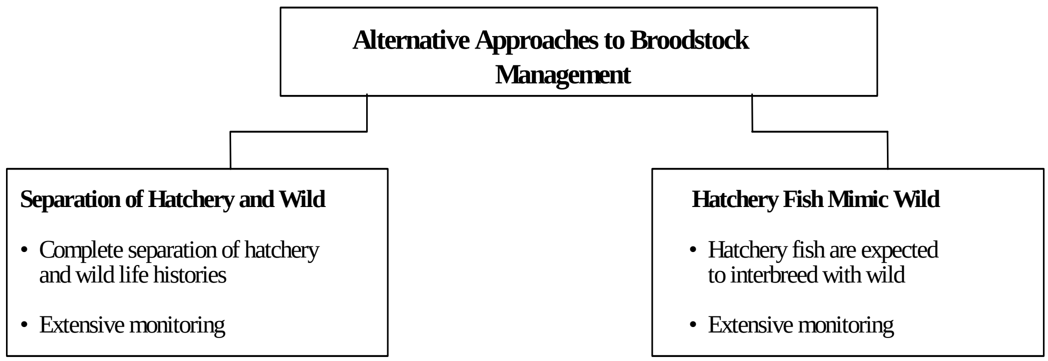


Figure 5: Two approaches to managing Oregon’s hatcheries and their broodstocks.

In the first approach, negative interactions with wild fish are eliminated by eliminating the chance for interaction. This approach is appropriate where the management purpose of the hatchery is harvest augmentation (NRC 1996). However, the National Research Council, in making that recommendation, recognized that complete separation may be hard to achieve, resulting in the possibility of competition or predation among juveniles and overharvest of wild fish in mixed stock fisheries. It is possible to augment a fishery by using a hatchery broodstock whose life history is different from the native population in a watershed. This is likely to contribute to the fishery goals of the Oregon Plan, but it will not directly contribute to wild fish recovery or ESA delisting goals of the Oregon Plan. Furthermore, if the separation is not complete, it could negatively impact the native population and reduce progress towards the goals of the Oregon Plan. Hatcheries that employ the separation approach require careful monitoring to assess any interactions, especially on the spawning grounds.

When the objective of a hatchery is to prevent extinction of a stock or to enhance the recovery of a depleted wild population (i.e., supplementation), another approach to management of the broodstock is appropriate. The broodstock should be managed so the artificially propagated fish are similar genetically and mimic the wild stock the hatchery is attempting to rebuild. This goal is also difficult to attain. In fact, some participants at a recent workshop voiced doubts that it could be accomplished. Some of the difficulties are described in the IMST's report on the workshop on Conservation Hatcheries and Supplementation (IMST 2000a). Similar to the separation approach, the attempt to mimic the wild population requires extensive monitoring.

Purposes and Policies Guiding Oregon's Current Hatchery Program

Unfortunately, there is no comprehensive policy or overarching set of policies that governs the management of Oregon's artificial propagation program. Consequently, the policies, Administrative Rules, and management guidelines are not necessarily consistent with one another or with the goals of the Oregon Plan. We have listed the relevant policies found in an assortment of documents in Appendix B.

Artificial propagation, which is the largest single program devoted to fish management, needs a coherent set of goals, policies and administrative rules. Policies related to artificial propagation must recognize the need for integration between hatchery operations and the management purposes those operations serve. Policies should clearly assign responsibility for integration and for monitoring of hatchery performance relative to the specific management purposes they support.

The following example shows why there is a need for explicit and accountable linkage between artificial propagation and management programs that intend to benefit from hatcheries. Oregon operates 13 hatcheries whose primary purpose is to augment harvest (ODFW 1999b). In addition, hatchery programs primarily operated for other purposes (mitigation and restoration) are usually expected to contribute to the fisheries. Hatchery programs may provide the majority of fishing opportunity in some cases. For example, in 1994, 81% of the commercial salmon landings below Bonneville Dam in the Columbia River were caught in the Youngs Bay terminal fishery. That fishery primarily harvests hatchery coho and fall chinook (ODFW and WDFW 1995).

Generally, a pair of salmon spawning in the wild produces fewer offspring than a pair of salmon spawned (same number of eggs) in the hatchery (see Science Question 1, Table 1). This enables the hatchery population to withstand higher harvest rates than the wild population in the same river (Lichatowich and McIntyre 1987). Hatchery stocks that can withstand high harvest rates obviously benefit the fishery. However, if salmon managers permit high harvest rates on hatchery stocks when they are mixed with wild stocks of the same species, it can lead to the overharvest of the wild populations (Wright 1981). This scenario describes what happened to wild coho in the 1960s and 1970s, which contributed to the listing of coastal stocks and the potential listing stocks in the lower Columbia River under the federal Endangered Species Act (Flagg et al. 1995; Lichatowich 1997).

Developing a comprehensive hatchery policy is not as daunting a task as it may appear at first. The IMST recognizes, however that the current workload of the Department makes any additional task difficult. Many of the elements of a comprehensive policy already exist, scattered among several documents. The Department might consider a three step approach to the development of a comprehensive policy: 1) assemble all the existing hatchery policies; 2) examine those policies looking for contradictions and gaps; and, 3) remove the inconsistencies and write new policies to fill the gaps.

Are Hatchery and Wild Fish Different?

In recent decades, two questions regarding hatcheries have been asked repeatedly. Are hatchery and wild fish different, and if they are, do the differences result in negative effects on wild fish or on progress towards meeting management objectives? These questions were given to the attendees of a workshop on conservation hatcheries and supplementation held in Portland, Oregon, June 19 to 21, 2000. Because they are important and frequently asked questions, we reprint the entire response of the workshop here.

> "Two additional questions were included on the agenda of the workshop. These questions were discussed by participants in the three work groups, and during the plenary sessions. Some very general answers to these questions were given. The workshop participants considered these questions to address important issues to consider when using supplementation to conserve salmonids, but they were not able to assemble the necessary information to adequately answer the questions in the available time.
>
> *Question 1. 'Are hatchery and wild salmonids different in ways that are important to the design and implementation of supplementation projects?'*
>
> The initial answer to this question is, yes, there are differences between salmonids reared in the wild, and salmonids reared in hatcheries, but similarities remain. Differences and similarities may appear in physical attributes, genetic structure and gene expression, behavior, and or life strategies. However, the implications of these differences to the design and implementation of supplementation projects depends on the individual combinations of circumstances. Little information is known, requiring further research and/or monitoring of supplementation efforts.
>
> *Question 2. 'What are the effects of hatchery management and hatchery fish on wild salmonids?'*
>
> The initial answer to the second question addressed by all of the groups was that it depends on the circumstances. Some effects of traditional production hatchery management on hatchery fish, and the success of these fish in the wild, are known but many are not. Interactions with and influences on wild fish are generally not known, and observations vary with each case documented and at different geographical scales. Again, caution is recommended when general statements or answers are given. There are many aspects of genetic and ecological interactions between hatchery and wild salmonids about which there are little or no data. Implementation of supplementation should not be carried out until a sound scientific basis for procedures has been established. Areas of potential interactions or interactions of concern need to be identified and monitored as part of a supplementation project to prevent unintentional or unwanted effects within the supplemented population and to other populations, and to develop better knowledge and understanding of the effects which occur.

Conclusions

In both cases, there was agreement that the answers to these two questions depend on the circumstances. The answers would involve a rather detailed analysis of how hatchery and wild salmonids differ, how they affect one another, and when these factors might be important. This analysis could be conducted through research on supplementation at different scales." (IMST 2000a)

Our work in completing this report leads us to accept this conclusion of the scientific workshop regarding the differences between hatchery and wild fish from the workshop. However, we feel additional work on this matter remains to be done by the IMST

SCIENCE QUESTIONS

Two science questions are the foundation for the IMST's assessment of the use of artificial propagation in support of the Oregon Plan for Salmon and Watersheds.

1. What is the scientific basis for artificial propagation of anadromous salmonids?

2. Scientifically, how could Oregon's artificial propagation program be consistent with the recovery of wild salmonids in Oregon?

Science Question 1: What is the scientific basis for the artificial propagation of anadromous salmonids?

To answer the first science question, we evaluate the scientific basis for the key management assumptions associated with artificial propagation. The IMST examined several assumptions and discussed them with staff at ODFW in a public meeting on October 11, 2000. We then selected five assumptions that appear to be the conceptual foundation for artificial propagation. Four of those assumptions deal with the use of hatcheries in salmon management (assumptions 1, 2, 4, and 5) and one (assumption 3) deals with domestication. The five assumptions are:

1. Higher survival in the egg to smolt life stage in the hatchery results in a net increase in adult ocean recruits. Ocean recruits are the total of hatchery and wild fish.
2. Hatchery production can mitigate for wild fish production lost due to human activities in a watershed.
3. Hatchery operations retain behavioral, physiological, and genetic characteristics that facilitate returns of hatchery adults.
4. Interactions between hatchery and wild fish do not negatively impact the survival of wild fish.
5. Augmentation and supplementation hatcheries add to existing natural production without replacing it.

Assumption 1: Higher survival in the egg to smolt life stage in the hatchery results in a net increase in adult ocean recruits. Ocean recruits are the total of hatchery and wild fish.

Historical Background

This assumption addresses a core justification for the use of artificial propagation in Pacific salmon management. It is fundamental to the success of the hatchery program and it was one of the first assumptions that justified human intervention in the reproduction of salmon, a brief history of its use is in order. During the salmon's early life stages (egg to fry and fry to smolt), the protected environment of the hatchery is expected to enhance survival rates compared to survival rates of eggs or fry in the natural environment of the river. The general expectation is that this early advantage in survival will carry through to the adult stage and the hatcheries will increase the number of ocean recruits. This expectation is valid for augmentation hatcheries, but it may not apply to supplementation programs.

Supplementation or the attempt to rebuild natural production using artificial propagation, is generally implemented during periods of low abundance and less than full seeding of the habitat. Under those conditions, the artificially propagated fish need to do more than add more ocean recruits. They must survive and return to the stream to spawn naturally in greater numbers than could be obtained through natural production alone. If the supplemented fish returned fewer adults than could be obtained with natural propagation, it would undermine the economic and biological justification for artificial propagation.

Early fish culturists recognized that the large salmon runs into the rivers carried a huge surplus of eggs, more eggs than were needed to replace the parent run. The difference between the reproductive potential (number of eggs) and the size of the subsequent adult runs was attributed to the high mortality of eggs deposited in the gravel. Many fish managers shared the belief that nature was a hostile place and that with cultivation by humans higher levels of productivity would be attained (Bottom 1997). Many early salmon managers assumed that nature was wasteful and that human intervention in salmon reproduction was necessary to increase productivity. The following statements from the older literature illustrate that belief:

> *It is imperative, therefore, that some means be adopted to counteract the depletions arising from this source (habitat degradation); but the most important reason for the artificial propagation is the fact that the natural method is extremely wasteful, which is not true of the artificial method." (Smith 1919 p. 6)*

> *"In my opinion, if the salmon runs of this state are to be maintained and increased, it is going to be necessary to constantly construct new hatcheries. The much greater effectiveness of hatchery operations, as compared with natural propagation, has in my judgement been so effectively proven as to no longer permit discussions among those who are acquainted with the situation." (WDFG 1921 p. 17)*

> *"There can be no doubt in the mind of anyone who has studied the question, that the future prosperity of our salmon fisheries depend largely upon artificial propagation... I am convinced that not more than 10 percent of the ova spawned in the open streams are hatched, owing principally to spawn-eating fish that prey on them... while from artificial propagation 90 percent are successfully hatched. What more need be said in favor of fish culture?" (Oregon State Fish and Game Protector 1896 p. 33)*

The concept of carrying capacity in the river, estuary, or ocean did not appear to concern fish culturists in the late 19th and early 20th century (Lichatowich et al. 1996). They believed that predation causing high egg-to-fry mortality could be circumvented by incubating the eggs in a hatchery and releasing the sac fry into the river, and that this would increase adult production. The more eggs that were incubated the greater the adult runs. This naturally led to the common practice (common until the 1940s) of blocking streams and collecting all the eggs from the adult salmon in the run (Wallis 1963a). It is now generally agreed that these early practices produced few adult salmon (CBFWA 1988) and led to declines in some streams (e.g., Wallis 1963a). Following their review of the historical record, Flagg et al. (1995) concluded that the overstocking (exceeding the carrying capacity) of streams with fry contributed to the depletion of naturally produced coho salmon in tributaries to the lower Columbia River. Today, salmon managers and management policies generally recognize that watersheds have limited capacity to produce salmon of hatchery or wild origin (see OAR 635-007-0825 1997 in Appendix B, page 88); however, carrying capacity remains difficult to define. Even though management recognizes that watersheds have limited carrying capacity, it is usually not taken into account when setting hatchery production targets. Exceptions are the newer programs such as the northeast Oregon supplementation programs (October 11, 2000, public meeting with ODFW staff[5]).

Scientific Test of Assumption 1

Higher survival in the egg to smolt life stage in the hatchery results in a net increase in adult ocean recruits. Ocean recruits are the total of hatchery and wild fish. We partitioned this assumption into two parts:

a. Survival rate from egg to smolt stage (or release stage) in the hatchery is higher than the survival rate through the same stages in the wild.
b. A higher survival rate during the egg to smolt stage translates to an overall increase in the number of ocean recruits sufficient to achieve the objectives of the program.

The quantitative data to evaluate assumption 1 have been captured in our report in five tables. Table 1 contains information relevant to both assumption 1a and assumption 1b. Table 1 was an attempt by ODFW to identify the survival rates through various life stages through the entire life cycle of coho salmon; therefore, it is relevant to both sub-assumptions 1a and 1b. The strength of Table 1 is that it compares survival rates of wild fish to various types of artificial propagation through their entire life cycles. The weakness of Table 1 is that it is a composite of different studies in different watersheds at different times, and it does not reflect the effect of changing ocean conditions, which would influence the smolt to adult portion of the table.

Assumption 1a: Survival rate from egg to smolt stage (or release stage) in the hatchery is higher than the survival rate through the same stages in the wild.

Sandercock (1991) reviewed the literature and reported egg to smolt survival rates for naturally spawned coho salmon that ranged from 0.7 to 9.65 %. The information he presented suggests that the average survival rate was probably in the 1 to 2 % range, which is consistent with Bradford's (1995) more recent review. ODFW reported 3% average egg to smolt survival

[5] Minutes from October 11, 2000 public meeting available from Oregon Watershed Enhancement Board Office (contact Bev Goodreau (503) 986-0187)

rate for five streams in Washington and Oregon (ODFW 1982, Table 1). The egg to smolt survival rate for coho salmon in public hatchery programs was 79.7% (ODFW 1982, Table 1). Survival rates of coho salmon from egg to fingerling at selected Oregon hatcheries ranged from 71.2 to 90.7 % during the 1950s (Table 2). Current egg to fry survival rates of coho salmon at Big Creek, Cascade, and Sandy hatcheries ranged from 83.5 to 91.2%. Survival rates from fry to smolt at the same hatcheries ranged from 87.7 to 91.2% (Table 3). Survival of coho salmon at other hatcheries appeared to be similar to those reported in Table 3. Clearly, for coho, there is an increase in the rate of survival from egg to smolt in the protected environment of the hatchery compared to egg to smolt survival rates for wild fish. Survival to the smolt stage of artificially propagated fish diminishes with shorter periods in the hatchery. The rate of survival to the smolt stage for presmolts released at 200 fish/lb was 7.5% (Table 1). It should be noted the smolt to adult survivals in Table 1 do not show survival during extremely poor ocean conditions, such as those experienced in the 1990s.

Table 1: Coho salmon survival under alternative incubation and rearing programs. [a,b]

TYPE	Eggs	Percent to Hatch	No. Hatched	Percent Fry to Smolt	No. Smolts	Percent Smolt to Adult	No. Adults	Percent Egg to Adult
Wild coho salmon natural spawning and rearing	2500[c]	3%[d] survival from egg to smolt. Average for 5 streams in Oregon and Washington (Wallis 196[8]; Moring & Lantz 1975)			75	7.5% most optimistic estimate from Minter Cr. (Salo & Bayliff 1958)	6	0.2
Egg box incubation, released as unfed fry	2500	75-80% for eyed eggs; 48% for green eggs (Dave Heckeroth pers. comm.)	1875	5%[e] Same as unfed fry releases (McIsaac 1977; Rothfus et al. 1974) 10% Same as wild (Moring & Lantz 1975)	94 188	7.5% - Assumed same as wild Same as above	7 14	0.3 0.6
Public hatchery presmolt released at 200/lb	2500	87.4% Files from several ODFW hatcheries	2185	Range: 3-10% Assumed 7.5% (Hostick & McGie 1974; Salo & Bayliff 1958)	164	Same as above	12	0.5
Full term public hatchery yearling	2500	Same as above	2185	79.7% (Hublou & Jones 1970)	1741	2.53%[e] (Garrison & Rosentreter-Peterson 1979) 5.4%[e]	44 94	1.76 3.76

a. This table is reproduced from Table II.B-1. in ODFW 1982.

b. The survival data presented in this table do not reflect the effect of changing ocean conditions.

c. Estimated average fecundity for Oregon coho (Moring & Lantz 1975).

d. Freshwater survival is density dependent; high egg survival results in low fry to smolt survival. Therefore, freshwater survival is best expressed as egg to smolt survival.

e. Survival of egg-box fry would probably range from 5% to 10%. Average survival would likely be on the low end of this range since egg-box fry do not undergo the selection process [that] wild fish undergo in the gravel. As with wild fish, density would also be a factor. Where eggs from hatchery stocks are used, survival would probably be around 5%.

f. The range of data was 0.07-14.46% (average = 2.53% and average of yearly maximums = 5.4%). Since this table presents potential survival rates, the average of the yearly maximums is reasonable. The goal for hatchery smolt survival stated in the plan is 5.7%, which is similar to the value presented here.

Healey (1991) reviewed the literature on egg to fry/smolt survival of wild chinook salmon and reported data that ranged from 5 to 16%, with one study reporting no survival. In a more recent review, egg to smolt survival rates for stream type chinook was 6.4% and for ocean type 8.6% (Bradford 1995). Recent survival rates of fall chinook at Big Creek and Bonneville hatcheries ranged from 86.8 to 91.3% (egg to fry) and 93.4 to 98.1% (fry to smolt) (Table 3). The data support the assumption that the hatchery environment gives a survival advantage to chinook salmon compared to the survival of naturally produced fish.

There have been few cases where the comparative survival rates of hatchery and wild fish in the same watershed have been determined. The spring chinook in the Warm Springs River (tributary to the Deschutes River) is an exception. Waples (1991) reported survival rates from egg to smolt of wild and hatchery spring chinook in the Warm Springs River (tributary to the Deschutes River) as 4.1% (wild) and 61% (hatchery).

Table 2: Percent survival of coho salmon from egg to fingerling at selected Oregon hatcheries.[a,b]

Hatchery	Brood Years	Percent Egg to Fry Survival	Source
Alsea	1949-1959	74.4	Wallis 1963a
Siletz	1949-1959	71.2	Wallis 1963b
Trask	1949-1959	80.4	Wallis 1963c
Klaskanine	1949-1959	82.3	Wallis 1963d
Big Creek	1949-1959	77.4	Wallis 1963e
Coos	1949-1958	77.8	Wallis 1961
Sandy	1951-1959	90.7	Wallis 1966

[a] Wallis reported these data as rearing losses, which we converted to survival rates by subtracting from 100.
[b] The survival data presented in this table do not reflect the effect of changing ocean conditions.

Table 3: Egg to fry and fry to smolt survival rates at selected hatcheries in recent years (Source ODFW and USFWS 1996).[a]

Species	Egg to fry survival	Fry to smolt survival	Hatchery
Fall chinook	90.2%	98.1%	Big Creek
Coho	83.5%	89.1%	Big Creek
Winter steelhead	84.8%	87.0%	Big Creek
Tule fall chinook	91.3%	98.0%	Bonneville
Up river bright fall chinook	86.8%	93.4%	Bonneville
Coho	87.5%	91.2%	Cascade
Winter steelhead	88.2%	87.2%	Clackamas
Wallowa summer steelhead	92.0%	89.0%	Irrigon
Imnaha summer steelhead	90.0%	90.9%	Irrigon
Coho	91.2%	87.7%	Sandy

[a] The survival data presented in this table do not reflect the effect of changing ocean conditions.

The STEP program utilizes hatchboxes to incubate eggs and release emergent fry into the stream. Survival rates of incubated eggs are generally high, ranging from 80 to 90% (Table 4).

Subsequent survival to the smolt stage following release from the hatchbox is estimated at 5% from studies of the survival of unfed fry plants (Table 1). However, the actual rate of survival to the adult of salmon fry released from hatchboxes has not been determined.

Table 4: Mean percent survival of egg to emergent fry for streamside incubators in Oregon, all river systems combined. (Source: Smith et al. 1983).

	Brood Year		
Species	1982-83	1983-84	1984-85
Spring chinook salmon	88.5%	27.8%	73.5%
Fall chinook salmon	(a)	89.4%	79.3%
Coho salmon	(a)	78.0%	83.1%
Summer steelhead	(a)	85.6%	93.0%
Winter steelhead	(a)	89.5%	89.0%

[a] Not available

Based on our analysis, the IMST concludes that the hatchery environment does give a survival advantage from the egg to smolt stage compared to survival for the same life stages for naturally produced fish.

<u>Assumption 1b: A higher survival rate during the egg to smolt stage translates to an overall increase in the number of adult ocean recruits sufficient to achieve the objectives of the program.</u>

There are different objectives and criteria by which success is judged for different kinds of hatchery programs. Therefore, we have structured this section by hatchery type.

Conventional Hatcheries (mitigation and augmentation)

Whether a hatchery's purpose is to augment a fishery or mitigate for lost habitat, survival from egg to smolt and smolt to ocean recruit should, in combination, be sufficient to achieve the specific management goals of the program.

Under assumption 1a, we showed that hatcheries increase the rate of survival from egg to smolt over that which can be obtained in the wild. However, artificially propagated salmon generally show lower survival rates after release from the hatchery than their wild counterparts. White et al. (1995) list 61 papers that discuss the possible morphological, physiological, and behavioral reasons for the poor performance of hatchery fish after they are released into the wild.

The smolt to adult survival rate for the same stock of spring chinook salmon in the Warm Springs River was 2.3% for the naturally spawned fish and 0.09% for the artificially propagated fish (Waples 1991). In the Burrishoole River, Ireland, the rate of survival from smolt to adult of Atlantic salmon from natural spawning was four times that of hatchery-reared fish (Piggins and Mills 1985). Seiler (1989) compared smolt to adult survival rates of coded-wire-tagged wild and hatchery coho salmon in the Chehalis River for the 1980-1983 brood years. Over those brood years, the rate of survival of hatchery smolts was lower than the rate of survival of wild smolts (2.45% compared to 4.48%). These data are summarized in Table 5. Coronado and Hilborn (1998) analyzed coded-wire-tag returns for coho and chinook salmon and steelhead from Alaska to California. They concluded that survival rates of wild salmon were generally higher than their hatchery counterparts. Chilcote (1999) showed that in Lower Columbia River coho salmon, smolt to adult survival rates fluctuated widely from year to year in both wild and hatchery fish. However, in most years since 1970, smolt to adult survival rates were lower for hatchery coho than for wild fish (see Figure 6).

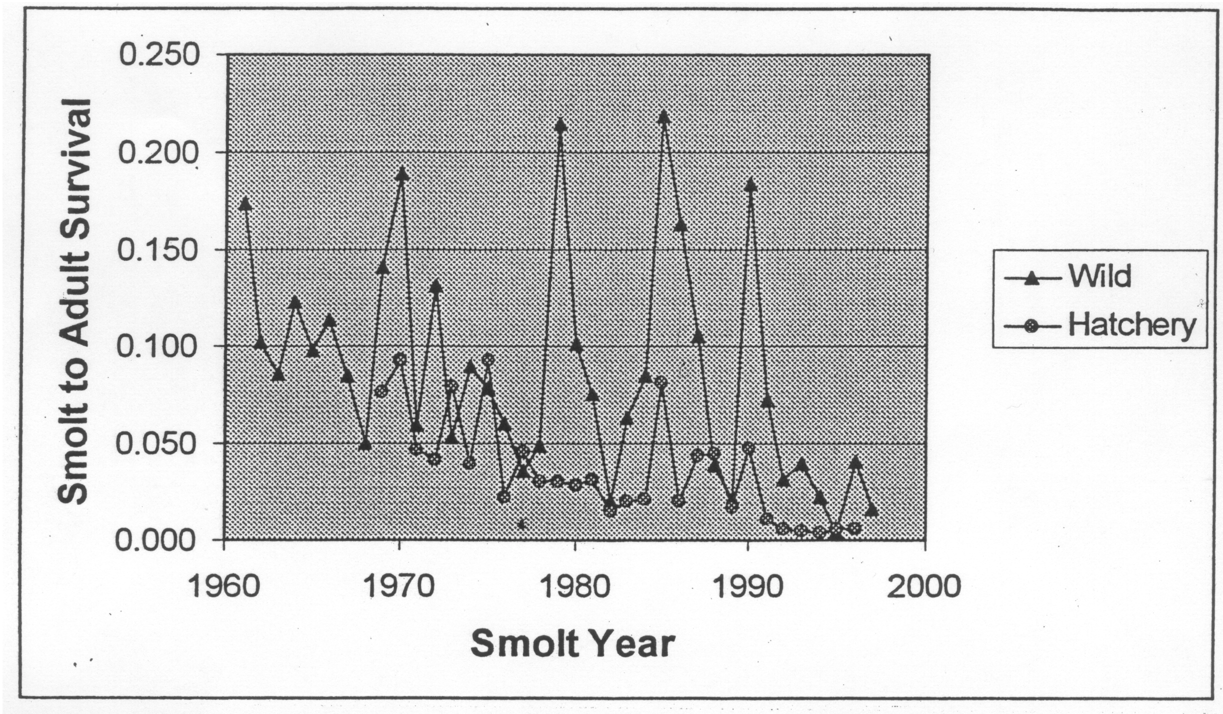


Figure 6: Comparison of smolt to adult survival rates for wild coho from the Clackamas basin and hatchery coho from the Lower Columbia Basin (Source: Chilcote 1999)

Table 5: Smolt to adult survival data for hatchery and wild salmonids.

Species	Basin	Smolt to Adult Survival		Source
		Hatchery	Wild	
Chinook salmon	Warm Springs River	0.09%	2.3%	Waples 1991
Atlantic salmon	Burrishoole River, Ireland	1.9%[a]	6.7%[a]	Piggins and Mills 1985
Coho	Grays Harbor Basin	2.45%	4.48%	Seiler 1989

[a]Average survival from data provided for 1970-1983

From the information presented here, we conclude that hatchery fish from augmentation and mitigation hatcheries generally survive at lower rates than wild fish after release from the hatchery. The lower rate of survival of artificially propagated salmon after release from the hatchery raises an important question. Is the higher rate of survival in the hatchery environment sufficient to overcome lower survival rates after release from the hatchery and produce a net higher ocean recruitment for the artificially propagated fish compared to wild fish? Table 1 shows that theoretically, for coho salmon, the higher egg to smolt survival rates in the hatchery do translate to higher net adult recruitment. However, Table 1 is a composite of survival data from different studies of different stocks and watersheds. It does not reflect survivals during poor ocean conditions. This question has to be answered on a program-by-program basis where the survival of hatchery and naturally produced fish in the same basin are monitored.

The IMST notes that the recent audit of ODFW's coastal and Willamette hatchery programs contained an evaluation category called "adult return goals." Only nine out of 51 programs were able to provide information on the adult returns. Information on smolts released and number of eggs collected were available from most of the programs. We find the omission of adult returns puzzling because it appears that data on survival to the adult is available for more than nine programs. Since adult returns including contribution to fisheries are directly related to management objectives and egg takes and smolt releases are directly related to hatchery operations, it suggests a disconnect between hatchery operations and the management programs and objectives they serve. The IMST concludes that either hatchery monitoring or the linkage between hatchery operations and management objectives or possibly both are inadequate.

Supplementation

As stated in the definition of supplementation (page 10), its purpose is to increase natural production. Because the objective is to increase the production of depleted populations, supplementation programs can make a direct contribution to the goals of the Oregon Plan. The goal of increasing natural production means returning adults of hatchery origin are expected to spawn with naturally produced fish. It also means that evaluation of supplementation programs uses different criteria than conventional hatchery programs. For example, success for an augmentation hatchery can be measured as an increase in ocean recruits, depending on the specific management objective. Success in a supplementation program is an increase in natural production, meaning the artificially propagated salmon return as adults to the natural spawning area, successfully spawn and produce progeny that survive and subsequently increase the number of naturally produced adults. This requires a longer term and more complicated monitoring program. Several large supplementation programs are currently being subjected to intensive monitoring and evaluation to test the premise that supplementation hatcheries can increase natural production.

Since wild populations are generally supplemented with artificially propagated fish (because they are in a depleted condition and the stream is not fully seeded) it is important that supplementation programs demonstrate that the artificially propagated fish have a survival advantage over wild fish to maturity (through the entire life cycle). Supplementation programs raise other concerns regarding genetic or ecological consequences of interactions between hatchery and wild fish. Those concerns are addressed in assumptions 3 and 4.

In Oregon, the spring chinook and summer steelhead supplementation programs in the Imnaha River have been in operation long enough to produce information relevant to this assumption. One way to evaluate the survival of artificially propagated fish compared to the survival of wild fish through the life cycle is through a comparison of the progeny to parent ratios (Figures 7, 8 and 9). The adult progeny to parent ratio[6] gives the number of adult progeny for each fish in the

[6] The conventional way of expressing this is *progeny to parent ratio*; however, we are using the term *adult progeny to parent ratio* to be clear that this reflects the number of adult progeny for each fish in the parent generation.

parent generation. An adult progeny to parent ratio of one means the number of progeny returning as adults equals the number of parents, i.e., the parent generation just replaces itself. Ratios less than one mean that the population is not replacing itself and is declining. Persistent ratios less than one can lead to extinction. Ratios greater than one mean the population is increasing.

For the spring chinook in the Imnaha River, the adult progeny to parent ratios (Figure 7) show that the early survival advantage of the hatchery rearing carries through to the adult spawners. For the hatchery stock, the ratios have been greater than one for all the brood years from 1982 to 1992 except 1990 - 1992. For naturally produced fish, the ratio has been below one every year since 1983 (Figure 7). The higher survival rates of artificially propagated fish boosted the spawning population to a higher level than would have been attained through natural production alone (Figure 8). While supplementation with artificially propagated fish has boosted the size of the spawning population, the adult progeny to parent ratios of naturally produced fish remain at one or below. The Imnaha River summer steelhead supplementation program shows an increase in the adult progeny to parent ratio for artificially propagated fish compared to naturally produced steelhead (Figure 9).

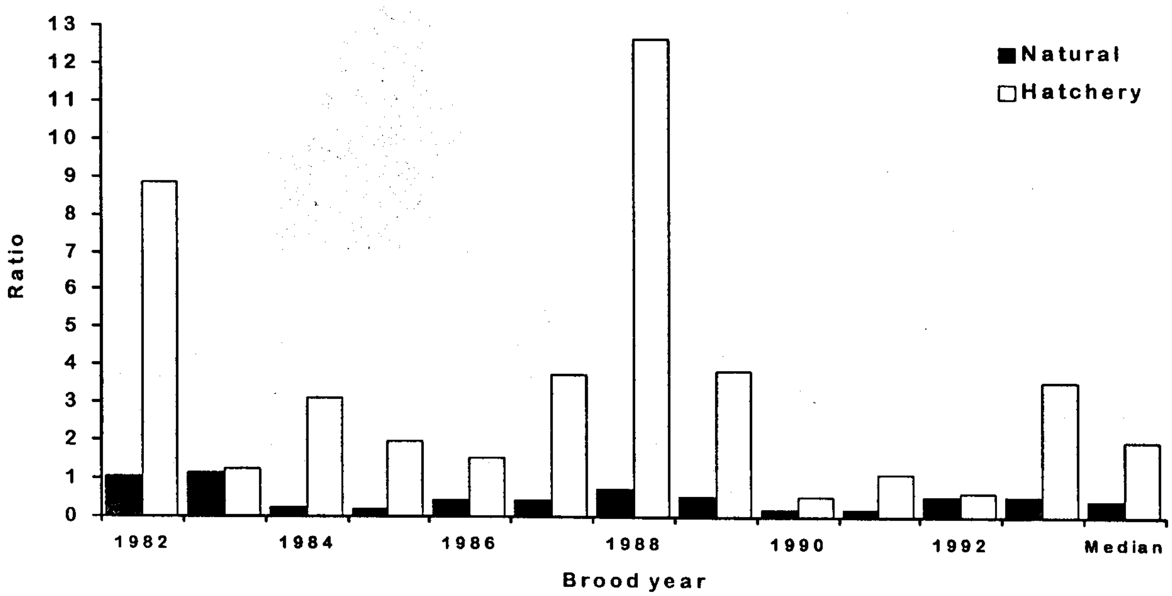


Figure 7:Adult progeny to parent ratios for natural and hatchery Imnaha River spring chinook salmon, brood years 1982-1992. (Source: Carmichael et al. 1998)

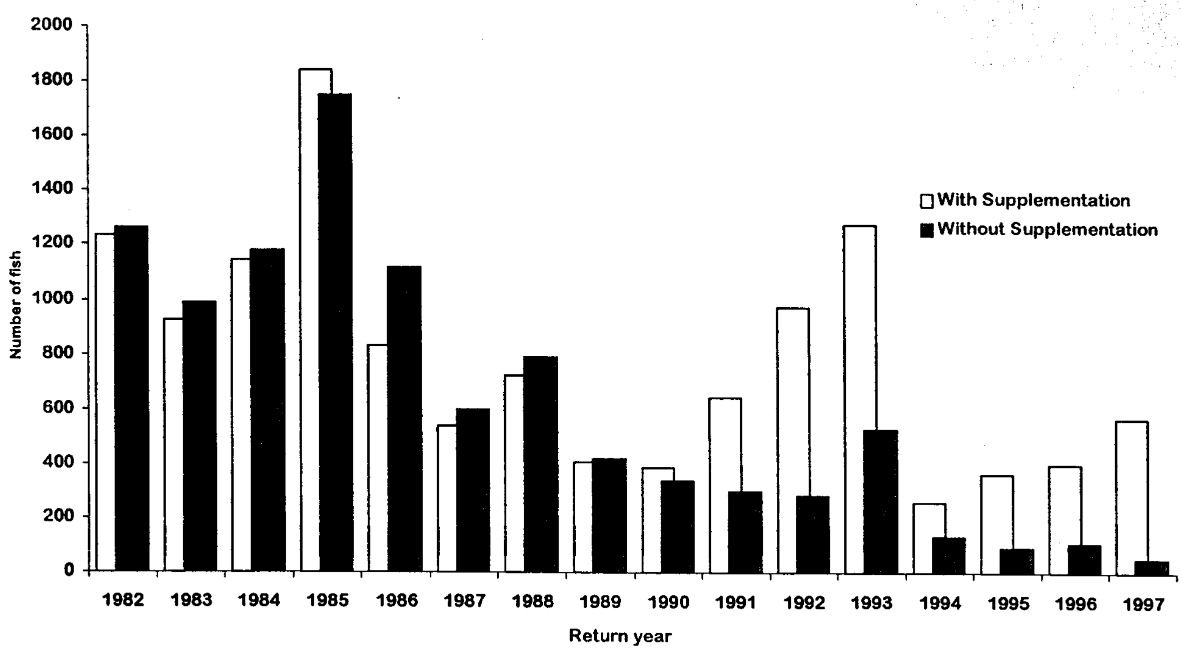


Figure 8: Comparison of actual number of natural spawners in the Imnaha River with estimated number of natural spawners assuming the hatchery program had not been in existence, return years 1982-1997. (Source: Carmichael et al. 1998)

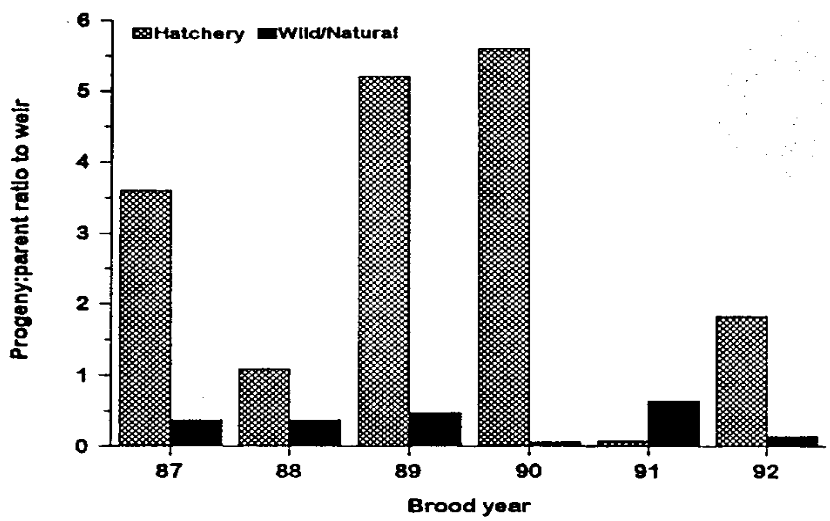


Figure 9: Adult progeny to parent ratios of steelhead in the Imnaha River. These ratios are based on the numbers of adults collected at the weir in Little Sheep Cr. These fish are either retained for hatchery broodstock or passed above the weir and allowed to spawn naturally. Progeny resulting from fish spawned in the hatchery have their adipose fin excised. This fin-clip allows hatchery and natural fish to be distinguishable. (Source: Whitesel et al. 1998)

The steelhead supplementation program in the Umatilla Basin provides another example of a supplementation program where the early survival advantage of hatchery rearing carries through the entire life cycle. The mean adult-to-adult return rate for hatchery-reared steelhead was significantly higher than the adult-to-adult return rate for naturally spawning fish for all brood years between 1985 and 1992, with an average ratio of 2.86 for hatchery-reared fish and an average ratio of 0.60 for naturally spawning fish (Phillips et al. In press). Like in the Imnaha program, supplementation with artificially propagated fish has boosted the size of the spawning population, but in most years, the adult-to-adult return rates of naturally produced fish have remained below one.

An increase in the total number of spawners following supplementation as shown in these examples supports assumption 1b. However, support for the assumption should not be confused with evidence of supplementation success. The number of spawners increased following supplementation due to the survival advantage of the hatchery environment in the early life stages, but for the Imnaha spring chinook, the number of natural spawners did not show an increase and continued to decline (Figure 8). The increase in spawners did not translate to an increase in natural production, which is the objective of supplementation.

Most supplementation programs are new and have not been fully evaluated. This led the IMST to this interim conclusion following a workshop on supplementation and conservation hatcheries (IMST 2000a).

> "Supplementation may be a useful strategy as part of a comprehensive program of species recovery. We note that it has not been extensively tested, therefore needs to be used cautiously and with a strong component of monitoring and adaptive management to ensure it is not harmful to recovery of wild stocks, and that it is achieving intended goals."

Based on our completion of this report on artificial propagation we now adopt this as a final conclusion.

Given this conclusion and the results of ongoing supplementation projects shown here, the IMST concludes that any new supplementation programs should be initiated with a high degree of caution and with adequate monitoring.

STEP Hatchboxes

ODFW recently conducted a review of the STEP hatchbox program for coho salmon in the Siuslaw Basin. The program was evaluated for its effectiveness in rehabilitating wild coho salmon populations (Solazzi et al. 1999). Although the survival of the hatchbox fry was not monitored in the study, the researchers found no difference in adult abundance or in juvenile density between the treatment and the control streams. In this case, the higher egg to fry survival rate that was provided by the protective environment of the hatchbox did not translate into increased adult production. The authors concluded that factors other than egg to fry survival rates were limiting adult production (Solazzi et al. 1999). The survival from fry to smolt and smolt to adult of juvenile salmonids released from STEP hatchboxes has not been determined (public meeting with ODFW staff, October 11, 2000,[7]).

The IMST concludes that there is an extremely limited basis on which to judge whether the STEP hatchbox program provides a net increase in ocean recruits. While the program may provide valuable opportunities for public involvement, monitoring and evaluation of the hatchbox program are inadequate to determine if it is having a negative impact on wild fish populations.

Genetics

So far, in this discussion of enhanced survival in the hatchery, we have focused on the change of numbers strictly from a demographic or accounting perspective. Behind the numerical increase in juveniles and adult salmon and steelhead that hatcheries can produce is a potential genetic problem that ODFW staff have called to our attention. The problem emerges when juvenile and adult fish from a small group of brood fish in the hatchery experience a large increase in survival relative to the wild population. When this occurs and the hatchery fish mix with wild fish and spawn in the river (this is expected in supplementation programs), it creates the potential for two genetic problems. It can decrease the effective population size because of an increase in inbreeding and a decrease in genetic diversity. The second problem is a potential increase in genetic load (personal communication, Kathryn Kostow, ODFW January 3, 2001).

Assumption 2: Hatchery production can mitigate for wild fish production lost due to human activities in a watershed.

Mitigation is an important purpose for artificial propagation in Oregon. Of the 34 hatcheries in Oregon, 17 of them have mitigation as their primary purpose. Clearly, the ability of hatcheries to mitigate the loss of natural production is important to Oregon's salmon management program. In highly developed watersheds like the Columbia, mitigation hatcheries provide nearly all the adult salmon (80%) that return to the river. However, mitigation success should not be measured by the percentage of hatchery fish in the run, but rather by the size of the hatchery population relative to the historical size of the population the hatchery was intended to replace. From the regional perspective, three scientific panels have raised questions regarding the ability of hatcheries to compensate for lost natural production due to overharvest or habitat loss or degradation (NFHRP 1995; ISG 1996; NRC 1996).

The apparent agreement among panels on the outcome of mitigation programs raises the question: what is the record of mitigation programs in Oregon? ODFW staff provided information showing that the mitigation program for Lost Creek, Applegate and the partially completed Elk Creek dams in Rogue River has met its mitigation targets in terms of returning adult fish (memorandum from Mike Evenson to Trent Stickell, ODFW, December 28, 2000). In addition, ODFW provided data for adult returns to Round Butte, Bonneville, McKenzie, and South Santiam hatcheries (Table 6, memorandum from Mark Lewis to Trent Stickell, ODFW, January 8, 2001). Two thirds of the programs that measured adult returns met their goals.

---

[7] Minutes from October 11, 2000 public meeting available from Oregon Watershed Enhancement Board Office (contact Bev Goodreau (503) 986-0187)

Additional data on juvenile release goals were also included in this memo, but are not included here. Other information provided by ODFW for the mitigation program for U. S. Corps of Engineers dams on the Willamette River showed the hatcheries were generally releasing the numbers of juvenile salmon specified in the mitigation contracts (Memorandum from George Nandor to Trent Stickell, ODFW, December 29, 2000). For the reasons discussed under assumption 1, we cannot assume that the release of a specified number or pounds of juvenile salmon or steelhead automatically meet the management intent of mitigation, i.e., to maintain the supply of adult fish to the ocean or river fisheries.

Table 6: Adult returns and goals for mitigation programs (from memorandum from Mark Lewis to Trent Stickell, ODFW, January 8, 2001).

Hatchery	**Species**	**Adult Run Years**	**Avg. Number of Adult Returns**	**Adult Return Goal**	**% of Goal**
Round Butte	Spring Chinook	1996-2000	815	1199	68.0%
Round Butte	Summer steelhead	1996-2000	3472	1800	192.9%
Bonneville	Fall Chinook	1995-1999	14,970	15,000	99.8%
McKenzie	Spring Chinook	1995-1999	1917	4061	47.2%
South Santiam	Spring Chinook	1995-1999	4423	1400	315.9%
South Santiam	Summer steelhead	1995-1999	4795	700	685.1%

Oregon's attempt to mitigate the loss of lost natural production has met with some success, as evidenced by the programs shown in Table 6 that have met adult return goals. However, because of the lack of comprehensive data, we cannot validate whether this assumption is generally true for Oregon’s hatchery mitigation programs. Many mitigation goals, especially the older programs, are artificial numbers that do not consider the productive capacity of the system. The IMST concludes that the mitigation program for Oregon, consisting of 17 hatcheries needs a comprehensive evaluation. Where mitigation contracts specify only the number of juveniles to be released from a mitigation hatchery, ODFW should renegotiate the contract and specify mitigation targets in more meaningful terms such as the number of adult recruits. These new targets should also consider the productive capacity of the system and changing ocean and climate conditions.

Assumption 3: Hatchery operations retain behavioral, physiological, and genetic characteristics that facilitate returns of hatchery adults.

The Oregon Plan identifies the loss of genetic adaptation of wild populations from interbreeding with genetically dissimilar, less fit hatchery fish as a factor for salmonid decline (Oregon Plan 1997). Interbreeding between hatchery and wild fish can alter a wild stock’s genetic makeup, leading to loss of fitness within local populations and loss of diversity among populations. Whether interbreeding negatively affects wild salmonids and the magnitude of any effects will depend on the specific circumstances as discussed earlier in this report.

The conclusions of several independent hatchery reviews have stressed the importance of maintaining behavioral, physiological, and genetic characteristics in hatchery populations. The

Independent Scientific Group (ISG 1996), the National Research Council (NRC 1996), and the Scientific Review Team (SRT 1998) all recognized the importance of maintaining these characteristics, recommending that hatchery populations be rigorously evaluated for evidence of artificial and/or domestication selection that could cause demographic, fish health, behavioral, physiological, and/or ecological problems.

To minimize artificial and domestication selection, there have been recommendations to utilize natural incubation and rearing conditions (SRT 1998; NWPPC 1999), follow established genetic breeding protocols (SRT 1998), maintain large breeding populations (SRT 1998; NWPPC 1999), utilize ambient natal stream waters and temperatures (SRT 1998; NWPPC 1999), and use local stock structure (NWPPC 1999). The full text of the conclusions and recommendations from these reports is in Appendix A.

<u>Assumption 3a: Domestication occurs in hatcheries but it is inconsequential.</u>

Domestication is defined as "the adaptation of organisms to an environment defined by humans" (Kohane and Parsons 1988), and examples in salmonids include earlier time of spawning, altered feeding behavior, and reduced predator avoidance. Both Busack and Currens (1995) and Flagg and Nash (1999) stated that, due to the increased egg to smolt survival in the hatchery, some domestication is inevitable. Kallio-Nyberg and Koljonen (1997) demonstrated that hatchery rearing could change the genetic composition of a salmon stock. Organisms subjected to an artificial environment can undergo rapid behavioral, genetic, and physiological change as they adapt to their surroundings. An experiment conducted by Reisenbichler and McIntyre (1977) demonstrated that genetic change could occur in the hatchery in as little as two generations. In another study, farmed Atlantic salmon were more aggressive and grew faster than salmon of wild origin, competing with the wild fish when released. However, because of these differences, the farmed salmon were also more prone to predation than wild fish (Einum and Fleming 1997).

The release of domesticated hatchery salmonids can be detrimental to the productivity of naturally produced salmon in a stream. For example, Nickelson et al. (1986) found that domesticated (early spawning) hatchery coho salmon fry stocked in Oregon coastal streams displaced the smaller, later-spawning wild coho fry. The returning adults from the hatchery stock spawned earlier than the wild fish. The eggs of these early spawners were subjected to higher flows than wild spawners, increasing egg mortality. Subsequently, streams stocked with the early spawning hatchery fish had lower juvenile coho salmon densities than unstocked streams. Early spawning may have been beneficial in the hatchery environment, but in the natural environment, it was detrimental.

Hatcheries have dual and possibly contradictory missions to produce fish that are fit in the hatchery environment (i.e., high egg survival and egg to smolt survival in the hatchery) and to produce fish that are fit in the environment outside the hatchery (i.e., overall survival consistent with the management goals). While a wild fish phenotype may not be best suited to survival inside the confines of a hatchery, participants of an IMST workshop on supplementation agreed that producing hatchery fish that mimicked wild fish is the best way to produce fish that will survive or spawn in the wild and have minimum impacts on wild populations (IMST 2000a). It may be difficult to maintain post-release survival (survival outside the hatchery) of fish while achieving high pre-release survival (survival within the hatchery). For example, participants at the IMST supplementation workshop noted that steelhead smolts survive best when they are released from hatcheries as yearlings; however, wild steelhead exhibit a wide range of life histories, spending two or more years in fresh water. Mimicking the natural life history variation in steelhead populations would reduce the benefit of the hatchery program (IMST 2000a). Based on evidence in the literature, Busack and Currens (1995) concluded that while some domestication may be beneficial when the fish are in the hatchery, at some point it begins to interfere with the second hatchery mission to produce fish that are fit outside the hatchery. If this occurs in hatchery salmonids, it would likely translate into decreased adult returns. More relevant to the mission of the Oregon Plan, if hatchery and wild fish interbreed, domesticated hatchery fish may have a negative impact on the wild fish population (see assumption 4) (Nickelson et al. 1986; Busack and Currens 1995; Einum and Fleming 1997) (see page 34)

The information presented above leads us to conclude that there is the potential for domestication to occur in any type of hatchery program. If genetic, physical, or behavioral change is substantial, it can result in decreased adult returns and have negative impacts on wild salmonid populations. When interactions between wild and hatchery fish are desired, all possible steps must be taken to minimize domestication. We conclude that domestication by the hatchery environment and the consequences of domestication to the post-release survival of the hatchery stock and post-release interactions with wild fish need to be monitored and incorporated into management decisions.

<u>Assumption 3b: Mate selection is not significant (i.e., there are no major detrimental consequences if hatchery personnel select the mates for salmon instead of salmon selecting their own mates).</u>

In wild fish populations, mate selection is not a random process. Fleming and Gross (1994) documented this in coho salmon, revealing that both natural and sexual selection occur. Natural selection occurs as females obtain and defend a territory. Sexual selection occurs as males compete for access to females. In the study conducted by Fleming and Gross, the opportunity for selection increased with increased competition. In the hatchery, mates are often randomly assigned, and the benefits of natural mate selection (i.e., the opportunities for natural selection and sexual selection) are lost (Kincaid 1993; NRC 1996).

Evidence from recent studies documents that mate selection does occur in the wild, and also documents the potential consequences that could occur if domesticated stocks are used in programs designed to integrate wild and hatchery production. Wild salmon have been shown to select wild mates over hatchery mates. In a study of wild and sea-ranched coho salmon, Fleming and Gross (1994) documented direct selection against hatchery males and females, which they attributed to behavioral differences. Berejikian et al. (1997) found that wild female coho salmon preferred to mate with wild males when given a choice between captively-reared hatchery fish and wild fish. In another study, Hard et al. (2000) documented morphological differences between captively reared and wild coho salmon. They noted an apparent mate selection by both captively reared and wild females in favor of wild males.

Selective breeding can occur both intentionally and unintentionally by hatchery personnel. Selectivity can occur during local broodstock selection through a biased sampling technique or by operational limits on the ability to collect and spawn fish (Busack and Currens 1995). The National Research Council (1996), in an independent hatchery review, concluded that intentional or unintentional selective breeding in the hatchery could lead to, among other effects, loss of adaptation to local conditions and loss of fitness. Kincaid (1993) reported that in the past, many hatchery programs collected eggs during only part of a run and jacks and individuals with other undesired phenotypes were excluded, changing the structure of the spawning population. The consequences of different selective pressures in the hatchery, including selective breeding, may result in divergence between hatchery and wild stocks.

If ODFW policies (Wild Fish Management Policy and Hatchery Fish Gene Resource Management Policy – see Appendix B) are carefully followed, problems of divergence between hatchery and wild stocks due to mate selection in the hatchery could be avoided. However, many broodstocks that may have been affected by past practices remain in existence. ODFW eliminated one such broodstock when they eliminated production of Fall Creek coho salmon that had, through the selection of early spawners in the hatchery, evolved earlier run timing than the wild stock in that system and was thought to be having a negative impact on wild coho smolt survival (ODFW 1997a).

In conclusion, we find that mate selection by hatchery personnel can have significant consequences. We cannot envision a process whereby hatchery staff could replicate natural mate selection. The consequences of violating this assumption, which are present in any artificial propagation program (programs that produce either intentional or unintentional interactions between hatchery and wild fish), will have to become a cost of the artificial propagation program. Mate selection may have major detrimental consequences on the characteristics of the hatchery population, post-release performance of hatchery fish, and the performance of the wild fish if the two interact.

Assumption 4: Interactions between hatchery and wild fish do not negatively impact the survival of wild fish

The conclusions of several independent hatchery reviews have stressed the importance assuring that interactions between hatchery and wild fish, which could include straying of hatchery adults to wild spawning areas or releases of hatchery juveniles that exceed the carrying capacity of the system, do not impact the survival of wild fish. The full text of these conclusions and recommendations is in Appendix A. In summary, the National Research Council (NRC 1996) and the Scientific Review Team (SRT 1998) both recommended that hatchery programs eliminate or avoid stock transfers to prevent unnatural patterns of straying by adult returns. Several documents also call for juvenile release factors that reduce effects on wild populations. These factors include targeting natural population parameters in size and timing when releasing hatchery fish (SRT 1998; NWPPC 1999) and considering carrying capacity, resource availability, and the residence needs of non-migrating members of the release population when releasing juveniles from the hatchery (NFHRP 1994; SRT 1998; NWPPC 1999). In addition to the conclusions of the independent hatchery reviews, the Oregon Plan (1997) lists competition with hatchery-reared fish as one of the factors for wild salmonid decline. These documents suggest that the consequences of interactions between hatchery and wild fish can be important risks to the recovery of wild salmonid populations and those risks need to be considered when assessing artificial propagation programs.

The assumption that interactions between hatchery and wild fish do not impact the survival of wild fish is implied in hatchery operations because it would be hard to justify an artificial propagation program if it negatively impacted the wild populations targeted for recovery. For example, a wild population could be negatively impacted if the artificially propagated fish replaced existing natural production (see Hilborn and Eggers 2000; Flagg et al. 1995; Chilcote 1998)

Hatchery fish interact with wild fish as adults on the spawning grounds or as juveniles after release from the hatchery. Depending on the goals of the specific type of artificial propagation program, different amounts of interaction between hatchery and wild fish are desired (and occur). Mitigation and harvest augmentation programs usually attempt to minimize interaction between wild and hatchery fish, but interactions can still occur through competition, predation, straying of hatchery adults onto the spawning grounds, and introduction of disease. Supplementation programs encourage interactions, at least during spawning, and therefore, most programs attempt to minimize differences between hatchery and wild fish. However, in all cases, hatchery programs operate under the assumption that any interactions that occur do not negatively impact the survival of wild stocks.

The Northwest Power Planning Council's Artificial Production Review (APR) (1999) stated that artificial production can lead to genetic changes in hatchery and wild populations, reducing the resiliency of the populations to environmental change, and Reisenbichler and McIntyre (1977) noted that the smaller the genetic difference between hatchery and wild fish, the smaller the impact on the wild population. The previous assumption addressed the potential domestication that can occur in the hatchery. In general, using local broodstock and minimizing domestication can reduce genetic, physiological, and behavioral differences between hatchery and wild fish and therefore reduce the impacts of interaction between the two.

We address this assumption by dividing it into two parts: 4a, dealing with interbreeding between hatchery and wild fish and 4b, dealing with the effects of juveniles released from the hatchery.

<u>Assumption 4a: The effects of hatchery fish interbreeding with wild fish are inconsequential.</u>

One potential interaction between hatchery and wild fish occurs when adult hatchery fish, whether through unintentional straying or by design (in supplementation programs), interbreed with wild fish. The latter will be discussed in detail under assumption 5 below. In the operation of other types of hatchery programs (mitigation and augmentation, in particular), it is assumed that any straying of hatchery fish onto wild spawning grounds does not negatively impact wild fish. However, some programs are designed to avoid such interactions between hatchery and wild fish by using broodstocks where life histories (i.e., time of spawning) do not overlap. In a recent report to the Northwest Power Planning Council, the Independent Scientific Advisory Board (ISAB) urged caution even when hatchery programs are designed to avoid overlap with the spawning times of wild fish. Without complete reproductive isolation of the hatchery fish, some interbreeding might occur between the hatchery fish that have undergone artificial selection and wild fish (ISAB 2000).

Based on a review of literature on straying (Quinn 1993) and the results of a study that recorded straying from Columbia River hatcheries (Quinn et al. 1991), it can be concluded that there will be some straying of hatchery fish to nearby wild populations as some straying occurs naturally in all populations. However, the extent of straying in hatchery salmonids varies with species, populations, abundances, among years, and with release strategies and stock origin. Quinn (1993) noted that some hatchery practices (e.g., time and place of release, as imprinting occurs most strongly during smolt transformation) can increase the amount of straying in a basin, but evidence is equivocal that standard hatchery practices increase the tendency of salmon to stray. In one study, hatchery rearing and release techniques did have a direct influence on the amount of straying in chinook salmon. From studies of tagged chinook salmon, Candy and Beacham (2000) found that less straying occurred when fish were well-imprinted, usually when reared and released in their natal stream. The tendency to stray increased if hatchery stocks were non-native or fish were released far from their rearing site. We conclude from this that management techniques exist that can be used to reduce, but not eliminate, the occurrence of straying by hatchery fish.

The genetic effects (positive or negative) of releasing hatchery fish into wild populations are not easily predictable, but unless the program is specifically designed to encourage interaction between hatchery and wild fish, interbreeding usually has negative effects on the wild population (Hindar et al. 1991). Based on the results of their study of breeding success in hatchery and wild coho salmon, Fleming and Gross (1993) concluded that when hatchery or captively reared fish that differ from wild fish stray onto natural spawning grounds they will have negative impacts on the wild population through introgression between hatchery and wild populations. Potential consequences of the introgression of genes from hatchery fish into the wild population include a reduction of fitness in wild fish, loss of genetic diversity both within and among populations, and consequently, reduced survival of the offspring of hatchery-wild matings. Following are several examples of the consequences of interactions between hatchery and wild fish reported in the literature:

- A recent experiment documented the impact of hatchery fish on a wild population by quantifying much lower reproductive success in farmed salmon than in native salmon. The study showed that the lifetime reproductive success (adult to adult) of farmed Atlantic salmon spawning in a river was 16% that of native salmon. The authors concluded that invasions of farmed salmon into wild salmon populations have the potential to impact productivity, disrupt local adaptations, and reduce genetic diversity of the wild populations (Fleming et al. 2000).
- Wade (1987) described an example of loss of disease resistance in wild coho salmon in the Nehalem River system after the introduction of stocks from other basins. The native stock of coho salmon, resistant to *Ceratomyxa shasta*, exhibited only intermediate resistance after interbreeding with susceptible stocks of coho, released into the system from nearby basins.
- Hemmingsen et al. (1986) demonstrated that crosses between *Ceratomyxa*-resistant native Columbia River coho salmon and nonresistant coho from outside the basin produced progeny with intermediate resistance to the disease. Wade (1987) found a similar effect in summer steelhead. Both concluded that interbreeding between non-native stocks and native, resistant stocks could have major impacts on the survival of the wild populations because of increased susceptibility to *Ceratomyxa shasta*.

- Numerous studies have found captively reared hatchery fish to be competitively inferior to wild fish when selecting mates (Fleming and Gross 1994; Berejikian et al. 1997). Captively reared salmon, released as adults can exhibit all expected coho reproductive behaviors and can successfully reproduce, but they will be competitively inferior to wild fish (Berejikian et al. 1997). The authors attributed this advantage of wild fish to phenotypic effects, since the hatchery fish had been captive for only one generation.
- Reisenbichler and McIntyre (1977) found that after only two generations in the hatchery, there were genetic differences in growth and survival between hatchery-reared steelhead and the wild fish in the population from which they were derived.
- Another example of differences in the ability of offspring of hatchery and wild steelhead to survive in streams was observed by Leider et al. (1990). Hatchery steelhead in the Kalama River spawned earlier, and those earlier-emerging offspring appeared to have a competitive advantage and often displaced wild juveniles. These hatchery fish then exhibited lower survival rates than wild fish between subyearling and smolt stages and during marine residence. In this study, throughout most of their life cycle, naturally-spawned offspring of hatchery fish had lower survival rates than the wild stock in the same basin. This could have been due to genetic consequences of hatchery rearing (genetic drift, long-term broodstock selection, or adaptations to hatchery conditions).
- In another study, Chilcote et al. (1986) found that wild steelhead spawners were more likely to have surviving smolts than naturally spawning hatchery fish. But, hatchery spawners greatly outnumbered wild spawners in the basin and so composed the majority of outmigrating fish. There were reproductive differences between the hatchery and wild fish observed, probably due to genetic differences in spawning time and other factors.

Many of these negative impacts can be avoided by following the recommendation of Hindar et al. (1991) to restrict and/or monitor gene flow from hatchery to wild populations. Straying should not be considered an effect of hatcheries, but an effect of management practices. Therefore, revised hatchery practices can reduce these effects (Campton 1995).

As described earlier in the background section, hatchery broodstocks may be managed to produce fish whose life histories have no spatial or temporal overlap with wild salmonids in the same watershed, or broodstocks can mimic wild stocks in an attempt to encourage interactions between hatchery and wild fish to rebuild wild stocks. In the former approach, eliminating the chance for interaction between wild and hatchery fish eliminates negative effects on wild fish. For example, this approach is appropriate where the management purpose of the hatchery is harvest augmentation (NRC 1996). However, the National Research Council, in making that recommendation, recognized that complete separation of wild and hatchery fish may be difficult to achieve. If complete reproductive isolation between hatchery and wild fish is not achieved, the worst-case scenario of directionally selected hatchery fish interbreeding with wild fish might be realized (ISAB 2000). If foreign or directionally selected hatchery stocks are used to maintain separation between hatchery and wild fish, the separation must be complete or nearly complete to ensure that interbreeding between the stocks does not occur. Hatcheries that employ the separation approach will require careful monitoring. However, when the objective of a hatchery is to prevent extinction of a stock or to enhance the recovery of a depleted wild population, the broodstock should be managed so the hatchery fish mimic the wild stock that the artificial propagation program is attempting to rebuild. This goal is also difficult to attain. Some of the difficulties were described in a recent workshop on conservation hatcheries and supplementation

(IMST 2000a). Once again, extensive monitoring is required. The trade-offs and risks involved in choosing between mimicking wild stocks or maintaining separation must be assessed as part of a risk analysis for each hatchery program to prevent irreparable harm to wild stocks.

For many hatchery programs, interactions with and influences on wild fish are generally not known, and observations vary with each case documented and at different geographical scales. There are many aspects of genetic and ecological interactions between hatchery and wild salmonids about which there are little or no data. Artificial propagation programs should not be implemented until a sound scientific basis for procedures has been established. Areas of potential interactions or interactions of concern need to be identified and monitored as part of hatchery programs to prevent unintentional or unwanted effects within the wild population and to other populations, and to develop better knowledge and understanding of the effects which occur.

Assumption 4b: Juvenile fish released from the hatchery do not adversely affect the long-term survival of wild fish.

Another potential impact of hatchery operations on wild fish is the effect of juvenile hatchery fish released into the stream. Differences between hatchery and wild fish can lead to competition between the two, in some cases to the detriment of wild fish. While traditional artificial propagation programs (e.g., harvest augmentation, mitigation) have focused on separating hatchery and wild fish, the success of supplementation and conservation programs is based on interactions between wild and hatchery fish. However, in both types of programs, it would be counterproductive to management goals for hatchery fish to negatively impact the survival of wild fish. Therefore, juveniles should be released from the hatchery only after it is determined that releases will not exceed the carrying capacity of the stream or result in increased predation on, competition with, or disease introduction to wild fish.

There is an apparent conflict among various guidelines dealing with the release of juvenile fish from hatcheries. One guideline in the Oregon Administrative Rules (OARs) that is 16 years old addresses the effects that juvenile fish released from the hatchery may have on wild fish. Rule 635-007-0810 (1984) states that "salmon will be programmed for release at a size, a time of year, and in such a manner that their release will contribute to attainment of management goals, management plans, and accepted programs." These actions will occur if smolts are of a size and released at a time when they are expected to move directly to the ocean. Presmolts, fry, and adults may be released to supplement natural production and for rehabilitation. A more recent recommendation suggests that hatchery production should mimic natural populations in size of fish and timing of emigration (NWPPC 1999). The report also states that provision for the biological needs of juvenile salmon after release has been a consistent oversight in hatchery management. On the other hand, the National Marine Fisheries Service, in its Biological Opinion on Artificial Propagation Operations in the Columbia River Basin (NMFS 1999a), recommends releasing larger steelhead to minimize competition and predation with listed salmon. There is a conflict in the various recommendations/guidelines regarding the size and time of release of hatchery fish. The conflict may have to be resolved on a case-by-case basis and the policy for doing so should be included in an overarching hatchery policy.

Carrying Capacity and Competition

Whether hatchery programs are operated with the intention of integrating hatchery and wild populations or keeping them separate, releases of juvenile fish from hatcheries can impact wild fish if the carrying capacity at any point along their migration corridor, including the estuary or nearshore ocean, is exceeded. If carrying capacity is exceeded, the fish released from the hatchery are likely to be less successful, and they may negatively impact wild fish, decreasing the productivity of the system as a whole. Reisenbichler and McIntyre (1986) stated that competition between hatchery and wild juveniles could become excessive if too many fish are released (number of juveniles in the stream exceeds carrying capacity) or released fish do not disperse. Large releases of fish from one hatchery on a tributary may use all available habitat in the system, to the detriment of populations on other tributaries. During low productivity, a population bottleneck may occur in an area of the system through which all stocks must pass while migrating. Therefore, both the numbers of hatchery fish released and the timing of the release(s) are important considerations.

In a recent review, Flagg et al. (1995) noted that studies have documented that overstocking streams, can subject the wild population to excessive density dependent mortality, competition for habitat, and can displace smaller wild fish downstream. Some studies show that hatchery fish, if released when wild fish are present in a system, can alter wild salmonid behavior by displaying more aggression than wild fish, dominating preferred habitats (Peery and Bjornn 1996; McMichael et al. 1999), and increasing the rate of emigration of wild fish (Peery and Bjornn 1996). Stocking unsmolted fish increases the potential for interaction (Flagg et al. 1995; Peery and Bjornn 1996), and stocking unsmolted fish in excess of carrying capacity can subject wild fish populations to excessive mortality. Hillman and Mullan (1989) found that hatchery releases of age-0 chinook salmon "pulled" 38-78% of the wild chinook and 15-45% of wild age-0 steelhead from stream margins and downstream as the hatchery fish moved. The study demonstrates how hatchery releases could impact wild fish distribution and migration timing. The APR (NWPPC 1999) recommends that the carrying capacity of the stream be used to govern numbers and timing of releases.

The analysis of ocean carrying capacity relative to hatchery production is difficult. For example, six published studies looked into the question of ocean carrying capacity relative to the size of the Oregon hatchery program for coho salmon (Lichatowich 1993). Three of the studies concluded that smolt releases exceeded ocean carrying capacity (McCarl and Rettig 1983; McGie 1983; Emlen et al. 1990), and three of the studies concluded that smolt releases did not exceed carrying capacity (Clark and McCarl 1983; Nickelson and Lichatowich 1983; Nickelson 1986).

Predation

Juveniles released from the hatchery could impact wild fish of the same or other species by either preying on them directly or by influencing the behavior and distribution of the wild fish so that they are more susceptible to other predators. In one study, Hillman and Mullan (1989) found that predaceous rainbow trout concentrated on smaller wild salmon within a moving group of hatchery fish.

In some situations, however, hatchery fish can be more susceptible to predation than their wild counterparts. Maynard et al. (1995) noted that when pre-release survival is increased in the hatchery, it is often at the expense of post-release survival. Morphological and behavioral conditioning that occurs in the hatchery may make hatchery-released smolts more vulnerable to predation than wild fish. For example, large numbers of surface-oriented coho smolts released from Oregon Aqua-Foods were eaten by common murres and gulls (Bayer 1986), probably because these fish were fed at the surface during hatchery rearing. In some types of artificial propagation programs (supplementation and enhancement programs), strategies such as decreasing rearing densities, using natural substrate, instream structure, subsurface feeding, and providing cover may help reduce vulnerability to predation (Maynard et al. 1995).

Disease

Without careful monitoring, there is always the potential for hatchery stocks, particularly non-endemic stocks, to introduce diseases detrimental to the native fish populations. Hatchery fish can introduce new diseases to a system or directly transmit endemic diseases to wild fish. There are no documented examples of the latter (NWPPC 1999). Another consideration, the potential loss of resistance to disease or parasites in wild stocks if nonresistant hatchery fish spawn with resistant wild fish, was addressed in the previous section.

Management Tactics for Minimizing Detrimental Interactions

Based on observations of steelhead releases in the Yakima River, McMichael et al. (2000) concluded that if hatchery fish are released in areas that contain wild salmonid populations, the effects on wild fish can be minimized by releasing as few hatchery fish as possible, releasing smolts that are ready to migrate, releasing fish that are the same size or smaller than the wild fish, releasing smolts in areas with complex habitat (to increase segregation from wild fish), releasing hatchery fish when stream temperatures are cold (wild fish are in the substrate while hatchery fish stay in the water column), and releasing fish at dark to minimize competitive interactions. Richards and Cernera (1989) found that larger hatchery fish tended to migrate earlier than smaller fish; therefore, stocking fish of a similar size to wild fish may help eliminate differences in migration timing and the potential for hatchery fish to influence wild fish migration timing. They also concluded that stream habitat would be better utilized if hatchery fish are stocked at low densities and numerous sites (Richards and Cernera 1989). In addition, instead of forcing fish that are not ready to migrate from hatcheries downstream, retaining those fish that do not leave the hatchery during volitional releases can help minimize effects on the wild populations (Viola and Schuck 1995).

Conclusion

Interactions between hatchery and wild fish impact the survival of wild fish and pose risks of detrimental impacts to wild populations. The occurrence and magnitude of the risks depend on the circumstances. Therefore, the assumption that interactions between hatchery and wild fish do not impact the survival of wild fish is not uniformly valid. We also conclude that there are techniques for avoiding these problems, and that the newer hatchery programs are more consistent with contemporary scientific understanding. The potential for these problems is significant, suggesting that specific monitoring for them must be part of hatchery programs.

Assumption 5: Augmentation and supplementation hatcheries add to existing natural production without replacing it.

The main objective of supplementation programs is to increase natural production in depressed wild stocks. Augmentation programs add to existing wild production to increase harvest opportunities. However, if supplementation and augmentation are not adding to existing natural production (either to increase the number of fish available for harvest or increase the number of wild spawners) or they are merely replacing wild production with hatchery production, those programs would be difficult to justify except under unusual circumstances. For example, supplementation may be used as an emergency action to prevent immediate extinction while habitat bottlenecks are being removed or modified.

Augmentation

Artificial propagation has augmented the harvest of salmon and steelhead in Oregon. There are numerous examples of hatchery fish contributing to fisheries and creating fisheries such as in Youngs Bay in the lower Columbia River or the South Santiam River summer steelhead fishery. In some cases, the magnitude of the hatchery augmentation is known; however, in many others, the actual contribution is not known or that information is not readily available as we pointed out earlier in this report relative to the 1999 hatchery audit. Where the purpose of the hatchery is to augment harvest and the fishery takes place where hatchery and wild stocks are mixed, there is the real risk of impact to the wild stocks. Under those conditions, the hatchery program may simply replace natural production, and true augmentation may not take place. We discuss examples of such replacement below. While augmentation hatcheries do contribute to the catch, monitoring has generally not been adequate to determine if replacement has occurred.

In a recent study, Hilborn and Eggers (2000) found evidence that hatchery production did not augment wild production, but rather replaced it. A pink salmon hatchery in Prince William Sound, which was designed for harvest augmentation, provided little or no increase in the total abundance of pink salmon compared with an area that was not supplemented with artificially propagated salmon. The decline in wild escapement due to harvesting of hatchery and wild stocks and the biological impacts of the hatchery fish on the wild fish probably brought about the replacement (Hilborn and Eggers 2000). However, Smoker et al. (2000) concluded that an Alaska ocean ranching program did enhance pink salmon harvests. This has led to overharvest of wild stocks in some areas, but in others, the effects on wild stocks have been minimized. Flagg et al. (1995) also showed replacement of wild coho with artificially propagated fish in the lower Columbia River. These studies point out the need for monitoring of other augmentation programs.

Supplementation

Most literature urges caution in implementing supplementation programs because methods are still largely untested (Hard 1995; Reisenbichler and Rubin 1999; IMST 2000a). The results of supplementation may vary among programs; therefore, comprehensive monitoring is always necessary. Even if supplementation adds smolts to a system, they may reproduce at the expense of natural production. This would be particularly detrimental if hatchery fish differed genetically from wild fish. Based on studies of the interactions between hatchery and natural chinook salmon, Peery and Bjornn (1996) concluded that when larger, more aggressive hatchery fish outnumber wild fish, replacement may take place and eventually natural production will decline. Reisenbichler and McIntyre (1986) stated that if hatchery fish are genetically different from wild fish, interbreeding between the two could reduce the number of surviving offspring per spawner. The source of the broodstock and the management of the population in the hatchery determine the genetic suitability of hatchery fish.

A model was used to predict the response of native steelhead in the Lochsa River, Idaho, to long-term supplementation with hatchery fry and smolts. Using a life history model, Byrne et al. (1992) found that if large numbers of hatchery fish spawn in a river, numbers of native fish will be reduced. While supplementation may be able to increase smolt yield, the number of naturally produced fish would be less than if there was no stocking. On the other hand, a model produced by Cuenco (1994) showed that under certain conditions, supplementation can result in the rebuilding and maintenance of abundance in depressed populations (for supplementation to be successful and increase the number of wild spawners, the combinations of wild stock productivity, hatchery stock productivity, and the proportion of hatchery spawners in the population must result in a combined stock productivity, or adult progeny to parent ratio, that is greater than one).

The case studies described below illustrate the point that, although supplementation can be a potentially valuable tool for the recovery of wild populations, the effects of supplementation vary with programs and only extensive monitoring and evaluation can assure that supplementation programs are indeed achieving their goals and adding to the existing natural production without replacing it.

Reasons for Caution

Chilcote et al. (1986), after conducting a study that found lower reproductive success in naturally spawning hatchery steelhead than in wild steelhead, recommended against supplementing low populations of wild steelhead with hatchery fish to increase smolt production because of the low reproductive success of hatchery spawners. In the Kalama River, Washington, hatchery fish had much lower reproductive success than wild fish, but outnumbered wild spawners by a large margin. Therefore, despite the lowered reproductive success, juveniles produced from hatchery fish dominated the total smolt production. The hatchery fish, with lower survival rates hatched before wild fish and had a competitive edge due to their larger size (Leider et al. 1990), limiting chances for a successful long-term supplementation effort.

In a study of supplementation in Oregon coastal streams, 44% of wild juvenile coho salmon were replaced with hatchery presmolts. In the following generation, adult returns to supplemented streams were not significantly different from adult returns in unstocked streams. However, hatchery-produced adults spawned earlier than wild fish and this may have contributed to the lack of success of the supplementation (Nickelson et al. 1986). This study was designed to produce conclusive results and included 15 treatment streams and 15 control streams. Released fish were followed through two generations, which is rarely done in supplementation studies.

Recent Examples

In the Umatilla River Basin, Phillips et al. (in press) reported that a project that entailed habitat restoration, flow enhancement, fish passage improvements, and supplementation has contributed to natural production in steelhead. The steelhead population is not yet self-sustaining, but the program has achieved smolt to adult survival above replacement in hatchery fish, seen escapement levels higher than they would have been without supplementation, maintained low stray rates, documented increased numbers of steelhead redds, and maintained genetic similarity between hatchery and wild stocks. However, adult-to-adult return rates of wild fish remained below one in most years. Also, hatchery and wild populations have diverged in age composition and sex ratios.

In an example described under assumption 1b above, steelhead and chinook salmon supplementation programs in the Imnaha River resulted in higher adult progeny to parent ratios in hatchery fish than in naturally produced fish (Carmichael et al. 1998; Whitesel et al. 1998) (see Figures 7, 8, and 9). Based on these figures, supplementation is adding additional spawners to the population. The higher survival of artificially propagated fish boosted the spawning population to a higher level than would have been attained through natural production alone. While supplementation with artificially propagated fish has boosted the size of the spawning population, the adult progeny to parent ratios of naturally produced fish remain below one. This confirms that the importance of removing the source or sources of depletion is critical to any supplementation program.

Both the Umatilla and Imnaha examples show that supplementation can increase the number of spawners on the natural spawning grounds. However, the goal of supplementation is to increase natural production. Success should be measured as an increase in the number of spawners that are the progeny of naturally produced parents. So far, that has not occurred; success has not been demonstrated.

<u>Conclusion</u>

Augmentation hatcheries have contributed to the catch of salmon and steelhead in Oregon. In general, however, the natural and artificial production in watersheds that employ augmentation hatcheries have been so poorly monitored that we cannot tell whether they replaced natural production or added to it. There is evidence of cases where replacement has occurred.

Evidence suggests that supplementation can increase the level of natural spawners over the numbers that would have been present without supplementation. It remains to be documented that an increased level of spawning activity translates into sustainable higher levels of natural production, especially in those cases where the factor(s) limiting natural production has not been corrected. Unless supplementation programs are carefully implemented, there is a risk that artificial production could replace natural production. Only careful monitoring can ensure that supplementation programs are meeting their goals of aiding in the recovery of wild salmonids. Without effective monitoring, it is not safe to assume that supplementation programs are adding to existing natural production without replacing it.

Science Question 2: Scientifically, how could Oregon's artificial propagation program be consistent with the recovery of wild salmonids in Oregon?

To be consistent with the goals of the Oregon Plan, ODFW must develop an overarching policy for artificial propagation and a complimentary strategic plan for the management of hatcheries, as recommended in the IMST's evaluation of ODFW's hatchery audit[8]. This section describes how Oregon's artificial propagation program could be consistent with the recovery of wild salmonids, within an overarching policy and strategic plan.

Our answer to science question 2 is subdivided into two parts: a) recommendations derived from the results of recent scientific panels; and b) advice on the use of the landscape perspective in the design and implementation of artificial propagation programs

A. Recent Scientific Reviews of Artificial Propagation

In the Phase I report of the IMST's review of Oregon's artificial propagation program, we compared recommendations from independent science panels with the hatchery measures contained in the Oregon Plan. We made several recommendations to revise the measures to make them more consistent with the recommendations common to these panels. Since the Phase I report, one additional independent review of artificial propagation has been conducted, and an analysis of the recommendations from all of the panels found that there were ten in common (SRT 1998; Flagg and Nash 1999). In this section, we recommend that the ODFW use those ten conclusions and recommendations as a basis for a review and revision of its policies, strategic plan and Administrative Rules governing artificial propagation programs. We feel that such a review would help ODFW's artificial propagation program be consistent with the mission of the Oregon Plan.

As described in the introduction to this report, there have been several recent reviews of hatchery operations by independent science panels. The IMST determined that these reviews are technically sound, and the points of agreement among three of the reports can be used as a starting point for making Oregon's artificial propagation program consistent with the recovery of wild salmonids. These recommendations, if implemented, would improve the performance of Oregon's hatchery programs and help ensure that they contribute to the goals of the Oregon Plan. Appendix A contains the full text of the recommendations. The IMST has summarized the salient points here.

Both the SRT (1998) and Flagg and Nash (1999) summarized the common themes in reports by the three different scientific panels: the National Fish Hatchery Review Panel Report (NFHRP 1994); the Independent Scientific Group Report, *Return to the River* (ISG 1996); and the National Research Council Report, *Upstream* (NRC 1996). The points of agreement among the three reports provide an initial set of general conclusions and recommendations for artificial propagation programs. These points, listed below as they were summarized by Flagg and Nash (1999), are broken down into conclusions and recommendations made by the science panels.

[8] October 25, 2000 letter to Kay Brown, ODFW

Common Conclusions about Hatchery Programs

- "Hatcheries have generally failed to meet their objectives"
- "Hatcheries have imparted adverse effects on natural populations"
- "[Many] managers have failed to evaluate hatchery programs"
- "[Past] hatchery production was based on untested assumptions"

Common Recommendations for Hatchery Programs

- "Supplementation should be linked with habitat improvements"
- "Genetic considerations have to be included in hatchery programs"
- "Stock transfers and introductions of non-native species should be discontinued"
- "Artificial production should have a new role in fisheries management"
- "More research and experimental approaches are required"
- "Hatcheries should be used as temporary refuges, rather than for long-term production"

The IMST is in agreement with the conclusions and recommendations listed above. Because we conclude that harvest augmentation and the existing mitigation hatcheries are legitimate uses of artificial propagation but must be operated in a way that is consistent with the Oregon Plan, we qualify the last recommendation *hatcheries should be used as temporary refuges, rather than for long-term production.* Harvest augmentation and mitigation programs that meet this criterion can have long-term production goals. We recognize that some supplementation programs, once they meet their goals, may change their objectives to augmentation or mitigation. Given the current status of freshwater habitat, some supplementation programs, particularly those in systems where salmonid populations have been reduced for a complex set of reasons, may have to operate for an extended period of time to achieve their goals.

The IMST recommends that ODFW conduct a review to determine the extent to which the four conclusions of the scientific panels apply to Oregon's hatchery program. The commission and the department should use that review along with the six recommendations from the independent panels to assess and revise the policies and Administrative Rules governing the use of artificial propagation in Oregon.

In addition, the IMST conducted a workshop on supplementation that resulted in 16 major points (IMST 2000a), listed in Appendix A. As a result of our review of artificial propagation, the IMST adopts those recommendations, and further recommends that ODFW and the Commission consider them in their assessment and revision of artificial propagation programs.

B. Managing Hatcheries from a Landscape Perspective

The IMST recommends that ODFW adopt a landscape perspective in the planning and implementation of Oregon's artificial propagation program. Adopting the landscape approach will entail major changes in the current program. To assist in clarifying what the landscape approach entails, we provide the following perspective and suggestions for how the landscape approach might be applied to artificial propagation.

Background

The structural and functional components of ecosystems that support salmonids, along with their dynamic interactions, form the conceptual basis for landscape ecology and the management of fish at the landscape level. Historically the artificial propagation component of fish management focused on individual hatcheries with inadequate attention to the system of which they were a part. In systems that are not fully seeded, the hatchery should produce a net positive change in adult recruits at the basin level. If it does not, then it becomes questionable whether it is scientifically compatible with the goals of the Oregon Plan. In systems that are fully seeded, the use of hatcheries to augment production is a policy decision. At the larger scale (evolutionarily significant unit or gene conservation unit), landscape perspective managers should consider the aggregate effect of a collection of hatcheries (see Figure 4). In addition to a larger spatial scale than the individual hatchery, the landscape perspective has a longer time scale to it. Rather than an annual or brood year planning horizon, artificial propagation with a landscape perspective would consider multiple generations of fish. This means taking into account: a) population abundance and its trends; b) availability of good or higher quality habitat; c) natural disturbance patterns d) harvest expectations and escapement levels; and e) climatic and ocean conditions. Hatchery management needs to factor in these longer-term considerations.

Structural components include the physical habitat occupied by salmonids, the materials that maintain the integrity of that habitat, and the components of the landscape that supply those materials. Functional interactions include the flows of energy (food) and materials within the ecosystem. Landscapes are dynamic: both structure and function change across time and space. Historically, the interaction between structure and function produced the heterogeneous habitats required by the various species, their different life-stages and the numerous life histories types of salmonids (Healey and Prince 1995). Periodic disturbance is a natural feature of the landscape and plays an important role in maintaining the integrity and variability of salmonid habitat. The extent, magnitude, and frequency of disturbance are key influences on salmonid habitat. Even when natural disturbance occurs at specific sites in a landscape, overall stability is ensured as long as ecosystem structure and function are maintained within certain bounds. For example, landslides supply important structural material for salmon habitat (habitat-forming large wood and spawning gravel). However, if the frequency of landslides exceeds the stream's capacity to incorporate the material, habitat degradation will occur.

Genetic components are also important. Salmonids evolved adaptations to diverse aquatic habitats at the landscape level. One of those adaptations recently recognized by biologists is the spatial organization of salmon across a diverse landscape into metapopulations. Consideration of the interrelated components of the entire ecosystem and the metapopulation structure of salmon should be an important part of the planning and implementation of artificial propagation programs.

A Landscape View of Hatcheries

Planning and managing hatcheries from a landscape perspective will require a major shift in the approach that has been employed. The landscape perspective entails a shift to an ecological approach, from a vision of hatcheries as separate from the watershed to a vision of hatcheries as artificial tributaries that must be an integral part of a larger watershed. The first step in developing a landscape perspective for hatcheries is to recognize that they must function in concert with the physical and ecological processes of the watershed instead of as a substitute for them. While there is a growing literature on managing/viewing streams with a landscape perspective, this approach has not been applied to the management of fish hatcheries.

There are two key steps to putting the landscape vision of hatcheries into practice:

a. Operate hatchery programs consistent with the attributes of the ecosystem of which they are a part, including the physical environment, the welfare of naturally produced salmon, and human systems. In order to do this, it is necessary to assess these attributes and manage accordingly.
b. Operate hatchery programs in a manner that is consistent with the existing structure and interaction among populations at various spatial scales. Recently biologists have adopted a conceptualization of the interaction among salmon populations. This conceptual framework, known as metapopulation theory, may provide a useful tool to aid in the design of hatchery operations from the landscape perspective.

Step a. Operate hatchery programs consistent with the attributes of the ecosystem of which they are a part.

The design and management of each hatchery program should explicitly take into account the attributes of the ecosystem into which the salmon will be released. This approach applies whether the goal is to mimic wild fish or maintain separation between wild and hatchery stocks (see Figure 5, page 16). Some of those attributes include, but are not limited to:

1. Carrying capacity of the stream, the migration corridor, the estuary, and the ocean.

   Carrying capacity of aquatic habitats is not easily observed, which is probably one reason why it is often not taken into account in the design and operation of hatchery programs. In terrestrial ecosystems, capacity constraints are more easily recognized. For example, overgrazed rangeland overstocked with cattle show easily observed signs of the problem. In rivers, estuaries, and oceans, the signs of overstocking are not clearly visible. Production targets for hatcheries are often fixed. For example, mitigation hatcheries have fixed production targets in their legal agreements. However, carrying capacities of the streams, estuaries, and ocean fluctuate through time. Changes in ocean conditions illustrate such variation. Fixed levels of hatchery production suggest that at times, it will exceed capacity, and at other times, the production targets will be lower than they need to be. To reduce the possibility of density dependent interactions between hatchery and wild fish, hatchery fish should be released at a time when they will move directly downstream or there needs to be habitat available for them in the stream in which they are released (see discussion under Assumption 4b). If there is not adequate habitat, and wild and hatchery fish interact, wild fish may be displaced.

   Failure to consider carrying capacity in hatchery programs can have serious consequences. In an analysis published in 1995, National Marine Fisheries Service biologists concluded that hatchery operations were at least partially responsible for the extirpation of wild coho salmon in the lower Columbia River. One of the factors they identified was the overstocking of the streams with hatchery fry, i.e., planting more fry than the carrying capacity of the stream (Flagg et al. 1995).

2. The mix of species native to the watershed and their relative abundance.

Kapuscinski (1997) noted that hatchery programs should not disrupt biodiversity in salmonid ecosystems, and existing patterns of genetic diversity between and within populations should be maintained. McMichael et al. (2000) suggested that to minimize deleterious ecological effects of hatchery fish on wild populations, hatchery fish should be released when they are actively migrating, smaller than wild fish, when water temperatures are cold, in areas where wild salmonids are absent, and where habitat diversity is complex. The minimum number of hatchery fish needed to meet management objectives should be released.

3. Diseases endemic to the watershed the fish will be released into and to the watershed that is the source of the broodstock if the two are different.

The potential for transmission of disease from hatchery stocks, especially non-endemic hatchery stocks, to wild fish populations should be considered to avoid the introduction of new diseases detrimental to the native fish populations. Another consideration is the potential loss of resistance to disease or parasites in wild stocks if nonresistant hatchery fish spawn with resistant wild fish. This effect is documented for *Ceratomyxa shasta* resistance. Hemmingsen et al. (1986) demonstrated that crosses between resistant native Columbia River coho salmon and nonresistant coho from outside the basin produced progeny with intermediate resistance to the disease. Wade (1987) found a similar effect in summer steelhead. Both concluded that interbreeding between non-native stocks and native, resistant stocks could have major impacts on the survival of the wild populations.

4. Habitat conditions above and below the hatchery.

Once they are released from the protected environment of the hatchery, artificially propagated fish depend on habitat quality as much as wild fish. Whitaker (1896) and Noble et al. (1994) noted that fish stocking sites should be chosen for their habitat features, not for convenience or proximity to the hatchery. Many of the guidelines for hatchery practices, ecological integration, and genetics suggested in the Northwest Power Planning Council's Artificial Production Review (NWPPC 1999) state that the hatchery environment should mimic the environment of the natal stream. Specific guidelines state that: a) hatchery production should target natural population parameters in size and timing of juvenile releases to mimic natural populations; b) hatcheries should utilize ambient natal stream temperatures to maintain genetic compatibility with the local environment; and c) hatcheries should use natal stream water for rearing to enhance home stream recognition in the hatchery fish (NWPPC 1999).

5. Natural temperature regimes in the river.

Stream temperature can have an impact on migration timing, amount of interaction between hatchery and wild fish, and disease transmission. The APR (NWPPC 1999) suggests that ambient natal stream temperatures be utilized in supplementation hatcheries to "reinforce genetic compatibility with local environments and provide the linkage between stock and habitat that is responsible for population structure of stocks from which hatchery fish are generated." Therefore, natural stream temperature regimes should be considered when integrating hatchery programs with the ecosystem.

6. Spatial/temporal description of the natural life histories of salmonids (spawning, rearing and migration).

   There is natural variation in salmonid life histories, including variation in time of spawning and migration. Hatchery programs should be designed to preserve the natural life history diversity of salmonids in the watershed. Bugert (1998) advocates appropriate broodstock collection for supplementation programs to ensure that life history variability is maintained. This includes collecting broodstock from the targeted population only, capturing all age classes, equal collection efficiency throughout the hydrograph, and sorting of marked and unmarked fish where the marks can identify life history variants.

7. Ocean conditions, climate trends, and natural productivity cycles.

   Analyzing Pacific salmon catch data, Hare et al. (1999) found that variation in salmon productivity varies with ocean and climate conditions. This needs to be considered when integrating hatchery and wild production in a watershed. Beamish et al. (1997) cautioned that while increasing escapements may be possible during a productive ocean regime, rebuilding of stocks to historic levels may not be possible during low productivity regimes. He also suggested that during periods of poor ocean survival, it may not be a prudent strategy to continue to release large numbers of artificially propagated salmon (Beamish and Bouillon 1993). In another report, the IMST recommends that harvest also take into account changes in ocean productivity cycles (IMST 2000b).

Step b. Operate hatchery programs in a manner that is consistent with the existing structure and interaction among populations.

The NRC (1996) concluded that salmon metapopulations, as well as local populations, are the important units of conservation for Pacific salmon. Ensuring the persistence of metapopulations is crucial and it leads to recommendations regarding salmon management, including the management of hatcheries (NRC 1996). Metapopulations are groups of local populations that are distributed across a heterogeneous landscape and genetically linked by dispersal of individuals (Hanski 1991; Hanski and Gilpin 1991). Metapopulation theory has only recently been used to interpret salmonid population structure and ecology and to formulate management strategies (Rieman and McIntyre 1993, 1995; Gresswell et al. 1994; Li et al. 1995; Mundy et al. 1995; Schlosser and Angermeier 1995; ISG 1996; NRC 1996). Since it is relatively new, its application to salmonid populations should be viewed as a hypothesis that must be tested through effective monitoring and evaluation (ISG 1996). Metapopulation theory is one approach to explain the interaction among closely related populations in a diverse landscape.

Metapopulation theory directly links populations to the natural disturbance regimes that shape landscape structure and function. This linkage is the balance between the extinction of local populations after severe habitat disturbance and the subsequent recolonization of previously disturbed habitats as they recover. This extinction-colonization balance depends on the dispersal of individuals and the connectivity between habitats occupied by populations making up the metapopulation. If the frequency of disturbance – whether human caused or natural – that degrades a species' habitat exceeds its ability to maintain a balance between extinction and recolonization, the individual populations and eventually the entire metapopulation will go extinct.

In salmonid metapopulations, the local populations are interconnected, linked through dispersal and straying. The management of hatchery populations should be consistent with the function of the local metapopulation and take into account the linkages among populations within a metapopulation. Instead of setting smolt output based on the capacity of the hatchery, artificial propagation programs need to set targets based on the carrying capacity of the stream and structure and dynamics of local wild populations.

Several models of metapopulation structure have been suggested. Li et al. (1995), Schlosser and Angermeier (1995), and the Independent Science Group (ISG 1996) suggest the core-satellite model to describe the structure of Pacific salmon populations (Figure 10). Core populations are large, usually occupying extensive and productive habitats; under natural conditions, a core population is expected to persist indefinitely. Satellite populations often occupy marginal habitat. Satellite population abundances may fluctuate widely in response to changes in climate, and they my go extinct after severe disturbance events. Dispersal of salmonids from a large core population will colonize vacant habitat, reestablishing satellite populations and generally minimizing the possibility of total extinction of the metapopulation (Harrison 1994). Connectivity between different habitats is crucial (Schlosser 1991).

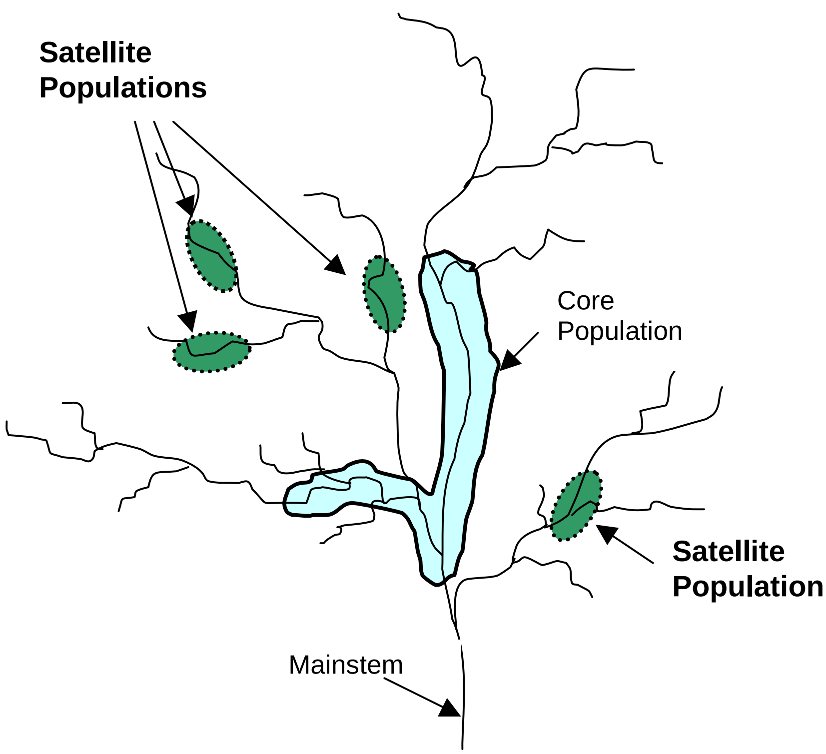


Figure 10: Schematic diagram of a core-satellite model of metapopulation structure. The figure shows a large core population and four satellite populations.

Where the objective of the hatchery is to maintain an artificially propagated population that mimics the wild population, hatchery operations must not only take into account the life history and genetic structure of the wild fish, they must also consider the metapopulation structure across the landscape. If the core-satellite model of metapopulations is accepted, then a hatchery could produce fish that function as either a core or satellite population. The choice between core or satellite function would have important implications to the hatchery operation. Most of Oregon's hatcheries, particularly those on the coast, would fall into the satellite category. The exceptions are the hatcheries that are designed to mitigate for the loss of large mainstem spawning populations such as in the Columbia and Willamette rivers, and possibly the Rogue River spring chinook population.

A satellite hatchery might operate on a tributary, releasing small numbers of fish and adjusting releases with fluctuations in natural productivity cycles (Figure 11). Hatchery operation could mirror natural responses to productivity cycles, in which populations in poor-quality habitat become severely reduced during periods of low ocean productivity. For example, during those periods hatchery operations might be severely reduced or cease altogether (Bugert 1998; Nickelson and Lawson 1998) and release fish again during periods of better marine survival.

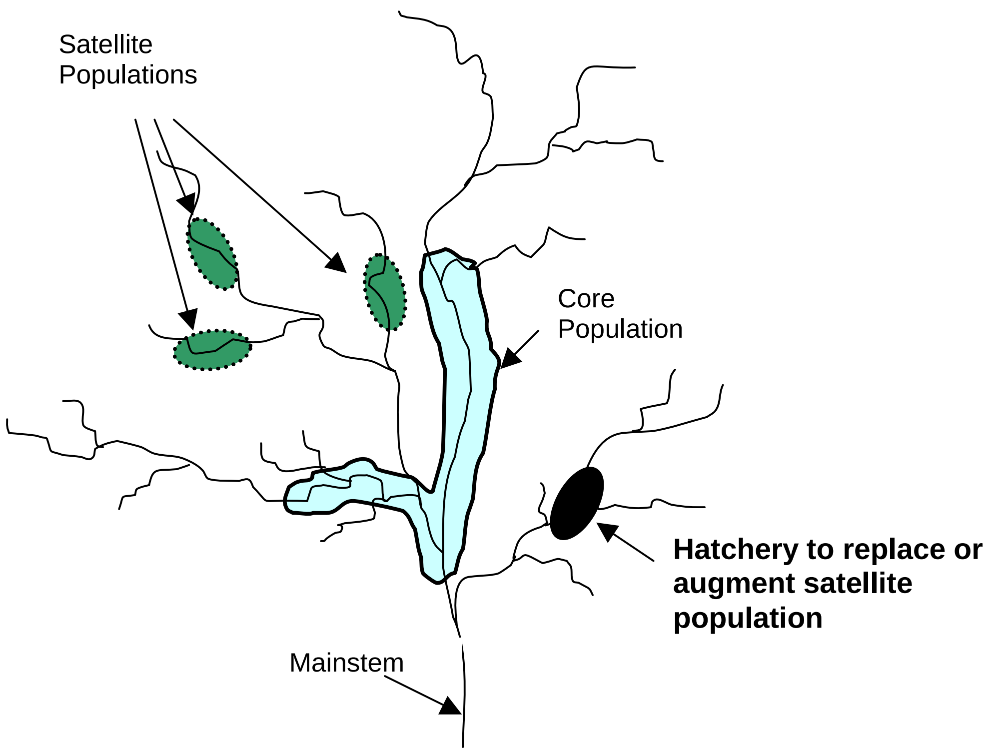


Figure 11: Schematic diagram of a salmon metapopulation in which a hatchery functions as a satellite population.

Replacing a core population with a hatchery would be very difficult and entail considerable risk. A core hatchery population should be larger and more stable than that of a satellite hatchery (Figure 12). Hatcheries should only try to mimic a core population when the original core population has been eliminated, for example through the construction of dams. The core hatchery populations would persist through the ups and downs of satellite populations, possibly providing a core population for naturally-spawning satellite populations on the periphery (tributaries) that may not be self-sustaining due to poor habitat conditions or other factors. The core population in the hatchery could serve to buffer the metapopulation against environmental change, making it more resilient/stable at a regional or landscape level (ISG 1996). Emigrants from the core areas (hatcheries) could colonize the peripheral habitats during favorable conditions (Harrison 1991). However, for this concept to be put into practice, the hatchery core needs to maintain the genetic and ecological attributes of the wild core population.

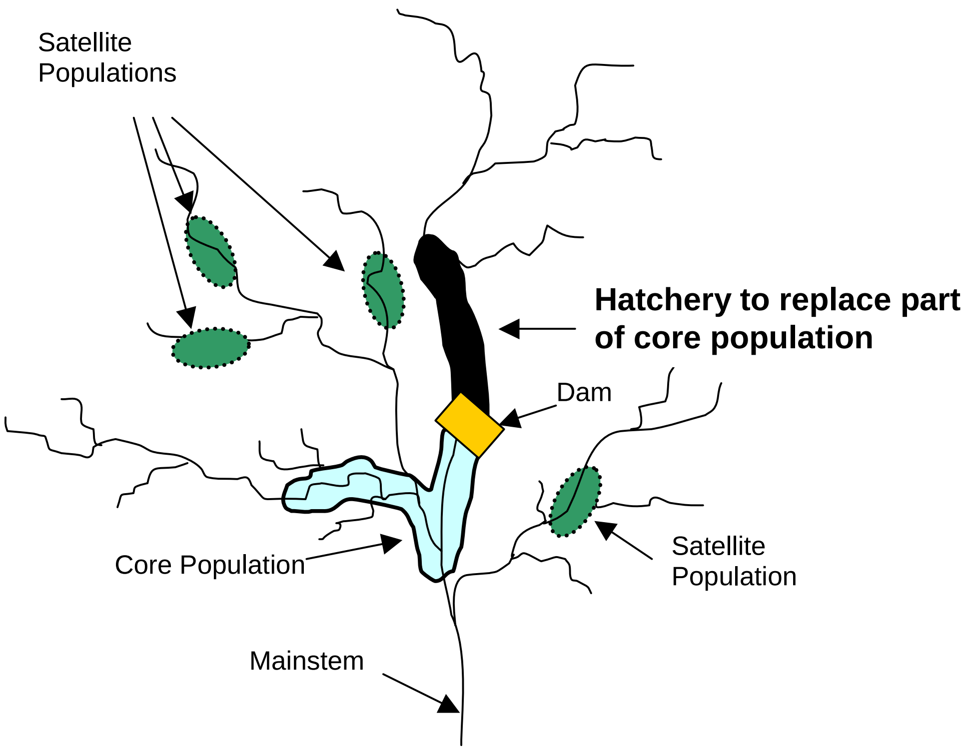


Figure 12: Schematic diagram of a salmon metapopulation in which a hatchery functions as a core population. The hatchery is attempting to mitigate the lost habitat of the core population.

Artificial propagation has the potential to modify natural population and metapopulation structure. Straying of hatchery fish can increase the stray rate among metapopulations or the sheer numbers of hatchery fish released may increase the absolute number of straying fish, artificially increasing the gene flow between metapopulations. Hatchery programs can disrupt natural genetic diversity patterns and local adaptation by moving fish across natural population and metapopulation boundaries at a greater rate and over a greater geographical area than would occur naturally (through straying), lowering the fitness of the locally adapted wild populations (Hindar et al. 1991; Fleming and Gross 1993; Quinn 1993; Utter et al. 1995). Flagg and Nash (1999) stated that hatcheries could also create new populations that are adapted to the artificial environment of the hatchery, but not to the natural stream ecosystem. However, this can be controlled through effective hatchery management by: using local, recently-founded broodstocks that originate from the wild population with which they will interact; avoiding artificial selection and minimizing domestication selection; using broodstock only temporarily; and restricting straying and natural spawning of hatchery fish (Kostow 1999).

Whether a hatchery is operated as a core or a satellite, hatchery releases must be coordinated among hatchery programs and between the hatcheries and the carrying capacity of the environment in which they are released. Even if complete separation of hatchery and wild fish is intended, releases in excess of the carrying capacity of the system can have an impact on wild fish. During periods of low productivity (reduced carrying capacity), hatchery production needs to be scaled back so that a hatchery does not impact stocks in other tributaries and to avoid merely replacing wild fish production with hatchery fish. Hatchery managers need to have an ecological understanding of the river, understanding habitat potential to maximize production in the entire system (both wild and hatchery).

The key to managing hatchery programs from a landscape perspective is to consider the impacts of hatchery releases both inside and outside of the hatchery, including consideration of the environment into which the hatchery fish are released (including the effects of the distribution of humans and their activities), the effects of hatchery fish on other species, and the effects of hatchery fish on wild populations of the same and other species. As with any hatchery program, monitoring, evaluation, and continual adjustment to changing conditions are necessary for success.

Findings and Proposed Actions from the Scientific Analysis of Assumptions

Assumption 1: Higher survival in the egg to smolt life stage in the hatchery results in a net increase in adult ocean recruits. Ocean recruits are the total of hatchery and wild fish.

Assumption 1a: Survival rates from egg to smolt stage (or release stage) in the hatchery is higher than the survival rate through the same stages in the wild.

Findings:

- Based on our analysis, the IMST concludes that the hatchery environment does give a survival advantage from the egg to smolt stage compared to survival for the same life stages in naturally produced fish.
- Monitoring of egg to smolt survival in hatcheries appears to be adequate.

Actions: No additional actions are necessary.

Assumption 1b: A higher survival rate during the egg to smolt stage translates to an overall increase in the number of ocean recruits sufficient to achieve the objectives of the program.
Mitigation and Augmentation Hatcheries

Findings:

- Post-release survival rates for hatchery fish are often lower than the survival rates of wild fish.
- In mitigation and augmentation hatchery programs, the IMST finds that post-release survival rates for hatchery fish are often lower than the survival rates of wild fish. However, we also find that under most conditions, smolt to adult survival of artificially propagated fish is sufficient to provide an increase in adults for the fishery.

We caution however that current monitoring is either not adequate to verify that the combination of artificial propagation and production by wild fish is greater than would occur from natural production alone, or the monitoring information is not being used for this purpose.

Actions:

- Establish monitoring programs at selected hatcheries to determine comparative survival of hatchery and wild stocks and continue monitoring through different climatic cycles. This should include experiments to compare survival rates of hatchery fish released at the same time and size as wild fish, with marking protocols to estimate survival of each group.
- Strengthen the linkage between artificial propagation and management programs to ensure the appropriate information is distributed and used.
- Use the results of monitoring to adjust the program consistent with the objectives of the hatchery and the watershed.

Supplementation and Conservation Hatcheries

Findings:

- Under some conditions, smolt to adult survival of artificially propagated fish is sufficient to provide a net increase in the number of naturally spawning adults. For supplementation hatcheries, increasing the number of spawning adults does not equate to success. Natural production must increase and evidence for this is weak or nonexistent.
- Monitoring in most existing programs appears to be adequate.

Actions:

- No additional actions necessary for existing programs.
- New programs, such as CHIP, should emulate the monitoring that is being done in the Umatilla, Grande Ronde, and Imnaha programs.

STEP Hatchboxes

Finding:

- There is no basis on which to judge whether the program provides a net increase in ocean recruits. Monitoring and evaluation of the hatchbox program is inadequate to determine if a net increase in adult recruitment is occurring. However, the hatchbox program does appear to have value as an educational tool.

Actions:

- Establish a monitoring program to assess the net effect of the program on adult recruitment and to compare survival of hatchbox fry with that of wild fish by pedigree analysis.
- Link educational objectives and hatchbox programs to the hatchery guidelines and hatchery objectives in the Oregon Plan.

Assumption 2: Hatchery production can mitigate for wild fish production lost due to human activities in a watershed.

Finding:

- The IMST finds that Oregon's hatchery mitigation programs have met with some success; however, many mitigation goals only specify the numbers of juveniles to be released. This does not allow assessment of whether hatchery programs are maintaining the premitigation, naturally-produced supply of adult fish to the fishery. Most mitigation goals do not take into consideration the productive capacity of the system or fluctuations in climate and ocean conditions.

Actions:

- ODFW should conduct a comprehensive evaluation of its mitigation programs to determine the success of the programs and to decide whether to continue recommending the use of hatcheries to mitigate for future losses of habitat and/or to undertake efforts other than hatchery mitigation, such as habitat restoration.
- ODFW should study their successful mitigation programs and incorporate the reasons for their success into other programs. The alteration of existing mitigation programs is a policy decision**.**
- Where mitigation contracts specify only the number of juveniles to be released from a mitigation hatchery, ODFW should renegotiate the mitigation contract and specify targets in more meaningful terms such as the number of adult recruits. These new targets should also take into consideration the productive capacity of the system and changing ocean and climate conditions.

Assumption 3: Hatchery operations retain behavioral, physiological, and genetic characteristics that facilitate returns of hatchery adults.

Assumption 3a: Domestication occurs in hatcheries but it is inconsequential.

Finding:

- Domestication does occur, and it is not necessarily inconsequential.

Actions:

- Minimize domestication in all hatcheries, except when this facilitates the goal of a program to maintain the separation between hatchery and wild stocks.
- Identify where domestication is occurring to the detriment of either the hatchery stock or the wild stock. An adequate monitoring program must be implemented and programs adjusted based on findings from the monitoring program.

Assumption 3b: Mate selection is not significant i.e., there are no major detrimental consequences if hatchery personnel select the mates for salmon instead of salmon selecting their own mates.

Finding:

- Mate selection can have major detrimental consequences on the characteristics of the hatchery population, post-release performance of hatchery fish, and the performance of the wild fish if the two interact.

Action:

- Monitor the characteristics of the population, and if the hatchery population is changing inadvertently, alter the way the hatchery personnel select the broodstock. If there is interaction between hatchery and wild stocks, hatchery fish should mimic the phenotypic and genotypic traits of the wild stocks to minimize negative consequences of the interaction.

Assumption 4: Interactions between hatchery and wild fish do not negatively impact the survival of wild fish.

Findings:

- This is not a uniformly valid assumption.
- Interactions between hatchery and wild fish at the adult and juvenile stages may pose real risks of detrimental impacts to wild populations. The occurrence and magnitude of the risks depend on the circumstances.
-
- Due to insufficient monitoring, we do not know enough about effects outside the hatchery.

Actions:

- The risks must be assessed for each program (hatchery-specific) through a formal process.
- Long-term monitoring of the survival (fitness) of wild and hatchery fish through genetic analysis/marking should be conducted where they co-occur.
- The risks must be reduced through adaptive management.
- For example, ODFW needs to assess the interaction between hatchery and wild fish on the spawning grounds and the consequences of those interactions. Merely monitoring the potential for interactions, based on the presence of hatchery and wild fish on the spawning grounds, does not assess whether interactions actually occur and the consequences of them (IMST 1998).

Assumption 5: Augmentation and supplementation hatcheries add to existing natural production without replacing it.

Findings:

- Evidence suggests that supplementation can increase the level of natural spawners over the numbers that would have been present without supplementation. It remains to be documented that an increased level of spawning activity translates into sustainable higher levels of natural production, especially in those cases where the factor(s) limiting natural production has not been corrected. Unless supplementation programs are carefully implemented, there is a risk that artificial production could replace natural production.

- Augmentation hatcheries have contributed to the catch of salmon and steelhead in Oregon. In general, however, the natural and artificial production in watersheds that employ augmentation hatcheries have been so poorly monitored that we cannot tell whether augmentation hatcheries have replaced natural production or added to it. There is evidence of cases where replacement of natural production with hatchery production has occurred (Hilborn and Eggers 2000).

Actions:

- The risk of replacing natural production with hatchery production must be assessed in the context of each program, and adequate monitoring is necessary to ensure that replacement does not occur. New supplementation programs need to emulate the monitoring that occurs in the Umatilla, Grande Ronde, and Imnaha basins.

CONCLUSIONS AND IMPLICATIONS FOR POLICY

Conclusions

Conclusion 1: ODFW lacks an overarching policy/framework for hatchery management that:

- **provides strategic guidelines for the entire hatchery program and for the management of individual hatcheries.**
- **provides specific management objectives.**
- **provides a link between hatchery objectives and management objectives.**
- **provides a link between hatchery management and the Oregon Plan.**

Currently, there is no single, overarching set of policies that governs the management of Oregon's hatchery program and integrates it explicitly with the management functions it serves (harvest and restoration) and with the mission of the Oregon Plan. Policies governing hatchery operations are located in a collection of federal documents, ODFW documents and Administrative Rules. Many hatcheries apparently do not have specific management objectives beyond the targeted juvenile releases.

Conclusion 1a: Three independent science panels (NFHRP 1994; ISG 1996; NRC 1996) have agreed on the following key points about artificial propagation. Oregon's artificial propagation program is large, so there are exceptions to these generalizations, but the IMST generally accepts the findings of these reports, as summarized by Flagg and Nash (1999):

a. "Hatcheries have generally failed to meet their objectives"
b. "Hatcheries have imparted adverse effects on natural populations"
c. "[Many] managers have failed to evaluate hatchery programs"
d. "[Past] hatchery production was based on untested assumptions"
e. "Supplementation should be linked with habitat improvements"
f. "Genetic considerations have to be included in hatchery programs"
g. "Stock transfers and introductions of non-native species should be discontinued"
h. "Artificial production should have a new role in fisheries management"
i. "More research and experimental approaches are required"

Conclusion 1b: As a result of our independent review of artificial propagation, the IMST adopts the recommendations of the IMST Workshop on Conservation Hatcheries and Supplementation.

Conclusion 2: Many of Oregon's hatchery programs fall closer to the hatchery-specific approach than to the landscape approach. Current management strategies do not provide a cohesive approach to manage hatcheries from a landscape perspective.

- **The guidelines/policies governing hatchery management, as a whole, are not consistent with the ecosystem of which hatcheries are a part.**
- **Hatchery management does not account for the existing structure and interaction among populations of salmonids.**

Hatcheries need to be considered as part of a larger system, and hatchery management needs to complement wild fish management goals. Hatchery management can be characterized by two basic approaches. The hatchery-specific and landscape represent two ends of a continuum of approaches to hatchery management. It is likely that no individual hatchery falls entirely at the hatchery-specific or landscape end of the continuum. However, the newer hatchery programs tend to fall closer to the landscape end of the continuum while some of the older hatchery programs fall closer to the hatchery-specific end of the continuum. It appears that efforts to begin the process of shifting hatchery management towards a landscape perspective are underway within the department. The IMST was shown several draft documents including draft Hatchery and Genetic Management Plans that appear to be positive steps in the right direction. These efforts should be encouraged and aided by an overarching policy and statewide guidelines.

Conclusion 2a: Hatchery and wild fish may be different in either genotype or phenotype. The consequences of the differences could be positive or negative.
The reproduction and rearing of salmonids in the hatchery environment can initiate behavioral, physiological, and/or genetic changes in hatchery fish. The consequences of these changes differ depending on the degree of difference and the amount and type of interaction between hatchery and wild fish.

Conclusion 2b: In some situations, augmentation and supplementation hatcheries can add to existing natural production.
Augmentation hatcheries have contributed to the catch of salmon and steelhead in Oregon. In general, however, the natural and artificial production in watersheds that employ augmentation hatcheries have been so poorly monitored that we cannot tell whether hatchery production replaced natural production or added to it. There is evidence of cases where replacement has occurred.

Evidence suggests that supplementation can increase the level of natural spawners over the numbers that would have been present without supplementation. It remains to be documented that an increased level of spawning activity translates into sustainable higher levels of natural production, especially in those cases where the factor(s) limiting natural production has not been corrected. However, without effective monitoring, it is not safe to assume that supplementation programs are adding to existing natural production without replacing it.

Conclusion 3: Current monitoring and evaluation of hatchery programs are inadequate. Monitoring is not:

- **Comprehensive or adequate.** Monitoring of smolt to adult survival in mitigation and augmentation hatchery programs and fry to smolt and smolt to adult survival in the STEP hatchbox program needs to be implemented where it is currently not being done. The effects of interactions between hatchery and wild fish outside the hatchery also need to be evaluated and monitored.
- **Producing easily accessible data**. Data need to be quickly and easily accessible for use in policy and management decisions and for research; therefore, monitoring data need to be placed in a single, user-friendly, accessible database. While there are some databases that contain easily accessible data, such as the Pacific States Marine Fisheries Commission coded wire tag database, other data are less accessible. In general, comprehensive data are not easily available.
- **Accompanied by an explicit process for adaptively using that information to improve hatchery management.**
  Monitoring and evaluation are necessary to determine the degree to which goals have been achieved and provide information for adaptive management. Monitoring and evaluation are essential to adaptive management.

Conclusion 3a: Mitigation hatcheries have generally not replaced fish lost to the fishery due to habitat alteration or loss. Oregon's hatchery mitigation programs have met with some success; however, many mitigation goals specify only numbers for juvenile releases, which does not allow assessment of whether hatchery programs are maintaining the supply of adult fish to the ocean or river fisheries. Most mitigation goals do not take into account the productive capacity of the system or fluctuations in climate and ocean conditions.
The department recognizes the need to develop an alternative strategy. On October 11, 2000, the IMST met with ODFW staff in a public meeting to discuss this artificial propagation report[9]. During the discussion of mitigation success, ODFW staff said they recognized that the assumption that hatchery production can mitigate for wild fish production lost due to human activities in a watershed was no longer valid.

Conclusion 3b: The consequences of differences between hatchery and wild fish are not adequately known. Therefore, a positive or a negative consequence cannot be assigned in every situation. Few studies have tracked the consequences of interactions between hatchery and wild fish to the long-term survival of wild populations.

Conclusion 3c: It appears that under most conditions, the higher survival of hatchery fish throughout their entire life cycle (egg to adult) translates into a net increase in ocean recruits, however monitoring data to verify this conclusion are not available for all hatchery programs.
When data were available, the egg to smolt survival rate in the hatchery environment was much higher than egg to smolt survival rate in the wild. A key question is whether this increased egg to smolt survival rate in the hatchery compensates for lower survival rate after release, resulting in a net increase in ocean recruitment. It appears that under most

[9] Minutes from October 11, 2000 public meeting available from Oregon Watershed Enhancement Board Office (contact Bev Goodreau (503) 986-0187)

conditions, smolt to adult survival rates of artificially propagated fish are sufficient to provide a net increase in adult recruitment over wild fish. The progress toward the management objective needs to be determined on a hatchery-by-hatchery basis and under different climatic conditions. Each hatchery program must be evaluated to determine whether it is achieving its specific management objective. Current monitoring is not adequate for this purpose.

Policy Implications

Several of our conclusions have important policy implications. We provide perspectives on these before we state the recommendations of the IMST. These perspectives should not be interpreted as policy recommendations. We recognize policy is outside the scope of our work. Our purpose here is to make clear that we understand that there are policy implications associated with our recommendations. In some cases, our recommendations may sound like policy, but this is not our intention. It simply illustrates the difficulty of working at the science policy interface.

Conclusions 1 and 2 deal with some broad strategic issues as they relate to artificial propagation. For a series of compelling technical reasons, the State of Oregon needs a comprehensive strategy for the management of artificial propagation that is consistent with the goals of the Oregon Plan. This strategy needs to have a landscape perspective. Key aspects of the landscape perspective are:

- Larger spatial scale – meaning individual hatcheries are part of a coordinated system of hatcheries, and the individual and aggregate hatcheries are operated in a manner that complements the production of wild fish in individual watersheds and their survival in the ocean.
- Longer time horizon – meaning management decisions take into account species population dynamics and the dynamics of freshwater, estuarine, and ocean conditions.
- Coordination – meaning coordination (and in some cases collaboration) with other aspects of fish management such as harvest management and habitat management, including those bodies with regulatory responsibilities.

The implication for policy is simply to adopt a policy framework that will result in these outcomes.

Conclusion 3 relates to monitoring that:

- Is comprehensive and consistent across time and space,
- Provides high quality information for policy and management decisions, and
- Makes the information readily available for research and other purposes.

The implication for policy is to ensure that the policy direction and the resources needed are made available.

Conclusion 3a relates to mitigation for fish lost to the fisheries. Historically, the sense has been that increased artificial propagation would mitigate for production lost due to human activities in the watershed. While it can at some level, it is our technical conclusion that habitat restoration also needs to be part of a strategy for mitigating lost production of wild fish. It appears to the

IMST that artificial propagation is managed separately from programs that focus on habitat analysis, management, and restoration. We believe this approach is not technically sound, but that it can be addressed in the development of the strategic plan for artificial propagation referred to in conclusions 1 and 2.

Conclusions 2a and 3b relate to differences between hatchery and wild fish and the implications of these differences for the recovery of wild stocks. These conclusions deal with some highly technical matters, but they lead to recommendations with policy implications that deal first with direction and resource allocation to determine more precisely the significance of these differences, and secondly (depending on the outcomes) possibly a policy decision to maintain either careful separation of hatchery and wild stocks, or their integration.

Conclusion 3c relates to better determinations of survival from egg to adult and the use of these findings in the evaluation of specific hatchery programs. Other than as these relate to the three major conclusions (1-3), we see no particularly critical implications for policy.

Conclusions 1a and 1b relate to hatchery management such that it is consistent with the best current knowledge. Dealing with the policy implications of conclusion 1 is likely to provide the policy remedy needed for conclusions 1a and 1b. Our assumption is that the development of a comprehensive strategy for artificial propagation that is consistent with the goals of the Oregon Plan will result in the adoption and implementation of the recommendations from the other reports cited.

RECOMMENDATIONS

Based upon the three major conclusions above, the IMST makes the following recommendations, which are organized by the topics of the three major conclusions.

Conclusion 1: ODFW lacks an overarching policy/framework for hatchery management.

Recommendations

Recommendation 1. ODFW should develop a comprehensive plan/cohesive policy for hatchery management. Artificial propagation, the largest single program devoted to fish management in ODFW, needs a single coherent set of goals, policies, and Administrative Rules. This policy should provide:

- specific management objectives.
- strategic guidelines for the entire hatchery program and for the management of individual hatcheries.
- a link between hatchery objectives and management objectives.
- a link between hatchery management and the Oregon Plan.
- **strategies for mitigation of fish lost to the fisheries that include a combination of artificial propagation, habitat improvements, harvest management, and other appropriate strategies.**

The process of developing an overarching policy might be achieved in three steps:

1. Compile all of the existing policy statements and OARs.
2. Evaluate the policies to attain internal consistency.
3. Fill in the gaps to make a complete overarching policy.

Recommendation 2. ODFW should adopt and incorporate the recommendations of the independent science panels into statewide comprehensive policy. There is an abundance of technical and scientific information on artificial propagation, harvest, and other aspects of fisheries management for anadromous salmonids, including several major reviews of hatcheries in recent years. The findings from these provide a rich source of information. The fundamental concepts can be synthesized into a comprehensive hatchery management plan that will allow artificial propagation to be integrated into and used as a tool in the management of the fish and the ecosystem of which they are a part. To specifically incorporate the conclusions and recommendations of the three independent science panels' hatchery reviews, ODFW should:

- minimize the adverse affects of hatcheries on natural populations.
- adequately evaluate hatchery programs.
- link supplementation programs with habitat improvements.
- include genetic considerations in hatchery programs.
- eliminate stock transfers and introductions of non-native species.
- incorporate more experimental approaches into their artificial propagation program.

Recommendation 3. ODFW should tie the operation of hatcheries to explicit, measurable management objectives. The performance measures that track the achievement of these objectives should include a quantitative measure that relates directly to management purposes. This will provide a technically sound basis for policy and management decisions.

Recommendation 4. ODFW should implement the recommendations made in IMST's Workshop on Conservation Hatcheries and Supplementation in the assessment and revision of supplementation programs.

Conclusion 2: Many of Oregon's hatchery programs fall closer to the hatchery-specific approach than to the landscape approach. Current management strategies do not provide a cohesive approach to manage hatcheries from a landscape perspective.

Recommendations

Recommendation 5. ODFW should incorporate the landscape perspective into hatchery management. Hatcheries need to shift from the narrow, hatchery-specific end of the continuum to a broader landscape perspective that has been recognized by several independent panels. While some hatcheries may need to continue to operate with a hatchery-specific focus to meet their goals, in aggregate, a shift to a broader landscape perspective is needed. It appears that efforts within the department to begin the process of shifting hatchery management to a landscape perspective, mainly the drafting of Hatchery and Genetic Management Plans, are underway. These efforts would be aided by an overarching policy and statewide guidelines. As with any hatchery program, monitoring, evaluation, and continual adaptation to changing conditions are necessary for success. The shift towards a landscape perspective should include consideration of the following:

- the stream and ocean environment into which the hatchery fish are released, the effects of hatchery fish on other species, and the effects of hatchery fish on wild populations of the same and other species.
- natural fluctuations in climate and habitat conditions in freshwater and the ocean.
- metapopulation structure and dynamics and the role of a specific hatchery to emulate a core or a satellite population within a metapopulation.
- system wide measures of performance that include a hatchery(s) as part of the watershed need to be utilized.

Recommendation 6. ODFW should initially, give priority for change from the hatchery-specific to the landscape perspective consistent with the direction of this report to coastal and Lower Columbia system hatchery programs.

Recommendation 7. ODFW should support and participate in collaborative research efforts to determine the consequences of interactions between hatchery and wild fish. Few studies have tracked the effects of interactions between hatchery and wild fish on the long-term survival of wild populations. Studies to resolve the consequences of differences between hatchery and wild fish are long and difficult to accomplish. Potential collaborators include, but are not limited to:

- Oregon State University Agriculture Experiment Station
- Oregon State University
- Sea Grant
- Oregon Department of Fish and Wildlife
- Oregon Watershed Enhancement Board
- National Marine Fisheries Service
- Northwest Power Planning Council
- Bonneville Power Administration
- U.S. Fish and Wildlife Service
- Tribes
- Washington universities and state Agencies
- U.S. Army Corps of Engineers
- Portland General Electric

Recommendation 8. IMST should convene a workshop to clarify the state of knowledge on the differences between hatchery and wild fish and the implications to supplementation programs and the fitness of naturally-spawning populations.

Conclusion 3: Current monitoring and evaluation of hatchery programs is inadequate.

Recommendations

Recommendation 9. ODFW should strengthen the monitoring and evaluation of hatchery programs.

All artificial propagation programs need to monitor what occurs after fish are released from the hatchery, including smolt to adult survival, effects on wild fish of the target species, and effects on non-target species. Monitoring needs to be done at the watershed and individual hatchery levels to produce different types of information to accomplish hatchery-specific and landscape management goals.

Specifically this recommendation includes but is not limited to:

- **Develop and implement a program to monitor smolt to adult survival for hatchery and wild fish on a watershed basis.** Data on smolt to adult survival should be summarized by ODFW, made available, and used for adaptive management.
- **Monitoring smolt to adult survival at each individual hatchery program.**
- **Monitoring fry to adult survival in the STEP hatchbox program.**
- **Determining the effects of interactions between hatchery and wild fish outside the hatchery.**
- **Placing monitoring data in an accessible, user-friendly database**. Data needed for assessment of hatchery programs and adaptive management decisions, such as egg to smolt or smolt to adult survival data, must be easily accessible for use in research and management and in policy analysis.

Recommendation 10. ODFW should establish an explicit process for adaptive management that makes effective use of the results from monitoring programs. Each artificial propagation program should assess risks through a formal process. These risks must be addressed through adaptive management. For example, ODFW needs to assess the existence of hatchery and wild fish on the spawning grounds and the consequences of these interactions.

Monitoring and evaluation are essential to adaptive management. However, determining the extent of monitoring and evaluation programs is a dilemma because, while they are very valuable, they require the allocation of scarce financial and human resources. The following approach helps determine what needs to be done, given that there is a limit to the amount of monitoring and evaluation that can be done:

a. Describe artificial propagation programs at the hatchery and at the landscape level in measurable management objectives that are meaningful within the context of the Oregon Plan.
b. Establish the variables that can be measured and will be used to represent the management objectives.
c. Measure and evaluate the variables with an intensity that will allow evaluation of the degree to which the management objectives are being attained, within some established level of certainty.

The measurable management objective is a matter of policy. Selecting the variable(s) that will represent it is a technical/scientific matter as are the methods used for data collection and analysis. The level of certainty required is a policy not a scientific question, but it should be established as the result of an active (rather than a passive) decision.

REFERENCES

Bayer, R. D. 1986. Seabirds near an Oregon estuarine salmon hatchery in 1982 and during the 1983 El Nino. Fish. Bull. **84**: 279-286.

Beamish, R.J. and Bouillon, D.R. 1993. Pacific salmon production trends in relation to climate. Can. J. Fish. Aquat. Sci. **50**: 1002-1016.

Beamish, R.J., Neville, C.-E.M., and Cass, A.J. 1997. Production of Fraser River sockeye salmon (*Oncorhynchus nerka*) in relation to decadal-scale changes in the climate and the ocean. Can. J. Fish. Aquat. Sci. **54**: 543-554.

Beiningen, K. T. 1976. Fish runs. Section E in Investigative Reports of Columbia River Fisheries Project. Pacific Northwest Regional Commission, Vancouver, Washington.

Berejikian, B.A., Tezak, E.P., Schroder, S.L., Knudsen, C.M., and Hard, J.J. 1997. Reproductive behavioral interactions between wild and captively reared coho salmon (*Oncorhynchus kisutch*). ICES J. Mar. Sci. **54**: 1040-1050.

Bottom, D.L. 1997. To till the water - a history of ideas in fisheries conservation. *In* Pacific salmon and their ecosystems: status and future options. *Edited by* D.J. Stouder, P.A. Bisson, and R.J. Naiman. Chapman and Hall, New York. pp. 569-597.

Bowles, E.C. 1995. Supplementation: Panacea or curse for the recovery of declining fish stocks? Am. Fish. Soc. Symp. **15**: 277-283.

Bradford, M.J. 1995. Comparative review of Pacific salmon survival rates. Can. J. Fish. Aquat. Sci. **52**: 1327-1338.

Bugert, R.M. 1998. Mechanics of supplementation in the Columbia River. Fisheries **23**: 11-20.

Busack, C.A. and Currens, K.P. 1995. Genetic risks and hazards in hatchery operations: Fundamental concepts and issues. Am. Fish. Soc. Symp. **15**: 71-80.

Byrne, A., Bjornn, T.C., and McIntyre, J.D. 1992. Modeling the response of native steelhead to hatchery supplementation programs in an Idaho River. N. Am. J. Fish. Manage. **12**: 62-78.

Calaprice, J.R. 1969. Production and genetic factors in managed salmonid populations. *In* Symposium on salmon and trout in streams. *Edited by* T.G. Northcote. H.G. MacMillan Lectures in Fisheries, Institute of Fisheries, The University of British Columbia, Vancouver, British Columbia, Canada. pp. 377-388.

Campton, D.E. 1995. Genetic effects of hatchery fish on wild populations of Pacific salmon and steelhead: What do we really know? Am. Fish. Soc. Symp. **15**: 337-353.

Candy, J.R. and Beacham, T.D. 2000. Patterns of homing and straying in southern British Columbia coded-wire tagged chinook salmon (*Oncorhynchus tshawytscha*) populations. Fish. Res. **47**: 41-56.

Carmichael, R., Parker, S. and Whitesel, T. 1998. Status review of the chinook salmon hatchery program in the Imnaha River, Oregon. Oregon Department of Fish and Wildlife, La Grande, Oregon.

Chilcote, M.W., Leider, S.A., and Loch, J.J. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Trans. Am. Fish. Soc. **115**: 726-735.

Chilcote, M. 1998. Conservation status of steelhead in Oregon. Information Report 98-3. Oregon Department of Fish and Wildlife, Portland, Oregon.

Chilcote, M.W. 1999. Conservation status of Lower Columbia River coho salmon. Information Report 99-3. Oregon Department of Fish and Wildlife, Portland, Oregon.

Clark, J. and McCarl B. 1983. An investigation of the relationship between Oregon coho salmon (*Oncorhynchus kisutch*) hatchery releases and adult production utilizing law of the minimum regression. Can. J. Fish. Aquat. Sci. **40**: 516-523.

Cobb, J.N. 1930. Pacific salmon fisheries. Bureau of Fisheries Document No. 1092, Washington, D.C.

Columbia Basin Fish and Wildlife Authority (CBFWA). 1988. Review of the history, development, and management of anadromous fish production facilities in the Columbia River Basin. Columbia Basin Fish and Wildlife Authority, Portland, Oregon.

Columbia Basin Fish and Wildlife Authority (CBFWA). 1990. Review of the history, development, and management of anadromous fish production facilities in the Columbia River Basin. Columbia Basin Fish and Wildlife Authority, Portland, Oregon.

Coronado, C. and Hilborn, R. 1998. Spatial and temporal factors affecting survival in coho and fall chinook salmon in the Pacific Northwest. Bull. Mar. Sci. **62**: 409-425.

Cuenco, M.L. 1994. A model of an internally supplemented population. Trans. Am. Fish. Soc. **123**: 277-288.

Einum, S. and Fleming, I.A. 1997. Genetic divergence and interactions in the wild among native, farmed and hybrid Atlantic salmon. J. Fish Biol. **50**: 634-651.

Emlen, J.M., Reisenbichler, R.R., McGie, A.M., and Nickelson, T.E. 1990. Density-dependence at sea for coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. **47**: 1765-1772.

Flagg, T.A., Waknitz, F.W., Maynard, D.J., Milner, G.B., and Mahnken, C.V.W. 1995. The effect of hatcheries on native coho salmon populations in the lower Columbia River. Am. Fish. Soc. Symp. **15**: 366-375.

Flagg, T.A. and Nash, C.E. 1999. A conceptual framework for conservation hatchery strategies for Pacific salmonids. U.S. Dept. Commer. NOAA Tech. Memo. NMFS-NWFSC-38.

Fleming, I.A. and Gross, M.R. 1993. Breeding success of hatchery and wild coho salmon (O*ncorhynchus kisutch*) in competition. Ecol. Appl. **3**: 230-245.

Fleming, I.A. and Gross, M.R. 1994. Breeding competition in a Pacific salmon (coho: Oncorhynchus kisutch): Measures of natural and sexual selection. Evolution **48**: 637-657.

Fleming, I.A., Hindar, K., Mjølnerød, I.B., Jonsson, B., Balstad, T., and Lamberg, A. 2000. Lifetime success and interactions of farm salmon invading a native population. Proc. R. Soc. Lond. **267**: 1517-1523.

Garrison, R.L. and Rosentreter-Peterson, N. 1979. Stock assessment and genetic studies of anadromous salmonids. Federal Aid Progress Reports, Fisheries. Oregon Department of Fish and Wildlife, Portland, Oregon.

Gresswell, R.E., Liss, W.J. and Larson, G.L. 1994. Life-history organization of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) in Yellowstone Lake. Can. J. Fish. Aquat. Sci. **51**: 298-309.

Grossman, G.D., Hill, J., and Petty, J.T. 1995. Observations on habitat structure, population regulation, and habitat use with respect to evolutionarily significant units: A landscape perspective for lotic systems. Am. Fish. Soc. Symp. **17**: 381-391.

Hanski, I. 1991. Single-species metapopulations dynamics: Concepts, models, and observations. Biol. J. Linnean Soc. **42**: 17-38.

Hanski, I. and Gilpin, M. 1991. Metapopulation dynamics: Brief history and conceptual domain. Biol. J. Linnean Soc. **42**: 3-16.

Hard, J.J. 1995. Genetic monitoring of life-history characters in salmon supplementation: Problems and opportunities. Am. Fish. Soc. Symp. **15**: 212-225.

Hard, J.J., Berejikian, B.A., Tezak, E.P., Schroder, S.L., Knudsen, C.M., and Parker, L.T. 2000. Evidence for morphometric differentiation of wild and captively reared adult coho salmon: A geometric analysis. Environ. Biol. Fishes **58**: 61-73.

Hare, S.R., Mantua, N.J., and Francis, R.C. 1999. Inverse production regimes: Alaska and West Coast Pacific salmon. Fisheries **24**: 6-14.

Harrison, S. 1991. Local extinction in a metapopulation context: An empirical evaluation. Biol. J. Linnean Soc. **42**: 73-88.

Harrison, S. 1994. Metapopulations and conservation. *In* Large-scale ecology and conservation biology. *Edited by* P.J. Edwards, R.M. May, and N.R. Webb. Blackwell Scientific Publications, Oxford, England.

Hatchery Scientific Review Group. 2000. Scientific framework for artificial propagation of salmon and steelhead (draft). Puget Sound and Coastal Washington Hatchery Reform Project, Seattle, Washington.

Hayden, M.V. 1930. History of the salmon industry of Oregon. Master's thesis, University of Oregon, Eugene, Oregon.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). *In* Pacific salmon life histories. *Edited by* C. Groot and L. Margolis. University of British Columbia Press, Vancouver, British Columbia, Canada. pp. 311-393.

Healey, M.C. and Prince, A. 1995. Scales of variation in life history tactics of Pacific salmon and the conservation of phenotype and genotype. Am. Fish. Soc. Symp. **17**: 176-184.

Hemmingsen, A.R., Holt, R.A., Ewing, R.D., and McIntyre, J.D. 1986. Susceptibility of progeny from crosses among three stocks of coho salmon to infection by *Ceratomyxa shasta*. Trans. Am. Fish. Soc. **115**: 492-495.

Hilborn, R. and Eggers, D. 2000. A review of the hatchery programs for pink salmon in Prince William Sound and Kodiak Island, Alaska. Trans. Am. Fish. Soc. **129**: 333-350.

Hillman, T.W. and Mullan, J.W. 1989. Effect of hatchery releases on the abundance and behavior of wild juvenile salmonids. *In* Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington: Final report to Chelan County Public Utility District, Washington. *Edited by* Don Chapman Consultants, Inc. Don Chapman Consultants, Inc., Boise, Idaho. pp. 265-285.

Hindar, K., Ryman, N., and Utter, F. 1991. Genetic effects of cultured fish on natural fish populations. Can. J. Fish. Aquat. Sci. **48**: 945-957.

Hostick, G.A. and McGie, A.M. 1974. Growth and survival of juvenile coho salmon introduced into Floras Lake, Oregon. Coastal Rivers Investigation Information Report 73-9. Fish Commission of Oregon, Portland, Oregon.

Hublou, W.F. and Jones, I.W. 1970. 1960-67 broods of fall chinook, spring chinook, coho and chum salmon and steelhead trout. Fish Commission of Oregon hatchery production summaries. Fish Commission of Oregon, Portland, Oregon.

Independent Multidisciplinary Science Team (IMST). 1998. Review of the Hatchery Measures in the Oregon Plan for Salmon and Watersheds. Report 1998-1 to the Oregon Plan for Salmon and Watersheds. Governor's Watershed Enhancement Board. Salem, Oregon.

Independent Multidisciplinary Science Team (IMST). 1999. Recovery of wild salmonids in Western Oregon forests: Oregon Forest Practices Act rules and the measures in the Oregon Plan for Salmon and Watersheds. Technical Report 1999-1 to the Oregon Plan for Salmon and Watersheds, Governor's Natural Resources Office, Salem, Oregon.

Independent Multidisciplinary Science Team (IMST). 2000a. Conservation hatcheries and supplementation strategies for recovery of wild stocks of salmonids: Report of a workshop. Technical Report 2000-1 to the Oregon Plan for Salmon and Watersheds, Governor's Natural Resources Office, Salem, Oregon.

Independent Multidisciplinary Science Team (IMST). 2000b. Salmon abundances and effects of harvest: Implications for rebuilding stocks of wild coho salmon in Oregon. Technical Report 2000-3 to the Oregon Plan for Salmon and Watersheds, Oregon Watershed Enhancement Board Office, Salem, Oregon.

Independent Scientific Advisory Board (ISAB). 2000. Consistency of the Council's artificial production policies and implementation strategies with multi-species framework principles and scientific review team guidelines. ISAB APR Report No. 2. Northwest Power Planning Council and National Marine Fisheries Service, Portland, Oregon.

Independent Scientific Group (ISG). 1996. Return to the river: Restoration of salmonid fishes in the Columbia River. Northwest Power Planning Council, Portland, Oregon.

Integrated Hatchery Operations Team (IHOT). 1995. Policies and Procedures for Columbia Basin Anadromous Salmonid Hatcheries. Annual Report 1994 to Bonneville Power Administration. Contract 92B160629, Project 92-043. BPA Report DOE/BP-60629 Portland, Oregon.

Kallio-Nyberg, I. and Koljonen, M.-L. 1997. The genetic consequence of hatchery-rearing on life-history traits of the Atlantic salmon (*Salmo sala*r L.): A comparative analysis of sea-ranched salmon with wild and reared parents. Aquaculture **153**: 207-224.

Kapuscinski, A.R. 1997. Rehabilitation of Pacific salmon in their ecosystems: What can artificial propagation contribute? *In* Pacific salmon and their ecosystems: Status and future options. *Edited by* D.J. Stouder, P.A. Bisson, and R.J. Naiman. Chapman and Hall, New York. pp. 493-509.

Kincaid, H.L. 1993. Selective breeding and domestication. *In* Genetic conservation of salmonid fishes. *Edited by* J.G. Cloud and G.H. Thorgaard. Plenum Press, New York. pp. 307-309.

Knudsen, E.E., MacDonald, D.D., and Steward, C.R. 2000. Setting the stage for a Pacific salmon fisheries strategy. *In* Sustainable fisheries management: Pacific salmon. *Edited by* E.E. Knudsen, C.R. Steward, D.D. MacDonald, J.E. Williams, and D.W. Reiser. CRC Press LLC, Boca Raton, Florida. pp. 3-13.

Kohane, M.J. and Parsons, P.A. 1988. Domestication: Evolutionary change under stress. Evol. Biol. **23**: 31-48.

Kostow, K. 1999. A framework for evaluating the risks and benefits of hatchery programs and developing program designs [draft].

Lawson, P. W. 1993. Cycles in ocean productivity, trends in habitat quality, and the restoration of salmon runs in Oregon. Fisheries **18**(8): 6-10.

Leider, S.A., Hulett, P.L., Loch, J.J., and Chilcote, M.W. 1990. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the returning adult stage. Aquaculture **88**: 239-252.

Li, H.W., Currens, K., Bottom, D., Clarke, S., Dambacher, J., Frissell, C., Harris, P., Hughes, R.M., McCullough, D., McGie, A., Moore, K., Nawa, R., and Thiele, S. 1995. Safe havens: Refuges and evolutionarily significant units. Am. Fish. Soc. Symp. **17**: 371-380.

Lichatowich, J. 1993. Ocean carrying capacity: Recovery issues for threatened and endangered Snake River Salmon. Bonneville Power Administration, Technical Report 6 of 11, DOE/BP-99654-6, U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon.

Lichatowich, J. 1997. Evaluating salmon management institutions: The importance of performance measures, temporal scales, and production cycles. *In* Pacific salmon and their ecosystems: Status and future options. *Edited by* D.J. Stouder, P.A. Bisson, and R.J. Naiman. Chapman and Hall, New York. pp. 69-87.

Lichatowich, J. 1999. Salmon without rivers. Island Press, Covelo, California.

Lichatowich, J. A. and McIntyre, J.D. 1987. Use of hatcheries in the management of Pacific anadromous salmonids. Am. Fish. Soc. Symp. **1**: 131-136.

Lichatowich, J.A., Mobrand, L.E., Costello, R.J., and Vogel, T.S. 1996. A history of frameworks used in the management of Columbia River chinook salmon. A report prepared for Bonneville Power Administration included in Report DOE/BP 33243-1, Portland, Oregon.

Matson, R. G., and Coupland, G. 1995. The prehistory of the northwest coast. Academic Press, New York.

Maynard, D.J., Flagg, T.A., and Mahnken, C.V.W. 1995. A review of seminatural culture strategies for enhancing the postrelease survival of anadromous salmonids. Am. Fish. Soc. Symp. **15**: 307-314.

McCarl, B.A. and Rettig, R.B. 1983. Influence of hatchery smolt releases on adult salmon production and its variability. J. Fish. Res. Board Can. **40**: 1880-1886.

McGie, A.M. 1983. Commentary: Short-term climatic variability in the northeast Pacific Ocean. *In* The influence of ocean conditions on the production of salmonids in the North Pacific. *Edited by* W.G. Pearcy. Oregon State University Sea Grant, Corvallis, Oregon, ORESU-W-83-001. pp. 37-49.

McIsaac, D. 1977. Success of unfed coho fry plants in Canyon, Lawton, and Gibbons creeks. Washington Department of Fisheries. Unpublished memo to Dick Laramie, March 25, 1977.

McMichael, G.A., Pearsons, T.N., and Leider, S.A. 1999. Behavioral interactions among hatchery-reared steelhead smolts and wild *Oncorhynchus mykiss* in natural streams. N. Am. J. Fish. Manage. **19**: 948-956.

McMichael, G.A., Pearsons, T.N., and Leider, S.A. 2000. Minimizing ecological impacts of hatchery-reared juvenile steelhead trout on wild salmonids in a Yakima Basin watershed. *In* Sustainable fisheries management: Pacific salmon. *Edited by* E.E. Knudsen, C.R. Steward, D.D. MacDonald, J.E. Williams, and D.W. Reiser. CRC Press LLC, Boca Raton, Florida. pp. 365-380.

Moring, J.R. and Lantz, R.L. 1975. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part I – Biological studies. Oregon Department of Fish and Wildlife, Fishery Research Report no. 9.

Mundy, P.R., Backman, T.W.H., and Berkson, J.M. 1995. Selection of conservation units for Pacific salmon: Lessons from the Columbia River. Am. Fish. Soc. Symp. **17**: 28-40.

National Fish Hatchery Review Panel (NFHRP). 1994. Report of the National Fish Hatchery Review Panel. The Conservation Fund, Arlington, Virginia.

National Marine Fisheries Service (NMFS). 1938. Mitchell Act. 16 U.S.C. 755-757.

National Marine Fisheries Service (NMFS). 1993. Interim policy on artificial propagation of Pacific salmon under the Endangered Species Act. Federal Register **58**: 17573-17576.

National Marine Fisheries Service (NMFS). 1999a. Biological opinion on artificial propagation in the Columbia River Basin - Incidental take of listed salmon and steelhead from federal and non-federal hatchery programs that collect, rear and release unlisted fish species. Endangered Species Act Section 7 Consultation. March 29, 1999.

National Marine Fisheries Service (NMFS). 1999b. Endangered and Threatened Species; Proposed Rule Governing Take of Threatened Snake River, Central California Coast, South/Central California Coast, Lower Columbia River, Central Valley California, Middle Columbia River, and Upper Willamette River Evolutionarily Significant Units (ESUs) of West Coast Steelhead. Federal Register **64**: 73479-73506.

National Marine Fisheries Service (NMFS). 2000a. Endangered and Threatened Species; Final Rule Governing Take of 14 Threatened Salmon and Steelhead Evolutionarily Significant Units (ESUs). Federal Register **65**: 42422-42481.

National Marine Fisheries Service (NMFS). 2000b. Endangered and Threatened Species; Proposed Rule Governing Take of Seven Threatened Evolutionarily Significant Units (ESUs) of West Coast Salmonids: Oregon Coast Coho; Puget Sound, Lower Columbia and Upper Willamette Chinook; Hood Canal Summer-run and Columbia River Chum; and Ozette Lake Sockeye. Federal Register **65**: 170-196.

National Research Council (NRC). 1996. Upstream: Salmon and society in the Pacific Northwest. Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, National Academy of Science, Washington, D.C.

Nickelson, T.E. 1986. Influences of upwelling, ocean temperature, and smolt abundance on marine survival of coho salmon (*Oncorhynchus kisutch*) in the Oregon production area. Can. J. Fish. Aquat. Sci. **43**: 527-535.

Nickelson, T.E. and Lawson, P.W. 1998. Population viability of coho salmon, *Oncorhynchus kisutch*, in Oregon coastal basins: Application of a habitat-based life cycle model. Can. J. Fish. Aquat. Sci. **55**: 2383-2392.

Nickelson, T.E. and Lichatowich, J.A. 1983. The influence of the marine environment on the interannual variation in coho salmon abundance: An overview. *In* The influence of ocean conditions on the production of salmonids in the North Pacific. *Edited by* W.G. Pearcy. Oregon State University Sea Grant, Corvallis, Oregon, ORESU-W-83-001. pp. 24-36.

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

Noble, R.L., Jackson, J.R., Irwin, E.R., Phillips, J.M., and Churchill, T.N. 1994. Reservoirs as landscapes: Implications for fish stocking programs. Trans. 59th No. Am. Wildl. & Natur. Resour. Conf. **59**: 281-288.

Northwest Power Planning Council (NWPPC). 1999. Artificial production review. Report and recommendations of the Northwest Power Planning Council. Council document 99-15.

Oregon Administrative Rule (OAR) 635-007-0510. 1992. Fish Management Goals.

Oregon Administrative Rule (OAR) 635-007-0515. 1992. Management Plans.

Oregon Administrative Rule (OAR) 635-007-0522. 1992. General Policies for Natural Production Management.

Oregon Administrative Rule (OAR) 635-007-0523. 1992. Operating Principles for Natural Production Management.

Oregon Administrative Rule (OAR) 635-007-0524. 1990. Implementation of Natural Production Rules.

Oregon Administrative Rule (OAR) 635-007-0526. 1990. General Policies of Wild Fish Management.

Oregon Administrative Rule (OAR) 635-007-0527. 1992. Operating Principles for Wild Fish Management.

Oregon Administrative Rule (OAR) 635-007-0536. 1992. General Policies for Wild Fish Gene Conservation.
Oregon Administrative Rule (OAR) 635-007-0537. 1992. Operating Principles for Wild Fish Gene Conservation.
Oregon Administrative Rule (OAR) 635-007-0540. 1992. General Policies for Hatchery Fish Gene Conservation.
Oregon Administrative Rule (OAR) 635-007-0541. 1992. Implementation of Hatchery Fish Gene Conservation.
Oregon Administrative Rule (OAR) 635-007-0800. 1990. Maintenance of Genetic Variability.
Oregon Administrative Rule (OAR) 635-007-0805. 1990. Depressed Wild Stocks of Salmon.
Oregon Administrative Rule (OAR) 635-007-0810. 1984. Salmon Size and Time at Release.
Oregon Administrative Rule (OAR) 635-007-0815. 1990. Salmon Release Program.
Oregon Administrative Rule (OAR) 635-007-0817. 1997. Priority of Fish Releases.
Oregon Administrative Rule (OAR) 635-007-0820. 1997. Salmon Production Programs.
Oregon Administrative Rule (OAR) 635-007-0825. 1997. When Salmon Eggs are Surplus.
Oregon Administrative Rule (OAR) 635-009-0110. 1988. Project Application.
Oregon Administrative Rules (OARs) 635-500-0002 to 635-500-3880. 1986-1997. Fish Management Plans.
Oregon Department of Fish and Wildlife (ODFW). 1982. Comprehensive plan for production and management of Oregon's anadromous salmon and trout. Part II. Coho salmon plan. Oregon Department of Fish and Wildlife, Portland, Oregon.
Oregon Department of Fish and Wildlife (ODFW). 1997a. Alsea River Basin fish management plan. Oregon Department of Fish and Wildlife, Portland, Oregon.
Oregon Department of Fish and Wildlife (ODFW). 1997b. Strategic Operational Plan. 15 pp.
Oregon Department of Fish and Wildlife (ODFW). 1998. Fish propagation program: Oregon Department of Fish and Wildlife. Presentation to the Independent Multidisciplinary Science Team, April 8, 1998.
Oregon Department of Fish and Wildlife (ODFW). 1999a. Coastal Salmonid and Willamette Trout Hatchery Program Review - Draft Final Report.
Oregon Department of Fish and Wildlife (ODFW). 1999b. Fish Hatchery Purposes, Goals, and Objectives. 15 pp.
Oregon Department of Fish and Wildlife (ODFW) and National Marine Fisheries Service (NMFS). 1998. Final assessment of risk associated with the harvest management regime of the Thirteenth Amendment to the Pacific Coast Salmon Plan. October 1998, Portland, Oregon.
Oregon Department of Fish and Wildlife (ODFW) and U.S. Fish and Wildlife Service. 1996. Operation Plans for Anadromous Fish Production Facilities in the Columbia River Basin. Volume II - Oregon. Annual Report 1995 to Bonneville Power Administration. Contract DE-B179-91BP60629, Project 92-043, (BPA Report DOE/BP-60629-10), Portland, Oregon. 365 electronic pages.
Oregon Department of Fish and Wildlife (ODFW) and Washington Department of Fish and Wildlife (WDFW). 1995. Columbia River fish runs and fisheries, 1939 - 1994. Oregon Department of Fish and Wildlife, Clackamas, Oregon.
Oregon Plan. 1997. Oregon Plan for Salmon and Watersheds (consisting of the Oregon Coastal Salmon Restoration Initiative, March 10, 1997 and as amended with the Steelhead Supplement, December 1997). Governor's Natural Resources Office, State of Oregon, Salem, Oregon.

Oregon State Fish and Game Protector. 1896. Third and fourth annual reports of the State Fish and Game Protector of the State of Oregon, 1895-1896. State of Oregon, Salem, Oregon.

Pacific Fishery Management Council (PFMC). 1992. Review of the 1991 ocean salmon fisheries. Pacific Fishery Management Council, Portland, OR.

Peery, C.A. and Bjornn, T.C. 1996. Small-scale investigations into chinook salmon supplementation strategies and techniques: 1992-1994. Technical Report 96-3 for Idaho Supplementation Studies Project. Idaho Department of Fish and Game and Bonneville Power Administration, Portland, Oregon.

Phillips, J.L., Ory, J., and Talbot, A. Anadromous salmonid recovery in the Umatilla River Basin, Oregon: A case study. J. Am. Water Resour. Assoc. In press.

Piggins, D.J. and Mills, C.P.R. 1985. Comparative aspects of the biology of naturally produced and hatchery-reared Atlantic salmon smolts (*Salmo salar* L.). Aquaculture **45**: 321-333.

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

Quinn, T.P., Nemeth, R.S., and McIsaac, D.O. 1991. Homing and straying patterns of fall chinook salmon in the Lower Columbia River. Trans. Am. Fish. Soc. **120**: 150-156.

Reeves, G.H., Benda, L.E., Burnett, K.M., Bisson, P.A., and Sedell, J.R. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. Am. Fish. Soc. Symp. **17**: 334-349.

Regional Assessment of Supplementation Project (RASP). 1992. Supplementation in the Columbia Basin: Summary report series. Final Report DOE/BP-01830-14, Bonneville Power Administration, Portland, Oregon.

Reisenbichler, R.R. and McIntyre, J.D. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, *Salmo gairdneri*. J. Fish. Res. Board Can. **34**: 123-128.

Reisenbichler, R.R. and McIntyre, J.D. 1986. Requirements for integrating natural and artificial production of anadromous salmonids in the Pacific Northwest. *In* Fish culture in fisheries management. *Edited by* R.H. Stroud. Fish Culture Section and Fisheries Management Section of the American Fisheries Society, Bethesda, Maryland. pp. 365-374.

Reisenbichler, R.R. and Phelps, S.R. 1989. Genetic variation in steelhead (*Salmo gairdneri*) from the North Coast of Washington. Can. J. Fish. Aquat. Sci. **46**: 66-73.

Reisenbichler, R.R. and Rubin, S.P. 1999. Genetic changes from artificial propagation of Pacific salmon affect the productivity and viability of supplemented populations. ICES J. Mar. Sci. **56**: 459-466.

Richards, C. and Cernera, P.J. 1989. Dispersal and abundance of hatchery-reared and naturally spawned juvenile chinook salmon in an Idaho stream. N. Am. J. Fish. Manage. **9**: 345-351.

Rieman, B.E. and McIntyre, J.D. 1993. Demographic and habitat requirements for conservation of bull trout. General Technical Report. INT-302, USDA Forest Service, Intermountain Research Station, Ogden, Utah.

Rieman, B.E. and McIntyre, J.D. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Trans. Am. Fish. Soc. **124**: 285-296.

Rothfus, L.O., Erho, M.W., Remmington, J.D., and Hamilton, J.A.R. 1974. Experimental rearing of coho salmon in Speelyai Creek, Washington. Pacific Power and Light Co., Draft report.

Salo, E.O. and Bayliff, W.H. 1958. Artificial and natural production of silver salmon, *Oncorhynchus kisutch*, at Minter Creek, Washington. Washington Department of Fisheries, Research Bulletin no. 4.

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). *In* Pacific salmon life histories. *Edited by* C. Groot and L. Margolis. University of British Columbia Press, Vancouver, British Columbia, Canada. pp. 397-445.

Schalk, R. 1986. Estimating salmon and steelhead usage in the Columbia Basin before 1850: The anthropological perspective. Northwest Environ. J. **2**(2): 1-29.

Schlosser, I.J. 1991. Stream fish ecology: A landscape perspective. BioScience **41**: 704-712.

Schlosser, I.J. and Angermeier, P.L. 1995. Spatial variation in demographic processes of lotic fishes: Conceptual models, empirical evidence, and implications for conservation. Am. Fish. Soc. Symp. **17**: 392-401.

Scientific Review Team (SRT), Independent Scientific Advisory Board. 1998. Review of artificial production of anadromous and resident fish in the Columbia River Basin. Part I: A Scientific basis for Columbia River production programs. Northwest Power Planning Council. Document no. 98-33, Northwest Power Planning Council, Portland, Oregon.

Seiler, D. 1989. Differential survival of Grays Harbor Basin anadromous salmonids: Water quality implications. *In* Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. *Edited by* C.D. Levings, L.B. Holtby, and M.A. Henderson. Can. Spec. Publ. Fish. Aquat. Sci. no. 105. pp. 123-135.

Smith, E.V. 1919. Fish culture methods in the hatcheries of the State of Washington. Washington State Fish Commissioner, Olympia, Washington.

Smith, E.M., Miller, B.A., Rodger, J.D. and Buckman, M.A. 1983. Outplanting anadromous salmonids: A literature study. Report DOE/Bp23109-1, Bonneville Power Administration, Portland Oregon.

Smoker, W.W., Bachen, B.A., Freitag, G., Geiger, H.J., and Linley, T.J. 2000. Alaska ocean ranching contributions to sustainable salmon fisheries. *In* Sustainable fisheries management: Pacific salmon. *Edited by* E.E. Knudsen, C.R. Steward, D.D. MacDonald, J.E. Williams, and D.W. Reiser. CRC Press LLC, Boca Raton, Florida. pp. 407-420.

Solazzi, M.F., Nickelson, T.E., Johnson, S.L., and Rodgers, J.D. 1999. Final Report: Development and evaluation of techniques to rehabilitate Oregon's wild salmonids. Study 1. Evaluation of the STEP hatchbox (fry release) program. Oregon Department of Fish and Wildlife. Fish Division Final Report F-125-R-13. Portland, Oregon. Available: http://osu.orst.edu/Dept/ODFW/freshwater/salmonidhab/docs/study1a.pdf

Utter, F.M., Chapman, D.W., and Marshall, A.R. 1995. Genetic population structure and history of chinook salmon of the Upper Columbia River. Am. Fish. Soc. Symp. **17**: 149-165.

Viola, A.E. and Schuck, M.L. 1995. A method to reduce the abundance of residual hatchery steelhead in rivers. N. Am. J. Fish. Manage. **15**: 488-493.

Wade, M.G. 1987. The relative effects of *Ceratomyxa shasta* on crosses of resistant and susceptible stocks of summer steelhead. Master's thesis, Oregon State University, Corvallis, Oregon.

Wallis, J. 1961. An evaluation of the Coos River hatchery. Oregon Fish Commission Research Laboratory, Clackamas, Oregon.

Wallis, J. 1963a. An evaluation of the Alsea River salmon hatchery. Oregon Fish Commission Research Laboratory, Clackamas, Oregon.

Wallis, J. 1963b. An evaluation of the Siletz River salmon hatchery. Oregon Fish Commission Research Laboratory, Clackamas, Oregon.

Wallis, J. 1963c. An evaluation of the Trask River salmon hatchery. Oregon Fish Commission Research Laboratory, Clackamas, Oregon.

Wallis, J. 1963d. An evaluation of the Klaskanine River salmon hatchery. Oregon Fish Commission Research Laboratory, Clackamas, Oregon.
Wallis, J. 1963e. An evaluation of the Big Creek salmon hatchery. Oregon Fish Commission Research Laboratory, Clackamas, Oregon.
Wallis, J. 1966. An evaluation of the Sandy River salmon hatchery. Oregon Fish Commission Research Laboratory, Clackamas, Oregon.
Wallis, J. 1968. Recommended time, size and age for release of hatchery reared salmon and steelhead trout. Fish Commission of Oregon, Research Division, Clackamas, Oregon.
Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: Lessons from the Pacific Northwest. Can. J. Fish. Aquat. Sci. **48**: 124-133.
Washington Department of Fisheries and Game (WDFG). 1921. Thirtieth and thirty-first annual reports of the State Fish Commissioner to the Governor of the State of Washington. Olympia, Washington.
Whitaker, H. 1896. Some observations of the moral phases of modern fish culture. Transactions of the American Fisheries Society, 24th Annual Meeting. June 12-13, 1895, 59-74, Thos Humphrey, New York.
White, R.J., Karr, J.R., and Nehlsen, W. 1995. Better roles for fish stocking in aquatic resource management. Am. Fish. Soc. Symp. **15**: 527-547.
Whitesel, T. and three others. 1998. Summer steelhead in the Imnaha River Basin, Oregon. Oregon Department of Fish and Wildlife. La Grande, Oregon.
Wright, S. 1981. Contemporary Pacific salmon fisheries management. N. Am. J. Fish. Manage. 1: 29-40.

Appendix A

Recommendations for Artificial Propagation from Other Scientific Reviews

Independent Scientific Group (ISG). 1996. Return to the river: restoration of salmonid fishes in the Columbia River ecosystem. Northwest Power Planning Council, Portland, Oregon.

1. Use of artificial propagation to restore depleted salmon populations should be preceded by an assessment of the risks, and supplementation applications must be accompanied with a well-designed and adequately funded monitoring and evaluation program.
2. There are three questions that need to be answered in evaluating the hatchery program: Do the artificially propagated fish contribute to the fishery and/or escapement and is the economic benefit of that contribution greater than its cost? Has the program achieved its objective; i.e., has it replaced lost natural production if it is a mitigation hatchery? Has the operation of the hatchery incurred costs to natural production? The first and the third questions are related in that a meaningful cost-benefit analysis should include ecological costs. Most evaluations of hatchery programs, when they have been carried out, attempted to answer the first question. Information needed to answer the second and third questions has in most cases not [been] collected or has been of poor quality. The Fish and Wildlife Program (FWP) should require evaluation which adequately answers all three questions for all funded hatcheries.
3. The FWP should include a valid comprehensive evaluation of the role of artificial propagation in the Columbia Basin. The evaluation should cover the entire 120-year history of the program and include direct and indirect, positive and negative effects. For example, the evaluation should include a discussion of the role that heavy reliance on hatcheries has had on habitat degradation in the tributaries and mainstems and the contribution of hatcheries to the extinction and depletion of naturally producing stocks in the basin. The comprehensive evaluation should also include an assessment of the adequacy of existing monitoring to answer ecological questions.
4. The FWP should include as a separate measure a comprehensive evaluation of the mitigation hatcheries in the basin. What were their objectives, did they achieve their objectives, and if not, why not?
5. The region needs to develop an interim policy regarding the operation and harvest management of production from each hatchery where monitoring has been inadequate to complete a comprehensive evaluation. The interim policy should be designed to minimize the ecological costs of the hatchery until he evaluation can be carried out.
6. The objectives of each hatchery need to be evaluated and redefined if necessary. The objectives should be established within the contexts of the subbasin where the hatchery operates, and our conceptual foundation with particular reference to rebuilding of populations and metapopulations. The hatchery’s objectives need to be integrated and defined by the rebuilding objectives of the subbasin. The objectives should consider nontarget species and the existence of metapopulation structure of the target species.
7. Artificial propagation must be treated as an experiment, with hypotheses related to uncertainties, experimental design, analysis, and integration of results with available knowledge consistent with the adaptive management provisions of the FWP.
8. The decision about when and where to use supplementation programs should take into account the principles of the metapopulation concept.
9. Existing hatchery populations may prove to be valuable genetic resources in the future and may prove useful in programs that attempt to rebuild salmon populations and metapopulation structure in the basin.
10. Hatchery populations should be evaluated for evidence of selection, and changes in fitness or genetic diversity associated with residence in the hatchery environment.

National Research Council (NRC). 1996. Upstream: salmon and society in the Pacific Northwest. Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, National Academy of Science, Washington, D.C.

1. The approach to hatchery operations should be changed in accordance with the goal of rehabilitation and the ecological and genetic ideas that inform the goal.
    a. The term "supplementation" as a goal of hatchery programs should be abandoned.
    b. Hatcheries should be dismantled, revised, or reprogrammed if they interfere with a comprehensive rehabilitation strategy designed to rebuild wild populations of anadromous salmon to sustainability.
    c. Hatcheries should be rigorously audited for their ability to prevent demographic, genetic, fish-health, behavioral, physiological, and ecological problems.
2. All hatchery programs should adopt a genetic-conservation goal of maintaining genetic diversity that exists between and within hatchery and naturally spawning populations.
    a. Intentional artificial selection should be discouraged.
    b. Genetic and ecological guidelines, based on the most up-to-date information base, are needed for all aspects of hatchery operations.
    c. Hatchery programs should avoid intentional transplantation of fish and unnatural patterns of straying by adult returns.
3. All hatchery fish should receive identifiable marks.
4. Decision-making about uses of hatcheries should occur within the context of fully implemented adaptive-management programs that focus on watershed management, not just on the fish themselves.

Scientific Review Team, Independent Scientific Advisory Board. 1998. Review of artificial production of anadromous and resident fish in the Columbia River Basin. Part I: A Scientific basis for Columbia River production programs. Northwest Power Planning Council. Document no. 98-33.

1. Linking supplementation with habitat improvements, and monitoring of hatchery programs are required through formal studies and increased emphasis on hatchery related research.
2. Stock transfer should be eliminated from hatchery programs, except in those situations where the purpose is to restore an extirpated run.
3. Continue using and developing technology to more closely resemble natural incubation and rearing conditions in hatchery propagation to include:
    a. incubation in substrate and darkness
    b. incubation at lower densities
    c. rearing at lower densities
    d. rearing with shade cover available
    e. exposure to in-pond, natural-like habitat
    f. rearing in variable, higher velocity habitat
    g. non-demand food distribution during rearing
    h. exposure to predator training
    i. minimize fish-human interaction
    j. acclimation ponds at release sites
    k. volitional emigration from release sites
4. New hatchery facilities need to be incorporated in hatchery programs that are designed and engineered to represent natural incubation and rearing habitat, simulating incubation and rearing experiences complementary with expectations of wild fish in natural habitat.

5. New hatchery technology for improving fish quality and performance needs to have a plan for implementation and review at all hatchery sites where appropriate to assure its application.
6. Genetic and breeding protocols consistent with local stock structure need to be developed and faithfully adhered to as a mechanism to minimize potential negative hatchery effects on wild populations and to maximize the positive benefits that hatcheries can contribute to the recovery and maintenance of salmonids in the Columbia ecosystem.
7. Hatchery propagation should use large breeding populations to minimize inbreeding effects and maintain what genetic diversity is present within the population.
8. To mimic natural populations, hatchery production strategy should target natural population parameters in size and timing among emigrating juveniles to synchronize with environmental selective forces shaping natural population structure.
9. Hatchery policy should utilize ambient natal stream habitat temperatures to reinforce genetic compatibility with local environments and provide the temporal synchrony between stock and habitat that is responsible for population structure of stocks from which hatchery fish are generated.
10. Hatchery incubation and rearing experiences should use the natal stream water source whenever possible, to enhance homestream recognition when supplementation projects are designed for natural populations.
11. Hatchery release strategies need to follow standards that accommodate reasonable numerical limits determined by the carrying capacity of the receiving stream to accommodate residence needs of nonmigrating members of the release population. Standards should include impact consideration on the wild fish residing in the system, and should be based on life history requirements of the cultured stock.
12. New hatchery programs should dedicate significant effort in developing small [facilities] designed for specific stream sites where supplementation and enhancement objectives are sought, using local stocks and ambient water in the facilities designed around engineered habitat to simulate the natural stream, whenever possible.
13. Hatchery supplementation programs must avoid using strays in breeding operations with returning fish. Stock hybridization breaks down genetic homeostasis and disrupts adaptive linkages, which lowers the fitness of the local stock and defeats the objective.
14. Restoration of extirpated populations should follow genetic guidelines to maximize the potential for reestablishing self-sustaining populations. Once initiated, subsequent effort must concentrate on allowing selection to work, by discontinuing introductions.
15. Germ plasm repositories be developed to preserve genetic diversity for application in future recovery and restoration projects in the Basin, and to maintain a gene bank to reinforce diversity among small inbred natural populations.
16. The physical and genetic status of all natural populations of anadromous and resident salmonids need to be understood and routinely reviewed as the basis of management planning for artificial production. Information should include life history, population structure, and the habitat utilized.
17. An in-hatchery fish monitoring program needs to be developed on performance of juveniles under culture, including genetic assessment to ascertain if breeding protocol is maintaining wild stock genotypic characteristics.
18. A hatchery fish monitoring program needs to be developed on performance from release to return, including information on survival success, interception distribution, behavior, and genotypic changes experienced from selection between release and return.

19. A study is required to determine cost of monitoring hatchery performance, and source of funding.
20. Regular performance audits of artificial production objectives should be undertaken, and where they are not successful, research should be initiated to resolve the problem.
21. The Northwest Power Planning Council should appoint an independent peer review panel, to develop a Basin-wide artificial production program plan to meet he ecological framework goals for hatchery management.

National Fish Hatchery Review Panel (NFHRP). 1994. Report of the National Fish Hatchery Review Panel. The Conservation Fund, Arlington, Virginia.

1. The primary mission of fish hatcheries into the next century will be to provide fish for support of ecosystem management and habitat restoration activities.
2. Artificial propagation should **not** be used as a substitute for an aggressive program of habitat restoration or as an alternative to habitat protection.
3. Since protection and restoration of habitat is considered to be the key to perpetuation of our national fishery resources, governmental agencies and private organizations should coordinate their efforts to restore the habitat of depleted native stocks, rather than to rely on hatchery fish to compensate for habitat losses.
4. When federally-produced fish are used to stock waters built with federal funds, the obligation should end as soon as self-sustaining populations are achieved or it is determined that such populations are not possible.
5. Any stocking of propagated fish in ecosystem resource management, in the restoration of depleted stocks, or in the perpetuation of threatened and endangered species should only be done in areas where it has been determined that suitable habitat, and adequate food base, and appropriate spawning areas are available, based on specific analyses and implementation plans. An appropriate inland and marine harvest regime should be an agreed upon element of an ecosystem management plan.
6. All stocking of fish in waters on federal lands should be consistent with an approved aquatic ecosystem resource management plan that precludes deleterious competitive and genetic effects of the stocked fish on native species. This will require identification of unique species, stocks or strains, threatened or depleted stocks, or endangered species. If stocking is part of the management effort, fish from the wild populations should be used as broodstock to help maintain genetic diversity and to keep planted stocks from over-running the native genetic stock. When a decision is made that species or stocks should be brought into captivity, fish health personnel should be involved from the outset so that vital data on disease status, habitat requirements, behavior, and spawning habits will be available when needed.
7. Hatcheries within a region should be evaluated for their compatibility with resource and ecosystem management needs. Some criteria are:
    a. Is the hatchery's current role consistent with ecosystem management goals?
    b. Is the facility operation mandated under mitigation, tribal, or treaty obligations?
    c. Can the hatchery produce any of the species complex needed? If so, which species and how many?
    d. Is it cost effective and efficient?
    e. Is the facility or part of it sufficiently flexible that it could readily be adapted for production of other and non-traditional organisms, if necessary or appropriate?
    f. Can all or part of the facility be used as a center for aquatic ecosystem assessment, restoration, or management projects?

g. Is the facility in good physical condition? Can it be renovated to make "state of the art"?
h. Can the hatchery and products be demonstrated as to not be disruptive to the ecosystem structure and functions?

8. All mitigation hatcheries should be reviewed critically to determine if the original mitigation goal is being achieved. If suitable habitat no longer exists with no likelihood of restoration, the type of needed mitigation may differ greatly from the original concept.
9. Adoption of the concept of using native populations in an ecosystem as broodfish will require knowledge of the health status of wild fish.
10. After-stocking evaluations should be conducted to test how well hatchery-produced fish achieved program goals (returns, harvest, survival to spawning, impacts on endemic species, etc.).

National Marine Fisheries Service (NMFS) 1999. Biological opinion on artificial propagation in the Columbia River Basin - Incidental take of listed salmon and steelhead from federal and non-federal hatchery programs that collect, rear and release unlisted fish species. Endangered Species Act Section 7 Consultation. March 29, 1999.

1. Minimize inter-basin stock transfers in any waters that support listed fish.
2. Operate artificial propagation programs for fishery augmentation/mitigation in the Columbia River Basin in a manner that emphasizes the production and release of juveniles that are ready to migrate to the ocean and spend a minimum amount of time in the fresh water environment. This should minimize interactions with, and thus impacts to listed salmon and steelhead, and unlisted natural fish in the migration corridor.
3. Adopt measures to improve homing and reduce straying of all hatchery releases.
4. Evaluate the use of NATURES type rearing designs and strategies, to increase survival and minimize impacts to listed salmon and steelhead.
5. The use of acclimation ponds and volitional release strategies should be considered to reduce potential straying and minimize potential competition between hatchery fish and listed salmon and steelhead.
6. Consider monitoring and evaluating ecological interactions between listed salmon and steelhead and hatchery releases in nursery and rearing areas. Evaluating the [effects] of hatchery fish is prudent because density dependent effects may occur even when the streams' estimated carrying capacity is not limited.
7. Support studies designed to assess carrying capacity and density-dependent effects on listed salmon and steelhead in the migration corridor.
8. Consider monitoring and evaluating predation by residualized hatchery steelhead. Alternative methods/schemes to reduce steelhead residualism should be explored to minimize impacts to listed salmon and steelhead.
9. Spawning ground carcass surveys should be conducted to determine the composition of listed and hatchery fish on the spawning grounds of listed salmon and steelhead.
10. Consider using excess hatchery adult returns for instream carcass distribution to increase nutrients, where necessary in the freshwater environment.
11. Use the most appropriate broodstock for re-introduction of salmon and steelhead into historical or vacant habitat.
12. Implement a program to develop a cost-effective externally distinguishable mark(s), which can be applied to all hatchery fish released into the Columbia River Basin. This would allow the discrimination between hatchery fish and those of wild/natural origin, including listed salmon and steelhead. This should assist in minimizing adverse effects and assist in

evaluating the effects of hatchery programs on listed salmon and steelhead and unlisted natural fish.

13. When hatchery programs are located in an area where wild fish are listed, the hatchery program should be modified to adopt a conservation role along with an enhancement role.
14. Adopt management strategies to separate returning hatchery fish from listed naturally spawning fish including, but not limited to, releasing hatchery fish outside primary spawning and rearing areas and dead-ending returns at weirs.

Northwest Power Planning Council (NWPPC). 1999. Artificial Production Review. Report and recommendations of the Northwest Power Planning Council. Council document 99-15.

<u>Suggested Guidelines on Hatchery Practices, Ecological Integration and Genetics</u>

1. Technology should be developed and used to more closely resemble natural incubation and rearing conditions in salmonids hatchery propagation. In developing hatchery technology, hatchery programs should work toward the goal of providing environments that resemble natural conditions during artificial propagation. These may include:
    - Incubation in substrate and darkness;
    - Incubation at lower densities;
    - Rearing at lower densities;
    - Rearing with shade cover available;
    - Exposure to in-pond, natural-like habitat;
    - Rearing in variable, higher velocity habitat;
    - Non-demand food distribution during rearing;
    - Exposure to predator training;
    - Minimize fish-human interaction;
    - Acclimation ponds at release sites;
    - Volitional emigration from release sites.
2. Hatchery facilities need to be designed and engineered to represent natural incubation and rearing habitat, simulating incubation and raring experiences complementary with expectations of wild fish in natural habitat.
3. New hatchery technology for improving fish quality and performance needs to have a plan for implementation and review at all hatchery sites, where appropriate, to assure its application.
4. To mimic natural populations, anadromous hatchery production strategy should target natural population parameters in size and timing among emigrating anadromous juveniles to synchronize with environmental forces shaping natural population structure.
5. To mimic natural populations, resident hatchery production strategy should target population parameters in size and release timing of hatchery-produced resident juveniles to correspond with adequate food availability and favorable prey to maximize their post-stocking growth and survival.
6. Supplementation hatchery policy should utilize ambient natal stream habitat temperatures to reinforce genetics compatibility with local environmental and provide the linkage between stock and habitat that is responsible for population structure of stocks from which hatchery fish are generated.
7. Salmonid hatchery incubation and rearing experiences should use the natal stream water source whenever possible to enhance homestream recognition.

8. Hatchery release strategies need to follow standards that accommodate reasonable numerical limits determined by the carrying capacity of the receiving stream to accommodate residence needs of non-migrating members of the release population.
9. Hatchery programs should dedicate significant effort in developing small facilities designed for specific stream sites where supplementation and enhancement objectives are sought, using local stocks and ambient water in the facilities designed around engineered habitat to simulate the natural stream, whenever possible.
10. Genetic and breeding protocols consistent with local stock structure need to be developed and faithfully adhered to as a mechanism to minimize potential negative hatchery effects on wild populations and to maximize the positive benefits that hatcheries can contribute to the recovery and maintenance of salmonids in the Columbia ecosystem.
11. Hatchery propagation should use large breeding populations to minimize inbreeding effects and maintain what genetics diversity is present within the population.
12. Hatchery supplementation programs should avoid using strays in breeding operations with returning fish.
13. Restoration of extirpated populations should follow genetic guidelines to maximize the potential for re-establishing self-sustaining populations. Once initiated, subsequent effort must concentrate on allowing selection to work by discontinuing introductions.
14. Germ plasm repositories should be developed to preserve genetic diversity for application in future recovery and restoration projects in the basin, and to maintain a gene bank to reinforce diversity among small inbred natural populations.
15. The physical and genetic status of all natural populations of anadromous and resident fishes need to be understood and routinely reviewed as the basis of management planning for artificial production.
16. An in-hatchery fish monitoring program needs to be developed on performance of juveniles under culture, including genetic assessment to ascertain if breeding protocol is maintaining wild stock genotypic characteristics.
17. A hatchery fish monitoring program needs to be developed on performance from release to return, including information on survival success, interception distribution, behavior, and genotypic changes experienced from selection between release and return.
18. A study is required to determine cost of monitoring hatchery performance and sources of funding.
19. Regular performance audits of artificial production objectives should be undertaken, and where they are not successful, research should be initiated to resolve the problem.
20. The NPPC should appoint an independent peer review panel to develop a basinwide artificial production program plan to meet the ecological framework goals for hatchery management of anadromous and resident species.

<u>Policies to Guide the Use of Artificial Production</u>

1. The manner of use and value of artificial production must be considered in the context of the environment in which it will be use[d].
2. Artificial production must be implemented within an experimental, adaptive management design that includes an aggressive program to evaluate benefits and address scientific uncertainties.
3. Hatcheries must be operated in a manner that recognizes that they exist within ecological systems whose behavior is constrained by large-scale basin, regional and global factors.
4. A diversity of life history types and species needs to be maintained in order to sustain a system of populations in the face of environmental variation.

5. Naturally selected populations should provide the model for successful artificially reared populations, in regard to population structure, mating protocol, behavior, growth, morphology, nutrient cycling, and other biological characteristics.
6. The entities authorizing or managing a[n] artificial production facility or program should explicitly identify whether the artificial propagation product is intended for the purpose of augmentation, mitigation, restoration, preservation, research, or some combination of those purposes for each populations of fish addressed.
7. Decisions on the use of artificial production tools need to be made in the context of deciding on fish and wildlife goals, objectives and strategies at the subbasin and province levels.
8. Appropriate risk management needs to be maintained in using the tool of artificial propagation.
9. Production for harvest is a legitimate management objective of artificial production but to minimize adverse impacts on natural populations associated with harvest management of artificially produced populations, harvest rates and practices must be dictated by the requirements to sustain naturally spawning populations.
10. Federal and other legal mandates and obligations for fish protection, mitigation, and enhancement must be fully addressed.

Independent Multidisciplinary Science Team (IMST). 2000. Conservation hatcheries and supplementation strategies for recovery of wild stocks of salmonids: report of a workshop. Technical Report 2000-1 to the Oregon Plan for Salmon and watersheds. Oregon Watershed Enhancement Board. Salem, Oregon.

<u>Workshop Summary: Major points that emerged during the workshop.</u>

Overview and Conceptual Framework

1. Supplementation is part of a suite of strategies (e.g., habitat enhancement and restoration, changes in land use, changes in fish harvest activities, removing impediments to fish passage) that may be used together for recovery of wild salmonid populations.
2. When possible, limiting factors (e.g., ecological or habitat conditions, impediments to fish passage) should be addressed before implementing a supplementation program.
3. Supplementation may help to maintain a gene pool but is not likely to lead to recovery of salmonid populations unless the root causes of decline are addressed.
4. Supplementation is still in experimental stages; alternative strategies for meeting the goals of a particular project should be considered before supplementation is used.
5. During the design, implementation, and monitoring of supplementation, programs should, as much as possible, utilize what is know about wild salmonid life cycles while developing and testing supplementation strategies and tactics.
6. Clearly defined goals and monitoring of their attainment a re important to the success of supplementation programs.

Assessment and Design of Supplementation Programs

1. The population status of the target population is a prime factor in considering supplementation. Supplementation efforts of greater risk can be tolerated in areas where the current probability of existing population/stock survival is very low.
2. Risks and benefits should be evaluated before implementing a supplementation program.
3. Supplementation might be implemented to provide “genetic conservation” while other measures (e.g., habitat improvement) that will greatly improve the chances of success of a supplementation program over the long term are also being implemented.
4. Ideally, supplementation should end when recovery goals are met.

Methods

1. It is extremely important to identify areas with suitable habitat and underutilized carrying capacity when choosing supplementation as a tool to aid recovery of salmonid populations.
2. Supplementation should be placed in an ecosystem context. Important considerations include carrying capacity, the connectivity of the population, the impacts on existing populations/stocks and on other species, levels of adult returns, as well as additional ecological factors.
3. Preservation of genotypic and phenotypic diversity is extremely important when stocks are selected or developed for supplementation. Domestication selection should be minimized. Use "local broodstocks" or an appropriate alternative to minimize divergence from the wild population. When possible, allow for a natural range in the diversity of life history patterns.

Evaluation

1. Monitoring and evaluation are essential to assessing whether supplementation was successful and goals of a particular program were met. This requires adequate experimental design and "references or controls" for comparisons.
2. Abundance, stock productivity, ecological and genetic diversity, and fish distribution data are all important when evaluating the results and/or success of supplementation.
3. Due to the inherent cost and limitations of monitoring programs, monitoring efforts will be most efficient, and will provide the most comprehensive information, when coordinated among agencies.

Appendix B

Summary of Policies Regarding the Artificial Propagation of Fishes in Oregon

Appendix B: Summary of Policies Regarding the Artificial Propagation of Fishes in Oregon

The overriding objective of the Department is the protection of wild fish populations (ODFW 1999a). "It is the first priority of the Department to sustain wild fish populations. Introduction of hatchery fish will be made when consistent with Department policy, where there are measurable sport and commercial benefits, and where returns are cost effective" (ODFW 1997b). "Hatchery produced salmon shall be programmed, reared, and released in such a manner as to achieve the optimum harvest of the hatchery product while protecting natural production and the genetic resources of wild fish" (OAR 635-007-0815 1990). The Department currently has the following fish management goals: 1) Prevent serious depletion of any indigenous fish species; 2) Naturally producing fish populations should be managed to take advantage of natural habitat productive capacity; 3) Hatchery fish should be managed for maximum benefit of consumptive users; and 4) Fish productivity losses from habitat degradation should be addressed through habitat restoration, not long-term harvest restrictions (OAR 635-007-0510 1992).

Under these general guidelines, the following policies provide direction to Oregon's artificial propagation program.

Management Plans

Management plans establish goals, objectives, and operating principles for the management of species, waters, or areas. These plans are developed by ODFW and are used to implement state fish management policies for specific hatchery programs (OAR 635-007-0515 1992). OARs 635-500-0002 to 635-500-3880 (1986-1997) provide objectives and links between harvest policy, enhancement policy, and other management goals. In addition to fish management plans, basin plans give additional direction to some hatchery programs, listing specific policies, objectives, and actions (ODFW 1999a).

Natural Production Policy

The natural production policy states that the policy of the fish commission is to protect and promote natural production of indigenous and, "where desirable, foreign fishes" (OAR 635-007-0522 1992). Hatchery programs are to be designed to make full use of the potential for enhancement of natural production, where there is an existing hatchery program and the potential for enhancement exists (OAR 635-007-0523 1992). The Department shall oppose introductions that allow competition, predation, or disease to prevent meeting natural production goals (OAR 635-007-0523 1992). Natural production rules are implemented through ODFW basin plans (OAR 635-007-0524 1990).

Wild Fish Management Policy

The Wild Fish Management Policy states that "protection of genetic resources shall be the priority in the management of wild fish" (OAR 635-007-0526 1990), and genetic variability of salmon stocks should be maintained in both wild and hatchery fish. ODFW will oppose actions that allow mortality from competition, predation, or disease that could cause a population to experience a decline in abundance that could reduce the number of spawners to 300 breeding fish. If a population has been depressed to 300 or fewer spawners, the Department will advocate measures to correct the cause of the population decline (OAR 635-007-0527 1992). If appropriate, a sudden loss of genetic variation within a wild fish population shall be mitigated (OAR 635-007-0527 1992).

Interbreeding between hatchery fish and wild fish of the same species poses risks to conserving the genetic resources of wild populations. Therefore, naturally spawning hatchery fish shall be limited by the number of fish in the natural spawning population and by genetic characteristics (OAR 635-007-0527 1992). Consistent with the Wild Fish Management Policy operating principles

(OAR 635-007-0527 1992), if hatchery fish are released in an area where there is an existing wild fish population of the same species, the number of hatchery fish in the naturally spawning population must be limited to less than 50% of the naturally spawning population and: 1) originate from wild fish belonging to the population; 2) incorporate at least 30% wild fish, on average, every brood year; 3) limit the take from the wild donor population to 25% or less in any year; 4) include no artificial genetic changes; 5) maintain wild-type phenotypes in hatchery fish; and 6) the hatchery program should include annual monitoring and assessment of the above criteria every ten years. The greater the deviation of the hatchery program from the above requirements, the more limited the allowable number of hatchery fish spawning in the natural population will become. However, there may be exceptions to the above rules associated with "special rehabilitation programs" to restore depressed wild populations. In addition, to limit or prevent species hybridizations, OAR 635-007-0527 (1992) states that non-indigenous hatchery fish shall not be released where species hybridizations could occur.

Wild Fish Gene Resource Conservation Policy

The Wild Fish Gene Resource Conservation Policy states that, to prevent the depletion of wild fish, genetic diversity shall be maintained (OAR 635-007-0536 1992). Wild fish are composed of gene conservation groups (populations or groups of populations in which there are measurable genetic differences due to low gene flow among groups) that contain one or more breeding populations. "The loss of any gene conservation group shall be considered by the Department to constitute a serious depletion of that species" (OAR 635-007-0537 1992).

Hatchery Fish Gene Resource Management Policy

The Hatchery Fish Gene Resource Management Policy states that: 1) hatchery fish populations should be managed to maintain genetic diversity, assure that the populations meet the management objectives for which they are produced, and maintain their optimum biological and economic value (OAR 635-007-0540 1992); 2) management objectives will be developed and implemented as part of basin plans for all state hatchery programs; and 3) the development of objectives should be followed by the development of operational guidelines to accomplish the objectives and maintain the genetic resources of the hatchery populations (OAR 635-007-0541 1992).

Salmon Management Policies

To maintain genetic variability in hatchery programs, breeding programs should be designed to maintain diversity in migration timing, spawning timing, age at maturity, and age specific size (OAR 635-007-0800 1990). Depressed wild populations of salmon may be rehabilitated or supplemented with hatchery fish to optimize natural production in the future, if this is consistent with wild fish management (OAR 635-007-0805 1990).

Hatchery Policies

Several policies guide the number, timing, and location of fish released from hatcheries. The number of hatchery fish spawning with wild fish and the number of hatchery fish released into waters managed for wild fish will be limited. Releases will be authorized annually (OAR 635-007-0817 1997), and summaries of releases will be prepared each year (OAR 635-007-0820 1997). Monitoring and evaluation occur under the wild fish management policy. Salmon smolts must be released at a size and time at which they are expected to move directly into the ocean. However, presmolts and fry may be released to supplement natural production, and adult salmon may be released in underseeded streams to supplement or rehabilitate natural spawning/production (OAR

635-007-0810 1984). Department fish culture staff must authorize moving fish between facilities or releasing fish (OAR 635-007-0820 1997).

There are both general and biological limitations for hatchery production that determine when the state's fish production needs have been met. Biological limitations include carrying capacity, probability of disease transfer, maintenance of genetic integrity or compatibility of stocks, and impacts of other species of fish. After all natural and artificial fish production needs are met, remaining salmon eggs can be declared surplus (OAR 635-007-0825 1997).

Salmon and Trout Enhancement Program (STEP)

STEP projects may include egg incubation, fish propagation, broodstock development, and fish stocking (OAR 635-009-0110 1988).

Other Policies

NMFS Policies

In addition to the state guidelines, NMFS provides rules governing the take of federal endangered and threatened species evolutionarily significant units (NMFS 1999b; NMFS 2000a; NMFS 2000b). These rules provide additional genetic guidelines for hatcheries.

Mitchell Act

The Mitchell Act (NMFS 1938) calls for the establishment of hatcheries in the Columbia River Basin.

Oregon Plan for Salmon and Watersheds

Many measures in the Oregon Plan (Oregon Plan 1997) also provide policy direction to Oregon's hatcheries.

ODFW-II.A.1 Implement wild fish management strategies

ODFW-II.A.2 Reduce hatchery steelhead and coastal hatchery coho smolt releases

ODFW-II.A.3 Develop management objectives for each hatchery program, including genetic guidelines

ODFW-II.A.4 Mark all hatchery steelhead and coho

ODFW-II.B.1 Utilize hatcheries to rebuild wild runs

ODFW-IV.B.4 Use hatchery carcasses to increase stream nutrient levels

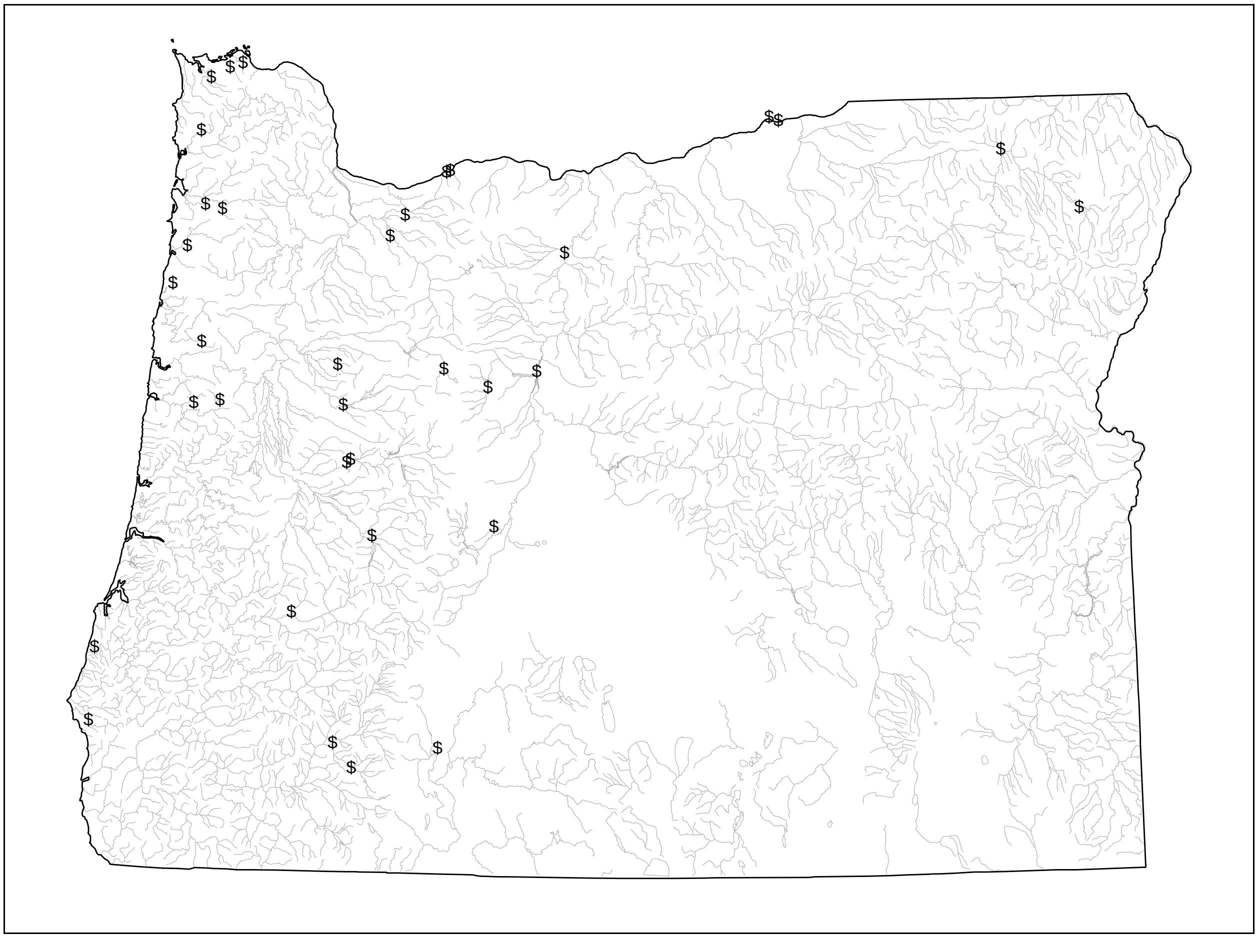
Columbia Basin Hatcheries

The Integrated Hatchery Operations Team (IHOT) coordinates hatchery operations in the Columbia River Basin and sets regional standards for hatchery operations. Policies include eliminating disease importation, minimizing ecological interactions that adversely affect the productivity of aquatic ecosystems, and maintaining adequate genetic variation in populations to protect the biological diversity of wild, natural, and cultured anadromous salmonid populations (IHOT 1995). The Operation Plans for Anadromous Fish Production Facilities in the Columbia River Basin (ODFW and U.S. Fish and Wildlife Service 1996) provides operation plans and objectives for individual hatcheries in the Columbia Basin.

Appendix C:

Map of Locations of State Hatcheries in Oregon

Appendix C:
Map of Locations of State Hatcheries in Oregon



Note: There is a discrepancy between the fish hatchery location data on ODFW's web site, which shows 35 hatcheries, and other ODFW documents, which state that the Department currently operates only 34 hatcheries.

Data sources:
State Boundary: USGS, 1:2,000,000; 11/17/00
Oregon Spatial Data Library, Oregon Department of Administrative Services
Political Boundary Data Sets; http://www.sscgis.state.or.us/data/themes.html

Rivers: EPA- 1:250,000; 11/17/00
Oregon Spatial Data Library, Oregon Department of Administrative Services
Natural Thematic Data Sets; http://www.sscgis.state.or.us/data/themes.html

Oregon Fish Hatcheries, 2/16/00
from ODFW web page, http://rainbow.dfw.state.or.us/data.html