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CALIFORNIA GENE RESOURCE CONSERVATION PROGRAM
2855 Telegraph Avenue, Suite 216 Berkeley, California 94705 (415) 540-0226
A Program of the National Council on Gene Resources

MEMORANDUM

DATE: July 13, 1982

TO: Reviewers

FROM: David Kafton, Ph.D.
Program Director

RE: Reviewers of Anadromous Salmonid Genetic Resources -- An Assessment and Plan for California

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The California legislature recently voted to continue the California Gene Resources Program this next fiscal year. Opportunities exist now for members of our staff to work with you and with other members of the salmonid community in attempts to implement the recommendations contained in the enclosed document. We certainly look forward to working with you this next year.

Due to time constraints of the program, we have had to sacrifice some depth and ~~time~~ for review. Nevertheless, this assessment and plan should accurately cover the major gene resources related needs and issues, and the proposed plan should be both practical and supportable. Taking these factors into consideration we would appreciate your prompt review of the assessment, primarily for its coverage and accuracy, and the plan for its practicality and priorities. We will not be able to respond to your comments in the document if they are received after July 23. Please feel free to call us.

We shall contact you soon to determine your interest in implementing the proposed plan for managing salmonid genetic resources.

Thank you for your participation and assistance.

Department of Fishery and Wildlife Biology

Colorado State University
Fort Collins, Colorado
80523

22 July 1982

Dr. David Kafton
California Game Resource Conserv. Prog.
2855 Telegraph Avenue, Suite 216
Berkeley, CA 44705

Review of: Anadromous Salmonid Genetic Resources

P. 1-2 illustrates the great economic benefits from application of genetic research--but all examples are of domesticated agricultural species. What must be emphasized here, that makes anadromous salmonid genetics very different from the typically cited examples of "genetic improvement," is the fact that domesticated plants and animals respond to artificial selection in a controlled environment throughout their life cycle, whereas anadromous salmonids (unless raised for market under aquaculture conditions) undergoing hatchery selection are released to be subjected to 2-3 years of natural selection. How "genetically improved" are the most productive strains of wheat, corn, and barley, if all cultivation, irrigation, pesticides, and herbicides are removed from their environment and the artificially selected strains left to compete with wild species?

I would suggest the role of genetics be delineated in the plan in relation to 1. wild stocks, 2. hatchery rearing for release and natural selection for part of the life cycle, and 3. aquaculture, where the entire life cycle is in a controlled environment. The role of artificial selection is very different in the three cases. With 1, the goal would be to avoid genetic change from artificial selection and hybridization with hatchery fish; with 2, the goal would be to select for traits that yield the best survival and growth but at the same time to select for traits that would allow maximum harvest of hatchery fish while avoiding hybridization and overexploitation of wild stocks using the same river for spawning; with 3, the principles of agricultural genetics apply.

On p. 2-2 the stock concept is discussed and it is concluded that in California there is insufficient data to apply the stock concept of management. This theme is developed throughout, but I failed to find just how this data would be obtained and how it would be used once it was obtained.

A basic assumption is made in the text that each run of an anadromous species homing to a particular river or segment of a drainage with different life history attributes can be considered as a "stock." I would certainly agree with this, but the logical conclusion of characterizing the genetic diversity of the stocks by this simple method of assembling all information on distinct runs known to exist in California is never made. What concerns me here is that the report sets the stage for a massive genetic characterization study based on electrophoretic data as a basis for stock management. The committee should be fully aware that the intraspecific genetic relationships of stocks are extremely close and dangerously false conclusions might be made in situations where no consistent quantified genetic differentiation can be demonstrated. For example, Chilcote et al. 1980, Trans. Am. Fish. Soc. 109:203-206, found no consistent differences in allelic frequencies between summer-run and winter-run steelhead trout in the Kalama R., Washington, and concluded that the Washington Dept. of Game should reevaluate the separate stock status of summer and winter steelhead trout. I obtained the annual reports of the Kalama R. project and the most significant aspect I found was that the native runs of steelhead are continuing to exist in the Kalama River. For 30 years the river has been heavily stocked with non-native hatchery steelhead. Up to 80% of the spawning run in some years are of hatchery origin. Although no consistent differences were found between native summer and winter run fish, there is a gene locus that can differentiate about 50% of the summer-run hatchery fish. Hatchery steelhead do spawn and the "hatchery gene" occurs in young-of-the year steelhead, but these fish are eliminated by the following year prior to smolting and seaward migration. The point is, that the native summer and winter run steelhead of the Kalama River are valuable stocks that should be preserved but their genetic characterization can only be made indirectly from manifestation of life history differences.

Also, in the upper Snake River drainage, Wyoming, two "stocks" of cutthroat trout exist that are phenotypically and ecologically very distinct. Loudenslager and Kitchin, 1979, Copeia (4):673-679, could find no differentiation between these two stocks from an assessment of 26 gene loci.

Todd, 1981, Can. J. Fish. Aquat. Sci. 38:1808-1813, discusses genetic studies of Great Lake ciscoes where both inter and intraspecific variability, extremely important for stock management, bears no resemblance to genetic characterization by allelic frequency data.

I urge that the information for stock characterization first be made on the basis of known differences in life history traits--home spawning area; time of run, size-age variability of run, etc. before more intensive genetic characterization is carried out--it is a matter of arranging the cart and the horse in the most logical sequence. Thus, for priority 8 (p. 7-26) "Facilitate research to scientifically document genetic diversity that exists within and among species populations," I would like to be kept informed on the details of this "research" development--precisely what would be done and precisely how would the information be used once it was obtained. That is, what would we know then that we don't already know now?

P. 3-7 discusses the superiority of native stocks over non-native introduced stocks, and then mentions an apparent contradiction--the successful introduction of salmon into the Great Lakes and New Zealand. These examples are certainly not contradictions, the non-native salmon established in the Great Lakes and New Zealand had no native populations of their species to compete with, so they were successful. A comparable situation occurs in Glacier National Park where I have been involved in a research project with Fred Allendorf (Univ. Montana, performing electrophoretic studies). Over many years, millions of cutthroat trout from Yellowstone Lake were introduced into Glacier Park lakes. In lakes originally barren of fish, the Yellowstone trout is successfully established and thrives. In lakes with native cutthroat trout (two subspecies of S. clarki are involved), we find no Yellowstone trout nor evidence of a hybrid influence--that is, strong natural selection favors the native cutthroat trout in its native environments over non-native cutthroat trout, and the success of Yellowstone trout in previous barren lakes supports, not contradicts this hypothesis. Thus, it should not be assumed that because a river system has a long history of stocking, for example steelhead trout, that the native runs have been significantly influenced by non-native genes.

I would point out a useful reference I did not see listed in the reference section: Ryman, N. (ed.) 1980. Fish gene pools. Ecol. Bull. 34. Publ. by FRN Box 6710, S-11385 Stockholm, Sweden.

A distribution map (fig. A-12) contains errors. The symbols for *S. c. henshawi* and *S. c. seleniris* are reversed. *S. c. pleuriticus* never occurred in the lower Colorado River (Snyder's old reference to the Salton Sea is based on introduced rainbow trout). How authentic are the data on which other maps are based?

Sincerely,

Robert J. Behnke
Associate Professor,
Fishery Biology

RJB:pt
Enclosure

cc: Mr. Richard May
Mr. James Mullan

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San Francisco, CA 94126

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Review of: Anadromous Salmonid Genetic Resources

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(5)

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Nugent - Rec. Plan

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Sincerely,

1-2 - Yes, but all Agri. select breed. -
controlled environment throuout life -
culture, irrigate, pesticide, herbicides - not so w/ salmonids
- 2 aspects - wild & hatchery aquaculture (pen rearing)

2.2 - Paucity of genetic data on coho, chinook, steelhead, cutthroat wrong - one of best studied
* Ryman's book —— besides citation - look at Campton, Utter,
- any other group so characterized?

What good when get data?? - may relate to differentiation unless, but worse day -
may be 'real' summer - winter run - but undetected in
limited loci examined - ex. Kalama R. study - - unless
not related to life history attributes - - - characterize of
significant manifestations of genetic diversity -
- S.R. - cutts - Leary, Kitchen
Yellowstone L. - st... 'biol. complex' systems - very import. - not detected - salmonids very sl. ...
genetic diff. only apparent in life history traits - - -

Thorgaard - 2N 60, 62, 64 vi Calif. and 58 - -
3-7 - NO! - not contradiction - no
competition from native pop. at own ...
- McMillan Bloedel - ex - Glacier Park - Arrow L. - Grace L. - Trout L.
- Glacier P - Allendorf

* - Sweden 2. ... S. salar - dif stocks dif size - age - -
genetic chan - it no dif - wrong ... S.R. cutts
what if dif. ... - then only age - -
obvious that reprod. isol. - heredit. basis - some grow large ...
- also Kootenay L. - RIB.
review - 1972 - Wash. - steelhead hatch. 1955 - ... → 5 million
catch when was before - question raised 1920 - Kalama
supports - but TAFS pub. - weak apology for business as usual

3-10 - ex situ - hatch. prop. - will change - Allendorf Phelps
- Ryman.
→ Baltic see trout - Ferguson
~~T...~~ E-3A - N 1 Z ~~wrong~~ origin - ref correct.

anglers

commercial fish

– reality – Oncorhynchus little concern if hatch. or wild, now steelhead & no commercial fish – anglers divided

– thus, only steelhead of practical concern – w

but Oncorhynchus – product.; – catch – improvement.

– aquaculture | hatchery | wild.

entire life cycle under cont | spawning – young stg. – smolt | –

– native strongly favored over non-nats thus,

– should not assume that records of introductions means loss of genetic integrity – Glacier Park – Kalama R.

ex all steelhead.

Economic eval. – good – but value – rarity – gold a comm or lead – summer-run low number – chance to reestablish – – –

finding 6 6-3-4

" 14 –

Rec. #1 (6-10) – stocking records incomplete – can't assume hybrid. influ.

Priority #8 (7-26) – already said – each stock spawning dif. can be assumed to be genetically diff.

– why sci document – suppose no dif. (Kalama summer winter runs, S. R. cutt.)

figs – question historical accuracy

no. ex A-12 S. clarki – pleuriticus Colo. R. – No; – never symbols reversed – subspecies reversed

* Todd: 1808

– Great Lk ciscs

– plectroplastic char. – cont. characters sp.

re bilateral polymorphy

– years c big dif.

– high flow warm

drought yrs cold –

dif selection pres

CALIFORNIA GENE RESOURCES PROGRAM
2855 Telegraph Avenue, Suite 216 Berkeley, California 94705 (415) 540-0226
A Program of the National Council on Gene Resources

January 10, 1983

TO: Recipients of Anadromous Salmonid Genetic Resources: An Assessment and Plan for California

FROM: Dr. David Kafton, Executive Director
National Council on Gene Resources

I would appreciate it very much if you would provide us with a written statement regarding the quality and contents of the assessment and plan. The main purpose of this request is to help demonstrate the value of the California Gene Resources Program.

We also welcome your comments on how the assessment and plan could be modified, and any of your other ideas and opinions.

Thank you for assisting us in this important matter. We look forward to hearing from you and continuing to work with you.

CALIFORNIA GENE RESOURCES PROGRAM

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ANADROMOUS SALMONID GENETIC RESOURCES

Introduction

Many species of anadromous salmonids are native to the Pacific states and provinces of North America. Chinook and coho salmon, steelhead, and cutthroat trout are the four important commercial and sport fishing species in California. Other anadromous salmonid species are important in commercial and sport fishing in other states and in Europe, Australia, New Zealand, and Canada Thus, gene resource problems and needs of anadromous salmonids may range in importance from the local to the international levels. Furthermore, the problems and needs of one anadromous species may be shared by other anadromous species.

Many individuals and organizations, both public and private, have an interest in anadromous salmonid genetic resources. Given this situation, the opportunity exists to search for ways for problems and needs to be solved collaboratively. In this way, benefits of improved resource management can be obtained while keeping the costs as low as possible per individual investor.

The State of California has recognized the need for improved planning, more information, and collaboration in order to resolve gene resource problems and, in turn, meet production objectives. The state initiated the California Gene Resources Program to address these needs. The California Gene Resources Program has been carried out through contracts with the National Council on Gene Resources, a private nonprofit research and education organization. Enclosed are brochures describing the Council and the Program.

The Model

Anadromous Salmonid Genetic Resources: An Assessment and Plan for California (National Council on Gene Resources, 1982) was developed as a model for making similar assessments and plans for other fisheries species. The assessment and plan is intended to help remedy the lack of specific information, coordinated action, and sufficient support in the management and conservation of anadromous salmonid genetic resources. This document was developed by the California Gene Resources Program staff with the direct involvement of representatives from industry, federal and state agencies, the academic community, and conservation organizations.

The assessment contains recommendations in five areas: management and conservation; planning; information management; technical and educational assistance; and research. A general plan was developed based on these recommendations.

The next step in this process is to form a task force to develop and begin carrying out a detailed coordinated plan of specific projects aimed at improving the current management of anadromous salmonid genetic resources. The task force will include public and private representatives from California, other states, British Columbia and the national level.

The Projects

Attached to this briefing is a partial list of proposed projects that address the technical and policy needs for improved management and conservation of anadromous salmonid genetic resources. This list was developed by CGRP staff members on the basis of the recommendations made in Chapters 6 and 7 of Anadromous Salmonid Genetic Resources. Some activities relate to ongoing projects currently conducted by various organizations and interest groups concerned with salmonid management, conservation, research and other programs. Members of the fisheries resources community are encouraged to offer further suggestions and to assist in developing priorities among the various activities.

The projects have been tentatively grouped in five categories corresponding to common programmatic divisions within organizations:

-Management and Conservation. Projects that might be undertaken by resource managers and would relate directly to on-the-ground management activities.

-Planning. Projects that might be undertaken by the planning division of an organization or by organizations primarily involved in planning.

-Information management. Projects which relate to the gathering, storage, retrieval, and/or analysis of information pertinent to genetic resource management of salmonids and other fisheries species. This includes the development of information management systems.

-Education and training. Projects that would contribute to the transfer of technical information to policy makers, specialists, and managers in fisheries, and to the education of fisheries students.

-Research. Projects related to the development of research programs and to the conduct of specific research investigations.

Whenever possible, different kinds of activities required to fulfill each recommendation were distinguished as separate projects. Each project description is subject to considerable latitude in interpretation. This should be a benefit to Task Force members in reviewing proposed projects since different approaches and objectives may emerge from the diverse perspectives of Task Force members.

Reviewers will note that many of the proposed projects may overlap with those ongoing or planned under various timber resource management programs. Proposed projects may involve expansion of these existing programs.

Reviewers may also find gaps in the suggested projects needed to achieve management and conservation goals. Input from Task Force members is needed to identify these gaps, to determine priorities in addressing these gaps, and to provide the detail necessary to fill them.

A member of the California Gene Resource Program technical staff will be available to meet with representatives of all Task Force members to discuss specific projects and priorities. This briefing and the projects lists may serve as an initial focus for discussion. Input to project development priorities are essential to the success of these efforts.

The California Gene Resource Program staff will assist Task Force members by providing baseline information; by helping to develop technical, organizational and financial options for carrying out projects and by making progress reports. The staff will also help coordinate and facilitate meetings and communications among Task Force Members.

Benefits

Much of the management, conservation, research, and information in gene resources is non-proprietary in nature. Thus, new organizational and financial arrangements can be made to link public and private fisheries interests in California with similar interests in other states and perhaps in other nations. Increased collaboration will improve coordination, efficiency, and effectiveness in managing salmonid gene resources, conducting research, and sharing information. This collaboration need not compromise any proprietary interests that might arise in the future.

Many of the members (both individuals and organizations) invited to participate on the Anadromous Salmonid Genetic Resources Task Force have an interest in other fish species. Many of the projects designed to resolve gene resource problems in anadromous salmonids may be applicable to non-anadromous fish species. The organizational and financial arrangements developed through the anadromous salmonid work may also be useful for coordinating work on other fish species.

Gene resources can provide short-term as well as long-term benefits. Genes can provide much faster growth rates, lower mortality rates, and lower production costs.

CALIFORNIA GENE RESOURCES PROGRAM

2855 Telegraph Avenue, Suite 216 Berkeley, California 94705 (415) 540-0226
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January 6, 1983

Dr. Robert Behnke
Department of Fisheries and Wildlife
Colorado State University
Fort Collins, CO 80523

Dear Dr. Behnke:

As a former member of the Anadromous Salmonid Genetic Resources Advisory Committee, I would appreciate it very much if you would participate in the implementation phase of the anadromous salmonid work. This year's activity includes the formation of a task force to continue work on anadromous salmonids. The overall purpose of the task force is to develop and begin carrying out a detailed plan of specific projects aimed at improving the current management, conservation, and use of anadromous salmonid genetic resources.

The first step will be the development of a list of specific projects by each interested organization, including priorities. To save time, the California Gene Resources Program staff has developed the enclosed preliminary list of projects, along with a briefing. Our staff will be available to assist you in completing your list of projects, including establishing priorities.

One point I would like to stress is that you review the list of projects without thinking about the financial constraints of your organization or company. Think of this project list and any other projects as a "needs list" and evaluate the projects according to your own criteria. Please feel free to add to the list or modify the ones listed. We would like to know which projects rank high using your criteria.

The CGRP staff will then identify projects rated high by a number of organizations and identify possibilities for collaborative financial and working arrangements. Project proposals will then be developed, and arrangements can be established. The projects can start after the arrangements are established. In the short term, implementation can proceed with activities having minimal costs and still achieve important short-term objectives.

We are confident that several new opportunities for increased collaboration will be identified, and as a result, costs per investor in a project will be much lower than without this increased collaboration. Consequently, worthwhile projects may be expanded and new ones started.

The California Gene Resources Program has a target date of July 1, 1983, for initiating some projects, because this is the start of California's new fiscal year.

We look forward to working with you and hope you share with us the excitement of making significant progress in this area.

Sincerely yours,

for Dale W. White

David Kafton, Ph.D.
Executive Director

DK/ld
Enclosures

CALIFORNIA GENE RESOURCES PROGRAM

2855 Telegraph Avenue, Suite 216 Berkeley, California 94705 (415) 540-0226
A Program of the National Council on Gene Resources

February 9, 1983

To: Participants in the Implementation of the Salmonid Gene Resource Assessment and Plan

From: David Kafton, Ph.D., Executive Director

Re; Responses to List of Salmonid Gene Resource Projects

I would appreciate it very much if we could receive your responses by February 28.

Two methods that some respondents have used may be useful to you. Some participants have ranked the projects by writing "High, Medium or Low" next to each project list, and then mailed the list to us. Others have ranked the projects in numerical order within each functional category (Management and Conservation, Planning, Information, Management, Research and Education) by placing a number next to each project on the list ("1" highest). They then just mail the list to us.

Approximately 150 individuals from more than 100 public and private organizations, primarily in the western United States and British Columbia, are participating in this process. We plan to summarize the responses and send them to you. We will also identify projects where increased collaboration might be possible, and also estimate how soon projects might be initiated or expanded.

Thank you again for participating in this program. We look forward to receiving your response.

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Anadromous Salmonid
GENETIC RESOURCES
An Assessment and Plan for California

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GENE RESOURCES

Anadromous Salmonid
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California Gene Resource Program
National Council on Gene Resources
2855 Telegraph Avenue, Suite 216 / Berkeley, California 94705

Prepared for the State of California under the administration
of the Department of Food and Agriculture, Contract No. 9146.

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ACKNOWLEDGMENTS

The staff of the California Gene Resource Program wishes to acknowledge the technical assistance of the following persons in the preparation of this report:

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Frank Ventrola, Production Manager

Particular acknowledgment and thanks are due the members of the Salmon Gene Resources Advisory Committee, the members of the California Gene Resource Program Advisory Committee, the members of the Advisory Board for the National Council on Gene Resources, and the many scientists, administrators, and technicians who generously contributed information and perspective to this report.

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Mr. Robert Hannah, Hoopa Valley Fisheries Department
Mr. Chester Hart, Wildlife Conservation Board
Mr. Ken Hashagen, California Department of Fish & Game
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Dr. John Helle, National Marine Fisheries Service
Mr. Richard Hubbard, U.S.D.A., Forest Service
Mr. Paul Hubbell, California Department of Fish & Game
Mr. Huey Johnson, Secretary, Resources Agency
Dr. Herbert Joseph, California Trout, Inc.
Senator Barry Keene, California State Legislature
    Representative: Mr. Greg DeGiere
Dr. Eric Loudenslager, North American Salmon Research Center
Mr. Richard May, California Trout, Inc.
Dr. John McIntyre, U.S. Fish & Wildlife Service
Mr. William McNeil, Oregon Aqua-Foods, Inc.
Mr. Stephen Nicola, California Department of Fish & Game
Mr. Melvyn Odemar, State/Federal Fisheries Management Programs
Mr. Mark Palmer, Sierra Club
Mr. David Phillips, Friends of the Earth
Senator Robert Presley, California State Legislature
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Mr. J. Gary Smith, National Marine Fisheries Service
Mr. Kent Smith, California Department of Fish & Game
Mr. Vernon Smith, Sport Fishermen Representative
Ms. Debbie Stefan, U.S.D.A., Forest Service
Mr. Roger Thomas, Sport Fishermen Representative
Ms. Stephanie Thorton, Humboldt Fish Marketing Association
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Mr. Dave Vogel, U.S. Fish & Wildlife Service
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EXECUTIVE SUMMARY

Future opportunities to manage salmon and anadromous trout to meet California's needs will primarily be determined by how the genetic resources of these valuable species are currently maintained and used. This report proposes a comprehensive program for ensuring the wise use and conservation of salmon and sea-run trout genetic resources. These fishes are among California's most important fish species.

In compiling this study, the California Gene Resources Program (CGRP) has drawn on the experience and knowledge of aquatic biologists; forestry, hatchery, and watershed managers; policy makers; and conservationists from throughout the country. The report emphasizes the importance of genetic considerations in fishery management and suggests a number of technical and policy measures aimed at maintaining and fully using salmonid genetic resources. This is the first comprehensive assessment and plan developed for the genetic resources of anadromous fish species.

THE IMPORTANCE OF ANADROMOUS SALMONIDS TO THE PEOPLE OF CALIFORNIA

Chinook and coho salmon and steelhead and cutthroat trout are the four most important anadromous salmonid species in California. These fish migrate to the ocean to mature, and they return to their freshwater origins to spawn. The major freshwater salmonid-producing areas in the state are found in the Sacramento-San Joaquin Valleys and along the North Coast, primarily in the Klamath-Trinity Basin.

Salmon support a commercial fishery contributing more than $50 million to California's economy each year. The salmon and sea-run trout sport fishery is enjoyed by about 150,000 fishermen and contributes more than $17 million annually to the state economy. Commercial salmon caught in California are processed in local plants, then refrigerated and sold immediately to restaurants, markets, or fish brokers who ship fish throughout the country and to Europe and Japan.

While both commercial and sport salmonid catches have been maintained at relatively stable levels during the past few decades, salmon and steelhead populations have declined by an estimated 60% in California inland waters since 1900. A number of traditional native salmon runs are now at dangerously low levels or are extinct. And in a number of cases, escapement levels set by management agencies to sustain the productivity of natural and hatchery stocks currently are not being met.

The decline in salmonid runs is generally attributed both to the continued effects of fishing and to human impacts on aquatic habitat. Anadromous fish habitat has declined from 9000 to 7500 miles during this century. The principal causes for the decline are dam construction, diversion of water, and siltation of streams due to timber harvesting, road building, and other disturbances. The loss of suitable spawning habitat from these activities during the first part of this century led to extensive study and implementation of techniques for artificial propagation.

The state's ability to maintain present catch levels or to increase salmonid production and quality relies on a range of programs.

Particularly in recent years, federal and state agencies and private groups have instituted new programs to regulate the ocean and inland fishery and to restore and enhance salmonid runs and habitats in coastal and inland rivers and streams. Investments are presently being made in stream rehabilitation, hatchery programs, and ocean ranching. But, unfortunately, most decision makers are unaware of the importance of genetic diversity in the advancement and coordination of these efforts. While the potential impacts of harvesting on the genetic diversity of salmon and sea-run trout have been recognized for more than a century, the role of natural diversity in maintaining the ocean fishery and in developing salmonid aquaculture is only now being explored, and information on the status of this natural diversity is largely unavailable or unanalyzed. This situation makes it difficult to resolve the problems encountered in managing and in conserving the salmonid resource and in allocating the resource among fishery participants.

IDENTIFYING THE GENETIC RESOURCES OF SALMON AND ANADROMOUS TROUT

The genetic resources of salmon and sea-run trout are the basis for the present and future productivity of California's salmonid fishery. Although hatchery technology has had some success in replacing and supplementing natural runs of salmonids, uncertainty remains as to the long-term genetic consequences of both harvesting and replacement practices currently used. A broad understanding of the importance of salmonid genetic diversity to fishery productivity and stability is a prerequisite to reevaluating management alternatives and long-term conservation needs.

Salmonid genetic diversity is useful in two ways. First, it is a basic underpinning of salmonid management programs. Second, it provides natural variability in disease resistance and a variety of other traits that help solve problems encountered in artificial propagation and domestication of salmonids, as well as in the maintenance of natural runs. The significance of the natural diversity that can still be found in native wild salmonid populations is revealed by studies of variation in behavioral, physiological, morphological, and biochemical traits within and among populations. Much of this variation has a genetic basis and is adaptive; that is, it enables individual fish to cope successfully, on average, with the specific environmental conditions that they encounter in both freshwater and ocean environments. Some genetic variation is not demonstrably adaptive but may nevertheless be significant for the future viability of natural populations and for artificial propagation and breeding purposes.

The possession of different characteristics, both adaptive and nonadaptive, by different populations of salmonid species, is the basis for the stock concept. The stock concept is an integration of scientific knowledge about fish genetic diversity and its significance in a form designed to facilitate application of this knowledge to management decisions. While the stock concept has been successfully employed in fishery management elsewhere, the data required to identify and manage salmonid stocks important to the California fishery are presently inadequate. A review of existing knowledge of genetic variation in populations of chinook and coho salmon and anadromous rainbow (steelhead) and cutthroat trout reveals a paucity of data on all of these species. Opportunities for future uses of stock diversity can be identified in three areas: replacement and enhancement of native runs, development of domestic stocks, and overall maintenance of fishery productivity. If these opportunities are to be realized, measures must be taken to document and conserve the genetic resources on which they will be based.

The present necessity for managers to restore or augment propagation to sustain salmonid populations is now not disputed, but means to this end are still being explored. Hatchery technology permits the production of massive numbers of young fish. However, scientific uncertainties still exist about how best to use hatchery-bred fish in natural aquatic systems. Indeed, the ways in which both harvest and propagation techniques affect the genetic resources of the salmonid fishery are just beginning to be documented and understood. Most importantly, there is not, at present, an explicit formulation of genetic knowledge into a working hypothesis for salmonid management.

MAINTAINING GENETIC RESOURCES

A number of options exist for conserving the genetic resources of California's anadromous salmonid species. *In situ* conservation can be effected through genetic resource management, population protection, and information exchange among interest groups (the "watch" concept). *Ex situ* approaches potentially include cryopreservation of salmonid sperm, ova, and embryos and various means to maintain fish populations in lakes, pens, ponds, or introduced anadromous runs. Currently, *in situ* genetic resource management is the most feasible means to maintain both the adaptive and nonadaptive variation of salmon and sea-run trout for future needs.

Many technical problems hamper the implementation of genetic resource conservation measures, and most of these are caused by inadequate information. For instance, the distribution of salmonid genetic diversity is not adequately documented in California to guide efforts to acquire, evaluate, and conserve representative genetic material. Insufficient knowledge about both the distribution and significance of genetic diversity has impaired implementation of the stock concept in California. The determination of which populations in California's rivers and streams still represent native runs of anadromous salmonids is complicated by the absence of information about the genetic impacts of past management practices in harvesting, salmonid culture, and watershed management. Because the research required to supply the information needed for the solution of these technical issues will take some time to complete, and because current practices appear to be eroding the genetic resource, interim measures for genetic conservation should be taken (see Recommendations).

ESTIMATING ECONOMIC IMPACTS

The logic and concepts of political economy can aid in sound resource planning to prevent further loss of salmonid genetic diversity. In the planning process, resource managers must be cognizant of the irreversible damage that any alteration in freshwater salmonid habitat may inflict on the salmonid genetic resource. Simultaneously, managers should determine how best to reconcile different and often conflicting use of salmonid resources. Thorough economic analysis may aid in the selection of policy alternatives. Above all, however, resource management plans should be flexible in the sense that they should not foreclose future opportunities for preserving the diversity of salmonid species.

The usefulness of economic analysis is nullified where valid alternatives are excluded from the planning process. Preservation of salmonid genetic resources is likely to succeed in a particular watershed only when the development of water, land, forest, and mineral resources there is based on identifying all valid alternatives. Full alternative planning means that planners should consider in a balanced way all the values involved--nonmarket as well as market--in maintaining salmonid genetic diversity.

To date in California, formal economic analyses and full alternative planning have not been used to make decisions affecting salmonid gene resources. There are no recent creditable studies of the values of salmon sport fishing or commercial fishing. The costs of preserving wild runs of salmon are largely unknown. Furthermore, thorough economic studies of the demand and supply of salmon within California and other states and countries have yet to be undertaken.

An urgent need exists to undertake those economic analyses to determine the costs of preserving salmon genetic diversity in many of the watersheds of the state still supporting wild runs of salmon. Equally high priority should be given to the conduct of strategic economic studies by managers in conjunction with fishery biologists and geneticists to help determine to what extent the renewable but exhaustible salmonid resource should be preserved.

The costs of instituting such a policy might be viewed as insurance premiums paid by society to avoid or reduce the probability of the catastrophic loss of a wild run of salmon and its inherent genetic diversity.

Economic methodology is sufficiently advanced to measure many of the nonmarket values intrinsic to salmon habitat preservation, including salmon sport fishing. The rules for social benefit-cost analysis developed by the U.S. Water Resources Council provide the framework and procedures for valuing alternative management strategies for salmonid freshwater habitat. This framework was devised on the assumption that the rules will be applied to all possible management alternatives. Furthermore, the inclusion of an Environmental Quality Account in the set of rules implies that retaining a run of wild salmon in a watershed can result in a net gain for society even though that use may not be the most economically profitable one. Indeed, maximizing profits in the short run cannot be considered an operational policy objective for salmonid habitat management.

An appropriate cost-benefit analysis should be based on a comparison of the need to alter the habitat with the hazards and dangers of undesirable changes in the salmonid environment. Thus, the magnitude of maximum possible losses--namely, the ultimate loss of California's salmonid resource and the ensuing diffuse cultural impoverishment and socioeconomic disruption--must be assessed against the magnitude of the costs (including market and nonmarket benefits foregone) of habitat alteration.

Setting a "safe minimum standard" in all habitat modification will help to avoid the irreversible loss of salmon genetic diversity, but this standard can be established only after hydrologists, biologists, geneticists, and others have collected basic information on habitat conditions and the consequences of management actions. Analysis of the full effects of past water and land use decisions in salmonid watersheds on the systems of water, soil, and vegetation would greatly enhance the accuracy with which the consequences of any planned habitat alteration could be predicted.

INSTITUTIONAL AND ORGANIZATIONAL OPTIONS

State and federal agencies, commercial and sports fishing interests, Native Americans, and a variety of other concerned Californians all have a stake in ensuring that the state's anadromous fishery is well managed. This concern and attention creates opportunities and problems for those developing an institutional framework for salmonid genetic resource management programs. Problems arise because of overlapping jurisdictions between state and federal agencies, lack of coordination among and within management entities, and difficulties in allocating a scarce resource among different user groups. Opportunities exist because current programs represent important organizational resources for the resolution of California salmonid enhancement problems.

A number of public agencies currently administer programs which influence genetic resource conservation, research, and management activities. The Pacific Fisheries Management Council (PFMC) has recognized the need for conservative management of salmon stocks. Its programs, including mid-run closures, area registration, and escapement goals, reflect a commitment to rebuilding salmonid population levels. The Trinity River Basin Fish and Wildlife Task Force has proposed a comprehensive program for restoring native and hatchery stocks within its area of jurisdiction. California Department of Fish and Game (CDFG) hatchery managers informally recognize two major salmonid distribution areas--the Sacramento River system and the coastal river region--for releasing fish from the facilities they operate and manage. Once the department's new fish and wildlife plan is made final, a 10-year plan for managing anadromous habitat and populations will be in effect. The U.S. Fish and Wildlife Service recognizes restricted zones for releasing fish from its hatcheries in California. In addition, the agency's cooperative and research programs for restoration of anadromous salmonid runs favor native fish strains over hatchery strains.

However, the value of native fish as a genetic resource and the application of the stock concept in salmonid management have not been sufficiently integrated into current programs. To accomplish this integration, a number of technical measures will be necessary, including stream classification, research, and conservation activities. These technical opportunities can be realized if state, federal, and private interests improve the coordination of various programs now in operation and increase their financial support for genetic resource management work. CDFG, PFMC, or other organizations or coalitions will need to provide additional leadership to ensure an improved organizational and financial framework for meeting salmonid genetic resource needs.

RECOMMENDATIONS

- Initiate an inventory of California rivers and streams, recording the genetic integrity (i.e., intactness) of their salmonid stocks, based on hatchery transfer and outplanting records. Streams and watersheds might be classified as to the number and currentness of stock introductions and as to their sources. This inventory would be a necessary first step in the design of a management strategy for maintaining California's native salmonid stock while research progresses on fundamental questions.

- Design and implement a marking study for both hatchery and natural stock within a major watershed system in California. The study should focus on determining the success of emigration of artificially reared and naturally reared salmonids and it should determine their rate of return as adults, both to fisheries and to natal streams. The study would permit researchers to evaluate the genetic basis, performance consequences, and adaptive value of phenotypic differences among stocks. Creel censuses, adult trapping and tagging, and spawning ground surveys can be used to measure stock returns.

- Initiate a study to monitor the relationship between Pacific Fisheries Management Council (PFMC) season closure and harvest regulation programs with resulting escapement and hatchery return levels within a mixed stock watershed.

- Initiate on-site case studies to obtain fundamental data on the specific impacts on genetic diversity and salmonid productivity that result from management practices. Information needs to be collected to determine the changes in genetic composition of California's salmonid species over time, and research is required to ascertain the effects of these changes on fish production and quality. Sites for case studies should include streams and watersheds chosen for differences in management history and administrative jurisdiction.

- Case studies should also be done to obtain precise knowledge regarding the technical measures required for in situ and ex situ conservation, such as the feasibility of the cryogenic storage of ova or embryos, and the rearing of salmonids in ocean pens.

- Continue the analysis begun in Appendix E of the feasibility of using introductions to ex situ waters as a conservation technique.

- Hold a regional working conference on the biological basis and management applicabilility of the stock concept to salmonid management. The stock concept has wide acceptance among fisheries managers and scientists and has been utilized to varying degrees as a basis for planning and management in Oregon, Washington, British Columbia, and Alaska, as well as by the PFMC and in California. Nevertheless, the scientific and technological basis for identifying and monitoring discrete stocks is limited; the research necessary to identify population units that are important for species productivity and stability will take considerable time and effort. This conference could enable researchers and managers to share state-of-the-art information about the stock concept and thus to efficiently and effectively plan future research.

- Facilitate the development of research activity in several areas, including the following:

  1. scientific documentation (e.g., isozyme studies) of genetic diversity that exists within and among species' populations; and
  2. determination of genetic consequences of population phenomena (e.g., density-dependent mortality, homing and straying, and ocean migration patterns) affected by management practices.

- Economic studies and investigations should be conducted to appraise the value of the nonmarket services provided by California's salmonid resources.

- Competent analysis should be employed to evaluate the market and nonmarket values inherent in each management alternative for salmonid habitat. "Procedures, Principles and Standards," promulgated by the U.S. Water Resources Council for water and related land resources, should be used in the analysis in conjunction with the Environmental Quality Account and the National Economic Development Account (see Chapter 4).

- Hold a working conference to examine the appropriate roles and responsibilities for the management of salmonid genetic resources among the federal, state, and private sectors. The purpose of this conference would be to bring together representatives of each sector, to review means for avoiding jurisdictional overlap, to identify statutory incompatibilities, and to begin to develop an appropriate distribution of roles and responsibilities among all parties with a stake in maintaining California's anadromous fishery.

  Representatives of the following federal, state, and private groups should attend this conference: the Pacific Fisheries Management Council, Native Americans, the Pacific Coast Federation of Fishermen's Associations, the California Department of Fish and Game, the California Department of Forestry, other state agencies, the University of California, Sports Fishermen Associations, the U.S. Forest Service, the U.S. Fish and Wildlife Service, the National Marine Fishery Service, and other salmon and sea-run trout interests in California.

- Hold a series of working conferences to provide conflict-resolution and negotiation services for the various interests involved in the management of the anadromous fishery. A successful initiation and implementation of the projects recommended in this report will depend, at least in part, on a consensual agreement on the need for salmonid genetic resource management activities and on adequate voluntary compliance to achieve relevant goals. Negotiation services should help in reducing conflicting interests and in generating consensus.

- Develop a carefully planned and coordinated information system to assemble, analyze, and distribute data related to salmonid genetic resources. The information should be on the following subjects:

  1. Current and future production problems,
  2. Economic data related to production problems,
  3. Marketing,
  4. Land availability,
  5. The distribution of native and mixed stocks and their significance for production problems,
  6. The current status of salmonid resources,
  7. The impacts of human activities on these resources,
  8. Land and resource use plans that might affect native and mixed stocks,
  9. In situ and ex situ conservation techniques,
  10. The utility of using genetic material to solve production problems,
  11. Genetic enhancement and salmonid culture techniques,
  12. Other related information of importance and interest.

- Develop an educational program to communicate effectively with public decision-makers, commercial and sport user groups, Native Americans, scientists, and the general public regarding:

  1. Problems in maintaining salmonid productivity,

2. The importance of genetic resources in resolving these problems, and

3. Specific issues and needs related to salmonid genetic resource management, conservation, and use.

- <u>Hold a working conference in California to consider the financial and organizational arrangements needed to carry out the technical and policy measures recommended in this report.</u>

Establish a new funding base to support research, conservation, and management activities. Financial arrangements should be developed that spread out investments among all relevant management agencies and user groups so that costs per participant are kept low, but additional monies are generated. Costs ideally should also be spread across human generations in an equitable fashion.

PREFACE

The State of California initiated the California Gene Resources Program (CGRP) in September 1980. The CGRP was organized in response to mounting concern about irreplaceable losses of and changes in the gene resources of many types of animals, plants, and microorganisms upon which the economy of the state depends. It was recognized that existing support and program coordination were insufficient to prevent these losses. The well-being of California could be seriously jeopardized if these irreversible losses of gene resources prove to be of significance.

One of the major objectives of the California Program is to identify the specific measures required to safeguard the state's economically important gene resources. The CGRP is also intended to provide the information and assistance needed to make the state more effective in its role as guardian of essential biological resources. In particular, the CGRP is intended to determine the types and level of support needed to carry out necessary gene resource maintenance and conservation activities.

The CGRP is designed to overcome the major obstacles which presently hinder the acquisition of sufficient support for existing gene resource management, conservation and use programs. The first of these obstacles is a lack of awareness about gene resource problems among decision makers in both the public and private sectors. A second obstacle is that, although many interest groups are concerned with living, renewable resources, there is no organized, broad base of support in the gene resources field. A third major obstacle has been the paucity of documentation that decision makers in both the public and private sectors need to become informed about gene resource problems and potential solutions. Without this information it is difficult to build a broad base of support or to justify significant changes in support and policies.

This report has been prepared in response to the California Gene Resources Program Advisory Committee recommendation that comprehensive, standard assessments and implementation plans be developed for the gene resources of different types of individual species and commodities of importance to California (CGRCP, 1981). The Advisory Committee intended such reports to remedy the lack of information and coordinated effort in gene resource management and conservation. One of the major objectives of this report is to serve as a model and catalyst for making similar efforts concerning other crop species. It is also intended to provide the specific information that is needed to justify the increased investments required to maintain salmonids as a productive resource in California and elsewhere. Funds for this report have come from the Environmental License Plate Fund and have been administered by the California Department of Food and Agriculture.

Other plans developed by CGRP will focus on commodities such as barley, Douglas fir, and strawberries. In developing these assessments and implementation plans, the CGRP staff works with advisory committees and other interested persons who represent various components of the living, renewable resource interest communities--industry, government, the academic community, conservation and consumer organizations. In developing this salmonid assessment and implementation plan, the CGRP staff has worked with this group of advisors to assemble and analyze relevant information from publications, manuscripts, raw data, interviews, and surveys.

It is hoped that the standard format for assessments and implementation plans established by this report will allow ease of comparison among species and commodities, making setting priorities among them more efficient and allowing activities to be integrated to avoid duplication and gaps. Comprehensive assessments and plans should make it possible for decision makers to compare the various measures needed to manage and use salmonid genetic resources with other methods that also might be used to resolve current production problems.

INTRODUCTION

Gene resources are an insurance policy against the economic and biological disasters that can occur when environmental conditions change and become less favorable to a species' survival. The continued success of California's multibillion-dollar agricultural, forestry, and fishing industries depends on the availability of appropriate genetic materials. The term "gene resources" refers to the genetic diversity of the animals, plants, and microorganisms that society needs to meet its basic requirements for food, fiber, pharmaceuticals, energy, and recreation. Gene resources are essential to the continued production of improved domestic animal breeds, native fishes, and crop varieties.

There is reason to be concerned about declining genetic resources of fish species, including California's salmon and trout. Agriculture has provided a number of examples in which gene resources have been critical to achieving recovery from significant crop disasters. Preservation of fish genetic resources may prove equally important. In 1970, for example, 15% of the United States' major crop, corn, was destroyed by corn leaf blight, and increasing destruction, accompanied by enormous economic losses, in subsequent years seemed inevitable. Rapid recovery from this disaster was possible only because an appropriate blight-resistant corn variety was found shortly after disaster struck (Ullstrop, 1972). This recovery was a key event that focused attention in the United States on the country's reliance on gene resources and on the significance of genetic resource problems.

California also has used genetic resources as an insurance policy. For example, in 1961 and again in 1974, wheat in the Sacramento Valley was heavily damaged by stripe rust. However, wheat strains introduced from Mexico proved resistant to the rust, quelling the epidemics and making successful harvests possible (Qualset et al., 1977). California agriculture earns millions of dollars annually through investments in gene resources that help reduce important crop losses and increase production. Examples of the successful returns from investments in gene resources include:

- A single Ethiopian gene now protects California's barley crop ($128 million farm gate value in 1979) from the devastating effects of the barley yellow dwarf virus (Schaller, 1977).

- The grape industry in California receives an additional $5 million annually due to the introduction of new varieties which ripen two weeks ahead of the Thompson Seedless variety, allowing a longer marketing season (USDA, 1976).

- Increased productivity of genetically improved corn varieties has resulted in annual benefits of about $120 million (USDA, 1976), and new wild relatives of domestic corn have recently been discovered, raising the possibility of increased pest resistance and cultivation range.

Examples of the economic importance of genetic resources to fishery production and aquaculture have not yet been so dramatically documented. Large-scale applications of aquaculture are only now being developed, and fishery failures can seldom be ascribed to a single genetic factor. Nevertheless, the dependence of both wild fisheries and aquaculture on genetic resources is clear. Overfishing of wild stocks has led repeatedly to at least temporary fishery collapse (Cooley, 1963; Radovich, 1981) or to undesirable changes in the growth rate, size at maturity, and homing ability of fish (FAO, 1981a). The potential for gains in growth and yield achievable in aquaculture through use of stocks with particular characteristics, hybridization of wild and domesticated stocks, and coordination of genetic traits with fish farming practices is best illustrated by experience with carp (Moav et al., 1976, 1978; Wohlfarth and Moav, 1978; Moav, 1979). Success with carp was achieved through insight and research into the relationship between genetic and environmental factors determining the success of aquaculture. Many other species show promise of contributing importantly to the world's food supplies, if their genetic resources can be properly managed and utilized.

SALMON AND SEA-RUN TROUT IN CALIFORNIA

Salmon and sea-run populations of trout (known collectively as "salmonids") hatch from eggs in California's rivers and streams and spend variable periods feeding on aquatic insect larvae and small fish in freshwater habitats before migrating downstream to the ocean. The young fish must undergo a physiological change, called smoltification, before they move out into the ocean to feed on other fish and grow to maturity. After two to four years, depending on the species, adults migrate back into freshwater, usually ascending rivers and streams to the same spawning grounds where they originated. There, females deposit eggs in gravel nests called redds, and males fertilize the eggs with milt to complete the life cycle. Fish species that exhibit this life history are called "anadromous."

California has four anadromous salmonid species that are important to commercial and recreational fishing: chinook or king salmon, and coho or silver salmon, steelhead trout (anadromous rainbow trout), and cutthroat trout. These species were selected for this assessment for a number of reasons. The commercial salmon fishery contributes more than $50 million to California's economy each year. Furthermore, about 150,000 fishermen participate in salmon and sea-run trout sport fishing and contribute more than $17 million to the state economy annually. Habitat loss and competing uses for water and watershed resources have precipitated concern about the fishery's future prospects and about the status of wild stocks in California's rivers. Although total commercial landings of salmon have not declined very markedly, fishermen have reported smaller catches and are calling for extended seasons and higher catch limits. Managing the salmonid fishery has become a complicated process of attempting to satisfy the current demands of many interest and user groups while conserving the fishery resource for sustained production in the future.

The populations of salmon and trout still found in California's rivers and streams are the reservoir of genetic resources on which present and future production depends. These populations and subpopulations, or stocks, spawning in different seasons in particular stretches of water on specific streams, are often genetically distinct. Their particular life history patterns have evolved during many thousands of years and may be critical to their population's present and future viability. Their capacity for optimal growth under the range of watershed conditions found over time in spawning and rearing habitats is vital to fishery production.

Many of California's populations of anadromous salmonid species have declined in the past several decades. Spawning numbers of chinook salmon in the Klamath and its tributaries, for example, declined from 160,000 per year in the early 1960s to less than 30,000 in 1980. In the main stem of the Trinity River system, chinook spawning declined 80% between 1968 and 1979. Chinook and steelhead spawning on the Sacramento River system has declined by 25% in the past two decades. Fall chinook on the San Joaquin River, formerly exceeding 100,000 spawners annually, have been reduced to only a few thousand fish. Spring chinook in the San Joaquin, which historically exceeded the fall run in numbers, are now extinct. Thus, genetic resources of salmonid species have already been lost from California's rivers.

Natural events produce pronounced population fluctuations in salmonids. The declines cited above, however, are largely attributable to the construction of dams that eliminate or reduce access to the upper tributaries of rivers where habitat and spawning conditions are appropriate to the life cycles of the various species. Additional degradation of spawning habitat has resulted from water diversion and changes in water quality and temperature due to logging, mining, and other land-use activities. The result is a diminished contribution by natural spawning to populations of harvestable salmon.

While hatchery production of salmonids has been somewhat successful in compensating for declines in natural production, hatchery programs are no longer viewed as an adequate or "best" means of meeting fishery demands. Commercial and sport fishermen alike are calling for preservation of the wild stocks. Yet hatchery practices may have already contributed to losses and changes in salmonid genetic diversity. If the productivity and stability of California's salmon and anadromous trout fisheries are to be assured, policies and practices for the management and use of their genetic resources must be reevaluated.

CHAPTER 1

CALIFORNIA'S ANADROMOUS SALMONID RESOURCE: PAST, PRESENT, AND FUTURE

CHAPTER ABSTRACT

King and silver salmon and steelhead and cutthroat trout are the four most important anadromous salmonid species in California. These fish migrate to the ocean to mature but must return to their freshwater origins to spawn. The major freshwater salmonid-producing areas in the state are found in the Sacramento-San Joaquin Valleys and along the North Coast, primarily in the Klamath-Trinity Basin.

Salmon support a commercial fishery contributing more than $50 million to California's economy each year. The salmon and sea-run trout sport fishery is enjoyed by about 150,000 fishermen and contributes more than $17 million to the state economy annually. Commercial salmon caught in California are processed in local plants, then refrigerated and sold immediately to restaurants, markets, or fish brokers who ship fish throughout the country and to Europe and Japan.

While both commercial and sport salmonid catches have been maintained at relatively stable levels during the past few decades, salmon and steelhead populations have declined by an estimated 60% in California inland waters since 1900. A number of traditional native salmon runs are now at dangerously low levels or are extinct. And in a number

of cases, escapement levels set by management agencies to sustain the productivity of natural and hatchery stocks are not currently being met.

The decline in salmonid runs is generally attributed both to the continued effects of fishing and to human impacts on aquatic habitat. Anadromous fish habitat has declined from 9000 to 7500 miles during this century. The principal causes for the decline are dam construction, diversion of water for agriculture and urban uses, periodic natural flooding, siltation of streams due to timber harvesting, road building, and other disturbances.

The state's ability to maintain present catch levels or to increase salmonid production and quality relies on a range of programs. Particularly in recent years, federal and state agencies and private groups have instituted new programs to regulate the ocean and inland fishery and to restore and enhance salmonid runs and habitats in coastal and valley rivers and streams. Investments are presently being made in stream rehabilitation, hatchery programs, and ocean ranching. But knowledge of the importance of genetic diversity in the advancement and coordination of these efforts is not readily accessible to decision makers. The role of natural diversity in maintaining the ocean fishery and in development of salmonid aquaculture is now being recognized. However, information on the status of this diversity is largely unavailable or unanalyzed. This situation complicates resolution of the problems encountered in managing and conserving the salmonid resource and allocating the resource among fishery participants.

THE SALMONID FISHERY

California's anadromous salmon and trout species are one of the state's most important renewable resources. King salmon, also known as chinook (Onchorhynchus tschawytscha), and silver salmon, also known as coho (Onchorhynchus kisutch), are the only two salmon species which appear in significant numbers in California. The migratory rainbow trout, known as steelhead (Salmo gairdneri), and the cutthroat trout (Salmo clarki) are the most important anadromous trout species. The major salmonid-producing areas in the state are found in the Sacramento-San Joaquin Valleys and along the North Coast, primarily in the Klamath-Trinity Basin (Figure 1-1). Since 1900, salmon and steelhead populations have declined approximately 60% in California inland waters. Salmon support an important commercial and recreational industry; approximately 750,000 were caught in 1981, whereas the steelhead catch was 122,000.

Anadromous salmon and trout are unique among fishes in their biology and behavior. The life history of these salmonids begins in freshwater streams, where the fish spend up to a year before migrating to the ocean. After their ocean migration, they return to their native streams three to four years later to spawn and to die. This life history is the same for fish reared in hatcheries. They also undergo a transformation from freshwater to saltwater fish and live out a migratory existence over a range of up to 2000 miles or more. This complicated life cycle delineates large habitats which must be maintained to ensure the species' continued productivity. Without adequate ocean, coastal, estuarine, and freshwater habitat, California's salmonid resource would be unlikely to survive (see Appendix A).

Adequate habitat alone, however, cannot guarantee the health and resilience of the state's salmon and anadromous trout. The genetic and biological characteristics of the species must also be retained and managed if salmon and its close relatives are to continue to populate California's ocean and inland waters. This report attempts to define and identify the role of genetics in maintaining immediate and long-term salmonid productivity and quality and proposes a plan for ensuring the use and conservation of this genetic resource.

Any program to maintain and manage the salmonid genetic resource depends on a number of factors: (a) an understanding of the scientific and technical aspects of genetic resource composition, evaluation, and use; (b) an assessment of the economic environment within which salmon germplasm will be needed and utilized; and (c) the development of institutional arrangements appropriate for directing and supporting these necessary scientific, technical, and assessment activities. This chapter introduces these three areas of concern, emphasizing the long-term commercial and recreational uses of salmonids and describing current California programs of fish and habitat management. To put these issues in perspective, the chapter begins with some brief historical background on the salmonid fishery of California.

History of the Salmonid Fishery

Eighteenth century accounts of California's vast natural

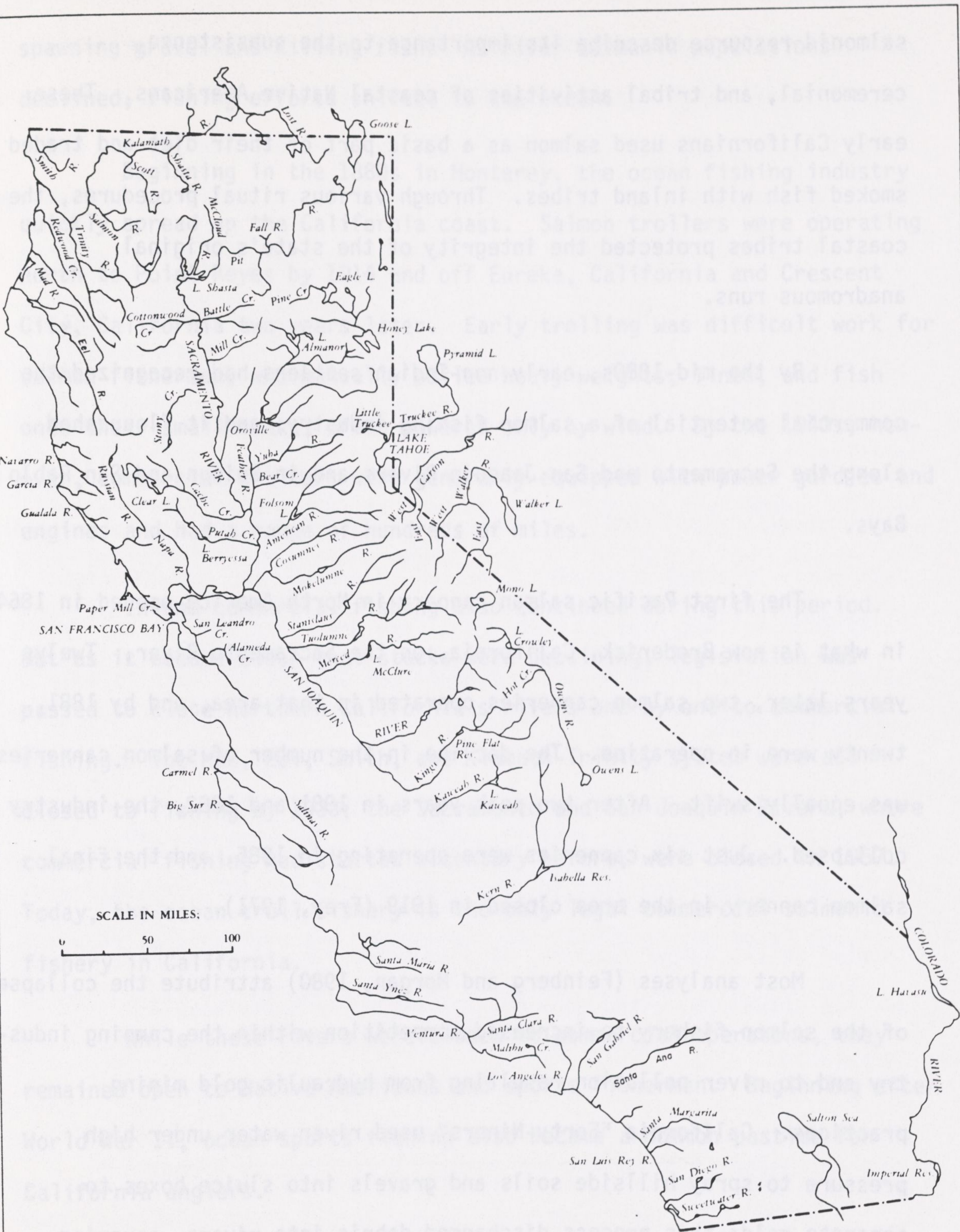


Figure 1-1. Base map of selected streams in California.
Source: Lucoff, 1980.

salmonid resource describe its importance to the subsistence, ceremonial, and tribal activities of coastal Native Americans. These early Californians used salmon as a basic part of their diet and traded smoked fish with inland tribes. Through various ritual procedures, the coastal tribes protected the integrity of the state's original anadromous runs.

By the mid-1880s, early non-Indian settlers had recognized the commercial potential of a salmon fishing industry, and it flourished along the Sacramento and San Joaquin Rivers and in Suisun and San Pablo Bays.

The first Pacific salmon cannery in North America opened in 1864 in what is now Broderick, California, on the Sacramento River. Twelve years later, two salmon canneries operated in that area, and by 1881, twenty were in operation. The decline in the number of salmon canneries was equally swift. After two peak years in 1881 and 1882, the industry collapsed. Just six canneries were operating in 1885, and the final salmon cannery in the area closed in 1919 (Frey, 1971).

Most analyses (Feinberg and Morgan, 1980) attribute the collapse of the salmon fishery to increased competition within the canning industry and to river pollution resulting from hydraulic gold mining practices. California "Forty-Niners" used river water under high pressure to spray hillside soils and gravels into sluice boxes to separate gold; this process discharged debris into rivers, covering spawning gravel and killing fish. As river salmonid populations declined, fishing efforts shifted to the ocean.

Beginning in the 1880s in Monterey, the ocean fishing industry quickly spread up the California coast. Salmon trollers were operating north to Point Reyes by 1914 and off Eureka, California and Crescent City, California two years later. Early trolling was difficult work for salmon fishermen, who manually pulled heavy weights, lines, and fish onto their small boats, often powered only by wind. By the 1940s, however, commercial trollers were generally equipped with power gurdies and engines and had a range of hundreds of miles.

Inland commercial fishing also continued during this period. But as it became clear that stocks were declining, legislation was passed to close northern California's rivers one by one to commercial fishing. The Mad, Eel, Smith, and Klamath-Trinity system were all closed to fishing by 1933; the Sacramento and San Joaquin Rivers, where commercial fishing had started a century before, were closed in 1957. Today, the ocean troll fishery is the only legal commercial salmonid fishery in California.

While these rivers were closed to commercial operators, they remained open to Native Americans and sports fishermen. Beginning after World War II, ocean sports fishing also became a common pastime for California anglers.

<u>Today's Fishery</u>

Today, approximately 5000 commercial salmon boats fish the coast between the Oregon border and Los Angeles. Most of the salmon are located along the North Coast of California, and the largest catches are landed at Crescent City, Eureka, Fort Bragg, and San Francisco. Point Conception is normally the southern limit of the salmon range, but a few fish are caught as far south as San Diego.

Salmon catch statistics of varying accuracy have been compiled for California from 1874 on (Frey, 1971), and these statistics indicate pronounced fluctuations in salmon harvests since the beginning of this century. Figure 1-2 shows the catch trends for both troll and sport ocean fishing since 1971. The average annual commercial salmon catch in California is about 7,000,000 pounds of salmon--almost 800,000 fish. California follows Alaska, Washington, and Oregon as the fourth leading salmon producer in the nation. Most of the California catch is sold within the state.

Since the last cannery closed in 1919, almost all of the salmon caught in California has gone directly from fishermen to buyers who represent the state's processing plants. Most processing plants are located at the larger harbors, like Crescent City, Eureka, Fort Bragg, and San Francisco, although a few are inland in Santa Rosa and Sacramento.

Once processed, most of the salmon is refrigerated and sold immediately to restaurants, markets, or fish brokers, who may buy several loads of salmon for shipment to Los Angeles, San Francisco, the Midwest or the East Coast. Salmon is also exported to Japan and Western Europe.

The value of salmon to the California economy was approximately $50,573,000 in 1981 from a primary industry employing about 5500 people. Table 1-1 indicates the markets for California coho and chinook for 1976. Since 1976, distribution patterns within the state and U.S. markets have remained largely the same while the value of foreign exports appears to be gradually declining. During this period, Japan has become slightly less important as an importer of salmon products while France has become the number-one importer. Available salmon price and value data by species indicate that, after adjustment for inflation, chinook prices rose gradually from 1971 to 1976 and then appear to have fluctuated around an average price from 1977 to 1981. For coho, California prices have generally kept pace with inflation (PFMC, 1982). In 1982 fishermen sold their catches to wholesale buyers at prices ranging from $1.94 to $2.45 per pound, depending upon species, size, port, and time of year.

The recreational ocean salmon fishery has actually declined in recent years. The California Department of Fish and Game estimated that, while sportsmen are responsible for 15-20% of the total annual salmon catch, the number of angler trips has declined 47% from the 1971-1975 average. Still, the ocean and inland sport fishery has a significant impact on the state's economy.

Although no conclusive figures are available to determine the contribution of sport fishing to the economy, some 1,800,000 trout/salmon license stamps were sold to allow sport fishing for anadromous species in 1980 (CDFG, personal communication, 1982). In

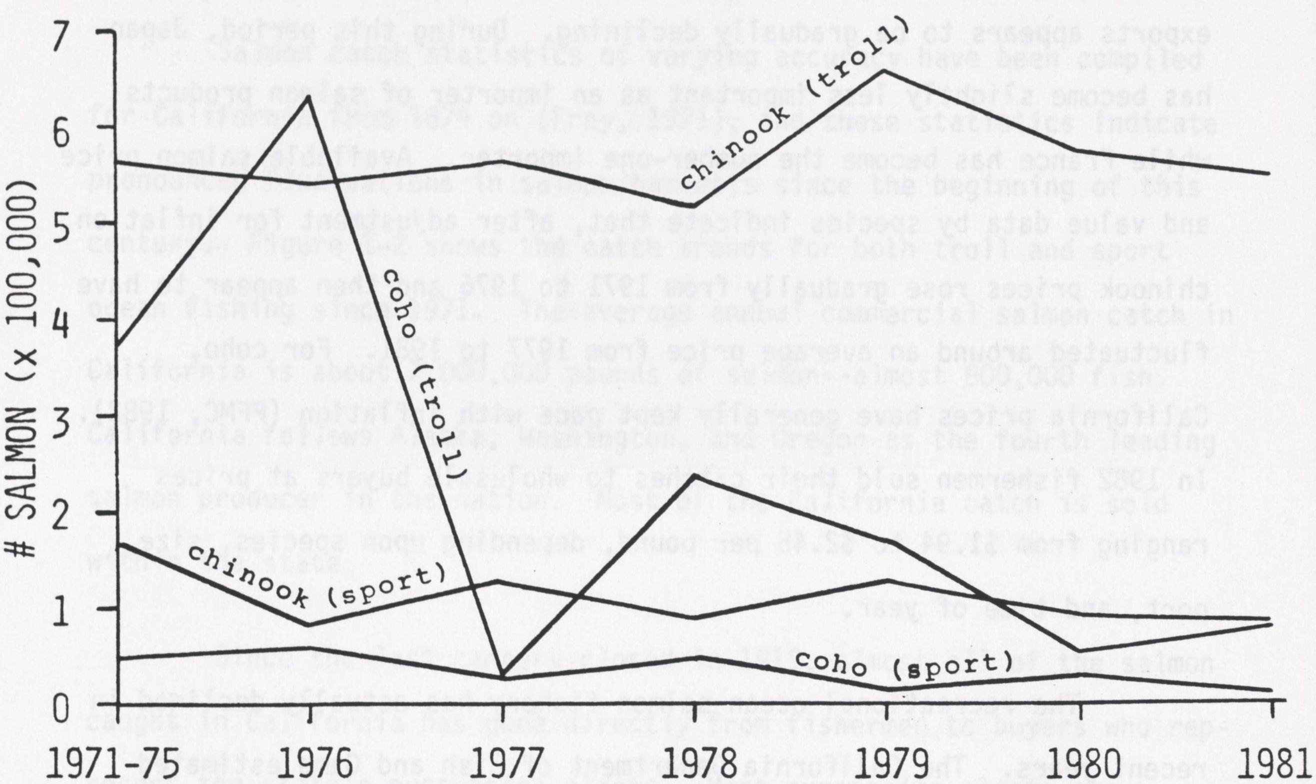


Figure 1-2. California ocean commercial and recreational salmon catch, 1971-1981.
Source: Pacific Fishery Management Council, 1982.

1978, the salmonid fishery was enjoyed by about 150,000 fishermen and contributed more than $17 million to the state economy (Resources Agency, 1979).

Population Estimates

While both commercial and sports salmon catches have been maintained at relatively stable levels during the past decades, overall population estimates are below "historic levels," which are roughly defined as the largest numbers of fish known to have occurred in California. The California Department of Fish and Game and others (e.g., the California Advisory Committee on Salmon and Steelhead Trout, 1971) have officially documented declining runs in all of California's major salmonid rivers. For example, studies indicate that spawning chinook salmon in the Klamath and its tributaries have declined from 160,000 per year in the early 1960s to less than 30,000 in 1980 (PFMC, 1978). In the main stem of the Trinity River system, chinook spawning declined 80% between 1968 and 1979. Chinook and steelhead spawning on the Sacramento River system has declined by 25% in the past two decades. Fall chinook on the San Joaquin River, formerly exceeding 100,000 spawners annually, have been reduced to only a few thousand fish. Spring chinook in the San Joaquin, which historically exceeded the fall run in numbers, are now extinct. In addition, in a number of cases, escapement levels set by management agencies to sustain the productivity of natural and hatchery stocks are not being met (PFMC, 1982).

Human Impacts

The decline in salmonid runs is generally attributed both to the continued effects of fishing and to human impacts on aquatic habitat. Before 1900, the San Joaquin, Sacramento, and North Coast river systems had 9000 miles of anadromous fish habitat. Today, this area has declined to 7500 miles. The principal causes for the decline are dam construction, diversion of water for agriculture and urban uses, periodic natural flooding, siltation of streams due to timber harvesting, road building, wildfire, and other disturbances that remove vegetative cover which protects soils from excessive erosion.

The state's water control projects (Figure 1-3) have had the greatest of all impacts on salmonid habitats, yet these impacts seem never to have been considered in advance of construction. Three projects built in this century have succeeded in regulating the flow of the Sacramento River; providing water to irrigate the San Joaquin basin; and satisfying industrial and domestic water needs of the San Francisco Bay area as well as of central and southern California cities. Dams have been built on virtually every major river of the Central Valley system, and most of the North Coast rivers have been modified to control flows, supply domestic water, or generate hydroelectric power.

Much less of the water from the Central Valley rivers now flows into San Francisco Bay than in presettlement days. A large portion of the water from the north is shunted south from the Sacramento Delta, and most of the San Joaquin River is used locally or further south. The transported water supplements the limited underground water supplies for irrigation in the southern part of the Central Valley.

Table 1-1

CHINOOK AND COHO SALMON a/ MARKETS BY FISH WEIGHT, 1977

	Chinook Weight				Coho Weight				
	Less than 7 lbs.	7 lbs. to 11 lbs.	Greater than 11 lbs.	Unspecified	Less than 4 lbs.	4 lbs. to 6 lbs.	6 lbs. to 9 lbs.	Greater than 9 lbs.	Unspecified
Southern California	18 b/	41	49	1	12	4	18	3	1
San Francisco Bay Area	28	13	2	3	4	23	3	*	11
Northern California and Southern Oregon	4	10	1	35	* c/	*	1	5	21
Puget Sound	25	4	5	*	77	*	*	*	26
Other West Coast	8 d/	2 d/	2 d/	9 d/	*	1	1	1	2
West and Southwest (excluding West Coast)	11	*	*	*	*	*	*	*	2
Great Lakes Region	1	*	*	*	*	*	*	*	7
East Coast	2	12	24	52	*	*	*	*	*
Southeast	*	4	9	*	2	1	*	*	29
Exports	3	13	9	*	6	71	77	91	*
Total	100	100	100	100	100	100	100	100	100
% of total landings in each size class	22	32	41	5	14	34	36	2	14

a/ Troll-caught chinook and coho in fresh, frozen, or mild-cured form. A small amount was marketed in kippered or smoked form.
b/ Figures are percentages.
c/ Figure is less than 1%.
d/ Including Hawaii

Source: Oregon State University, 1978.

Table 1-2

CALIFORNIA ANADROMOUS SALMONID PROPAGATION FACILITIES

Name	Stream or River	Nearest Town	Owner	Operator	Species Reared	Purpose
Prairie Creek	Lost Man Creek	Orick	Humboldt County	Humboldt County	Chinook Salmon Coho Salmon Steelhead Trout Cutthroat Trout	Augment north coast runs
Mad River Hatchery	Mad	Blue Lake	Calif.	CDFG	Chinook Salmon Coho Salmon Steelhead Trout	Augment north coast runs
Iron Gate Hatchery	Klamath	Hornbrook	PPL	CDFG	Chinook Salmon Coho Salmon Steelhead Trout	Mitigation
Trinity River Hatchery	Trinity	Lewiston	USBR	CDFG	Chinook Salmon Coho Salmon Steelhead Trout	Mitigation
Darrah Springs Hatchery	Battle Creek	Anderson	Calif.	CDFG	Coho Salmon	Augment north coast runs
Warm Springs Hatchery	Dry Creek	Geyserser-ville	USACE	CDFG	Chinook Salmon Coho Salmon Steelhead Trout	Mitigation
Tehama-Colusa Spawning Channel	Sacramento	Red Bluff	USBR	USFWS	Chinook Salmon	Mitigation and enhance-ment
Coleman National Fish Hatchery	Battle Creek	Anderson	USFWS	USFWS	Chinook Salmon Steelhead Trout	Mitigation
Feather River Hatchery	Feather	Oroville	DWR	CDFG	Chinook Salmon Steelhead Trout	Mitigation

Table 1-2

Name	Stream or River	Nearest Town	Owner	Operator	Species Reared	Purpose
Nimbus Hatchery	American	Fair Oaks	USBR	CDFG	Chinook Salmon Steelhead Trout	Mitigation
Mokelumne River Hatchery/Rearing Pond/Spawning Channel	Mokelumne	Clements	EBMUD	CDFG	Chinook Salmon	Mitigation
Merced River Spawning Channel and Rearing Ponds	Merced	Snelling	MID	CDFG	Chinook Salmon	Mitigation

KEY:

CDFG	=	California Department of Fish and Game
DWR	=	Department of Water Resources
EBMUD	=	East Bay Municipal Utility District
MID	=	Merced Irrigation District
PPL	=	Pacific Power and Light
USACE	=	U.S. Army Corp of Engineers
USBR	=	U.S. Bureau of Reclamation
USFWS	=	U.S. Fish and Wildlife Service

Sources: CDFG, 1978; Sanders, personal communication, 1982.

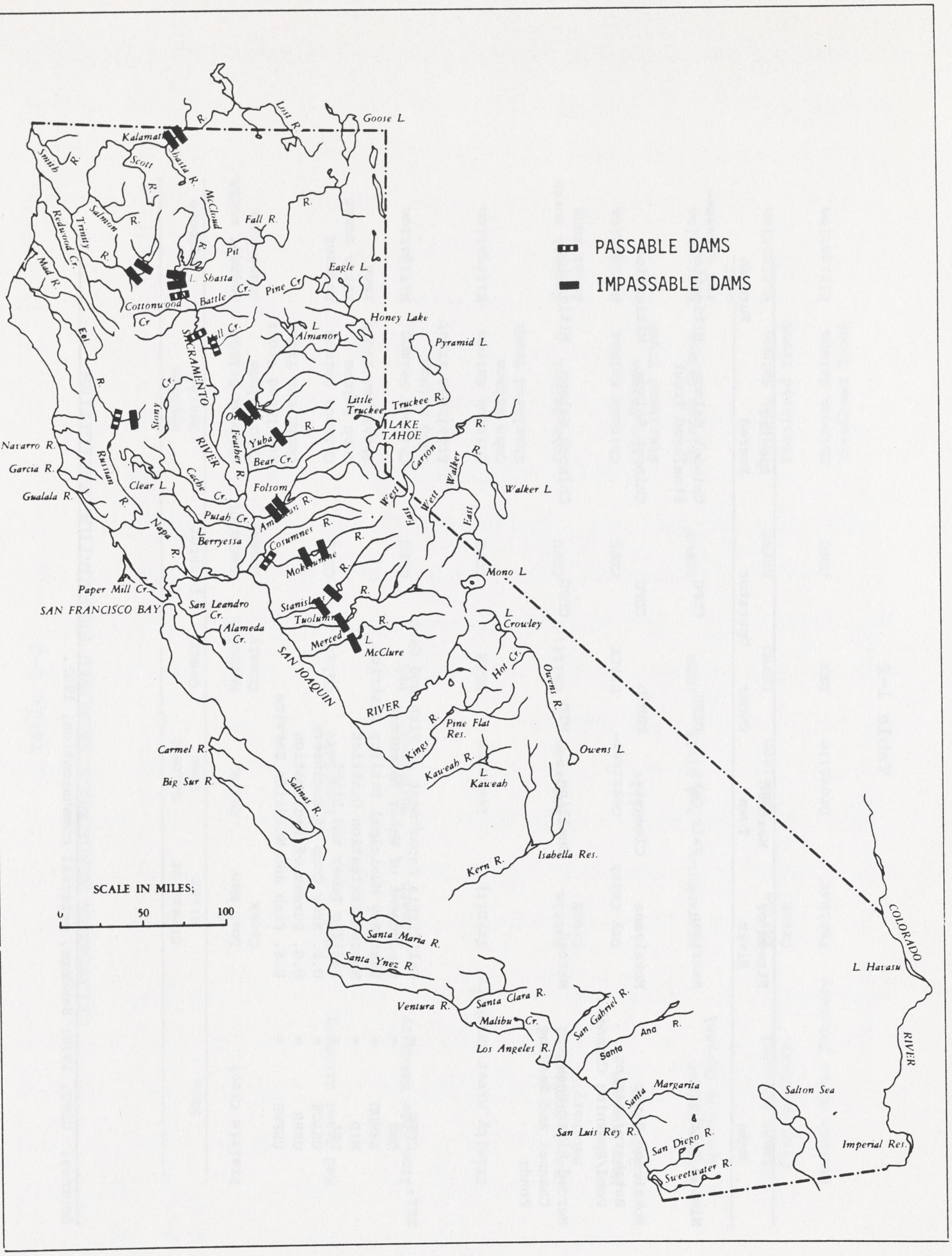


Figure 1-3. California water projects: dams.

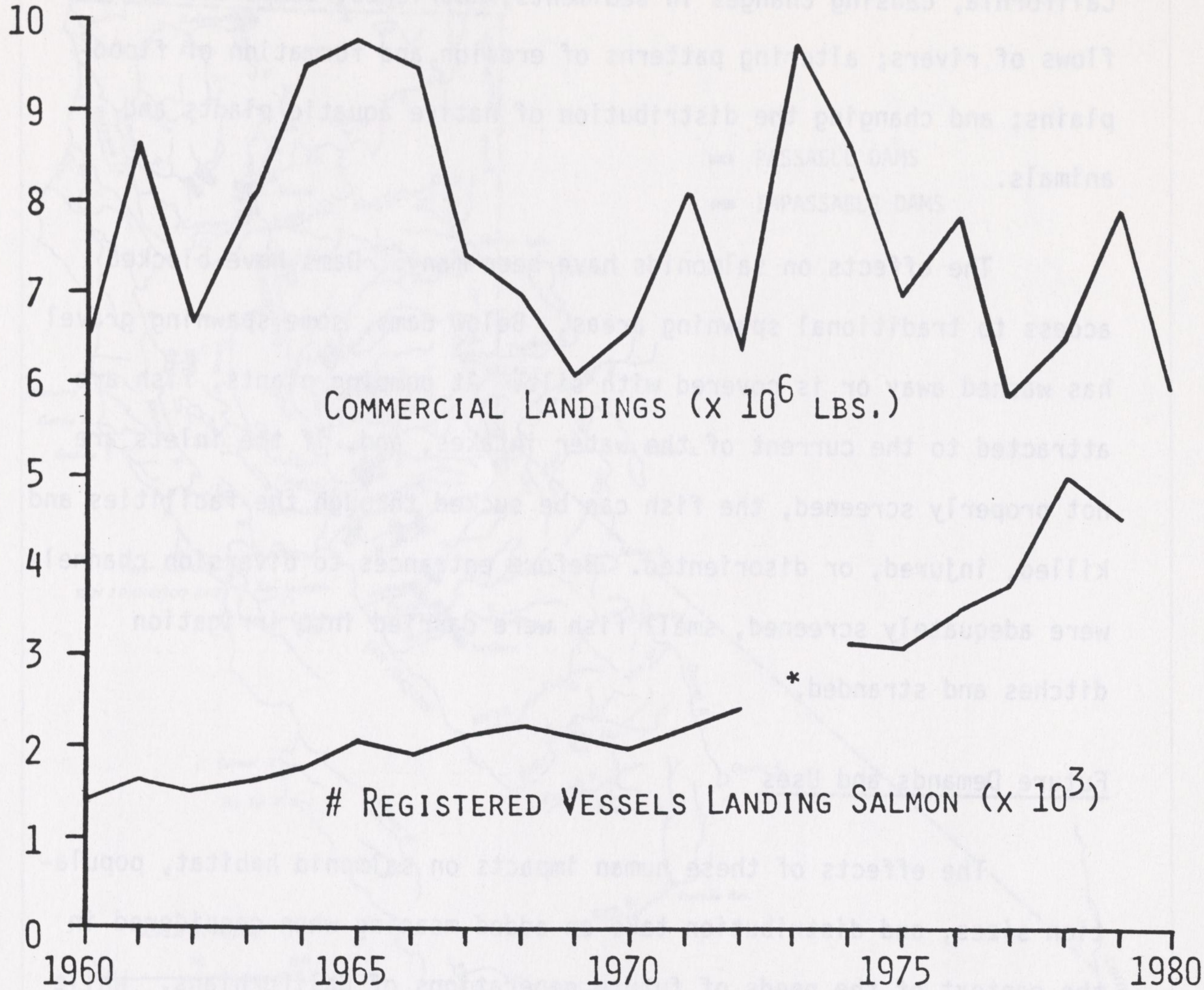
Source: Feinberg and Morgan, 1980; Base Map: Lucoff, 1980.

Water projects have dramatically altered the natural ecology of California, causing changes in sediments, nutrients, temperatures, and flows of rivers; altering patterns of erosion and formation of floodplains; and changing the distribution of native aquatic plants and animals.

The effects on salmonids have been many. Dams have blocked access to traditional spawning areas. Below dams, some spawning gravel has washed away or is covered with silt. At pumping plants, fish are attracted to the current of the water intakes, and, if the inlets are not properly screened, the fish can be sucked through the facilities and killed, injured, or disoriented. Before entrances to diversion channels were adequately screened, small fish were carried into irrigation ditches and stranded.

Future Demands and Uses

The effects of these human impacts on salmonid habitat, population sizes, and distribution take on added meaning when considered in the context of the needs of future generations of Californians. While it is difficult to project future markets and uses of salmonids, the present rate of consumption of salmon in the sport and commercial fisheries is expected to continue through 2020 (PFMC, 1981). Although harvest levels have been maintained to some degree in the past, it appears that in order to take the same quantity of salmon, increased economic and management inputs are required. As an example, the size of the California troll fleet has tripled since 1960 while the average



* Note: Data unavailable for 1973.

Figure 1-4. California commercial salmon landings and fishing effort, 1960-1980.
Source: Pacific Fishery Management Council, 1982.

landings per vessel have decreased significantly over this 21-year period (Figure 1-4).

The state's ability to maintain present consumption levels or to increase salmonid production depends on a range of programs which have been developed. Particularly in recent years, numerous public and private groups have instituted programs to regulate the ocean and inland fishery and to restore and enhance salmonid habitat in coastal and valley rivers and streams.

MANAGEMENT PROGRAMS

Regulation of the Ocean Fishery

Depletion and overfishing of certain fish stocks off the U.S. coasts and evidence of industry inefficiencies prompted Congress in 1976 to pass the Fishery Conservation and Management Act. The law extended U.S. jurisdiction to 200 miles off its coast and asserted the right to limit or exclude foreign fishing in that zone. It regulates fishing, and it requires that both foreign and U.S. fishermen conserve fishery resources within the 3- to 200-mile federal management zone.

To plan management of the resource and to enforce the Act, the act established eight regional fishery management councils. California, along with Oregon, Washington, and Idaho, is part of the Pacific Fishery Management Council (PFMC). PFMC's major task is the preparation of management plans for a number of fisheries (i.e., anchovy, dungeness crab, pink shrimp, and salmon) in their respective geographical areas. The salmon plan contains information on the resource's condition, the harvesting sector, the processors, the market, and the consumers. Based on the information in the plan, it recommends specific allocations of the predicted catch. The various user groups affected by the plan may participate in the planning process during council meetings and at public hearings held throughout particular states. After review and approval by the U.S. Secretary of Commerce, regulations are established, and the plans are put into effect.

An important principle found in the Act is that the fishery plans should use optimum yield as the primary management goal. Implicit in the optimum yield concept is that the multitude of data described in the Act must be combined to determine the catch that will provide the greatest overall benefit to the nation. The exact meaning of a fishery's optimum yield and its determination is left to the judgment of the regional councils. However, before developing the optimum yield concept, the councils must determine the total allowable catch that each species could sustain without damage to the fish stock. This is known as the maximum sustainable yield--a biologically determined catch independent of economic and social factors.

The 1982 salmon management plan (PFMC, 1982) for the Pacific region was prepared by a team of planners from the various state fishery departments and the U.S. Fish and Wildlife and National Marine Fisheries Services. The National Oceanic and Atmospheric Administation supplied the funding.

The plan essentially sets a number of escapement goals for the major salmon production areas of the coast and develops and recommends programs for achieving these goals. The programs employed include the establishment of opening and closing dates for the fishing season, regulation of the type of gear used, establishment of management boundary areas, and a limitation on entry for commercial trollers. The plan was accepted by the Secretary of Commerce in the spring of 1982 and is now in effect.

Under the act, the California Department of Fish and Game (CDFG) retains the authority to determine whether the plan's regulations should apply to California territorial waters (within three miles of the shoreline). A state statute authorizes the CDFG director to suspend any state regulation in order to make California law conform to the salmon plan approved by the Secretary. This provision was voided by the California State Superior Court in 1980, and thus, during the 1981 season, California waters were managed under a season different from that used on federal waters. Recently, however, both the California Appellate and Supreme Courts overruled the lower court so that, for the 1982 season, California and federal waters will be managed on the same schedule.

Regulation of the Inland Fishery

California's inland salmonid fishery is primarily under the jurisdiction of the CDFG, except for parts of the Klamath-Trinity Basin, where federal and state laws uphold Indian rights to catch fish for subsistence and ceremonial purposes.

No commercial fishing is allowed in inland waters, and thus, CDFG regulations are limited to sports, recreational, and scientific uses. These regulations are actually set by a five-person Fish and Game Commission appointed by the Governor. Inland salmon and trout fishermen in California must have a valid sport fishing license. Sport fishing gear is limited to hook and line, and, in general, the daily limit is two fish. Season openings vary by geographical area. With the exception of special spawning area closures, most California streams are open to angling during the period that adult fish are present.

Within the Klamath-Trinity Basin, three different authorities have attempted to exercise jurisdiction over Indian fishing--the Hoopa Valley Business Council and, because the Yurok Indians are not formally organized as a legally recognized tribe, the state and federal governments on the Klamath River.

Though California has sought to regulate fishing on the Klamath River portion of the Klamath-Trinity River system for more than a century, a series of court decisions have reestablished the Indian right to fish for subsistence purposes. Whether commercial fishing is included within the definition of permitted fishing remains unclear. In 1975, the California Court of Appeals held that the state did not have jurisdiction to regulate Indian fishing on the lower 20 miles of the Klamath and upheld the Indian right to fish free from state regulation. However, in 1977, the Del Norte County Superior Court concluded that regulating commercial fishing by Indians on the Klamath River reservation is a valid exercise of the state's police powers.

In 1979, the Bureau of Indian Affairs (BIA) promulgated rules for Indian fishing on the reservation, permitting fishing for subsistence and ceremonial use but not for commercial use.

On October 18, 1979, the State of California became a plaintiff in a suit against the Secretary of the Interior and staff who are responsible for carrying out the trust responsibility of the United States for the Yurok Indian Tribe. The controversy concerns the applicability of California law on the lower 20 miles of the Klamath River. This case is still pending.

Most recently, the BIA delivered a position paper to the Pacific Fishery Management Council in which curtailment of harvest by the Indians was asserted to be necessary to protect the resource, but the BIA recommended that other user groups also reduce their harvests. The paper urged that the Pacific Fishery Management Council and other governmental agencies address the issue of allocating the total harvest.

Mitigation and Enhancement

Hatcheries have been one of the mainstays of California's salmonid management efforts since the 1960s. Currently, there are nine hatcheries and three spawning channels in California (Table 1-2), funded all or in part by state and federal agencies, the Bureau of Reclamation, utility companies, or county government. Eight of the facilities were built to mitigate fish population losses due to state water development and flood control projects. The California Department of Fish and Game (CDFG) operates a total of nine rearing facilities; another two are operated by the U.S. Fish and Wildlife Service (USFWS); and Humboldt County administers the remaining facility. CDFG has authority over all egg collecting in the state.

Lately, rearing space has also been created for fry that are surplus to the CDFG program's needs or hatchery capacity. The fish are being raised to the smolt stage in artificial ponds by community-run projects in the North Coast area. These experiments are the result of interest by fishermen and the general public in replenishing local salmon stocks. The projects are operated using relatively low-cost materials, with technical assistance from the CDFG, from Humboldt County's hatchery, and from the California Sea Grant Marine Advisory Program.

For many years, salmon hatcheries were built solely to raise fish to be caught by commercial and sport fishermen. However, over the past decade, the business of ocean ranching or aquaculture has developed.

Ocean ranching of salmon has many similarities to public hatchery operations; the main differences are in goals, facility locations, and funding. Ocean ranches are privately funded and are operated for profit from the harvest and sale of adult fish. These ranching operations are located at tide-water, while public hatcheries are usually upstream.

Anadromous salmonids are particularly suitable for aquaculture for the following reasons:

1. They do not require elaborate containment systems and can be released to the natural waters during their early life stages.

2. Culture methods are well developed.

3. Their homing instinct permits a high percentage of the adult fish to be captured during their spawning run.

4. Their market value is high.

California presently has only one commercial salmon aquaculture facility, which is located just north of Santa Cruz. Several environmental, economic, and political issues remain to be resolved before salmon ocean ranching in California can develop further; however, California has the potential for a viable salmon ocean ranching industry (Living Marine Resources, Inc., 1980).

While commercial salmon ranching is a relatively new activity in California, it has been successfully developed in Japan and Russia and is developing in Alaska, Oregon, and Canada. For example, as of 1980, Oregon has issued 20 private salmon hatchery licenses to 12 firms or individuals to raise coho, chinook, and chum (Onchorhynchus keta) salmon. Although private salmon ranching has not yet been legalized in Washington, a commercial net-pen system has been established which produces more than 450,000 kilograms of pan-sized salmon (mostly coho) per year (Thorpe, 1980).

Habitat Protection

To protect fish and wildlife and the recreational and scenic values of underdeveloped rivers, the State Wild and Scenic Rivers Act was adopted in 1972. The act prohibited state assistance for construction of dams or diversions (except for local needs) on segments of nine designated Northern California rivers. Under this legislation, water from these rivers can still be withdrawn for domestic purposes, but their free-flowing character needs to be preserved. Federal Wild and Scenic River regulations also apply in California, and the U.S. Department of the Interior recently included portions of the Klamath and Trinity Rivers in the National Wild and Scenic River system.

Standards for stream flow requirements of fish are currently considered on a case-by-case basis by the State Water Resources Control Board each time requests are made for water diversions. Some groups, including the Governor's Commission to Review Water Rights Law, have recommended that instream standards be established for each stream to protect fish. Some of these groups have asked that instream values be given priority over offstream uses, such as irrigation.

By revision of the State Water Code in 1969, the California Department of Fish and Game (CDFG) was included in the formulation and enforcement of water quality control plans. The Department investigates the effects pollution has on fish and recommends water quality standards to regional control boards. Presently, CDFG studies are helping find solutions to severe problems caused by heavy metal poisoning in the upper Sacramento River.

The overall effectiveness of the state in controlling non-point-source water pollution depends largely on the stringency of institutional standards and the cooperation of forest users. The California

Forest Practice Act (FPA) provides for formulation and enforcement of forest practice rules on private timber lands and public nonfederal timberlands. Beyond the regulation of forest practices, FPA also provides for streamside protection zones. For example, in the North Coast District, the rules provide for at least a 50-foot buffer zone on streams where fish are absent and a 100-foot buffer in streams where fish are present.

In addition, public agencies often sponsor programs to attempt to restore damaged streams by re-creating lost spawning areas and resting pools, stabilizing eroding hillsides, and removing log jams and other impediments. Almost 100 miles of North Coast salmon and steelhead spawning and rearing habitat was restored in 1981 under a $1 million contract between CDFG and the California Conservation Corps. A similar experimental program is also being applied on U.S. Forest Service lands by the federal agency.

Other Programs

Another important entity with a role in California fishery management is the Trinity River Basin Fish and Wildlife Task Force. This multiagency committee was formed in 1974 to formulate and implement immediate and long-range remedial actions to restore the anadromous fishery within the Trinity Basin. Members include the Water and Power Resources Service, CDFG, USFWS, the Department of Water Resources, National Marine Fisheries Service, the Bureau of Land Management, the BIA, and the U.S. Soil Conservation Service. In 1980, this task force published a proposed fish and wildlife management program which, if implemented, would direct watershed rehabilitation, harvest regulation, monitoring, and artificial and native stock production projects under a single coordinating authority.

Improved Salmonid Management

All of these management agencies and their programs represent significant organizational resources for the resolution of salmon and trout production-and-genetic problems in California. If well coordinated, these programs can provide the key to maintenance and protection of one of the state's most important renewable resource systems. However, as the next several chapters contend, California needs to place more emphasis on the value of native fish as a genetic resource and the application of the stock concept in salmonid management activities.

CHAPTER 2

IDENTIFYING THE GENETIC RESOURCES OF SALMON AND ANADROMOUS TROUT

CHAPTER ABSTRACT

The genetic resources of salmon and sea-run trout are the basis for the present and future productivity of California's salmonid fishery. Intensive harvesting and loss of habitat have had major impacts on this fishery. Although hatchery technology has had some success in replacing and supplementing natural runs of salmonids, uncertainty remains as to the long-term consequences of both harvesting and replacement practices currently in use. A broad understanding of the importance of salmonid genetic diversity to fishery productivity and stability is required for a reevaluation of management alternatives and long-term conservation needs.

The usefulness of salmonid genetic diversity is summarized in two respects. The first is its usefulness for salmonid management programs. A second perspective is provided by consideration of problems encountered in artificial propagation and domestication of salmonids. The usefulness of natural variability in disease resistance and a variety of other traits is apparent from this perspective.

The significance of the natural diversity that can still be found in native wild salmonid populations is revealed by studies of

variation in behavioral, physiological, morphological and biochemical traits within and among populations. Much of this variation has a genetic basis and is adaptive, i.e., enables individual fish to cope successfully, on average, with the specific environmental conditions that they encounter in both freshwater and ocean environments. Some genetic variation is not demonstrably adaptive but may nevertheless have significance to the future viability of natural populations and for artificial propagation and breeding purposes.

The possession of different characteristics, both adaptive and nonadaptive, by different populations of salmonid species is the basis for the stock concept. The stock concept is an integration of scientific knowledge about fish genetic diversity and its significance in a form designed to facilitate application of this knowledge to management decisions. While the stock concept has been successfully employed in fishery management elsewhere, the data required to identify and individually to manage individual salmonid stocks important to the California fishery are presently inadequate for these purposes. A review of existing knowledge of genetic variation in chinook and coho salmon, and anadromous rainbow (steelhead) and cutthroat trout populations reveals a paucity of data on all of these species. ?

Recognition and use of salmonid stock diversity in California is reviewed from the perspectives of historical and current management practices. Opportunities for future uses of stock diversity can be identified in three areas: replacement and enhancement of native runs, development of domestic stocks, and overall maintenance of fishery productivity. If these opportunities are to be realized, measures must be taken to document and conserve the genetic resources on which they will be based.

The genetic diversity of salmon and sea-run trout is the basis for the current and future productivity of California's anadromous salmonid fishery. These genetic resources have been modified by management practices in the past (Thorpe et al., 1981; Ricker, 1981). The potential for impacts on this genetic diversity of harvesting salmon and anadromous trout populations has been recognized for more than a century (Anderson, 1880, 1881, cited by McDonald, 1981). The loss of habitat suitable for natural spawning due to the construction of dams and watershed management activities during the first part of this century led to extensive study and implementation of techniques for artificial propagation (Larkin, 1979).

The present necessity for managers to actively restore or augment propagation to sustain populations is now not disputed, but means to this end are still being explored. Hatchery technology permits the production of massive numbers of young fish. However, some scientific uncertainties still exist about how best to use hatchery-bred fish in natural aquatic systems (AIFRB, 1975; Larkin, 1979). Indeed, the ways in which both harvest and propagation techniques affect the genetic resources of the salmonid fishery are just beginning to be documented and understood. There is not, at present, an explicit formulation of genetic knowledge into a working hypothesis for salmonid management (Larkin, 1981).

THE USEFULNESS OF GENETIC MATERIALS

Diverse salmonid genetic resources are necessary to the continued productivity and stability of California's fishery. Genetic materials are used to increase productivity, to improve quality, and to provide an insurance policy against natural disasters and adverse human impacts.

Genetic materials, or germplasm (referring to genetic diversity and its organization in genes, individual genotypes, and populations) are originally derived from natural populations native to free-flowing portions of California's rivers and streams. Natural propagation of these populations depends directly on the native germplasm for its success.

Artificial propagation of chinook and coho salmon and steelhead trout also requires native germplasm resources (see Appendix B). Eggs are collected from mature females returning to hatchery locations or seined from rivers, and the eggs are fertilized with milt from similarly obtained males. Most anadromous hatchery programs in operation today continue to use naturally returning fish in artificial spawning procedures. The option of developing a hatchery-held brood stock is not feasible because of the limited success and expense of maintaining fish in fresh-water to reproductive maturity. Some domestication of hatchery runs may occur, however, as evidenced by changes in size of returning fish, run-timing, and other features.

Genetic materials can be employed in three general ways in fish culture:

1. If there is sufficient knowledge of the differences in characteristics among species and species' "stocks" (i.e., genetically distinct subpopulations), then managers may simply select and propagate stocks with desired characteristics. Because stocks often do not perform in an area of introduction as they did in their native habitat (because they may not be genetically well adapted to the new environment), selected stocks may have to be raised and released on an experimental basis. Salmon ranching in the United States currently uses this approach.

2. Hybridization is a second means of using genetic materials through artificial propagation. Evidence of "hybrid vigor" (e.g., faster growth rate, larger size at maturity) in crosses between species, races, or stocks of many species of plants and animals is the basis for using this approach. Hybridization is feasible with salmonids because spawning in the hatchery gives the fish culturist control over which individuals' eggs and sperm are mixed for fertilization. Many crosses between salmonid species and stocks are fertile (Dangel et al., 1973). However, hybridization does not always result in superior performance. As in the case of stocks selected from nature, hybrid stocks must be tested for viability and performance.

3. Another means of using genetic materials is controlled breeding and selection of stocks one or more generations removed from wild populations (see Appendix C). This approach generally requires the maintenance of a brood stock in a hatchery so that specific individuals with known geneology and characteristics may be crossed with one another to enhance certain traits or to develop new trait combinations. In agriculture, selection and breeding may be carried out on whole populations (population improvement), or on inbred lines with or without extensive use of hybridization. In the long term all three ways of using genetic materials require periodic access to new germplasm in order to proceed efficiently toward production objectives.

The attainment of production objectives also requires healthy and hardy broodstock. Salmonid populations are subject to both predictable and unpredictable patterns of climatic variation, long-term environmental changes, and challenges by pests, diseases, and predators. Native stocks represent lineages of salmonids that have contended with these factors for tens of thousands of years in California's rivers and streams. Consequently, they tend to be disease-resistant relative to domesticated hatchery-bred fish. While a great deal is known about the prevention and treatment of diseases found in salmonids raised under hatchery conditions (Wood, 1968), fish kills remain a major and persistent problem in hatchery operation. Legislative restrictions on the use of fungicidal chemicals have made the discovery of alternative remedies critically necessary. The exploitation of genetic variability in resistance to various diseases present in natural populations will probably become important in the development of alternative solutions to fungicides.

While the genetic resistance to disease occurring in some populations of salmon and trout has not been widely used to combat hatchery problems in the past, such resistance is now sought by salmon ranchers in stocks selected for run development. Disease resistance and many other traits useful in hatchery stocking (e.g., tolerance of high densities, responsiveness to thermal enhancement of growth and food conversion) have only begun to be evaluated in native stocks.

Natural propagation remains a major contributor to salmonid production. Artificial propagation still relies heavily on native germplasm, and survival of fish under hatchery conditions may be enhanced by native germplasm. For these reasons, knowledge of the significance of natural diversity is fundamental to improved management and use of the salmonid fishery.

THE SIGNIFICANCE OF NATURAL GENETIC DIVERSITY

Genetic differences may exist between individuals and groups of individuals at several levels. Individuals may differ by having various forms of the same genes (called alleles) represented in the genetic blueprint of their DNA. Differences may also exist in the way alleles are combined to form the total "genome" of an individual. Most individuals in sexually reproducing species (with the exception of identical twins, triplets, etc.) are different from all others in possessing a unique combination of alleles for hundreds of thousands of genes. Populations may differ in the frequency of both specific alleles and genotypes (combinations of alleles) carried by member individuals. Populations, and whole species, are also likely to exhibit differences in both allelic and genotypic frequencies in different parts of their range. Such differences are referred to collectively as geographic variation.

<u>Adaptive Variation</u>

Some of the variation observable at the genic, genotypic, and population levels in salmonids may be "adaptive," i.e., it may be the product of the sorting or "culling" effect of natural selection. Genes and genotypes characteristic of individuals with better-than-average survival and reproductive output tend to increase in relative frequency in populations. Evidence of genetic adaptation by organisms is compelling. However, it is difficult to demonstrate unequivocally that a particular variant or pattern of variation is adaptive, because the scientific method can only disprove, not prove, hypotheses. The tendency for anadromous salmonids to return to rather precise locations in freshwater streams where they hatched (natal areas) has been taken as evidence that genetic differences exhibited by fish from different areas are caused by adaptation. Many studies have provided indirect but convincing evidence of adaptation. In many cases, however, variation has been shown to be genetically based, but is not known to be the result of adaptation to environmental conditions.

Fisheries biologists now generally agree that a very significant component of the variation in behavior, physiology, and morphology observed in anadromous salmonid species is adaptive and important to the viability and productivity of local populations. There remain many practical difficulties in applying this knowledge to management planning, policy, and practice (Larkin, 1981; MacLean and Evans, 1981). Development of a definition or framework for the stock concept has been the first step in applying knowledge of salmonid genetics to resource management.

The Definition of Stock

A stock has been generally defined as "a species group, or population, of fish that maintains and sustains itself over time in a definable area" (Booke, 1981). A more precise definition requires some understanding of the ways in which genetic diversity exists among individuals and populations of a species.

A stock can be defined quite precisely on the basis of theoretical population genetics. It is a group of fish in which every individual theoretically has the same probability of mating with every other individual of the opposite sex (Booke, 1981; Kutkuhn, 1981; Ihssen et al., 1981). (Such a group is known variously as a randomly mating population, panmictic unit, or deme, and is said to be in Castle-Hardy-Weinberg equilibrium.) Further qualifications have been added by various authors. Ihssen et al. (1981) indicate that a stock should have temporal or spatial integrity, i.e., that the stock should be relatively isolated from other stocks by the location and the timing of its spawning run. Kutkuhn (1981) specifies that a "unit stock" exhibits persistent genetic integrity whether it is temporally or spatially isolated from other stocks or not. Larkin (1972) added a management feasibility constraint by defining a stock as "a population of organisms which, sharing a common gene pool, is sufficiently discrete to warrant consideration as a self-perpetuating system which can be managed" (emphasis added).

Because genetically distinct populations of salmonids may have genetic resource value whether or not they are currently recognized as "manageable," a definition without management constraints will be used in the balance of this report. A stock will be defined as a genetically distinct subpopulation of fish which mate randomly and tend to be temporally or spatially isolated from other subpopulations.

Identifying Stocks

In practice, stocks can be defined by a variety of methods based on observation of traits known to have at least a partial genetic basis. Traditionally, differences between species and populations in fish have been documented by "meristic" (measurable) features of morphology (e.g., caeca [outpocketings of gut], fork length, number of gill rakers, scale patterns, vertebral number), or by behavioral or physiological characteristics (e.g., juvenile dispersal, age at migration to the ocean, age at spawning, spawning season, homing behavior, etc.). Interpretation of such data must take into consideration that many observable (phenotypic) traits vary considerably because of differences in environmental conditions experienced by individuals or populations during their development and growth.

Ricker (1972) reviewed morphological and physiological-behavioral data for evidence of geographic variation and evaluated their genetic and environmental determinates. The inadequacies in scientific knowledge for defining stock differences that he pointed out a decade ago currently remain largely unremedied by research. Differences among stocks that Ricker found to be significant are unlikely to be the only ones in existence. As he observed, the design and sampling procedure of many studies made of variable traits in Pacific salmon and steelhead did not allow differences between stocks and their genetic basis to be properly evaluated. The fact that studies still have not systematically sampled natural populations over large portions of their range further complicates the application of these data to stock identification.

Recently, data based on biochemical characteristics of cellular enzymes called isozymes has been shown to be more reliable in reflecting the genetic component of variation. Ihssen et al. (1981) provide an up-to-date compendium of procedures for stock identification. Electrophoretic analysis of isozymes has provided a tool for rapid evaluation of genetic differences between populations of fish (Utter et al., 1974). There has been considerable debate over the origin of isozyme variation (Lewontin, 1974) and its relevance to the prediction of performance characteristics. Isozyme differences between populations may not be due to selection. However, isozyme data are indicative of genetic differentiation and reproductive isolation among populations, which has provided the opportunity for differences in adaptive features and performance characteristics to arise. Genetic distance (Nei, 1972) is calculated from allelic frequency differences among populations and is an estimate of the time since two populations were a single effective breeding unit (Sarich, 1977; Clayton, 1981). The greater the differences are between populations in their nonselective isozymic variation, the greater has been the opportunity for both random and selective differences in other characteristics to appear.

Genetic similarity, measured by various attributes, tends to be highest among geographically adjacent populations (Utter et al., 1974, cited by Utter, 1981; May 1975; Kristiansson and McIntyre, 1976; Grant, 1977; Thorgaard, 1977a, 1977b; Allendorf and Utter, 1979). One notable exception has been documented for rainbow trout and steelhead (Behnke, 1979; Allendorf et al., 1975; Utter et al., 1980). Populations on the east side of the crest of the Cascade Mountains in Oregon, Washington, and British Columbia are more similar to one another than they are to populations on the west side of the crest. Geologic events and the recolonization of coastal areas are thought to explain this situation. Similar discontinuities in isozyme allelic distributions have been reported for chinook and coho salmon (Allendorf and Utter, 1979).

A number of the most intensive studies of genetic variation in vertebrate populations have shown that different conclusions about the geographic distribution of variation may be reached depending upon what traits are examined. One interpretation of discordant results is that patterns of mating, migration, and natural selection have permitted, perhaps even necessitated, differences in the vulnerability of genes and gene complexes to the effects of natural selection and random events.

Some portions of the genome (the genetic complement of the individual) may be "buffered" against change, or permitted to change only intermittently by mechanisms not yet understood. Populations in which genetic changes apparently fail to correspond to the broad geographic trends apparent over the species range may be those where natural selection or accidents of evolutionary history have created unusual combinations of traits. Such populations may be especially worthy of evaluation for features useful in artificial propagation and breeding.

Overlapping data sets have not been obtained for salmonid species of the North American Pacific coast. Exemplary studies by Casselman et al. (1981) show how a combination of morphometric, osteometric, and electrophoretic characteristics permit the definition of whitefish stocks in Lake Huron. Similarly, a broad geographical perspective on whitefish stock distribution was obtained by Ihssen et al. (1981) using a combination of observations on life history, morphology, and electrophoretic characteristics. Studies of this kind should be done on salmonids in California if management of their genetic resources is to be effective.

KNOWLEDGE OF GENETIC VARIATION IN CHINOOK, COHO, STEELHEAD, AND CUTTHROAT

The data required to identify the native stocks of California's four principal anadromous salmonid species are either not available or are inaccessible at the present time. None of the measures of genetic variation routinely used in studies of geographic variation have been obtained on enough populations in the state to permit the genetic classification of California salmonid stocks. Existing data from other portions of each species range outside California are incomplete and are an inadequate substitute for knowledge of genetic variation in California because of the many biological, geological, and historical variables that affect interpretation (Utter, 1981).

Chinook Salmon

Geographic variation in chinook has been extensively documented in Oregon and Washington by isozyme studies within the past decade. Numerous populations on the Columbia River have been sampled (Utter et al., 1974; Kristiansson and McIntyre, 1976; Utter and Allendorf, 1977), providing a detailed view of the genetic diversity in that system. Populations have also been sampled from coastal rivers from British Columbia to California (Kristiansson and McIntyre, 1976; Milner et al., 1982).

The utility of these data for identifying the relative contributions made by various river systems to the mixed fishery in the ocean has been demonstrated (Milner et al., 1981, 1982), but interpretation of geographic patterns pertinent to the definition of stocks requires complementary data. Comparable data sets for morphological, chromosomal, osteological, or other possible indicators of genetic differentiation in California chinook are not available. Chinook life history variation exists in abundance (Ricker, 1972) but has not been systematically reviewed or evaluated by means of the necessary experimentation.

Isozymic variation has been reported recently for chinook populations sampled at six locations in Northern California (Milner et al., 1982). Preliminary analysis of these data show populations from the Trinity and Klamath rivers to differ more than populations sampled from four locations in the Sacramento drainage. The greatest difference among California populations occurred, as expected, between coastal and Sacramento system populations.

Coho Salmon

Information relevant to an understanding of geographic variation in coho salmon is quite limited. High levels of variation have been found in only one of 24 enzymes that have been examined (Utter et al., 1970). Occasional variants have been detected in five additional enzymes (Utter et al., 1980), but are so infrequent that they cannot be used as a basis on which to distinguish coho stocks. Interestingly, two enzymes show relatively high frequencies of these rare variants in populations sampled from the Feather River in hatchery in California (Utter et al., 1980, citing unpublished data). Ricker (1972) reviewed the status of coho populations and found evidence for heritability of observed traits.

Two other studies (Seidel, 1977; Murphy, 1981) may ultimately contribute to an overview of geographic variation in coho when more data are available.

Use of interracial hybridization to examine differences among three coho hatchery stocks from the Puget Sound area in Washington is described by Seidel (1977). Results of the early life history portion of this study showed that the three stocks used retained significant differences in growth and food conversion in replicate experiments at two different hatcheries. The establishment of a scale collection, or archive (Murphy, 1981) may ultimately permit geographic patterns to be evaluated over time.

Steelhead Trout

More complete data are available for at least a portion of the species range of steelhead (sea-run rainbow trout) than for any of the other species included in this report. Rainbow trout and their close relatives have been studied more thoroughly than any other salmonid species (Utter et al., 1980). Variability in life history characteristics of steelhead has been documented by Smith (1960, 1969--reviewed by Ricker, 1972) and Withler (1966) for populations in British Columbia.

Isozyme variation is well studied in populations in Washington and British Columbia and has been used to identify tentatively two major geographic units, an inland and a coastal group (Utter et al., 1980). The coastal group, occurring as far south as the Mad River in California, is distinguished from the inland group found only in the Columbia and Fraser river drainages east of the Cascade mountain range. Sampling at the northern and southern extremes of the range (e.g. California) has been inadequate to confirm the boundaries of the coastal group.

Sampling of isozymic variation has also been inadequate to demarcate population units or stocks within these two major groups. However, cytogenetic studies (Thorgaard, 1977a, 1977b) and the occurrence of apparently unique isozyme variants in some river drainages (Allendorf et al., 1975) indicate that stocks are likely to be identified with further study. Some direct evidence of populational differences in the inland group has been obtained by Milner (1977).

Cutthroat Trout

Very little research has been done on coastal or sea-run cutthroat trout relative to other salmonids. Life history data have been recently obtained for the Puget Sound-Hood Canal region by the Washington Department of Game and from outer coastal streams by Fuss (1978). Life history and food habits of sea-run cutthroat are also available from southeastern Alaska (Armstrong, 1971; Jones, 1977). These data do not come from enough populations to provide a clear picture of population differences across the species range.

Isozyme data collected as an offshoot of studies on rainbow trout have begun to provide an indication of geographic patterns in the Puget Sound-Hood Canal region (Utter et al., 1980). Coastal cutthroat are more polymorphic (i.e., reveal more isozyme variation) than any other salmonid species yet studied. Sampling has shown that Hood Canal and north Puget Sound populations are as different, electrophoretically, as coastal and inland groups of rainbow trout and steelhead, with relatively little variation appearing within each population (Campton, 1980). Marking studies have indicated that coastal cutthroat avoid open, deep water areas, such as exist between Hood Canal and north Puget Sound (Johnston and Mercer, 1976, cited by Utter et al., 1980). Lack of gene flow between these two areas is thus indicated by both physical and genetic evidence. Historical and current effects of such isolation should be looked for in California cutthroat populations.

USES OF STOCK DIVERSITY: PAST, PRESENT, AND FUTURE

As noted, managers of the salmonid fishery in California have not had the data required to delineate stocks, and policy makers until recently have not had access to information on the geographic distribution of salmonid stocks. Consequently, genetic considerations have little impact on current management practice. Written guidelines exist only for management of steelhead and recognize potential adverse effects of artificial propagation on natural salmonid stocks without making explicit recommendations for avoiding such effects.

HISTORICAL PRACTICES

During the first three decades of this century, both managers and academicians considered all populations of a fish species genetically homogeneous (Ricker, 1972). Population differences were ascribed to environmental differences. This early philosophy led managers to carry out, in effect, a large number of "experiments" through the movement of eggs from one hatchery to another and the outplanting of fry wherever fish were desired. Some of the resulting observations were recorded in the literature and are reviewed by Ricker (1972) as documentation of the gradual recognition of important genetic differences among salmonid populations.

In California, anadromous species seem to have been subject to fewer stock transfers than land-locked species. This may be due to the fact that most of the presently operating hatcheries for anadromous species were built relatively recently after the stock concept was at least informally recognized for anadromous species (Lietritz, 1970). The California Gene Resource Conservation Program staff conducted an initial survey of records of egg and fish transfers and outplantings by hatcheries in Northern California. Records confirmed that resident trout, e.g. rainbows and browns, have been distributed widely in the state. But distributions of chinook, coho, and steelhead have been less extensive.

The result of California's hatchery program is that anadromous stocks have not been introduced outside their native river systems as indiscriminately as many have believed. Stock transfer guidelines can still be established and implemented for these species before remaining native populations are subjected to considerable stock mixing. The development and use of interim guidelines would permit the conservation of genetic materials until their precise resource value can be determined through sampling and evaluation. Research results would enable fishery managers to review such guidelines as the significance of salmonid genetic variation became better understood.

CURRENT MANAGEMENT PRACTICES

The principal activities in which fishery managers in California might employ the stock concept include artificial propagation (hatchery operation), egg and fish transfers among hatcheries, outplanting (see Glossary) of hatchery-reared fish, regulation of fishing, and stream management.

At present there is no written policy regarding egg and fish transfers or outplanting, although CDFG is aware of the stock transfer issue (Hashagen, personal communication, 1982). Transfers have been limited in practice by restrictions imposed on the basis of location and occurrence of diseases that might be carried with eggs or fish from one watershed to another.

California Department of Fish and Game managers informally recognize two major distribution areas of hatchery stock--the Sacramento system and the coastal river region--and they stock each area selectively. Operators of the two federally owned hatcheries in the state have effectively recognized smaller distribution zones. As a mitigation hatchery, the Nimbus facility contributes to releases downstream from the junction of the American and Sacramento Rivers. The distribution zone for anadromous species raised at the Coleman Hatchery has been quite consistently restricted to the upper Sacramento River from its junction with the Feature River north. Several of the state-operated hatcheries are relatively new and have not operated near capacity long enough to provide for extensive outplanting.

FUTURE NEEDS FOR GENETIC RESOURCES

Genetic variation of anadromous species is a resource that can be used to attain four management goals: (1) maintenance of native runs, (2) development of breeding stocks, (3) enhancement of fishery productivity and quality, and (4) creation of an insurance policy against natural and human-related disasters.

Strategies for rehabilitating salmonid populations (Appendix B) require both habitat and germplasm management. Knowledge and recognition of the adaptive requirements of native or available replacement stocks may increase the efficiency of habitat management, construction, or maintenance. Further knowledge of both salmonid genetic variation and habitat features in California may improve outplanting success as it has in Alaska (Kerns, personal communication, 1981).

Developing of breeding stocks of anadromous species will depend on the use of native stock diversity for some time to come. Variation in time of spawning, size at return, age at maturity, survival, ocean migratory pattern, and disease resistance is currently of interest in hatchery stock selection and plans for breeding. Breeding is a long-term process that is barely underway with anadromous species. Once initial stock selections are made as a basis for stock development, breeders may not often require access to new germplasm. But the history of crop and animal improvement shows that return to wild populations and primitive breeds or varieties is an eventual requirement for continued progress in many cases. Such long-term needs for native diversity should be anticipated in anadromous salmonid management planning, including that for breeding programs, and in identification of genetic resources meriting conservation.

Several options are available for maintenance of fishery productivity. The principal methods are management of native runs sustained by natural propagation and supplementation of these runs by artificial propagation in public or private hatcheries.

Hatcheries greatly increase juvenile survival and, presumably, the number of fish reaching harvestable size. Information acquired and analyzed by the Oregon Department of Fish and Game suggests that density-dependent mortality may negate the hatchery advantage when populations are high. By centralizing spawning, egg development, and rearing, hatcheries also incur risks of power failure, disease, changes in water temperature and quality, etc. But even failsafe management cannot forestall the ultimate occurrence of management failure. The cost of rare, but inevitable, failures is usually very high. An alternative approach to management has been characterized as "safe-fail" (Halling, 1981). Safe-fail management attempts to minimize the costs of a failure should one occur.

As with failsafe hatchery management policies, the designation of only a few rivers or tributaries as sites of natural propagation virtually assures that an eventual drought year, major flood, or other catastrophe will have a major impact on the designated populations. Decentralization of both hatchery operation and habitat rehabilitation and management therefore seems desirable. (A similar conclusion has been communicated by Altukhov and Salmenkova (1981) in recommending that fishing and management efforts be distributed evenly across all subpopulations (stocks) of salmonid species.) Die-offs and power failures are a given in hatchery operation and natural climatic variation and fluctuations in food supplies are the evolutionary <u>status quo</u> for salmonid populations. Consequently, a safe-fail program mixing natural and artificial regeneration at the maximum number of locations possible may be the most appropriate general strategy for maintaining salmonid productivity.

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CHAPTER 3

MAINTAINING CALIFORNIA'S ANADROMOUS GENETIC RESOURCES

CHAPTER ABSTRACT

Various options exist for the conservation of the genetic resources of California's anadromous salmonid species. *In situ* conservation can be accomplished through genetic resource management, population protection, and information exchanges among interest groups (the "watch" process). *Ex situ* approaches potentially include cryopreservation of salmonid sperm, ova, and embryos, and various means of maintaining populations of fish in lakes, pens, ponds, or introduced anadromous runs. Currently, *in situ* genetic resource management is the most feasible means to maintain both adaptive and nonadaptive variations of salmon and sea-run trout for future needs.

Many technical problems hamper immediate progress toward implementation of genetic resource conservation measures, and most of these are caused by inadequate information. The geographic distribution of the state's genetically diverse salmonid stocks is not adequately known in California to guide efforts to acquire, evaluate, and conserve representative genetic material. Lack of knowledge about both the distribution and significance of genetic diversity has impaired implementation of the stock concept as a management tool. The determination of which populations in California's rivers and streams still represent native runs of anadromous salmonids is complicated by the absence of information about the genetic impact of past management prac-

tices in three areas: harvesting, salmonid culture, and watershed management.

Because the research required to supply the information needed for the solution of these technical issues will take time to complete and because current practices appear to be eroding the genetic resource, interim measures for genetic conservation should be taken. Recommended measures include the following: (1) creation of a watershed inventory evaluating stock integrity on the basis of hatchery transfer and planting records, (2) development of appropriate management guidelines for watersheds and streams found to contain native stocks or mixed populations of native and introduced stocks, (2) design and implementation of monitoring programs, and (4) research on questions fundamental to salmonid genetic resource management.

INTRODUCTION

The inadequacy of existing data for the definition of anadromous salmonid stocks and the evaluation of their characteristics makes determination of genetic conservation measures difficult. Conservation of genetic resources requires an understanding of the distribution and significance of genetic variation and a knowledge or appreciation of its resource values. With such information, investments in the activities required to select and manage or maintain a portion of natural diversity can be justified. The materials sought may be those with recognized value or those which may confer future benefits. In the absence of adequate information on heavily utilized species such as salmon and trout, valuable sources of germplasm may be lost before the traditional kinds of genetic conservation activities can be undertaken. Under these circumstances, innovative steps may be required to retain access to genetic resources at minimal initial cost.

OPTIONS FOR GENETIC RESOURCE CONSERVATION

Means of conserving genetic resource materials are broadly characterized as _in situ_ or _ex situ_. _In situ_ approaches provide for the maintenance of a group of individuals or populations in their native habitats. _Ex situ_ approaches remove samples of populations (usually gametes or individuals) to locations where they can be stored or sustained under more closely controlled conditions. Examples of _ex situ_ genetic conservation techniques include seed banks for certain crop plants, clonal repositories for vegetatively reproduced crop species, clone banks and arboreta for forest trees, and zoos or animal farms for rare animals. The characteristics of salmon and anadromous trout raise challenges for _ex situ_ applications and currently are most amenable to _in situ_ conservation.

In Situ Approaches

The principal _in situ_ genetic conservation approaches applicable to anadromous species may be described as _genetic resource management_, _population protection_, and _watches_ (information exchange). Each of these may be most feasible to implement under particular conditions, and a combination of measures may be required to conserve adequately the germplasm resources of a species.

Genetic Resource Management

Germplasm management is accomplished through both habitat and population management. Habitat protection and rehabilitation is critical to the maintenance of viable populations in situ. Loss of summer-run steelhead and chinook salmon in California, for example, has been attributed to blocking of runs and loss of spawning habitat because of dams (and other) water diversions and to the temperature regimes resulting from river regulation (Behnke, personal communication, 1982). Without monitoring of stream conditions and management of watershed activities, genetic resource management in situ is not an adequate long-term conservation measure. Techniques for maintaining and reconstructing salmon habitats are being developed (Mundie, 1980; Amer. Fish Soc., 1982; Mitt and Bailey, 1982).

The second component of genetic resource management is maintenance of population or stock integrity. Genetic integrity depends primarily on the means of propagation, but it is also affected by management activities that may increase the rate of straying, or movement of fish reared elsewhere, into a spawning area (Lister et al., 1981). Reliance on natural propagation is an apparent means of maintaining genetic integrity. Populations that have not received transplants and that are not augmented by hatchery propagation are obvious candidates for genetic conservation. Hatchery runs derived from locally spawning fish may retain many of the adaptive features of native populations and are a genetic resource that is currently managed. Populations that have received significant infusions of introduced germplasm and hatchery runs that are a composite of local and introduced sources may also benefit from more explicit genetic resource management.

Sources of germplasm with particular resource value include native populations and introduced stocks whose performance has been monitored over time. The genetic resource value of an introduced stock increases with the length of time it thrives under the conditions of the introduction. An introduction may appear to do well initially, but unless it persists through drought years, disease outbreaks, and other environmental challenges, its reliability as a genetic resource is questionable. The value of a native stock resides in its adaptive characteristics and in its distinctness from other stocks. Adaptive characteristics reflect both prevailing environmental factors and patterns of long-term environmental variation, whether predictable or unpredictable. Characteristics that are not demonstrably adaptive or are apparently nonadaptive may have performance value relevant to market demands (e.g. meat color and texture) or to ex situ production problems (e.g. tolerance of high fry density). The association of performance traits with adaptive characteristics in native stocks is also valuable. Particular combinations of traits may take many generations of breeding to reassemble in domesticated populations. If desired combinations can be found in natural stocks, breeding efforts are given a head start.

In general, the genetic resource value of native stocks exists as long as stock integrity is maintained, and it can be verified by sampling the stock and documenting the environmental conditions and geograhic situation in which it occurs. The genetic resource value of introduced or mix-spawned stocks, however, is uncertain but may be better understood in time as research and experience demonstrate the genotype-environment performance relationship.

Information upon which a priori guidelines for genetic resource management may be developed is scant. Documentation of performance is difficult with anadromous fish. Measures of performance (e.g., survival, growth rate) must be compared among populations that disappear into oceanic feeding grounds for variable periods of time. Individual fish must be marked to permit identification, upon recovery, of their source and time of release. Many variables affect recovery rates. Mortality of fish (from both natural factors and fishing) in rearing areas, along migratory routes, and on ocean feeding grounds may account for the failure of many marked fish to return to their places of origin. The failure of surviving wild fish to return to their natal areas or of hatchery fish to return to their release site, called "straying," complicates studies of escapement and stock performance. Efforts must be made to recover fish from all parts of their range to determine some of the causes of observed performance differences.

Until recently, releases of introduced hatchery stocks or of outplanted fish in California were not regularly marked. The persistence of recognizably distinct introduced runs usually has been the only measure of performance obtainable from many stock plants and introductions. Without survival and other data obtainable from marked fish, comparison of performance by native and various introduced stocks has not been possible. This situation is gradually being rectified by marking studies in California and other salmon producing states and countries.

At present, genetic resource management policies must consider the significance of two observations. The first is that, historically, transplants from one stream to another have almost always resulted in lower survival to maturity and extensive straying of returning fish into streams other than the one where transplanted fish were released (Ricker, 1972). Similar results are indicated for fish transferred from one hatchery to another. A negative relationship between survival of transferred hatchery stocks, relative to local fish reared in the same hatchery, and distance between stream mouths for transferred and local stocks (Figure 3-1) has been found in the data obtained by the Oregon Fish Commission and the Washington Department of Fisheries (Reisenbichler, 1981). This relationship appears to substantiate the hypothesis that genetic similarity tends to increase directly with geographic proximity (Utter, 1981), in that environmental conditions were the same for native and transferred fish. The second observation, not yet widely documented, seems to contradict the first. Some transplants are successful. Long distance transplants of pink salmon to the Great Lakes and of chinook to New Zealand are prime examples (Larkin, 1981). Successful stocking of streams in southeastern Alaska is not always accomplished with geographically proximate sources; stocks from distant but ecologically compatible habitats are sometimes more successful (Kerns, personal communication, 1981), at least initially.

no not

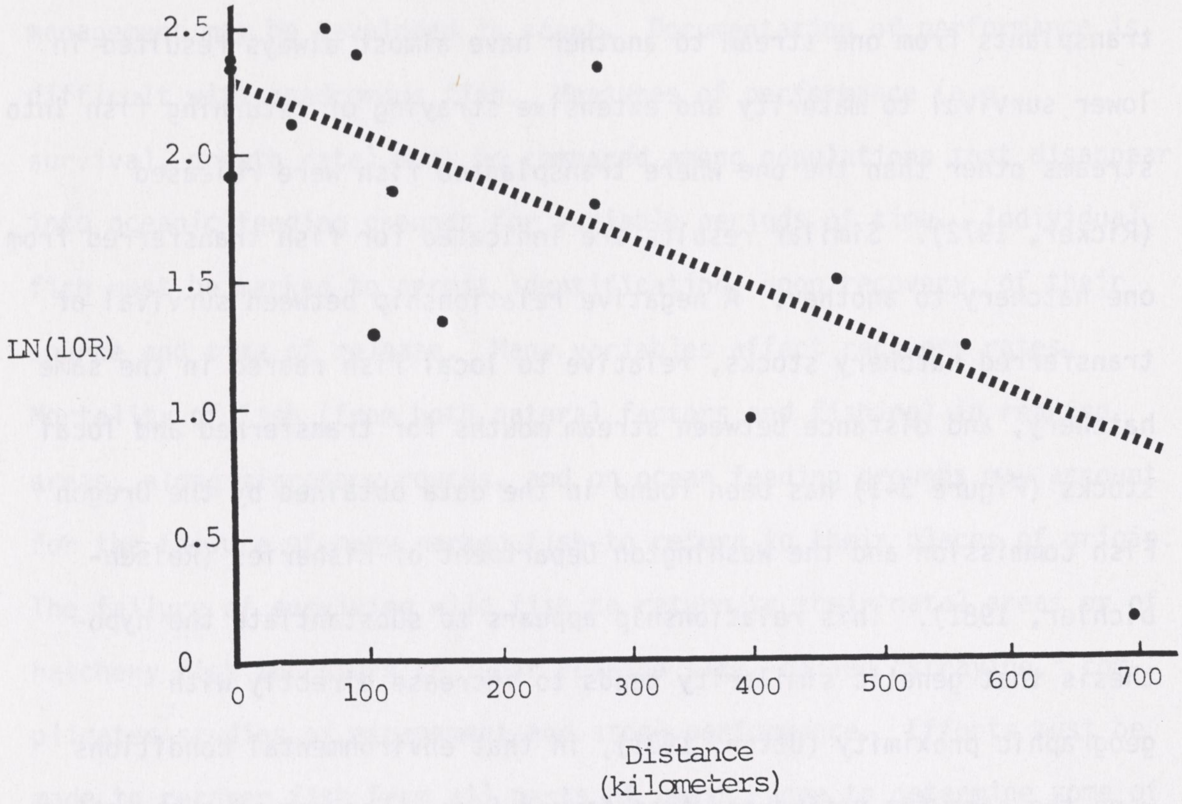


Figure 3-1. Relation between LN(10R) and distance between stream mouths for transferred and local stocks; R is the ratio of survival of transferred fish to survival of local fish reared in the same hatchery and released at the same time and location. Data from Table 2. The regression line is LN(10R) = 2.27-0.002·(Distance); the slope is highly significant (p 0.001).

Source: Reisenbichler, 1981.

Management will probably ultimately use principles derived from further observations of both these phenomena.

Genetic Resource Management Guidelines. If salmonid management is to maintain native stock diversity, discreteness, and genetic resource values, the following policy guidelines are suggested.

1. Natural propagation should be encouraged wherever possible.
2. Where introductions are deemed necessary, they should normally be made with geographically proximate sources and carried out in a manner designed to have minimal impact on native populations.
3. A fraction of all introduced stocking lots should be marked to enable monitoring of performance.
4. Large-scale introductions of a transferred or introduced stock should not be attempted until evidence of adequate performance is obtained from an initial introduction or series.
5. Initial success of an introduction should be viewed cautiously until evidence of reliable performance is obtained.
6. Introductions of exotic stocks or species should be made with full recognition of all possible effects on native stocks and should proceed on a limited scale until such effects have been demonstrated to be minimal or acceptable under the prevailing conditions.

Population Protection

Population protection is generally feasible only where all phases of the species' life history can be maintained or managed. Rare and endangered species of resident trout may be protected by special designation of lake or stream habitat areas or through fishing regulations. Anadromous stocks are not easily protected because of their migratory movements and their mixing with other species and stocks on ocean feeding grounds. Marking studies provide only a crude notion of stock movements in the ocean, and analysis of stock contributions to the mixed fishery (Milner et al., 1981) is still experimental. Even where stocks can be clearly identified by appearance or run-timing, enforcement of fishing regulations is often impractical. Critical habitats are often scattered along rivers or throughout river systems and cannot be contained within the boundaries of closely patrolled parks and reserves.

Currently, protection of some salmonid populations is afforded by the isolation of their native streams (in wilderness areas, for example) and by nondisclosure of the location of spawning areas known to fishery managers. Eventually, stock identification techniques and detailed documentation of life histories could enable managers to institute protective measures where required for the preservation of populations deemed to have genetic resource value.

Watches

The concept of a "watch" as a means of working toward in situ genetic resource conservation is appropriate to the nature of salmonid life history and distribution. Interest and user groups, united by their concern for continued access to the monetary, recreational, aesthetic, or other benefits to be derived from a species, form a network for exchange of information of mutual interest. An international wild salmon, trout, and char watch has been proposed (Regier and Power, 1979; Regier, 1980; Maitland et al., 1981) and recently initiated by the distribution of a newsletter and the solicitation of members.

Information exchange fostered by the wild salmon, trout, and char watch is expected to lead to international standardization of population survey design, sampling techniques, and data compilation. By conferring on global problems and individual case studies, participants may contribute to early recognition of conservation or rehabilitation problems and to their solution. The watch may have little or no capacity to institute management or conservation measures directly, but it could provide an important oversight and guidance function.

<u>Ex Situ</u> Approaches

Potential means of <u>ex situ</u> conservation of California's anadromous salmonid genetic resources include artificial propagation and breeding techniques and cryopreservation of sperm. The options more broadly applicable to fish are discussed in a recent report by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 1981a).

Cryopreservation technology may eventually permit the suspended storage of individuals (genotypes) and population samples. At present, only salmonid sperm can be successfully stored by this method. Sperm are stripped from males, diluted with extenders and cryoprotectants, frozen in liquid nitrogen or on dry ice, and then stored in liquid nitrogen (FAO, 1981a). Techniques vary for different species (Horton and Ott, 1976) and must be determined in detail for each new species to which the technology is applied. Cryopreservation is too recently developed for rates of sample degradation and recovery to have been well documented. Methods are not yet applicable to salmonid eggs or embryos, although research is proceeding (Whittingham and Rosenthal, 1978).

Some anadromous species of salmonids may be amenable to conservation through introduction to ex situ waters (see Appendix E) or through maintenance in closely managed populations (FAO, 1981a). Most introductions of North American salmon into European fresh waters, northern Russian marine waters, and the Baltic have failed (FAO, 1981a). But anadromous runs of chinook have been established in New Zealand and Chile, and anadromous coho have been successfully introduced into the Great Lakes and Chilean rivers. Steelhead are now established in three countries. Anadromous runs exist at Prince Edward Island in Canada and in the Black and Caspian Seas in the Soviet Union. A resident lake population of steelhead has reportedly been established in New Zealand. The precise origin of most of these introductions is not reported in the published literature (Appendix E). Without source information, these populations cannot be considered valid ex situ representation of species and stock diversity.

A proportion of anadromous stocks introduced into closed systems, such as lakes and reservoirs, may physiologically adjust enough for reproduction to occur. This phenomenon is called residualization. Residualization provides an opportunity for ex situ conservation of anadromous stocks under closely controlled conditions. The ability to residualize may be genetically variable, and the extent to which a genotype is responsible for determining which individuals successfully reproduce under landlocked conditions is unknown. Consequently, residualized populations may represent only a portion of the genetic diversity originally sampled and introduced.

Rearing of salmonids in ocean pens may eventually be another means of _ex situ_ maintenance of salmonid germplasm. Currently, the pen-rearing process, in which the pens are artificially restocked from hatcheries, is used to raise several anadromous salmonid species to marketable size. Natural propagation within populations enclosed in saltwater is not known to occur and is unlikely to be selected for inbreeding programs. However, pen rearing might be used in conjunction with a freshwater hatchery program to maintain hatchery brook stock or especially valuable breeding stock.

Certain breeding strategies may have application to the long-term _ex situ_ maintenance of salmonid germplasm. Gall (1969) explains why selection and inbreeding are necessary to maintain stability of genetic composition in a small population. Kinghorn (1980) estimates the long-term effects of introducing novel breeds or stocks into a native population. The range of techniques available for preservation and enhancement of genetic resources in closely managed fish populations is reviewed in a recent FAO technical paper (FAO, 1981a).

TECHNICAL CONSTRAINTS ON GENETIC RESOURCE MANAGEMENT

Initiation of a coordinated effort to sample and conserve the genetic resources of California's anadromous salmonid species will require identification of specific objectives and establishment of priorities for activities required to meet those objectives. A number of technical constraints resulting mainly from lack of information hamper immediate progress toward implementation of genetic resource conservation measures. Analysis of the research and information needs relevant to assessment of genetic variation, stock definition and identification, and evaluation of management impacts all are preludes to formulating recommendations for interim measures based on existing records and knowledge.

Assessing the Distribution of Useful Genetic Variation

Research is usually expected to provide the basic knowledge of taxonomy and geographic variation required to guide sampling of natural diversity for breeding or conservation. For a variety of historical reasons, little is known about the geographic variation of chinook and coho salmon, steelhead, and cutthroat trout in California (see Chapter 2). Since sampling of salmonid stocks is implicit in ongoing public and private programs for artificial propagation, research closely coupled with these programs may have the most immediate benefits. But research oriented to immediate applications may not correct historical deficiencies or anticipate information needs for long-term genetic resource management without special foresight and planning.

The allocation of sampling effort is fundamental to both research and genetic conservation efforts. Sampling for research must be consonant with statistical requirements for sample size and distribution if data are to test hypotheses. Experimental design is the basis for choosing a particular sampling scheme, and technical aspects of this process are treated in an extensive literature. In agriculture and forestry, sampling for genetic conservation has been closely coupled with sampling for breeding stock. Consequently, materials conserved in seed banks, clone banks, etc. are often a selected, rather than a random or systematic, sample of existing diversity. Studies of selected samples of natural diversity are not an entirely valid means of evaluating geographic variation, although in forestry, geographic variation in growth and phenology of tree species is known principally from such studies.

The determination of what genetic variation is useful directly affects the allocation of effort to acquire both baseline information and samples of materials for use in breeding. As is the case in forestry, domestication of wild species is only beginning in fisheries and is proceeding rapidly under existing technology and economic incentives. Genetic materials are employed in different ways by techniques available to two quite different systems of aquaculture (Helle, 1981). Confined systems (intensive culture) include pond or pen rearing. Genetic strategies for development of stocks that will grow rapidly and remain disease free under conditions of confinement include those developed in agricultural genetics: selective breeding, development of inbred lines, and exploitation of heterosis. The application of these techniques to aquaculture is discussed by Calaprice (1970), Simon (1970), and Purdom (1972). Unconfined systems (extensive culture) include augmentation of production by methods as diverse as the use of egg boxes in streams and large-scale hatchery operation. Breeding techniques that reduce or modify the genetic diversity of artificially propagated fish in ways consistent with rearing under confined conditions may not be appropriate to maintenance of a stock's ability to cope with variable conditions in streams or the ocean or to compete with other species for food.

Users of the salmonid fishery are unlikely to adopt a single system of fish culture. Rather, a variety of means of resource exploitation ranging from traditional "hunting" methods to intensive fish culture may be expected. Consequently, a broad perspective on the usefulness of genetic diversity should guide baseline studies assessing the distribution of genetic variation and more intensive sampling for genetic conservation.

<u>Stock Definition</u>

Stock definition has not been systematically undertaken in California for a variety of reasons (see Chapter 2). Descriptive life history data are incomplete and have not been compiled. In the absence of explicit documentation, considerable disagreement exists over the level of stock differentiation likely to be found. The significance of genetic variation exhibited in isozymic, chromosomal, and life history traits studied in Pacific Northwest populations has been debated. Documentation of performance of native and introduced stocks would assist in resolving the relationship between these apparent genetic differences and their significance to management and salmonid culture.

Conservation of salmonid genetic resources does not require stock definition, but consensus on conservation needs and priorities might be achieved more easily if consensus were available. Studies of geographic variation would facilitate the setting of conservation priorities and the definition of stock. Since current management constraints may become an element of stock definition and these constraints should not unduly limit perception of future genetic resource needs, the above activities should probably be conducted in parallel rather than jointly.

Evaluating Management Impacts

By manipulating populations of salmonid species in various ways, fishery management has potential genetic effects on the distribution and availability of genetic resources. The genetic consequences of past management practices must be understood and the management history of populations must be known if germplasm acquired for breeding or genetic conservation is to have well-documented characteristics.

Salmonid fishery management encompasses activities in three principal areas: harvesting, fish culture, and watershed management. Population and genetic effects of particular practices in each of these areas are difficult to determine because a number of natural and human factors may, individually or in combination, have indistinguishable effects. Delays between a management action and its observable population effect further complicate the evalution of management alternatives. For example, interpretation of comparisons of survival among marked salmonids must consider possible differences in juvenile survival due to watershed conditions and predation during downstream migration; differences in ocean survival related to use of different feeding grounds and exposure to different levels of predation, including fishing pressure; and differences in homing and straying by returning adults.

Determination of the relationship between management practice and historical trends in the fishery is complicated by natural events, such as upwelling cycles in the ocean (Radovich, 1981; ODFW, 1981) and climatic variation that affects river flows and water quality. Despite these difficulties, evidence that certain management practices have undesirable impacts on both the fishery and its genetic resources is emerging.

Harvest Technology and Regulation

Evidence that harvesting practices have had significant effects on the average size and age of Pacific salmon species is convincing though indirect (Ricker, 1981), and fishery management planning currently attempts to regulate fishing in a manner intended to avoid these effects (see Chapter 5). Impacts of overfishing are documented for a number of other fish species (FAO, 1981a), and observed effects on population demography coincide with those hypothesized to have genetic consequences.

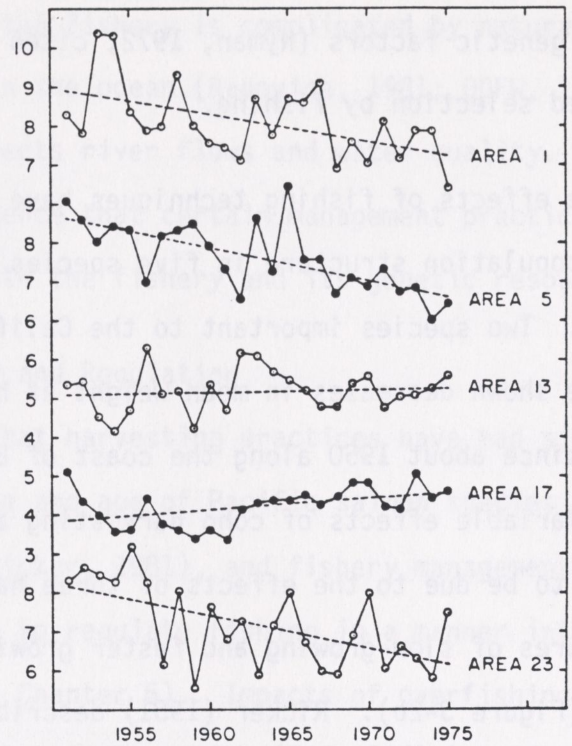
Overfishing is repeatedly shown to result in slower growth, smaller size at maturity, and various other effects. Growth and size effects and early homing are reported for overfished populations of Baltic salmon, and similar effects are inferred from a case study of Tilapia nilotica in Lake George, Uganda (FAO, 1981a). Turner (1977) describes effects of overfishing on an entire community of cichlid fishes in Lake Malawi. Early fishing efforts returned catches dominated by large species; small species predominate today. Comparisons among populations of Arctic char subject to different exploitation rates have shown that an intensely fished population matures earlier than a slow-growing, unexploited one (Nilsson and Filipsson, 1971). The difference is attributed to genetic factors (Nyman, 1972, cited by FAO, 1981), but may have pre-dated selection by fishing.

Selective effects of fishing techniques have been correlated with changes in population structure in five species of Pacific salmon by Ricker (1981). Two species important to the California fishery, coho and chinook, have shown decreases in mean weight at harvest in sampling areas monitored since about 1950 along the coast of British Columbia (Figure 3-2a). Variable effects of coho harvesting at different locations appear to be due to the effects of three harvesting techniques on variable mixtures of slow-growing and faster growing stocks in the different areas (Figure 3-2b). Ricker (1981) describes the relationship between the selective effects of fishing gear used and the effects of its seasonal use on stocks present or moving through fishing areas.

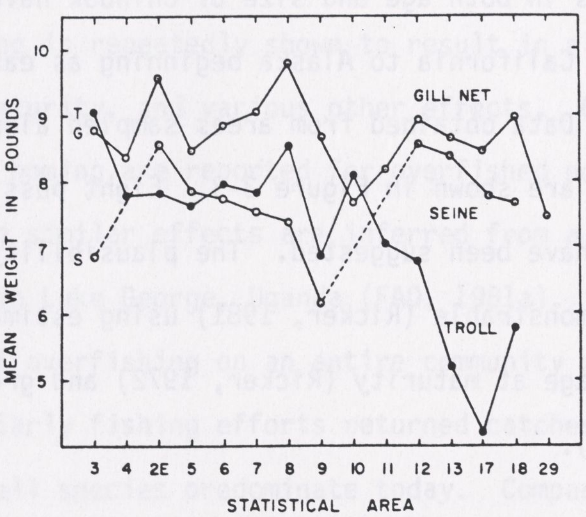
Decreases in both age and size of chinook have been observed in populations from California to Alaska beginning as early as the 1920s (Ricker, 1981). Data obtained from areas sampled along the coast of British Columbia are shown in Figure 3-3. Eight possible causes of these decreases have been suggested. The plausibility of genetic explanations is demonstrable (Ricker, 1981) using estimates of the heritability of age at maturity (Ricker, 1972) and growth rate (Donaldson, 1970).

In summary, existing population data strongly confirm that fishing has the potential to produce genetic effects through size selection

Figure 3-2



A. Mean weight of cohos caught by roll in five statistical areas, with linear trend lines.



B. Computed mean weight in 1963 of cohos caught by three different gears in statistical areas of the British Columbia mainland coast and adjacent Straits, arranged from north to south.

Source: Ricker, 1981.

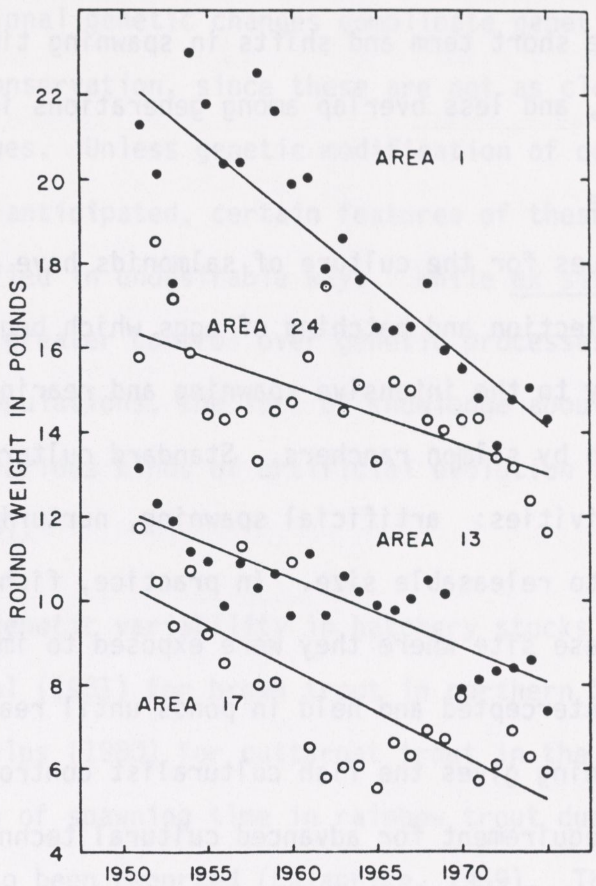


Figure 3-3. Mean weights of troll-caught chinook salmon in four statistical areas, with linear trend lines.

Source: Ricker, 1981.

Calaprice, 1969; Burgner, 1964); size-based sex selection (Calaprice, 1969; Hanson and Smith, 1967); and age-class reduction (Calaprice, 1969). Results of these kinds of selection over time might be stock depletion in the short term and shifts in spawning time, decreases in generation time, and less overlap among generations in the long term.

Salmonid Culture

Techniques for the culture of salmonids have ranged from the rudimentary collection and hatching of eggs which began at the end of the last century to the intensive spawning and rearing programs now being undertaken by salmon ranchers. Standard cultural programs include three basic activities: artificial spawning, nurturing of eggs, and rearing of fry to releasable size. In practice, fish returning to the rearing or release site where they were exposed to imprinting cues as juveniles are intercepted and held in ponds until ready to spawn. Artificial spawning gives the fish culturalist control over reproduction, a basic requirement for advanced cultural techniques involving breeding. Nurturing of eggs and fry under controlled environmental conditions prevents mortality at the levels suffered in natural populations.

Genetic changes in cultured stocks of salmonids may be intentional or inadvertent (Hynes et al., 1981). Adverse effects of inadvertent selection and inbreeding have been reviewed by Calaprice (1969) and Helle (1981) among others. Intentional selection and hybridization are the basis for stock improvement. Domestication of a stock may result from unintentional selection due to the particular conditions of egg culture and rearing. Both physiological adjustments and genetic adaptation may be involved.

Unintentional genetic changes complicate genetic resource management and conservation, since these are not as closely monitored as intentional changes. Unless genetic modification of conserved genetic resources can be anticipated, certain features of these resource materials may be modified in undesirable ways. While _ex situ_ conservation techniques offer greater control over genetic processes than _in situ_ maintenance of populations, the lack of knowledge about the ultimate consequences of various kinds of artificial evolution is cause for concern (AIFRB, 1975).

Loss of genetic variability in hatchery stocks has been reported by Ryman and Stahl (1981) for brown trout in northern Scandinavia and by Allendorf and Phelps (1980) for cutthroat trout in the Pacific Northwest. Alteration of spawning time in rainbow trout due to hatchery selection has also been reported (Calaprice, 1969). The various ways in which hatchery practices may lead to modifications of genetic diversity are outlined in Appendix D.

Watershed Management

Watershed management may in several ways lead to modifications or losses of genetic diversity in salmonid populations. Alterations of factors affecting egg and fry mortality (Allen, 1969) may change the frequency of genotypes represented among surviving fish that migrate to the ocean. Alteration of habitat may influence numbers of predators and the ability of growing fish to escape predation. Species that remain longer in freshwater habitats and exhibit territoriality on feeding grounds may be affected by any changes in habitat structure that influence the distribution of territories.

A variety of activities have direct or indirect effects on critical aspects of the salmonid freshwater environment. Certain timber harvest practices leave waste that can accumulate in stream channels, blocking passage by both downstream migrating juveniles and upstream migrating adults. Timber harvesting, grazing, and mining activities may contribute to increases in the turbidity of stream water, particularly at times when erosion is increased by rainfall. The resulting siltation of spawning gravels may reduce the reproductive efficiency of salmonids. Turbidity and siltation may also affect the distribution and abundance of aquatic insects, the primary food of young salmon. Deforestation may expose stream waters to direct heating by the sun, thus increasing water temperature, which in turn may affect salmonid egg development and the composition of the aquatic insect community.

Factors that restrict the number of adult fish contributing to reproduction in a stream may also have genetic effects. Even if ocean escapement is in excess of that required to assure natural propagation, restriction of access to spawning grounds by logjams or reduction in the number of returning adults by stream fishing may lead to genetic drift or inbreeding (see Glossary and Appendix D).

Streams can also be modified to augment salmonid production. Salmonid production by a particular stream is a function of reproduction, survival, and growth, all of which are affected by a complex of environmental factors (Allen, 1969). The principal environmental factors limiting production in streams are extremes in flow rate due to drought and spate, food availability (Mundie, 1974), and spawning habitat suitability. Intensive management of streams, including control over flow rates and streambed characteristics, is thought to be a low-cost alternative to centralized hatchery operation (Mundie, 1980).

When hatchery releases or plantings are used to aid rehabilitation of salmonid populations, the source of the stocks used and the manner of their introduction may have direct or indirect genetic effects. Many questions about the impacts of hatchery stocks on wild populations, the extent and consequences of straying, and the ability of natural selection to maintain adaptive features in mixed populations of native and introduced fish are currently unanswerable. Some of the key issues involved in alternative approaches to rehabilitation of salmonid populations are discussed in Appendix B. Currently, no data exist documenting the genetic consequences of either constructive or destructive habitat modification that could be altered by appropriate watershed management.

INTERIM MEASURES FOR SALMONID GENETIC CONSERVATION

Many questions basic to the identification of specific needs for salmonid genetic resource conservation cannot be properly posed or satisfactorily answered with the information presently available. While there is wide acceptance of the validity of the stock concept and the desirability of employing it in management policy formation and execution, science and technology have not yet provided the information and the tools to implement policies based on an appreciation of the concept.

The research necessary to identify the population units of species that have both short-term and long-term importance to the productivity and stability of the California anadromous salmonid fishery will take considerable time. Documentation of the genetic diversity that exists within and among populations of these species has only recently begun and will require many decades to complete unless special emphasis is placed on its importance. The genetic consequences of population phenomena (e.g. density-dependent mortality, homing and straying, and ocean migration patterns) affected by management practices will also take time to understand.

The Impasse

The inability to identify and distinguish salmonid stocks leads to an apparent impasse in their management. Meanwhile, intense pressures on the fishery resource endanger the genetic diversity of native stocks. Because mortality of salmonid fry is so much higher in native populations than in hatcheries, natural propagation is much less efficient than artificial propagation in replacing the harvestable resource. Since native and hatchery stocks cannot yet be distinguished in harvesting, they are harvested from the mixed ocean fishery in approximately equal proportions. If fishing is regulated to allow escapement (see

Glossary) of native stocks sufficient for effective stock replacement, then hatchery stocks would not be exploited as efficiently as they could be. However, if harvesting exploits hatchery stocks most efficiently, then native stocks are effectively overharvested and may not be able to repropagate successfully.

volume or selectivity

The genetic integrity of those native stocks that do remain viable today is further endangered by extensive transfer of germplasm from one stream or watershed to another. Since undesirable consequences of egg and fry transfers among hatcheries and plantings of introduced stocks were not documented until recently, a considerable amount of germplasm movement has occurred in California. Members of the fishery community have asked whether native stocks still exist in California rivers and streams.

Evaluating Stock Integrity

In an effort to answer this question, members of the California Gene Resource Program staff visited facilities operated by three agencies involved in salmonid management in California: the California Department of Fish and Game (CDFG), the U.S. Fish and Wildlife Service (USFWS), and the U.S. Forest Service (USFS). The goal was to determine whether records of egg and fry shipments and receipts and distribution records on hatchery-raised fish could be used to identify rivers and streams where native stocks are likely to be genetically intact.

Egg shipment and fry distribution records from the Coleman National Fish Hatchery (USFWS) were examined in detail for the period

1941 to the present. Stream files maintained by the Redding Office of the USFS were reviewed for records of salmonid planting in the North Fork of the Trinity River Watershed. Centralized files for Region 1 of CDFG were examined for records relevant to the Coleman hatchery distribution zone and the North Fork of the Trinity River. Finally, distribution records and planting receipts covering operation of the Mad River Hatchery from its inception in 1970 to the present were reviewed. Inspection of these various records and files provided insights on their usefulness in evaluating stock integrity. But only a portion of the data obtained could be formally analyzed for this report.

A preliminary analysis of hatchery transfer and distribution records for CDFG Region 1, with input from the Anadromous Fishery Branch and government hatchery personnel, leads to the following tentative conclusions.

1. The distribution, introduction, and planting of anadromous salmonid stocks has been much less extensive than distribution of resident trout species and stocks in California.

2. Egg and fry transfers between hatcheries in coastal river drainages and in the Sacramento River drainage have not been extensive and may not have had major impacts on runs native to the drainages involved.

3. Most anadromous species planting has been done on the main stem of river systems on which hatcheries were established. Many tributaries of the Sacramento River and several coastal rivers may not have received direct infusions of introduced germplasm (see Appendix F).

4. Some rivers and streams that have been planted with particular runs of a species may yet contain essentially native stocks of another run of the same species. For example, some coastal rivers in California may still support genetically pure stocks of spring run chinook and summer run steelhead.

5. Hatchery production and planting of coastal cutthroat trout has been very limited and probably has not affected the integrity of native stocks, except in Redwood Creek in Humboldt County.

A more complete analysis of the data acquired will be required to confirm these conclusions and to provide detailed documentation for individual watersheds and streams.

Opportunities for Progress

The technical conclusions of this assessment and the results of the preliminary survey described above suggest that an interim management strategy could be designed to conserve California's native salmonid stocks while research progresses on fundamental questions. The interim strategy might include the following elements:

1. Creation of a descriptive listing of streams, recording the genetic integrity (i.e., intactness) of their salmonid stocks, based on hatchery transfer and planting records. Streams and watersheds might be categorized as to the number and recency of stock introductions and the sources of these introductions;

2. Development of management guidelines for each watershed or stream category in each management region;

3. Design and implementation of monitoring systems necessary to provide ongoing confirmation of the validity of these guidelines and to supply information required for management decisions; and

4. Prioritization of research topics basic to this management strategy and to other questions fundamental to salmonid fishery management.

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4. Prioritization of research topics basic to this management strategy and to other questions fundamental to salmonid fishery management.

CHAPTER 4

POLITICAL ECONOMY: ITS ROLE IN THE MANAGEMENT OF SALMON GENE RESOURCES

"This same slackness of desire towards the future is also responsible for the tendency to wasteful exploitations of Nature's gifts. Some people will win what they require by methods that destroy as against the future much more than they obtain. . . . . Fishing operations so conducted as to disregard breeding seasons thus threatening certain species of fish with extinction is an instance in point. . . . It is the clear duty of Government, which is the trustee of unborn generations as well as for its present citizens, to watch over and if need be, by legislative enactment to defend the exhaustible natural resources of the country from rash and reckless spoilation." The Economics of Welfare (A. C. Pigou, 1928).

CHAPTER ABSTRACT

While the management and protection of salmonid resources is vested in public agencies, activities by both the public and private sectors impinge on these resources, usually reducing their productivity and frequently causing the extinction of salmonid stocks. The logic and concepts of political economy can aid in sound resource planning to prevent further loss of salmonid genetic diversity.

In the planning process, resource managers must remain cognizant of the irreversible damage that any alteration in freshwater salmonid habitat may inflict on the salmonid genetic resource. Simultaneously, managers must determine how best to reconcile different and often conflicting use of salmonid resources. Thorough economic analysis may be an aid to selecting and weighing alternative courses of action. Above all, however, resource

management plans should be flexible in the sense that they should not foreclose future opportuniites for preserving the diversity of salmonid species.

Resource managers should consider all practicable known alternatives for managing salmonid habitats and should also vigorously search for new management alternatives. The usefulness of economic analysis is nullified where valid alternatives are excluded from the planning process. Preservation of salmonid genetic resources are likely to succeed in a particular watershed only when the development of water, land, forest, and mineral resources there is based on identifying all valid alternatives. Full alternative planning means that planners should consider in a balanced way all the values involved--nonmarket as well as market--in maintaining salmonid genetic diversity.

Thus far in California, formal economic analyses and full alternative planning have not been used to make decisions affecting salmonid gene resources. There are no recent creditable studies of the values of salmon sport fishing or commercial fishing. The costs of preserving wild runs of salmon are largely unknown. Furthermore, thorough economic studies of the demand and supply of salmon within California and other states and countries have yet to be undertaken. An urgent need exists to undertake those economic analyses to determine the costs of preserving salmon genetic diversity in many of the watersheds of the state still supporting wild runs of salmon.

Equally high priority should be given to the conduct of strategic economic studies by managers in conjunction with fishery biologists and geneticists to help determine to what extent the renewable but exhaustible salmonid resource should be preserved.

The costs of instituting such a policy might be viewed as insurance premiums paid by society to avoid or reduce the probability of the catastrophic loss of a wild run of salmon and its inherent genetic diversity.

Economic methodology is sufficiently advanced to measure many of the nonmarket values intrinsic to salmon habitat preservation, including salmon sport fishing. The rules for social benefit-cost analysis developed by the U.S. Water Resources Council provide the framework and procedures for valuing alternative management strategies for salmonid freshwater habitat. This framework was devised on the assumption that the rules will be applied to all possible management alternatives. Furthermore, the inclusion of an environmental quality account in the set of rules implies that retaining a run of wild salmon in a watershed can result in a net gain for society even though that use may not be the most economically profitable one. Indeed, maximizing profits in the short run cannot be considered an operational policy objective for salmonid habitat management.

An appropriate cost-benefit analysis should be based on a comparison of the need to alter the habitat with the hazards and dangers of undesirable changes in the salmonid environment. Thus, the magnitude of maximum possible losses--namely, the ultimate loss of California's salmonid resource and the ensuing diffuse cultural impoverishment and socioeconomic disruption--must be assessed against the magnitude of the costs (including market and nonmarket benefits foregone) of habitat alteration.

Setting a "safe minimum standard" in all habitat modification will help to avoid the irreversible loss of salmon genetic diversity, but this standard can be established only after hydrologists, biologists, geneticists, and others have collected basic information on habitat conditions and the consequences of management actions. Analysis of the full effects of past water and land use decisions in salmonid watersheds on the systems of water, soil, and vegetation would greatly enhance the accuracy with which the consequences for salmonids of any planned habitat alteration could be predicted.

PART I. ECONOMIC LOGIC AND THEORY IN SALMON GENE RESOURCES MANAGEMENT

Economics: Implications for Planning Salmon Resource Management

State, national, and international institutions all have responsibilities for salmonid management. In concert, they seek the elusive objective of insuring the greatest return over time from the harvest of this renewable, but not inexhaustible, resource. The concepts and logic of political economy are therefore meaningful in guiding management decisions.

Economics, or preferably the political economy of resource management, is the systematic analysis needed for choosing alternative courses of action. It can aid in the selection of that alternative which will result in the greatest contribution to human welfare. Therefore, it can be basic to guiding management decisions in allocating and conserving salmonid resources, which include the gene resources of the surviving races of wild fish.

Salmon gene resources and the habitats that sustain them contribute directly to economic productivity in the tangible products of commercial and sport fishing, although these contributions have not always been recognized and to some extent are still underestimated.

Fishery management decisions (perhaps intuitively) give considerable weight to maximizing the escapement of wild salmon back to natal streams. The rationale is that the long run health and viability of the salmonid resource depends on maintaining wild stocks for use in improving hatchery stocks. Wild stocks, in surviving, have adapted to a wider range of environmental variation and possess more diverse traits and characteristics than salmonids reared for several generations in a hatchery. Salmonid management objectives, to avoid the creation of a fishery with little genetic capacity to adapt to changed environments and to avoid creation of a fishery totally dependent on hatchery production, necessarily have to include the maintenance of wild stocks. An abiding concern is that the adaptation by hatchery fish to "more standardized" conditions could result in fewer and less diversified hatchery stocks, thus increasing the risk of losing large segments of smolts due to disease or unexpected water quality changes.

Present and future productivity of salmonids and the flow of future economic worth from them depend on their inherent gene resources.

The economic value of wild salmonid stocks are significant when measured by the contribution to the annual catch of the commercial and sport fisheries. These values are also significant since the perpetuation of each of the different salmonid species and their future productivity is dependent ultimately on the retentions of the present wild fish stocks.

Failure to recognize the economic value of these gene resources and the aquatic habitat sustaining them, and thus to attribute economic value only to other market uses of that habitat, resulted in the extinction or severe depletion of wild stocks with ominous implications for the future of the total salmonid resource. Indeed, the increasing scarcity of gene resources brought about by the extinction process raises a question about equity from one generation to the next with respect to the way that these scarce biotic resources are presently allocated over time.

Loss of salmonid genetic resources stems from both overharvesting of different stocks and the loss of critical aquatic habitat for spawning and rearing.

Salmonids are vulnerable to overharvesting over time. In the absence of protection or regulation, these common property resources are vulnerable to extinction or depletion because no single harvester has the right to prevent others from sharing in the harvest (Crutchfield, 1977). Thus, when consumer demand for salmon rises, more fishermen are enticed to enter the harvest with each fisherman taking his share of the catch. As demand increases, so does fishing pressure and the total number of recruits, i.e., the number of salmon available for catch, declines.

This phenomenon has not been eliminated by recent efforts to regulate the Oregon Coho Salmon (Oncorhynchus kisutch). The rising price of coho over the past decade--an annual rate of 16.5%--has not only encouraged an increase in the number of commercial fishermen, but has led to an expansion in the number and size of private ventures in salmon ranching (Walker, 1982). Under such conditions, unless the catch is regulated and strictly monitored, stocks approach extinction, except in the situation where the cost of harvesting the greatly reduced stocks exceeds the present value of the catch.

The common property characteristic of salmonids also entails difficult choices for fishery management in allocating an acceptable level of catch among user groups while ensuring a level of escapement capable of regenerating an "optimum yield" in ensuing years. For a mixed-stock fishery consisting of hatchery and wild stocks, an excessive harvest rate will in time deplete wild stock which, as noted, are considered valuable on account of their potential contribution to production, which stems from their diverse genetic traits and characteristics.

Whether the salmonid gene pool is depleted by overharvesting or by the demise of the habitats on which they depend for their survival, this depletion, and in extreme cases extinction, is an economic externality--a cost arising in the production of market goods and services borne by society but not by the producer. The social and environmental cost represented in the loss of salmonid gene resources is not accounted for by ordinary market pricing mechanisms or supply-demand interactions.

The depletion or extinction of salmonid gene resources is very rarely intentional. More often, it is the inadvertent result of seeking to produce other market products, e.g., hydropower, timber, metallic ores, or industrial products, within the watershed, which provided the salmonid habitat.

A case can be made that the value of retaining a breeding popoulation or gene pool for perpetuation of the salmonid resource and the value of salmonid freshwater habitat has been unacknowledged, indeed unknown, and, if recognized, has been greatly underestimated.

These gene resources, along with the land and water-based resources which sustain them, are considered free goods rather than factors of production--e.g., labor and capital. Labor and capital must be applied to the salmonid freshwater habitat for it to produce hydropower, irrigation, and to provide municipal and industrial water supplies.

This traditional economic perspective has contributed to the persistent, but mistaken, belief in the past that the value in situ of these resources can be overlooked. Wildlands and unimproved biological resources are perceived as not contributing to present production and therefore are assumed to have little or no value.

Conservation and its converse, depletion, are highly significant economic problems and we shall attempt to show that economic concepts and logic have a vital role in the valuation of salmonid gene resources and in establishing policy objectives for managing these resources.

Useful economic analysis of the conservation of salmon gene resources, indeed of all natural resources, has to cope with two fundamental problems:

1. valuing the present and future stream of benefits and costs that stem from alternative ways of managing the resource (including its genetic diversity) and from its associated habitat, and
2. dealing with uncertainties created by the changes in society's preferences, in technology, and in the institutions which directly or indirectly are responsible for managing the salmonid resource and the many resources comprising its freshwater habitat.

Full-Alternative Planning

In the development or preservation of salmonid freshwater habitat, the most commonly employed tool to evaluate the relative worth of alternative courses of action is benefit-cost analysis. However, the potential aid that economic analysis can provide for choosing alternative habitat management strategies is greatly diminished where a full-alternative method of planning (principally for water resources, but also for related land, vegetation, and wildlife) is not adopted and strictly adhered to by public and private resource managers. By full-alternative planning, we mean planning that encompasses all valid alternative courses of action and their market and nonmarket benefits and costs.

Less than full-alternative planning means that one or more valid alternatives are excluded from the planning process; society is liable to lose the contribution that one of the neglected alternatives might make.

The eliciting of relative values placed by different segments of society on specific uses of the salmonid resource itself and its freshwater habitat, and a reasoned weighing of the many market and nonmarket values, is basic to developing the full-alternative method and is fundamental to useful benefit-cost analysis.

Water and related land resources planning which affects salmonid freshwater habitat in policy and practice should not limit consideration of alternative courses of development and/or preservation to those which are developed around the production of market products--irrigation, municipal and industrial water supplies, hydropower, or navigation--to the exclusion of the market uses of the salmonid resources and the nonmarket uses--scenery, aesthetics, or recreation--all the joint products which exist if productive salmon habitat is maintained. These nonmarket values cannot be expressed easily in monetary terms; nevertheless, this class of values does exist. Planning processes must change if such values are to be fully accounted for.

Full-alternative planning not only entails incorporation of recreational and aesthetic values of salmonid freshwater habitat into the formulas and procedures planners use in benefit-cost analysis; the consideration of a broader range of alternatives entails greater demands on scientists--hydrologists, fishery biilogists, geneticists, and others--to predict not only the immediate effect on the salmonid resource and vital components of its habitat, but also the more remote consequences on water resources and on related land resources.

The fundamental importance of increasing our biological, physical, and social knowledge to inform the political discussion when exploring alternatives for the enhancement and preservation of salmonid gene resources is readily apparent from studies of the effects of past water resources planning decision on the salmon resources (U.S. Fish & Wildlife Service, 1980).

The recent attempt by the U.S. Water Resources Council to formulate appropriate procedures and methods of planning water resources development has as its fundamental (though unstated) aim full-alternative planning where all practicable alternatives, including market and nonmarket benefits and costs, are assayed and presented to decision makers.

The "Principles and Standards and Procedures" for federal water and related land resources planning devised by the U.S. Water Resources

Council (U.S. Water Resources Council, 1979) consists of rules (currently under appeal) that increase the ability of federal water agencies to account for the nonmarket values intrinsic in salmonid freshwater habitat.

In essence, the Council's rules recognized that the social objectives of water and land-related planning considered desirable by society had grown increasingly important. The rules incorporate the premise that there can be a net social gain in the retention of a run of wild salmon at present or increased level though that use may not be consistent with the most economically profitable market use of the resource.

Society's interest in the preservation of the remaining wild salmonid runs and their sustaining habitat (in addition to society's interest in the other largely nonmarket products of unspoiled habitat, recreation, aesthetics, or scenery) could well indicate a willingness to have public monies spent in a way which does not lead to the highest benefit-cost ratio when computed exclusively for market goods. Society, when presented with a creditable appraisal of the scarcity of salmonid gene resources and the value of retaining the already greatly reduced gene pool, could opt quite willingly to pay for the nonmarket services provided by "undeveloped" salmonid habitat. Resource managers should be responsible for informing society what nonmarket services are made available and at what cost. Society can then determine what it is willing to pay (including benefit from the market products foregone) for the nonmarket services as well as for the perpetuation of the genetic resources inherent in the wild salmonid runs.

Improved management of (a) the salmonid gene pool inherent in the wild runs of salmon and (b) other resources vital to the freshwater habitat sustaining these gene pools ultimately depends on natural resources planning (principally water resources planning) which as a minimum is based on the following precepts.

First, the planning process must generate and evaluate alternative courses of action for consideration by the local populace, that of the state and that of the nation. Second, it must not only identify and quantify specific market uses, but seek to display all the values, including nonmarket ones, that different segments of society ascribe to the many uses of the salmonid freshwater habitat, including the preservation of salmonid gene resources. Third, the alternatives and evaluations have to be disseminated and pondered in the political arena. Fourth, the process must not only recognize but make it possible for all interested private, local, state and national entities to play a role in the planning of these resources. Judicious and reasoned public discussion of alternatives to reveal the relative values attached to different uses by different groups makes for more informed decision making. It would also create a climate where economic analysis and logic can be applied to aid in making choices which do result in the "best" allocation of resources--that choice which generates the greatest amount of welfare, i.e., net social value over time.

The Problem of Valuation

Different facets of the vexing problem of valuation have been addressed already. Salmon resources and the resources comprising their freshwater habitat which sustain the different gene pools produce both market and nonmarket benefits. The former, expressed in monetary terms, are--as in the case of the commercial salmon harvest--readily translatable into dollar terms which are useful in management decisions in hatchery production and the allocation of harvest. Many of the nonmarket benefits, including the benefit from maintaining genetic diversity by sustaining wild runs in "sufficient numbers," defy transformation into dollar terms.

If the contribution of these genetic resources to the productivity of the overall fishery at present and into the future could be gauged precisely, a market value could be assigned to the increment in product which accrues to the commercial fishery and a useful market surrogate computed for the increment in sport fishing experience attributable to the retention of the traits and characteristics embodied in the genes of wild stocks.

A reliable and precise understanding of the production or loss in production, in terms of salmonid yield, which stems from the retention or loss of specific gene resources represented by wild runs of salmon, is fundamental to an assessment of the economic worth of preserving the genes per se; it is also fundamental to preserving the habitat perpetuating them.

This complex assessment is more the task of the fishery biologist and geneticist than the economist, and the state of the art of resource assessment is in its infancy. Nevertheless, establishing the increment in annual yield--recruitment, number, average weight (and quality) which is attributable to the "increment" in genetic diversity inherent in wild salmonid stocks--would greatly facilitate economic analysis. Also, if it could be established that gene diversity in a wild stock allows its offspring to restock a stream to full capacity in a shorter period than is possible with other strains of hatchery-bred fish or even other strains of wild stock, it can be shown that society gains in that it does not have to wait so long for a return on the costs of restoration. The net gain directly attributable to that characteristic of the "superior strain" is assessable. Economics can suggest the types of investigations biological research might pursue to accomplish these assessments.

Other than contributing to the commercial fishery, the salmonid resource supports an ever-growing sport fishery in the ocean and inland streams. Economists have devised and are still devising innovative ways of measuring the value of a salmon fishing day, a salmon fishing trip, or a salmon fishing experience. Many of the proxies or surrogates for market value are derived by precise measurement, founded on sound economic demand theory, and account for the sport fisherman's actual behavior, not his hypothetical behavior. The values developed in this manner are useful, expecially in providing insight as to the minimum values (benefits) involved in a salmon sport fishing experience. A day spent sport fishing for salmon includes much more than the salmon, which may or may not be caught; the sport fish is only one element in an array of composite products consumed during a recreational outing. Boating, serenity, and isolation are but a few of the other products associated with the salmon sport fishing experience. However, advances in consumer theory suggest new ways to estimate the value of the sport fish (Lancaster, 1966; Kelvin, 1966).

The measurement of the value of a salmon sport fishing experience and of the more recent efforts by economists to value the salmon sport fish are dealt with in Appendix G.

Despite the considerable progress in measuring nonmarket benefits, in the absence of objective criteria (usually intended to mean a market price system) they can be overvalued or undervalued. Advocates of retaining freshwater salmonid habitat in California might feel justified in claiming these values are continually underestimated.

Nonmarket benefits stemming from the salmonid resources' freshwater habitat are real and neither zero nor infinite. Ehrenfeld (1976), in an interesting dissection of the many nonmarket natural resource values which can be assigned a monetary value (in an attempt to make them commensurable with the prices of market goods and services), lists the following as anthropocentric values:

1. recreational and aesthetic values,
2. undiscovered or underdeveloped values,
3. ecosystem stabilization values,

4. examples of survival,
5. environmental baseline and monitoring values,
6. scientific research values,
7. teaching values,
8. habitat reconstruction values, and
9. conservative value: avoidance of irreversible change.

The measurement of legitimate nonmarket values is not attempted without some risk to the ultimate preservation of the resource presently generating those nonmarket values. There are several reasons.

First, a value discovered for the nonmarket use of salmon habitat can be compared with the values found for competing uses of the habitat. A higher value for a competing use increases the propensity to convert the salmonid habitat to this use. If that higher value use is irreversible (most competing uses are), then irrespective of whether the values of salmon habitat in the future rise to outweigh the original competing use, the salmonid habitat will be lost and society in the long run will be the loser.

Values for salmon habitat change. If hatchery production costs were greatly lowered by some new technique, or if gene diversity could be retained without the necessity to preserve wild stocks, then that value component of the freshwater habitat is reduced, with negative implications for the retention of the habitat.

There is also the hazard that what amounts to a partial measurement of the nonmarket values of salmon habitat might be interpreted as a comprehensive treatment of all nonmarket benefits and costs. Those qualities and dimensions of the habitat which have not been given a value are therefore assumed to be unimportant--a dangerous presumption, given our present knowledge of these ecosystems.

In addition, even though the long-term social product from maintaining habitat for salmonids and other complementary uses may contribute most to society's welfare, high profits and a high discount rate for a competitive use can mean depletion if not extinction of the salmonid resource (Clark, 1973).

The tendency of some biologists and fishery managers to object to the identification and measurement of nonmarket uses of fish and wildlife habitat resources is readily comprehensible. Whether such a stance ultimately results in retaining a greater amount of habitat than that which would be reserved if sound economic analysis were employed in such management decisions must remain, for the present, conjecture. However, the historical trend is readily discernible: Salmon aquatic habitat has been continually diminished and degraded since the turn of the century. Highly creditable benefit-cost analysis has been employed infrequently in resources development decisions during this period.

The nonmarket benefits are diffused through the various components of the salmonid habitat: rivulets, streams, gravel beds--the myriad components of the ecology web which sustains salmon regeneration. This diffuseness makes measurement of the benefits more difficult; it does not mean that they do not exist.

That the direct beneficiaries in the case of a sustained salmonid habitat cannot be readily identified, much less numbered, does not mean nonmarket benefits do not exist. The need is urgent to explore methods for weighing explicitly nonmarket benefit (measured in whatever units possess relevance for sustaining the gene pools--miles of spawning gravels, acres of complementary riparian vegetation, seasonal quantity and quality of water, preferably in dollars of willingness to pay) together with market benefits for the resources comprising salmon habitat.

<u>Economic Logic: An Analytical Aid to Salmonid Resource Management</u>

Economic analysis can correct the deficiency in resources planning efforts that rely solely on market values; sound economic analysis can establish the "full value" for salmonid habitat resources which are finite in number, fixed in position, and growing increasingly scarce. The gene diversity which these habitats support is irreplaceable. Hatcheries, it is true, can provide rearing and nursery conditions, but the "standardized conditions" of a hatchery environment are different from the fluctuating and conditions found in wild habitats and fundamental to the perpetuation of diverse genetic characteristics considered vital for the regeneration of both wild and hatchery stocks. Habitats supporting wild stocks may therefore be replaced by hatcheries but at a cost that includes the loss of salmonid gene diversity. Quite possibly, some hatcheries built to "mitigate" the effects of salmonid habitat development have incurred costs which are greater than the costs of benefits foregone in not converting such salmonid habitats to other uses.

Water resource developments in California, Oregon, and Washington are replete with examples where costly fishways, hatcheries, and other devices to maintain salmonid runs, have been built with no certainty of success to mitigate the blockage of salmonid runs by reservoirs. Inadequate design information and sheer inability to predict consequences have been a feature of these less successful ventures. Economic logic would stress in these several instances that delay to obtain the information to avoid the costly irreversibilities of failure is a wise choice.

The accuracy of predictions of conditions and consequences for the salmonid gene resource created by particular water developments might be greatly enhanced by studies of the effects of past decisions. This is a much neglected area of study insofar as salmonid resources are concerned.

A comprehensive plan to retain and restore salmonid habitat and perpetuate the present gene diversity hinges on precise studies to determine the full effects of water developments not only on the systems of water, vegetation, and soil but also on the social and economic activities--e.g. fishing and the local economy and culture it supports--altered by these developments.

It has been contended that economic reasoning can be used in making informed decisions that require assessing the market and nonmarket values of different alternatives. Economic logic and concepts provide other insights useful for making decisions about the development or preservation of salmonid habitat. The salmonid habitat, for example, has the myriad attributes of a productive fishery system, adequately shaded by riparian vegetation. The initial competing market use is logging of the timber growing in the riparian zone with subsequent clearing and agricultural cultivation of this land and the ensuing certain destruction of the freshwater habitat sustaining the salmon run. The riparian lands can be purchased as a conservation easement.

A common sense economic approach is to find out the purchase price of the land before judging whether the salmon run is worth saving. If it would cost say $100 per fish produced, one may conclude on narrow economic criteria that there are better alternatives for this expenditure. (This statement, of course, has to be qualified in the case where the salmon run in question represents great value for its inherent genetic traits in terms of long-run productivity of the total fishery resource.) But if the cost would amount to only a fraction of a dollar per fish, although it is more than that of hatchery-produced fish and especially if the cost of production for the logger and the farmer at a different production site is raised only slightly, one might rationally conclude it would be in society's best interest to preserve the timbered riparian lands as wildlife and salmonid habitat.

This example indicates the type of information basic to a preliminary economic inventory of the status of existing habitat now supporting salmon, including an assessment of its vulnerability to conversion from competing market uses and the costs of countering such competition.

While it might be predicted that we can increase the number of fishing sites for many other species at reasonable cost--farm ponds and stretches of streams can often be converted to fishing sites at low costs for bluegill and trout, for example--this is not the case with migratory salmon. The costs of maintaining or restoring an "intact" ecosystem for wild salmon production can be quite high. Nevertheless, there are doubtless areas where the increment in expenditure to achieve such results may not be great. More needs to be learned of the costs of increasing the supply of salmon habitat, and how those costs are related to the value of the alternative uses of the alternative site. Many of these sites are managed by either federal or state agencies and in varying degrees are subject to degradation--a by-product from private economic activities in the watershed or the same types of activity carried out under license on public lands.

The attitudes of people to preservation and maintenance of a species change as the species grows scarce and more valuable, both in monetary terms and in terms of public regard for the species. Thus, as California salmonids have diminished and their habitat has continually shrunk, society has come to value them more highly. The change in attitude to a resource seems directly proportional to the resource's availability.

The task of valuing the joint products of salmonid habitat--its water quality, scenery, and recreational uses, etc.--is exceedingly difficult, but also highly useful for making informed decisions as to its future use. It is essential to know what amenity and recreational values, in addition to the potential loss of the salmon run, would be forfeited as a result of a pending encroachment. It is also important to know when these values are sufficiently high to justify "buying off" further encroachment or even extending a salmon sanctuary area by "buying out" the encroaching users. Sound appraisal of the many values involved must include an attempt to ascertain how values develop or degenerate with the passage of time. The value of preserving what little remains of salmonid habitat in its original uses relative to competitive uses, may be, and likely is, steadily appreciating.

In such a situation, future opportunities for preserving salmonid habitat should not be foreclosed. Indeed, the continual decline in natural runs indicates that remaining habitats for sustaining remnant runs of wild fish have greatly increased in social value and action in retaining and restoring these sites for salmonids is too slow; advantages of maintaining or increasing present and future productivity of the salmon fishery are being lost. This argument is developed more fully subsequently when irreversibility is discussed.

Decisions to preserve or restore salmon habitat lie chiefly in the public arena. Public ownership of much of the land and other watershed resources means federal and state agencies with responsibilities for the planning and management of their resources consequently play the dominant role in "allocating" and preserving scarce salmon habitat.

Comprehensive social benefit-cost analysis and full-alternative planning with all values carefully measured have been suggested as useful and necessary safeguards to ensure the social worth of salmon habitat is accounted for in the calculus. However, other economic considerations and reasoning enter an informed decision as to how much, if any, salmonid habitat is to be given up for other competing purposes. The decision should be based on a comparison of the relative scarcities of this habitat and its fish and other wildlife (and of the habitat's related amenities, e.g., recreational pursuits) with the relative scarcity of sites in that vicinity that can produce the competing products. For example, logging sites situated away from the streams may be plentiful and these will probably have less damaging potential impacts on salmonids. The question is, are there substitute opportunities for the proposed habitat use that would not irreversibly damage the salmonid resource?

Another argument for preserving salmonid habitat is that rare phenomena in the natural environment should be preserved. Advances in modern technology permit society to provide an ever-increasing flow of goods and services from our agricultural and industrial sectors at lower costs; however, the relatively scarce natural phenomena (such as those supporting natural salmonid stocks) are not reproducible. Even if society's tastes were not changing in favor of more natural environments, the costs of preserving it (in terms of the goods and services forfeited) are falling.

Both these arguments suggest there is a need for a careful examination of society's need for natural environment to see if it is a "sector" with appreciating values relative to other sectors.

Uncertainty and the Management of Salmonid Gene Resources

"Trend is not destiny"; uncertainty is the feature of the future. The streams of benefits and costs over time related to the salmonid resource are beset with uncertainties. There are uncertainties in the prices which will be set for quantities of salmonids demanded in both the commercial and sport fisheries. There are equally significant uncertainties as to the number of fish that will be available to fishermen at different times.

The social benefits-cost analysis nevertheless requires such forecasts. We must forecast conditions for the fishery both with respect to the economic conditions and the biological conditions expected at different times in the future. The future is always more or less unknown and any evolving salmonid resource plan, affecting salmonid genes, has to be flexible to cope with things that have not yet happened. We cannot change the past or the present but our actions can influence what the future will be for this resource.

Returns on society's investment (including salmon ranching ventures) and attendant costs have to be forecast on as sound a basis as possible to come as near as possible to estimating correctly what the future will be.

The difficulties inherent in quantitative definition and measurement of the social contributions by various alternative patterns of salmonid habitat use, have been emphasized already. The extent of such contributions over time is the nub of the assessment task, not the contribution of salmonid resources in the present or next decade but beyond.

For salmonids, we need to judge domestic demand and the demand for exports, and we need to estimate what is likely to happen in the future to the supply of different salmon species for the world's major salmon producers: Japan, the Soviet Union, Canada, and the United States. Within the United States, the respective demand and supply conditions in Alaska, Oregon, Washington, and California have to be carefully analyzed.

Many factors must be taken into account in studying demand for fresh, chilled, and frozen salmon in the United States and in major importing countries. These factors include population changes, price changes, changes in consumers' buying power or in the prices of substitutes. The overall demand for salmon from California is related to consumers' taste, real disposable incomes, exchange rates, prices for other salmon products (from Alaska, for example) and prices of other protein substitutes. Since supply can vary from year to year because of changes in the prices of competitive commodities, the estimation of long-term supply functions for salmon products requires meticulous and careful study.

Methods are available to construct an objective basis for determining what has been happening to demand and to supply for salmon products and hence there is a firm basis for forecasting what is likely to happen to demand and supply in the future. However, studies employing sound economic theory and measurement techniques in demand and supply have yet to be initiated. Market prices in the U.S. are not independent of supplies in other countries, and planned future supplies abroad will influence domestic prices in the U.S. Artificially propagated future supplies are likely to be appreciable. (For a preliminary review of projected artificial production in Alaska, U.S.S.R, Japan, British Columbia and Washington, Oregon and California, see Robert S. Roys, 1981). Without such studies, uncertainty in forecasts is greatly compounded.

Another complicating factor is that the stream of benefit over time and the stream of costs incurred by society in investing in salmon gene resources, have to be discounted back to present worth at the appropriate discount rate. The use of present values compresses and aggregates the time stream of costs and benefits into comprehensible single valued forms, but in so doing the process conceals the year-by-year fluctuations of costs and gains.

In salmon resource investment programs which include alternatives for preserving salmon gene resources, it would be unwise to simply look at only expected gains when examining different programs and policy alternatives.

The small chance of huge gains or of safeguards against disastrous losses could determine in the selection of that alternative which offers such advantages. For instance, the estimated benefits attained by investing one million dollars in hatchery production is probably less variable than the benefits obtained by investing one million dollars in wild salmon gene resources. The inherent variability of the outcome about the means from year to year is less for the hatchery expansion alternatives, and the uncertainty due to imperfect estimation procedures is less. However, decisions cannot be based solely on average or expected values. The largest expected gains that could be achieved through hatchery production should not be chosen mechanically rather than selecting a lower probability of catastrophic loss of the total resource at some future time.

In the situation described, it is doubtless worth a great deal to decision makers to reduce the chance of a bad if not catastrophic outcome; to hedge against such an outcome is a typical reaction. The suggested method for treating uncertainty is to avoid concealment of outcome risks and to set out relevant indicators. The trend in escapement could be one such indicator. Biological and genetic knowledge must be used in the decision process. To adopt as a policy objective for salmon management the "safe minimum standard" is a useful strategy.

Uncertainty as to future demands for salmon resources (including their gene pools) and the effects in the future of past and present water and land resources developments and fishing pressure on wild gene preserves (and the effect of hatchery operations to date) indicate a need for flexibility so as to foreclose as few alternatives as possible for maintaining "intact" the genetic diversity presently available.

In the situation where modern technology provides many alternative methods to produce substitutes for the products for which salmon habitat is converted, a primary tenet of resources planning once again should be to maintain flexibility for the future.

For water and land resources planning which alters salmonid habitat or compounds the difficulty of their survival, there is merit in delaying imprudent development, for which the need has not been demonstrated satisfactorily and the effects of which have not been evaluated adequately.

In addition, resource managers are often unable to predict the consequences of changes in stream flows and other habitat changes upon the productivity of specific salmon runs. Decisions to change components of salmonid habitat, once implemented, are usually irreversible. The ecological balance may be upset so severely as to set in motion a chain reaction; for example the siltation of streams and disappearance of streamside vegetation compounded by bank erosion and increased water temperature are but two of many examples. And, as noted, often such results are inadvertently caused as much by ignorance of the ecology of an area as by deliberate action to effect the change.

The exploration of alternatives for the management of salmonid habitat should reflect due concern with how uncertainty about the future may affect the most desirable course of action as well as how account may be taken of irreversible action.

The problem of irreversibility in relation to the projections of future social needs compounds the difficulties for establishing policy objectives for managing the salmonid resource and its habitat. The uncertainty is so great that only directions of change and possibly rates of change can be projected, even when competent social and biological studies are available.

These difficulties have to be recognized and taken into account in drafting management policy for the salmonid resource and the many resources comprising its natural habitats.

Safe Minimum Standard: A Relevant Management Policy Objective

It has been emphasized that maximizing social welfare is not an operational policy objective for managing the fishery, land, and water resources comprising salmonid habitat and when irreversibilities abound.

A more valid and relevant policy objective for resources management is the "safe minimum standard" proposed by Ciriacy-Wantrup (1963). A safe minimum standard is adopted as a requirement for maximizing social welfare in the long run.

This objective is frequently compared to the objective of an insurance policy against serious losses that are unamenable to statistical measurement. The objective is satisfied where premium payments to possible benefits are scheduled in such a way in time, that maximum future losses are guarded against with minimum present costs.

The order of magnitude of maximum possible losses compared with that of the insurance premium required is, of course, a major consideration.

The "maximum possible loss," given the continuing and probably accelerating disappearance of salmonid gene resources, would be the total loss of chinook, coho, and steelhead fisheries in California. Such a loss would seriously affect the economy in those areas dependent on fishing and on the many recreational and amenity uses of salmonid habitat.

A loss of such magnitude would not only mean the extinction of the many runs of salmon and steelhead but also a diffuse cultural impoverishment associated with an environment so degraded that the quality of other recreational pursuits would be greatly diminished. A valid quantitative estimate of the losses decade by decade leading up to the final and total loss of the salmon resource is not feasible.

The maximum possible future loss, however, would be a grievous loss in human welfare. To insure against such a loss would seem to be rational and in society's best interests. We should therefore carefully assess the premiums for such an insurance policy.

Those premiums consist of the higher costs the various users would have to pay to extract timber, water, minerals, and the other market products of those watersheds needed to preserve the salmonid gene diversity. Included would be the costs of research, education, and management to ensure the required performance standards. The use of the "safe minimum standard" as a management policy objective requires comprehensive management of the "total system" comprising all the resources which support viable wild salmonid populations. For example, within the watershed, logging, road construction, water diversions, farming, and several other practices which are damaging the salmonid resource, would have to be improved. The costs for doing so need to be assessed.

The costs of preserving watersheds or parts of watersheds as "salmon sanctuaries" may not be as high as a first appraisal might indicate. A safe salmon sanctuary need not preclude all logging, all farming, or any use of water or of any other resource. But the salmonid's freshwater environment could not be exposed to certain damaging externalities of man's activities. This doubtless means we need to use better ways of extracting and processing the market products we take from selected watersheds; it does not automatically mean total exclusion of such activities, and it does not necessarily impose great costs.

Salmon sanctuaries would continue to produce a wide range of anemity and recreational pursuits as at present and, in some instances, these might be augmented. Whether social overheads involved in water supply, drainage, wastewater disposal, and highways would be increased is difficult to gauge. Offsetting savings in some of these social overheads could occur.

Which watersheds might be selected as salmon sanctuaries to constitute part of the overall system to meet the "safe minimum standard" objective and what other actions would have to be taken to make it operative, are questions which biologists, geneticists, and fishery managers must answer. Competent economic research can, however, given such data, respond to the challenge to assess the cost of the needed insurance premiums.

Before a decision is made to adopt a "safe minimum standard" as an appropriate policy objective for managing California's salmonid resources, the question arises, "Who should pay the insurance premium?" The identification of beneficiaries and a decision as to who should share the increases in cost, if any, entailed in such an objective, is exceedingly complex since salmon habitat protection and restoration benefits many more than commercial and sport fishermen. Private salmon ranchers, for example, might participate in bearing the burden of the insurance premium. The larger issue is, "Which public entity should be involved--federal, state, or local--and what are their respective cost shares?" Deciding to adopt a safe minimum standard as a policy objective for salmonid management constitutes a choice between degrees of economic development in different regions of the state; the geographical dimension is important in that the well-being of people in different regions is affected. The effects of such a proposal and its geographical, economic, and social impacts should be analyzed by competent people.

PART II. ECONOMIC MEASUREMENT IN SALMON GENE RESOURCES MANAGEMENT

Salmon Sport Fishing Values

It would appear that the "value" of a salmon recreational fishery could be ascertained by asking the question, "How much do anglers spend fishing for salmon?" But this question leads only to a partial answer as to the value of the salmon recreational fishery. First, a salmon sports fishery provides salmon fishing, not salmon. Salmon fishing is a recreational experience encompassing not only anglers' demands for fishing, but for the intrinsic characteristics of the fishing site. Second, an appropriate measure of salmon fishing is not easy to define; the fishing experience is usually (and arbitrarily) defined in terms of time of a fishing day or a fishing trip. Third, it is very difficult to estimate directly the value of the sport fishery because the product--a salmon fishing day or trip--is not marketed.

Salmon sport angling is derived from the salmon fishery, which is common property both owned by everyone and by no one. Except for a license fee, the salmon sport angler does not pay a price for the use of the salmon resource.

Two measures of value are implicit in the foregoing discussion: gross expenditures and direct benefits. Gross expenditures, or how much salmon sport anglers spend on fishing, includes (1) travel cost, in terms of food, lodging, boat fuel, fees, etc., and (2) capital equipment expenditures for boats, tackle and other fishing equipment which can be used for many fishing experiences. Gross expenditures are one quantitative measure of anglers' desire to fish. And if these expenditures for salmon angling are switched to other sites or other activities, there can be an appreciable negative impact on a local area. Regional and local employment and income impacts resulting from such changes can be measured by employing such techniques as input-output analysis.

The regional development and economic impacts of an expansion or decline in salmon sports fishing for Northern California counties has not been comprehensively measured, although salmon fishing is a major "sector" of several coastal communities. The activities generated by the salmon fisheries, both sport and commercial, support processing and boat and equipment sales and repair, as well as grocery stores, gasoline stations, motels and restaurants.

The inforamtion that is available for Humboldt and Mendocino Counties shows that salmon processing (mainly commercial) in Humboldt County in 1977 generated approximately $12.4 million and had the fourth largest <u>relative</u> impact on the county's economy, in that $1.00 of output by salmon processing generated $3.75 of economic activity. In Mendocino County, salmon processing also has great relative importance in the economy, although it generated less economic activity in absolute terms than in Humboldt (Oregon State University, 1978).

The second measure of value is the <u>direct or user benefits</u>. The basic issue is to determine the value (net benefits of the salmon recreational fishing experience to the anglers involved). Anglers are willing to pay for the right to fish for salmon; they place a value on this product. The right to fish for salmon in ocean and rivers is worth something to the angler--it's just not measured. Techniques are available to measure indirectly how much an angler is willing to pay for a salmon fishing experience. However, measurement has not been attempted for salmon sports angling for any of the many fishing sites in California. See Appendix G for a discussion of the methodology employed in indirectly measuring sports anglers' willingness to pay and for a summary of results of studies conducted in Oregon and Washington states.

Chapter 5

INSTITUTIONAL OPTIONS FOR MANAGING SALMONID GENETIC RESOURCES

CHAPTER ABSTRACT

State and federal agencies, commercial and sports fishing interests, Native Americans, and a variety of other concerned Californians all have a stake in ensuring that the state's anadromous fishery is well managed. This concern and attention creates opportunities and problems in developing an institutional framework for salmonid genetic resource management programs. Problems arise because of overlapping jurisdictions between state and federal agencies, lack of coordination among and within management entities, and difficulties in allocating a scarce resource among different user groups. Opportunities exist because current programs represent important organizational resources for the resolution of California salmonid enhancement problems.

A number of public agencies currently administer programs which influence genetic resource conservation, research, and management. The Pacific Fisheries Management Council (PFMC) has recognized the need for conservative management of salmon stocks. Its programs, including mid-run closures, area registration, and escapement goals, reflect a commitment to rebuilding salmonid population levels. The Trinity River Basin Fish and Wildlife Task Force has proposed a

comprehensive program for restoring native and hatchery stocks within its area of jurisdiction. CDFG hatchery managers informally recognize two major salmonid distribution areas--the Sacramento River system and the coastal river region--for releasing fish from the facilities they operate and manage. The department is just completing a new fish and wildlife plan containing a 10-year plan for managing anadromous habitat and populations. The U.S. Fish and Wildlife Service also recognizes restricted zones for releasing fish from its hatcheries in California. In addition, the agency's cooperative and research programs for restoration of anadromous salmonid runs favor native fish strains over hatchery strains.

However, as indicated in preceding chapters, the value of native fish as a genetic resource and the application of the stock concept in salmonid management have not been sufficiently integrated into current programs. To establish this integration, a number of technical measures will be necessary, including stream classification, research, and conservation activities. These technical opportunities can be realized if state, federal, and private interests improve the coordination of various programs now in operation and increase their financial support for genetic resource management work. CDFG, PFMC, or some other organization or coalition will need to provide additional leadership to ensure an improved organizational and financial framework for meeting salmonid resource needs.

INTRODUCTION

Ever since California became a state, programs and policies have been developed to protect and manage salmonids as a resource important to the economy and to concerned user groups. Measures have been initiated to regulate the ocean and inland fisheries and to restore and enhance salmonid runs and habitats in coastal and valley rivers and streams. These interventions have increased significantly over the past few decades due to the efforts of legislators, resource agencies, private industries, and individuals to put conservation and allocation of salmonid resources on the agendas of various social groups and governments.

As explained in Chapter 1, state, federal, and private programs are presently attempting to ensure that California's anadromous fishery is well managed. The California Department of Fish and Game (CDFG) manages salmon and trout within its waters; offshore salmonid fisheries are managed by the Pacific Fishery Management Council in conjunction with the U.S. Secretary of Commerce. Other federal agencies, including the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS), cooperate with the above agencies and with others in salmonid regulation, monitoring, and hatchery operation. In addition, the U.S. Forest Service (USFS), fishermen's associations, and others help maintain and improve the freshwater habitat so important to the health and resilience of California's salmon and anadromous trout species.

All of these management agencies and programs represent important organizational resources for the resolution of California salmonid enhancement problems. However, as indicated in the preceding chapters, the value of native fish as a genetic resource and application of the stock concept in salmonid management have not been sufficiently integrated into current programs. To accomplish this integration, several technical measures will be necessary. They include the following:

- Determination of the status and composition of salmonid stocks, including both native and mixed stocks, in California and offshore waters;
- Classification of watersheds and streams on the basis of egg transfer and planting records and the presence or absence of native stocks;
- Assessment of the impacts of various management actions, including hatchery and stream management practices, on the integrity (intactness) and productivity of these stocks;
- Establishment of escapement guidelines adequate for maintaining hatchery and native stocks; and
- Development and application of <u>in situ</u> and <u>ex situ</u> conservation techniques.

These technical opportunities can be used if federal, state, and private interests improve the coordination of programs now in operation; increase their financial support for genetic resource management efforts; and further integrate genetic resource-related planning into current planning efforts.

An increasing competition for the state's salmon fishery is causing friction among the commercial and sports fishing industry, Native Americans, and regulatory agencies, and Californians who depend on, or appreciate, the salmon resource. In this environment, agreement and cooperation among the various management agencies and parties is not always easily achieved, and thus requires negotiation over the appropriate roles and responsibilities for each major sector. To put these issues in perspective, as they affect the adoption of the above measures, the chapter begins with a brief background on the development of the federal, state, and private role in managing the state's salmonid resource.

ROLES OF FEDERAL, STATE, AND PRIVATE SECTORS

Salmonids in both inland and ocean waters are generally considered a public resource, and thus their management is largely under the jurisdiction of public agencies. However, private groups and individuals have a major interest in the resource, as they are the providers, through taxes and user fees, of all public management funds and are the recipients of all benefits that accrue through salmonid uses.

Historically, from the standpoint of public management roles, the states have managed marine and anadromous fisheries resources while federal activities have been restricted principally to research and to negotiating international treaties for the protection of common resources. But following World War II, as a consequence of rapidly expanding human populations and increased foreign and domestic fishing efforts, greater national and regional attention was given to protecting marine and ocean anadromous fisheries resources. It soon became obvious that, in most cases, the intrastate approach to management was not working. Because most fisheries were regional in nature, effective management required concerted management in planning and implementation among the states. Recognizing this need in 1945, an attempt was made by the State of Washington to provide some control for offshore fishery operations. A resolution was submitted to the Washington legislature to surrender all interests of Washington in offshore fisheries to existing international fish commissions, which would be charged with regulation of all Pacific coast offshore fisheries. This resolution was defeated because legislators believed that management should be conducted by a commission, having representatives from the three contiguous Pacific coast states, with management responsibility for the Pacific fisheries. Subsequently, the states of California, Oregon, and Washington agreed to a compact to promote better use of marine and anadromous fisheries of mutual concern and to develop a joint program of protection management in all ocean and inland areas over which these states jointly or separately had, or might have, jurisdiction. Congress approved that compact in July of 1947, and it became known as the Pacific Marine Fisheries Commission. The Commission has since been expanded to include Alaska and Idaho.

In 1956, Congress again expressed concern for fisheries by passing the U.S. Fish and Wildlife Act, which recognized that inland fish resources also make a material contribution to the national economy and food supply and that the proper management of these resources requires federal government participation. As a result of this Act, the

USFWS became active in programs for protecting and enhancing freshwater fisheries.

In 1964, Congress enacted the Commercial Fisheries Research and Development Act to provide monetary grants to the states for research to improve commercial fisheries management. In 1965, Congress passed the Anadromous Fish Conservation Act to provide special protection and management for anadromous fisheries. This Act has provided major support in the Northwest, and limited support in California, for salmon and steelhead work. In 1966, Congress enacted the Marine Resources and Engineering Development Act, which established a national policy to rehabilitate U.S. commercial fisheries.

In 1969, the President's Commission on Marine Science, Engineering, and Research, known as the Stratton Commission, reached the following conclusions: Many of the domestic fishing fleets were outmoded; excessive harvesting capacities existed; some stocks were on the verge of being overexploited; catches were declining; user conflicts were prevalent; unemployment in the fishing industry was high; and low incomes from fishing were typical. The Stratton Commission concluded that these conditions could be traced to two basic causes:

1. Finite fishery resources are considered common property, available to unlimited access by users; and
2. Fisheries are regulated (or not regulated) under split or multiple jurisdictions, with no single management authority.

The commission determined that rehabilitation of domestic fisheries depended on eliminating overlapping, and sometimes conflicting, laws and regulations which were hampering even economically viable fisheries. In a summary report, the commission called for the development of a new framework based on national objectives and sound scientific data for a state/federal partnership to manage shared fisheries resources.

In 1971, based on the Stratton Commission's recommendation for action, and under the general authority of the Fish and Wildlife Act of 1956, the National Oceanographic and Atmospheric Administration instituted the NMFS joint state and federal fisheries management program. Perhaps the most valuable product of this program was the development of a cooperative approach to marine fisheries management. Much of this was written into the Fishery Conservation and Management Act (FCMA) of 1976. For example, the concept of regional fishery management councils, such as the Pacific Fishery Management Council, came from the joint state and federal program, as did the principle that management should be conducted according to a plan based on the best scientific information available, and on users' input. In short, the state-federal program encouraged state fisheries administrators to work more closely with each other and with the federal government to develop management plans for shared resources. The groundwork laid by the state-federal program undoubtedly facilitated the early implementation of the FCMA.

From the standpoint of establishing precedents for the most appropriate federal and state roles in ocean fisheries management, the significance of the FCMA cannot be overestimated (Greenberg and Shapiro, 1982). For the first time, Congress assigned specific domestic fisheries management responsibility to the federal government (beyond establishing the regional fishery management councils), by charging it wtih establishing effective management for fisheries resources harvested in the 3-200 mile offshore federal management zone. The Act also prescribed standards, principles, and procedures for developing management systems, while at the same time leaving essentially unchanged the states' responsibilities for managing marine and anadromous fisheries within their waters. The success of the Act depends greatly on effective federal-state interaction because most of the resources receiving attention under the Act occur, and are harvested in, both federal and state waters.

From California's standpoint, the work of the Pacific Fishery Management Council (PFMC) has not been without problems. In fact, the California legislature in 1982 passed Senate Joint Resolution No. 35, memorializing the PFMC, Congress, and the President to take specified action relating to the commercial salmon fishery off the California coast. The resolution charged that recent reductions in the commercial salmon fishing seasons "have been unsupported by the best available scientific data, have caused severe economic hardship to the seafood industry and to the local economies it supports, have forced fishermen to operate their vessels in dangerously bad weather, and have denied California much of the benefit of their efforts to restore and enhance the salmon resource" (SJR 35, 1982). In addition, the Pacific Coast Federation of Fishermen's Associations (PCFFA) and some of the individual associates have been quite outspoken about the council actions in allocating salmon catch among states and the procedures used for making in-season changes in regulations and closures of ocean commercial and recreational fishing. These challenges to the actions of the PFMC indicate the extent of political pressure to which the regional management is exposed. Nevertheless, the PFMC is likely to continue its present role for the foreseeable future, and the State of California and those groups within the state interested in offshore salmon management issues will need to find ways of pursuing California's interests through this regional federal-state mechanism.

Other federal and state agencies and programs are also involved in meeting the challenges of managing and protecting the estuarine and freshwater anadromous resource. The primary federal-state mechanism, as mentioned, developed from the impetus of the U.S. Fish and Wildlife Act of 1956 and involves CDFG and USFWS. In addition to this system, however, a complex maze of relationships and overlapping jurisdiction exists involving state and federal water, forestry, and other agencies and groups with interests in salmonid habitat and population matters. Coordination among all these management efforts is often difficult to achieve, requiring long-term planning and negotiation. In the meantime, of course, the anadromous resource must continue to be managed.

A variety of organizational resources exist for the initiation of research, conservation, and management programs for protecting the genetic resources of salmonids. To employ those resources constructively requires better planning and coordination, adoption of new activities, additional funding and personnel, and improved leadership.

COORDINATION AND PLANNING WITHIN AND AMONG EXISTING AGENCIES

The Pacific Fishery Management Council (PFMC) is at present providing a number of services that are useful for resolving genetic resource management issues. As a regional planning body, the council is attempting to develop an information base and a monitoring program adequate for determining ocean harvest rates, consistent with the requirement for planners' salmonid spawning escapement objectives for both native and hatchery fish along the entire Pacific Coast. In California waters, the council has worked with the CDFG to establish short- and long-term escapement goals for Klamath fall chinook; Sacramento winter, spring, and fall chinook; and for San Joaquin chinook. While there is debate over the adequacy of these goals and the reliability and completeness of harvesting and run data, the PFMC system, once improved, is likely to represent an important management tool. But much work remains to be done in developing a system which can ensure that specific native and hatchery stock are adequately identified and maintained.

The Trinity River Basin Fish and Wildlife Task Force is involved in attempting to monitor and restore salmonid populations, both native and domesticated, within a portion of the Klamath-Trinity Basin. In 1980, this multiagency task force published a proposed fish and wildlife management program which, if implemented, would direct watershed rehabilitation, harvest regulation, monitoring, and stock production projects under a single coordinating authority. Appendices to the proposed program (TRBFWTF, 1980) address physical habitat needs for various anadromous stocks in the basin and contain some of the most detailed biological data on the state's salmonids. However, the success of the program will depend on a genuine and cooperative commitment among the large number of federal and state agencies involved over a 25-year period. In addition, the program relates to a small, albeit important, part of California's anadromous resource.

The California Department of Fish and Game (CDFG) clearly has the broadest authority to manage and coordinate any comprehensive salmonid genetic resource program. CDFG is currently conducting an array of regulatory, hatchery, habitat restoration, planning, and research activities. The department has the authority to control all egg transfers and fry outplanting in the state, and in its hatchery operations, it recognizes at least two major fish distribution areas--the Sacramento River system and the coastal river region--for releases of hatchery-bred fish. (These areas are known as "outplanting zones.") However, at least in the past, the state has transplanted fish extensively, although this appears to be less the case with anadromous than with landlocked species (Hashagen, personal communication, 1972). Once the department's new fish and wildlife plan is finalized (the current plan was developed in 1965), a 10-year plan for managing anadromous habitat and populations will be in place. This plan, in addition to guiding CDFG programs during the next decade, will also communicate to other public agencies and to the private sector the agency's increasing concerns for protecting the resource as the state's population grows and its lands are more intensively developed. Even with such a plan, however, the CDFG will not be in a position to manage the anadromous resource--and its genetic base--on its own.

The U.S. Fish and Wildlife Service (USFWS) has adopted policies which affect salmonid genetic questions in California. The service recognizes a restricted outplanting zone in the operation of its hatcheries in California. In addition, the agency's cooperative programs favor native fish strains over hatchery strains (Vogel, personal communication, 1982). However, the USFWS presence in California is limited, although the agency is charged with providing national leadership in the development of integrated, comprehensive plans for the nation's anadromous fish populations.

MANAGEMENT ACTIVITIES NEEDED

While the programs just described do provide an administrative environment for meeting certain management needs identified in this report, additional programs will be necessary to ensure the best use of salmonid genetic resources. As previously noted, many questions basic to the identification of specific measures for genetic resource management cannot be properly addressed, given current technology and knowledge.

Chapter 3 describes an interim stream classification strategy that might be used to maintain California's native salmonid stocks while research progresses on fundamental questions. Needed biological research includes studies on genetic variation in native and hatchery stocks, stock composition, impacts of management, causes and effects of straying, and other subjects. As no provisions are now in effect for either *ex situ* or *in situ* conservation of stocks native to California, plans for such activities need to be prepared. To address these needs, interest groups in California should consider opportunities for working with others within and outside the state and for seeking additional sources of funding.

REGIONAL, NATIONAL, AND INTERNATIONAL LINKS

Management programs now in operation in the West Coast states may be useful models for California projects. As an example, the Oregon Department of Fish and Wildlife's recent coho management plan contains a provision for creating a geographical zone system for hatchery stocks management--a program virtually equivalent to the stream classification proposal made in this report. And in Southeast Alaska, the Alaska Department of Fish and Game and the U.S. Forest Service are exploring the feasibility of using Forest Service land designation regulations and programs to protect fragile fish stocks. Both these programs need watching, as they could provide important lessons for California.

FINANCIAL CONSIDERATIONS

The fiscal resources required to develop and carry out salmonid management programs are so large they are unlikely to be available from any one source, particularly a state or local source. For example, the first three years of operation of the Trinity River Basin Fish and Wildlife Task Force was financed as part of a $7.6 million appropriation from Congress. While the costs of the recommended actions in this report will certainly not require a similar level of investment, the initiation and development of a salmonid genetic resource plan will no doubt require the supplementation of present management budgets or at least the reallocation of funds within them. Table 5-1 presents the various federal, state, and private sources of funding that could potentially be used for genetic resource purposes. Any assessment of funding needs for fish projects must be made with an awareness that the fisheries area has been subjected to reduced public monies in recent years.

Federal Monies

The funding authorizations provided in the Fishery Conservation and Management Act (FCMA) combined with state grant-aid funds and National Marine Fisheries Service (NMFS) budget support, were considered adequate by Congress to finance necessary FCMA fisheries operations. However, in recent years, U.S. citizens, in response to high inflation and other problems, have asked for a retrenchment in federal spending. As a consequence, the present administration has recommended drastic cuts in the support for fisheries management programs. As an example, the NMFS budget for FY 1982 is $125 million, or $27 million less than the $152 million budgeted by Congress. For FY 1983, the administration is proposing a budget of $107 million. In addition to the NMFS cuts, NOAA is planning a $17 million cut to terminate its Sea Grant program (a program which includes support for university research), a $3.3 million cut in support for the regional fishery management councils, and a $4 million cut in the Marine Resource Monitoring Program (a program designed to furnish the scientific and technical information needed to assess and forecast the status of fishery stocks and the effects that both natural and human-induced changes to the environment have on stocks). In addition, federal funds for USFWS programs are scheduled to be reduced. All this indicates that additional federal monies for salmonid projects may not be forthcoming.

State Monies

In view of these reductions in federal funds, state governments may have difficulty in making up for the cuts as state resources are also now subject to greater restraint. CDFG is, however, in a somewhat unusual position in that the department is a special fund agency and does not receive a significant amount of general fund money. More than 80% of CDFG funds come from the Fish and Game Preservation Fund. The fact that the CDFG budget depends in large degree on a user tax allows the department a certain stability in a time of budget cuts. However, much of the department's research and salmonid restoration work comes from the sale of special salmon stamps, from AB 951 (1981) funds, and from various federal sources (see Table 5-1). Thus CDFG has a relatively tight budget at this time.

Private Monies

In the past, little direct private support has been offered in California for salmonid research and restoration. Recently, however, commercial and sport fishermen's groups have begun to take an immediate

Table 5-1

STATE, FEDERAL, AND PRIVATE SOURCES OF FUNDING, ACTIVITIES THEY SUPPORT, AND PRINCIPAL RECIPIENTS

Sources	Activities Funded	Principal Recipients
State of California		
Fish and Game Preservation Fund	Management and research activities	California Department of Fish and Game
Energy and Resources Fund	Habitat restoration	State agencies
Commercial salmon stamp fees	Salmon propagation and restoration	California Department of Fish and Game
Assembly Bill 951 (1981)	Habitat restoration	State agencies and nonprofit organizations
Federal		
Department of Commerce		
National Marine Fisheries Service	Research, support services (marketing)	Mainly in-house activities
Aid to Commercial Fisheries Programs (PL 88-309)	Research, development, improvement, and services	State agencies
Anadromous Fish Conservation Program (PL 81-681)[1]	Research, fish facility construction and operation, stream clearance	State fishery agencies, colleges and universities, and private companies
Office of Sea Grant	Research and development, education, training, extension and advisory services	Universities, public and private nonprofit research organizations
Marine Resources Monitoring, Assessment, and Prediction	Include resource surveys; survey and catch data analysis; fishery oceanography and climatology.	In-house
Department of the Interior		
Fish and Wildlife Service	Research, hatcheries, and support services (disease programs)	Cooperative fisheries at universities and in-house programs
Federal Aid in Fish Restoration (Dingell-Johnson Act)	Research, development, management projects, and land acquisition for sport fish	State fishery agencies

TABLE 5-1

Sources	Activities Funded	Principal Recipient(s)
Private		
Fishermen's associations	Habitat restoration and enhancement	—[2]
Communities and nonprofit organizations	Fish propagation facilities	Mainly in-house activities
Private industry	Fish propagation facilities	Mainly in-house activities

[1]This Act is also administered by U.S. Fish and Wildlife Service

[2]Information not available

Sources: Living Marine Resources, Inc., 1980; National Marine Fisheries Service, 1981; Pacific Coast Federation of Fishermen's Associations, Inc., 1982; U.S. Fish and Wildlife Service, 1979.

financial interest in maintaining the resource base on which their livelihood or leisure activities depend.

As an example, fishermen's associations in California this year will be collecting an assessment of five cents per pound for every salmon delivered. This money will be used for programs designed to protect fisheries and the resource, including one cent for restoration and enhancement and one cent for the Fishermen's Legal Defense Fund. Both the restoration and legal monies are deposited in separate funds and are administered by committees. Also, recreational organizations, such as Cal-Trout, directly support habitat and restoration work.

LEADERSHIP OPTIONS

Essentially, three principal options are available to interested parties who may wish to provide additional leadership in developing and coordinating a comprehensive management program for salmonid genetic resources important to California.

California Department of Fish and Game

CDFG appears to be a logical choice to take the primary leadership role in improving the degree to which genetic considerations are applied in salmonid management and planning in California. The department is currently conducting an array of regulatory, hatchery, habitat restoration, planning, and research activities with relevance to genetic resource management. CDFG has the authority to control all egg transfers and outplanting activities in the state. Once the agency's new fish and wildlife plan is adopted, a framework will exist for coordinating anadromous habitat and population programs for all relevant actors within the state area of jurisdiction. In addition, the state is in a better position to manage anadromous fisheries than the federal government for at least three general reasons (Skoog, 1982).

The first is its organizational and staff capabilities. State organizations and staff tend to have a close familiarity with local resources and the people who use them. Conversely, federal agencies tend to have a high personnel turnover, and this may inhibit the federal resource manager's understanding of local resource problems. The second reason that a state agency is more apt to have the necessary public support and involvement in managing its resources is because it is more sympathetic and dedicated to the needs of the public and resources within the state. This can be seen in salmon user reactions to the imposition of federal regulation through the PFMC. The third reason state agencies are likely to perform better is that a state program can be more flexible and can respond more quickly to change while the federal government often has a slower response time.

A number of reasons exist, though, why the state may not be able to perform a primary leadership role in a comprehensive salmonid genetic management program. First, the department is not likely to have the funding to undertake the wide range of necessary research, monitoring, and conservation projects needed. Second, CDFG is not primarily a research institution and thus may not be able to address many key questions relevant to the definition and use of the stock concept. Third, and most importantly, the management responsibilities for

California's salmonid resource are not restricted to the state's jurisdiction. As noted previously, a number of other agencies and groups exercise control over various aspects of the fishery and thus affect the genetic composition of salmonid populations. Because genetic resource management issues involve different levels of government and user groups, they perhaps should be resolved through a structure more broadly based than a single state government agency.

Pacific Fisheries Management Council

The congressional intent of PFMA was to create institutions that could respond to the regional nature of marine and anadromous fisheries by providing correspondingly broad administrative structures--the regional fishery management councils. These councils were designed to eliminate overlapping and sometimes conflicting laws and regulations and to ensure a sound scientific data base for the management of shared fisheries.

PFMC--the regional council for the Pacific Coast--has been making strides in guiding anadromous fishery planning among the three coastal state fish and wildlife departments and in beginning to generate a data base describing the status of the ocean salmonid resources. In addition, the council has become increasingly interested in habitat questions that affect the stability of salmonid populations. Although habitat questions are outside the PFMC's jurisdiction, the council is committed to providing assistance to the states and to other agencies conducting inland fishery management. Given its regional perspective, its concern for the complete life cycle of salmonids, and its emerging planning skills, the PFMC may provide leadership in activities relevant to the management of salmonid gene resources in California and along the entire coast.

PFMC is in a position to place salmonid genetic resource management issues in a regional perspective and to provide leadership in the development and coordination of assessment, conservation, and research work. The financial resources of PFMA might allow the council to provide the long-term financial backing necessary for the various conservation and research work. Furthermore, the council links the coastal state governments and (in cooperation with other councils) the national fishery communities. These links help in the dissemination of new management information and techniques.

PFMC also must contend with limitations that impede its ability to lead. Firstly, as a regional agency, the council has duties and responsibilities that relate to the concerns of all the states within its jurisdiction, and so PFMC may not be able to conduct a program designed to meet just California's needs. Secondly, PFMC leadership may discourage the participation of various groups within the state who feel that the federal role in the management of anadromous resources should be limited. And thirdly, PFMC does not presently have the staff or research capabilities to explore the full range of genetics management issues outlined in this report.

A SALMONID MANAGEMENT TASK FORCE

The most appropriate way for groups interested in California salmonids to proceed may be to form a public-private task force. Members could consist of all concerned parties, including representatives of the state's sport and commercial fishing industries, fish handlers, Native Americans, and representatives of all the various public agencies--CDFG, PFMC, California Department of Forestry, U.S. Forest Service, and various water resource agencies. The task force could then decide how to proceed in resolving the range of technical and institutional problems identified in this report. Once the task force determined which activities should be pursued, established priorities among them, and made arrangements for financing, a more permanent management group could then be formed.

planning units. Thus PFMC may provide leadership in activities relating to the management of anadromous stock resources in California and along the entire coast.

PFMC is in a position to place salmonid genetic resource management issues in a regional perspective and to provide leadership in the development and implementation of assessment, conservation, and research work. The scientific resources of NMFS might allow the council to provide the technical and financial backing necessary for the various conservation and research work. Furthermore, the council links the separate state governments and (in cooperation with other councils) the national fishery communities. These links help in the dissemination of new management information and techniques.

PFMC also must contend with limitations that impede its ability to lead. Firstly, as a regional agency, the council has duties and responsibilities that relate to the concerns of all the states within its jurisdiction, and so PFMC may not be able to conduct a program designed to meet just California's needs. Secondly, PFMC leadership may discourage the participation of various groups within the state who feel that the federal role in the management of anadromous resources should be limited. Additionally, PFMC does not presently have the staff or research capabilities to explore the full range of genetics management issues outlined in this report.

A SALMONID MANAGEMENT TASK FORCE

The most appropriate way for groups interested in California

CHAPTER 6

FINDINGS AND RECOMMENDATIONS

The current salmonid assessment was aimed at answering the following four questions:

1. What technical measures are needed to ensure that the salmonid genetic resources which are important to California are managed, conserved, and used so as to produce maximum sustained yields?
2. How might existing public and private policies and programs be modified to facilitate genetic resource management and use?
3. What new financial and organizational arrangements are required?

The main purpose of this chapter is to present answers to these questions and to recommend the measures necessary to meet desired production objectives. The Implementation Plan in the next chapter suggests how individuals and organizations concerned with salmonid genetic resource issues can carry out the recommended actions in a coordinated manner.

FINDINGS

The Importance of Salmonids and Their Genetic Resources

Finding 1: California's anadromous salmon and trout species are one of the state's most important renewable resources. Salmon support a commercial fishery contributing more than $50 million to California's economy each year. The salmon and sea-run trout sport fishery is enjoyed by about 150,000 fishermen and contributes more than $17 million to the state's economy annually. While it is difficult to project future markets and uses of salmonids, the present rate of salmonid consumption in the sport and commercial fisheries is expected to continue through 2020.

Finding 2: While both commercial and sport salmonid catches have been maintained at relatively stable levels during the past few decades, salmon and steelhead populations have declined an estimated 60% in California inland waters since 1900. A number of traditional salmon runs are now at dangerously low levels or are extinct. And in a number of cases, escapement goals set by management agencies to sustain the productivity of natural and hatchery stocks are not currently being met.

Finding 3: The state's ability to increase salmonid production and quality and to maintain present consumption levels depends on a range of existing programs. Particularly in recent years, federal and state agencies and private groups have instituted programs to regulate the ocean and inland fishery and to restore and enhance salmonid runs and habitats in coastal and valley rivers and streams. Investments are now being made in stream rehabilitation, hatchery production, and ocean ranching. But knowledge of the importance of genetic diversity in the advancement and coordination of these efforts is not readily accessible to decision-makers. The role of natural species diversity in maintaining the ocean fishery and in development of salmonid aquaculture is now being recognized. However, information on the extent and geographic distribution of this diversity is largely unavailable or unanalyzed. This situation complicates resolution of the problems encountered in conserving the salmon resource and allocating the resource among fishery participants.

Identifying Salmonid Genetic Resources

Finding 4: The existence of a significant amount of genetic diversity has been documented among populations of anadromous salmonid species. Variation in many morphological, physiological, behavioral, and biochemical traits studied has been shown to have a genetic basis. Detailed studies of genetic variation in populations of chinook and steelhead trout found outside California suggest that it is reasonable to infer the existence of genetic differences among salmonid populations spawning at different times in different rivers and streams of California.

Finding 5: Extensive evidence exists that a significant portion of the genetic variation observed in salmonid species is adaptive, i.e., results from the current or evolutionarily recent action of natural selection on native populations. Apparently, adaptive traits include homing behavior, migration to feeding areas and to and from the ocean, time of spawning, and other behavioral, physiological, and morphological characteristics. Information confirming the adaptive nature of these traits includes observations of consistent differences among populations, evidence of heritability of traits, and results of transplantation experiments.

Finding 6: Information on genetic variation of chinook and coho salmon, anadromous runs of rainbow (steelhead), and cutthroat trout in

California is inadequate to quantify populational differences within and across watersheds in California. In hatchery records, native stocks are referred to by name of the river or stream from which they originated, but the level of detail in documenting stock differences is variable, depending on the philosophy and style of fishery managers' record-keeping at different facilities. Data on adult size, run timing, and spawning season have been used by managers to informally distinguish stocks found in the Sacramento River system from those of the coastal rivers, but this informal policy has not been uniformly applied. No written policy or established guideline exists for the recognition or management of anadromous salmonid stocks in California.

Finding 7: Marking studies have seldom been carried out in conjunction with transplanting so as to permit evaluation of the genetic basis, performance consequences, and adaptive value of phenotypic differences among stocks of salmon and anadromous trout. Very few marking studies of wild salmonid populations have been done in California. Observations on survival and straying made possible by marking studies would permit an evaluation of the significance and performance value of the genetic differences among stocks or populations.

Impacts of Management Practices on Genetic Diversity

Finding 8: Marking of hatchery-reared fish released at some distance from the rearing site has revealed extensive straying, both in California (in the few marking studies done in the state) and in other

West Coast river systems. Straying of these "off-station" released fish is much in excess of natural rates in many cases studied.

Finding 9: There is no information on the breeding success of strays, either wild or hatchery-reared, in areas where they might ultimately spawn. Hence, there is no basis for determining the genetic consequences of straying for the integrity of native stocks.

Finding 10: Documentation of phenotypic and probable genetic effects of hatchery practices in general is available. In particular, documentation of such effects in California is obtainable from hatchery records.

Finding 11: Documentation of phenotypic and demographic effects of harvesting practices is available. Expectations that sometimes undesirable genetic consequences may accompany or follow these effects are highly plausible but have not been tested experimentally.

Finding 12: Possible genetic impacts of logging, grazing, mining, and of rehabilitation and intensive use of streams can be anticipated based on the effects of these activities on spawning and rearing habitats, food organisms, and predators. There is no documentation of such genetic impacts or of their importance to stock integrity and productivity because relevant studies have not been done.

Conservation of Salmonid Genetic Diversity

Finding 13: Presently available technology allows the cryogenic storage of salmonid sperm, but not of ova or embryos.

Finding 14: Populations of chinook salmon and steelhead have been successfully introduced to other countries and could be perpetuated ex situ. Other potentially effective means of ex situ conservation include (a) introduction of salmonid stocks to rivers within their native range that do not currently support salmonids, (b) maintenance of populations in ponds, raceways, or pens and provision for replacement of salmonid stocks with similar but artificially propagated stocks. The techniques required to maintain reproducing populations of anadromous species under confined conditions are not yet well established.

Finding 15: There is currently no formal procedure for recognizing or maintaining the diversity and integrity of native in situ salmonid stocks in California. Many technical problems hamper the implementation of genetic resource conservation measures, and most of these problems are caused by inadequate information. For instance, the distribution of salmonid genetic diversity is not adequately documented in California to guide efforts to evaluate and conserve representative native salmonid stocks in nature.

Finding 16: There is currently no ready means of monitoring salmonid diversity and population integrity in California. Preliminary studies suggest that populations could be definitively categorized using records obtainable from state and federally operated hatcheries. This procedure would indicate the genetic ancestry (e.g., wild, hatchery-bred, mixed) of salmonid populations.

The Role of Economics in Salmonid Management

Finding 17: The preservation of salmon gene resources in the different watersheds of the state is highly dependent on the exhaustive identification and meticulous appraisal of all the values--market and nonmarket--intrinsic in this resource and its many associated resources.

Finding 18: Economic methodology can provide creditable estimates of the value of nonmarket uses of salmon habitat and of the salmonid resource. The value of salmon fishing for different sites in the ocean inner marine and streams of California can be ascertained by two methods, the travel cost method and the contingent valuation method.

Results of studies in Washington using the contingent evaluation method approach indicate that fishermen are willing to pay from $40 to $75 per angler day at 1978 price levels. In Oregon, a study using the Travel Cost Approach found the value of a salmon fishing day to be $45 (1977 price level).

No such studies have been conducted in California, where it might be presumed that a day of salmon sport angling is worth at least as much as a day's salmon fishing in Oregon or Washington. Economic research to evaluate fishery management practices used to appraise (a) the need for hatchery expansion, (b) the allocation of catch between commercial and sport fishery, or (c) the values attaching to sport fishing and commerial catch has not been undertaken in California. Federal and state agencies are apparently lacking in economic expertise to conduct such investigation, and fishery managers seem inclined to forfeit the benefits of incisive economic evaluations.

Salmonid Management Policy

Finding 19: At present there is no institutional mechanism for establishing in situ protection for anadromous stocks native to California. Anadromous stocks are not easily protected because critical habitats are often scattered along rivers or throughout river systems and cannot be contained within the boundaries of closely regulated parks or reserves. In addition, the migratory movement of these fishes implies that they also need protection within ocean feeding grounds and not just within spawning and rearing. Clearly, the development of policies adequate for maintaining salmonid in situ is a challenge for decision-makers, and for interest and user groups.

Finding 20: At present, there are no statewide policies restricting hatchery egg transfers and hatchery outplants to specific geographic zones.

Developing a Comprehensive Salmonid Management Program

Finding 21: No agency or interagency group is currently providing the leadership necessary for initiating and implementing a program adequate for managing salmonid genetic resources important to the state, although some significant work is being done under the auspices of both state and federal agencies. CDFG, PFMC, the Trinity River Basin Fish and Wildlife Task Force, and others all now consider the need for the maintenance and use of anadromous stocks to some degree. However, none of these agencies has the planning, jurisdictional, funding, or administrative resources to pursue a comprehensive program.

Finding 22: There is a need to examine the most appropriate roles for the federal, state, and private sectors in directing and supporting salmonid genetic resource work. The federal-state partnership in managing the anadromous resources has emerged over time and is in continual need of reexamination, based on a clear assessment of biological, social, and economic requirements for optimal management of the resource.

Finding 23: Better coordination among and within existing institutional programs could improve the use and maintenance of salmonid genetic resources. A multitude of agencies are involved in the management of both the ocean and inland anadromous fishery. The goals of these agencies may conflict, whereas their jurisdictions overlap. Increased coordination and collaboration among agencies could help clarify discrete roles and may result in more support and attention to genetic resource issues.

Finding 25: Funding constraints may limit the development of a comprehensive program for managing the genetic base of salmonids. In recent years, fisheries projects and programs have not fared well in the federal budgeting process in comparison with most other programs. State fish and wildlife operations funds, based primarily on user fees, have remained rather stable; however, CDFG research work tends to be federally funded and is thus under financial constraints. Direct grants from private sources for salmonid research and management work have been rare.

RECOMMENDATIONS

Recommendation 1: Initiate an inventory of California rivers and streams, recording the genetic integrity (i.e., intactness) of their salmonid stocks, based on hatchery transfer and outplanting records. Streams and watersheds might be classified as to the number and currentness of stock introductions and as to their sources. This inventory would be a necessary first step in the design of a management strategy for maintaining California's native salmonid stock while research progresses on fundamental questions.

Recommendation 2: Design and implement a marking study for both hatchery and natural stock within a major watershed system in California. The study should focus on determining the success of emigration of artificially reared and naturally reared salmonids and it should determine their rate of return as adults, both to fisheries and to natal streams. The study would permit researchers to evaluate the genetic basis, performance consequences, and adaptive value of phenotypic differences among stocks. Creel censuses, adult trapping and tagging, and spawning ground surveys can be used to measure stock returns.

Recommendation 3: Initiate a study to monitor the relationship between Pacific Fisheries Management Council (PFMC) season closure and harvest regulation programs with resulting escapement and hatchery return levels within a mixed stock watershed.

Recommendation 4: Initiate on-site case studies to obtain fundamental data on the specific impacts on genetic diversity and salmonid productivity that result from management practices. Information needs to be collected to determine the changes in genetic composition of California's salmonid species over time, and research is required to ascertain the effects of these changes on fish production and quality. Sites for case studies should include streams and watersheds chosen for differences in management history and administrative jurisdiction.

Recommendation 5: Case studies should also be done to obtain precise knowledge regarding the technical measures required for in situ and ex situ conservation, such as the feasibility of the cryogenic storage of ova or embryos, and the rearing of salmonids in ocean pens.

Recommendation 6: Continue the analysis begun in Appendix E of the feasibility of using introductions to ex situ waters as a conservation technique.

Recommendation 7: Hold a regional working conference on the biological basis and management applicabilility of the stock concept to salmonid management. The stock concept has wide acceptance among fisheries managers and scientists and has been utilized to varying degrees as a basis for planning and management in Oregon, Washington, British Columbia, and Alaska, as well as by the PFMC and in California.

Nevertheless, the scientific and technological basis for identifying and monitoring discrete stocks is limited; the research necessary to identify population units that are important for species productivity and stability will take considerable time and effort. This conference could enable researchers and managers to share state-of-the-art information about the stock concept and thus to efficiently and effectively plan future research.

Recommendation 8: Facilitate the development of research activity in several areas, including the following:

1. scientific documentation (e.g., isozyme studies) of genetic diversity that exists within and among species' populations; and
2. determination of genetic consequences of population phenomena (e.g., density-dependent mortality, homing and straying, and ocean migration patterns) affected by management practices.

Recommendation 9: Economic studies and investigations should be conducted to appraise the value of the nonmarket services provided by California's salmonid resources.

Recommendation 10: Competent analysis should be employed to evaluate the market and nonmarket values inherent in each management alternative for salmonid habitat. "Procedures, Principles and Standards," promulgated by the U.S. Water Resources Council for water and related land resources, should be used in the analysis in conjunction with the Environmental Quality Account and the National Economic Development Account (see Chapter 4).

Recommendation 11: Hold a working conference to examine the appropriate roles and responsibilities for the management of salmonid genetic resources among the federal, state, and private sectors. The purpose of this conference would be to bring together representatives of each sector, to review means for avoiding jurisdictional overlap, to identify statutory incompatibilities, and to begin to develop an appropriate distribution of roles and responsibilities among all parties with a stake in maintaining California's anadromous fishery.

Representatives of the following federal, state, and private groups should attend this conference: the Pacific Fisheries Management Council, Native Americans, the Pacific Coast Federation of Fishermen's Associations, the California Department of Fish and Game, the California Department of Forestry, other state agencies, the University of California, Sports Fishermen Associations, the U.S. Forest Service, the U.S. Fish and Wildlife Service, the National Marine Fishery Service, and other salmon and sea-run trout interests in California.

Recommendation 12: Hold a series of working conferences to provide conflict-resolution and negotiation services for the various interests involved in the management of the anadromous fishery. A successful initiation and implementation of the projects recommended in this project will depend, at least in part, on a consensual agreement on the need for salmonid genetic resource management activities and on adequate voluntary compliance to achieve relevant goals. Negotiation services should help in reducing conflicting interests and in generating consensus.

Recommendation 13: Develop a carefully planned and coordinated information system to assemble, analyze, and distribute data related to salmonid genetic resources. The information should be on the following subjects:

- Current and future production problems,
- Economic data related to production problems,
- Marketing,
- Land availability,
- The distribution of native and mixed stocks and their significance for production problems,
- The current status of salmonid resources,
- The impacts of human activities on these resources,
- Land and resource use plans that might affect native and mixed stocks,
- *In situ* and *ex situ* conservation techniques,
- The utility of using genetic material to solve production problems,
- Genetic enhancement and salmonid culture techniques,
- Other related information of importance and interest.

Recommendation 14: Develop an educational program to communicate effectively with public decision-makers, commercial and sport user groups, Native Americans, scientists, and the general public regarding:

- Problems in maintaining salmonid productivity,
- The importance of genetic resources in resolving these problems, and

- Specific issues and needs related to salmonid genetic resource management, conservation, and use.

<u>Recommendation 15: Hold a working conference in California to consider the financial and organizational arrangements needed to carry out the technical and policy measures recommended in this report</u>.

Establish a new funding base to support research, conservation, and management activities. Financial arrangements should be developed that spread out investments among all relevant management agencies and user groups so that costs per participant are kept low, but additional monies are generated. Costs ideally should also be spread across human generations in an equitable fashion.

<u>Recommendation 13: Develop a centrally planned and coordinated information system to assemble, analyze, and distribute data related to salmonid genetic resources.</u> The information should be on the following subjects:

- Current and future production problems,
- Economic data related to production problems,
- Marketing,
- Land availability,
- The distribution of native and mixed stocks and their [illegible],
- The current status of salmonid resources,
- The impacts of human activities on these resources,
- Land and resource use plans that might affect native and mixed stocks,
- *In situ* and *ex situ* conservation techniques,
- The utility of using genetic material to solve production problems,
- Genetic enhancement and salmonid culture techniques,
- Other related information of importance and interest.

<u>Recommendation 14: Develop an educational program to communicate effectively with public decision-makers, commercial and sport user groups, Native Americans, scientists, and the general public</u> regarding:

- Problems in maintaining salmonid productivity,
- The importance of genetic resources in resolving these problems, and

CHAPTER 7

IMPLEMENTATION PLAN

This chapter describes a three-phase plan for carrying out the actions needed to improve the management, conservation, and use of salmonid genetic resources. The main purpose of this plan is to coordinate the recommended technical and policy measures that are required to reduce the increasing risks facing the salmonid fishery in California and elsewhere. There are, for example, problems of decreasing population size, rising costs of harvesting and of mitigating habitat damage, and conflicting and rising demands for a diminishing resource. As a means of reducing risks, the proposed plan is likely to increase the potential for improved salmonid productivity and economic returns from the fishery.

It is essential that this plan continue to be developed with the participation of those who will provide support and be involved in carrying out the recommended actions. Continued collaboration with individuals representing a broad range of interests in salmon and sea-run trout--industry, government, the academic community, Native Americans, sports fishing, and conservation organizations--should produce a practical final plan that can be implemented in a cost-effective manner.

This plan was developed in the following manner. First, the technical and policy-related measures recommended in the previous chapter were assigned priorities within their categories (management and conservation; research; information; planning; technical assistance; and institutional arrangements) (see Table 7-1). The priorities were established using feasibility, need, and importance as the main criteria. For example, a Salmonid Genetic Resources Task Force must be established before plans for an inventory study can be made.

After priorities were assigned to the recommended measures within each category, they were integrated into a three-phase plan (see Table 7-2). The same criteria previously used to establish priorities within each functional category were again used to integrate recommended actions into this general plan.

During the eight months of Phase 1, the Task Force will have to develop a more detailed plan than the one contained in this document. It will include budgets, define roles and responsibilities, describe tasks, and set time schedules. The Task Force will also have to initiate an education program to assist in communications with fishery interests in California. Potential Task Force members include representatives of sports fishermen, industry concerns, California agencies and the legislature, the University of California, the federal government, the PFMC, and public and private interests in other states.

Phase 2, lasting twelve months, will concentrate on the establishment of the institutional arrangements approved during Phase 1 and on acquiring the information needed to develop the programs to adequately manage, conserve, and use salmonid genetic resources.

Phase 3 will involve the development of cost-effective programs that will ensure the availability of new, appropriate genetic resources

Table 7-1

RECOMMENDED TECHNICAL AND POLICY MEASURES FOR SALMONID GENETIC RESOURCE MANAGEMENT, CONSERVATION, AND USE

RECOMMENDATIONS

Organizational and Institutional Arrangements

Priority 1:	Establish a Salmonid Genetic Resources Task Force composed of salmonid interests in California and elsewhere to take responsibility for carrying out the Implementation Plan during its early stages.
Priority 2:	Hold meetings of federal, state, and private sector interests at the state and regional levels to consider policies and financial and organizational arrangements needed to carry out the technical and policy-related measures recommended in this report.
Priority 3:	Modify existing policies and arrangements and establish new ones.

Management and Conservation

Priority 1:	Initiate inventory of California rivers and streams recording the genetic integrity of their salmonid stocks based on hatchery and outplanting records.
Priority 2:	Take adequate conservation measures based on this inventory and conservation actions already accomplished.
Priority 3:	Conduct on-site case studies to determine specific technical and policy-related measures required for _in situ_ and _ex situ_ conservation.
Priority 4:	Design and implement a marking study for both hatchery and natural stock within a major watershed system in California.
Priority 5:	Initiate on-site case studies to obtain fundamental data on the specific impacts on genetic diversity and salmonid productivity that result from management practices.
Priority 6:	Initiate a study to monitor the relationship between Pacific Fisheries Management Council season closure and harvest regulation programs with resulting escapement and hatchery return levels within a mixed stock watershed.
Priority 7:	Conduct economic studies and investigations to appraise the market and nonmarket value of salmonid resources.

Table 7-1

RECOMMENDATIONS

Priority 8:	Facilitate research to scientifically document genetic diversity that exists within and among species populations.
Priority 9:	Facilitate research to determine genetic consequences of population phenomena affected by management practices.

Information

Priority 1:	Develop an information management system to assemble, analyze, and distribute data related to salmonid genetic resources.

Education

Priority 1:	Develop an education program to communicate effectively with salmonid interests in California and elsewhere.

Table 7-2

IMPLEMENTATION PLAN

Phase I. Initiation of Plan (8 months)

A. Form Salmonid Genetic Resources Task Force.

B. Hold meetings of Task Force to develop detailed plans for implementation including institutional and financial arrangements.

C. Develop and implement plans for an education program.

D. Hold meetings with salmonid interests in other Pacific Coast states to inform them of Task Force proposals and obtain agreements regarding institutional arrangements.

E. Make a comprehensive analysis of the need for in situ and ex situ conservation measures.

F. Determine Phase II budget and acquire support for Phase II.

Phase II. Institutional Relationships and Initiation of Activities (12 months)

A. Task Force establishes permanent Salmonid Genetic Resources manager(s) or management group(s) in California and/or at regional and/or national levels.

B. Finish policy and institutional analyses of conservation, management, and use activities within California and in other regions of U.S.

C. Initiate stream and river inventory in California.

D. Hold conference to determine appropriate salmonid management roles among the federal, state, and private sectors.

E. Hold conference to identify research needed to resolve production problems, enhance conservation, and fill management and information needs.

F. Begin economic analyses to determine market and nonmarket values.

G. Develop a plan and budget for Phase III.

Phase III. Continuing Programs

A. Coordinate in situ and ex situ activities.

B. Implement plans for resolving salmonid production problems.

C. Implement plans for enhancing conservation and management activities.

essential to resolve production problems on a continuing basis.

On the surface, the development of effective management programs for salmonid genetic resources may appear complex and therefore beyond the effective involvement of those who have a vested interest in salmonids, yet have little technical knowledge about problems in salmonid production. However, experience has shown that the use of this type of step-by-step approach, together with a strong nucleus of dedicated people and a sound education program, is sufficient to provide the capability to effectively carry out programs of this apparent complexity.

Investments in genetic resources, including the information needed to use them efficiently and effectively, are an insurance policy essential to the foreseeable future. If managed properly, genetic resources will continue to provide economic benefits indefinitely.

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APPENDIX A

LIFE HISTORY, EVOLUTION, AND DISTRIBUTION OF FOUR SALMONID SPECIES IN CALIFORNIA

NATURAL HISTORY

Anadromous means "up-running" and refers to fish that reproduce and spend the juvenile part of their lives in freshwater but then migrate to sea, where most of their growth occurs. Whether salmon were originally of freshwater or marine origin is a subject of debate, but many researchers prefer the freshwater origin hypothesis, explaining that recurring ice ages caused a food shortage in inland waters, thus driving fish, such as salmon, out into the ocean in search of food (Netboy, 1974).

Although anadromous fish spend part of their life cycle in the ocean, they ascend the cool, oxygen-rich freshwater streams of their origin to reproduce. One characteristic of anadromous fish is that they have a homing instinct which enables a large proportion of the fish to find their natal stream. Spawning usually occurs in headwaters and tributary streams of larger rivers, although any stream with suitable conditions can be utilized. Salmonids need cold, clean water and a gravelly stream bottom free from silt which might smother the eggs. On entering freshwater, the fish stop feeding, and their bodies begin to deteriorate. When the salmonids reach their natal stream, the female deposits her eggs in nests, or redds, in the gravel on the stream bottom; the male fertilizes the eggs with his milt, and they are covered with gravel and left to develop.

While buried in the gravel, the eggs are vulnerable to many factors which might limit their survival, including siltation, floods, pollution, dissolved oxygen content of the surface and subsurface water, and water temperature fluctuations. The life cycles of most Pacific salmon are complete after spawning, and the fish then die. Steelhead and coastal cutthroat trout, also anadromous, usually live to spawn again. Following the fall spawning, the eggs hatch the following spring. The newly hatched salmonid fry, called alevins, live off their yolk sacs for their first few weeks of life. They then emerge from their redds and begin to search for food, often moving downstream in pursuit of richer feeding grounds. In the spring, various species and stocks within species will start their ocean migration at different life stages. Before they enter the ocean, they must first undergo a physiological change called smoltification (see Glossary) which preadapts them to living in salt water. Their appearance and behavior changes; they become silvery and swim with the current rather than against it.

Salmonids often travel in large unidirectional, circular patterns during their period in the ocean. Although there are many hypotheses, it is not known what migratory cues the fish use to find their way. Different species and stocks within species do have well-defined migratory patterns, and their timing of return to the natal stream is remarkably distinct, even though the individuals from each stock disperse upon entering the ocean (Burgner, 1980).

EVOLUTIONARY ORIGINS

Fish adapted to various environmental conditions over millions of years, resulting in approximately 20,000 different species. The large group of teleost (bony) fishes have their origin in the Cretaceous Period, 135 million years ago. They distributed themselves around the world, and by the process of evolution (through trial-and-error adaptations) were differentiated into many different families, including Salmonidae, which became habituated to the Northern Hemisphere. Fishes were very much like those of today by the Paleocene epoch, 60 million years ago (Netboy, 1974).

Whether the Atlantic salmon or the Pacific salmon evolved first is as yet scientifically unresolved. It is generally thought that the Pacific salmon (Oncorhynchus spp.) are a relatively recent offshoot of the genus which includes the Atlantic salmon (Salmo spp.). Salmon took advantage of the opportunity to migrate from the Atlantic to the Pacific during a time in history when there was no land bridge connecting North America with Asia, and there was no climatic barrier in the form of solid ice to prevent the migration of fish. Individual salmon populations became isolated and then through the process of evolution acquired different characteristics.

Classification within the genus Salmo, which contains the trouts and the Atlantic salmon, is complex and confusing. There are questions as to how many of the approximately 50 species of Salmo actually merit taxonomic differentiation. In Behnke's (1979) review of the taxonomic history of Western trouts, he refers to the evolutionary separation of

Western trouts (placed into the subgenus Parasalmo by Vladykov in 1963) from other members of the genus. Apparently a divergence occurred between the Western trouts of the subgenus Parasalmo and other species of Salmo (Atlantic salmon, brown trout, etc.) approximately 10 million years ago. All of the Western trouts are so closely related genetically that if any two individuals of the species interbreed, their offspring are fertile. But sterility barriers do exist between the subgenus Parasalmo and Salmo. Although Atlantic salmon and brown trout can interbreed with Western trout, their offspring are sterile. Pacific salmon, in the genus Oncorhynchus, derived from the evolutionary line of Salmo leading to Parasalmo. Thus, the Pacific salmons and the Western trouts are phylogenetically more closely related to each other than to the Atlantic salmon or brown trout (Behnke, 1979).

NATURAL RANGE OF SALMONIDAE

There are six species of Pacific salmon (in the genus Oncorhynchus (which means "hook-snout"). Five of those species are native to North America; in order of abundance, they are pink salmon (O. gorbuscha), sockeye (O. nerka), chum (O. keta), coho or silver (O. kisutch), and chinook or king (O. tshawytscha). All five of these species occur in California, although the order of abundance is almost reversed (i.e., chinook and silver are relatively abundant, pink is uncommon and erratic in its occurrence, chum is rare, and sockeye is very rare). In Asia, the most numerous species are pink, chum, and sockeye. In addition silver, chinook, and masu or cherry salmon (O. masu) are somewhat less abundant.

Of the approximately 50 species of trout in the genus Salmo, the natural distribution of species wtihin the subgenus Parasalmo is restricted to Western North America, except for S. mykiss, which occurs in Asia. Other Salmo, including the brown trout and Atlantic salmon, occur in Eastern North America and Europe. Whereas all species of Pacific salmon are migratory (anadromous), trout species exhibit both migratory and nonmigratory behavior. The chars (Salvelinus spp.) are a third genus in the family Salmonidae occurring in California, but it contains no anadromous species in California.

Four species of anadromous salmonids are found in California at significant levels of abundance: they are chinook salmon, steelhead, i.e. sea-run rainbow trout (Salmo gairdneri gairdneri), coho salmon, and coastal cutthroat trout (S. clarki clarki). Of the many pressures affecting the survival of salmonids, overexploitation of the fishery and habitat destruction are perhaps the most critical. The following maps show the distribution of chinook and silver salmon and steelhead and cutthroat trout in 1900, 1940, and 1980 (Lucoff, 1980). The construction of dams, logging and mining activities, and other forms of environmental degradatiaon, along with fishing pressures, are responsible for the dramatic decrease in range.

ANADROMOUS SPECIES IN CALIFORNIA

Chinook Salmon

Oncorhynchus tschawytscha (Walbaum, 1792) is called the king salmon in California, but other common names include chinook, spring, tyee, blackmouth, jack, and quinnat salmon. The largest spawning populations are found in the Sacramento-San Joaquin River System, but large populations are also found in the Klamath, Smith, and Eel River systems. The construction of dams in the upper Sacramento drainage drastically reduced the available spawning habitat. This species avoids the smaller coastal streams, preferring to spawn in larger tributaries. Adult fish always die after spawning. Eggs hatch in 50-60 days at California temperatures. Most young chinook salmon migrate to sea after 2-4 months, where they usually spend 1-3 years, though they may spend 1-5 years, before returning to their natal stream to spawn. The average weight of the mature chinook salmon is 20 pounds, although some grow to more than 50 pounds.

Chinook are strongly anadromous; self-maintaining, landlocked populations are rare. There are two major runs of chinook in California. The spring run enters freshwater in the spring when melted snow swells the rivers; there they remain for 3-6 months until they spawn in the fall. Spring chinook eggs incubate in the gravel of large tributary streams over the winter months. In the spring they hatch. The juveniles tend to spend a full year in freshwater. The spring chinook run has greatly decreased since the water projects were built in California due to increased water temperature caused by dams which check the natural water flows (Fry, 1979). The fall run does not enter freshwater until the autumn months, when it immediately travels upstream to spawn. The juveniles spend only 2-4 months in freshwater before migrating to the ocean.

Coho Salmon

Oncorhynchus kisutch (Walbaum, 1792) is called either silver or coho salmon. They are common in the northern coastal streams of California and are rare in the Sacramento-San Joaquin River System, although attempts were made to introduce them beginning in 1956; this explains why the 1980 distribution map (Figure A-8) indicates the presence of coho in the Sacramento River, although the 1900 and 1940 maps did not.

Coho spawning habits are similar to those of the chinook although they do prefer smaller tributary streams and start their migration run in the fall. Young coho stay at least one year in freshwater before migrating to the ocean, so they need streams which remain cool during the summer months. Mature coho typically weigh 8-10 pounds.

In the Pacific Ocean, coho have been found from about 100 miles south of the Mexican border north to the Bering sea and south along the Asiatic coast to Japan. Landlocked races are rarely established although they were established in the Great Lakes with resounding success. Coho have been artificially reared with very good results; increases in the catch are largely due to hatchery programs in Oregon and Washington (Fry, 1979).

Steelhead Trout

Salmo gairdneri gairdneri (Richardson, 1836) are usually called "steelhead." They are found in most northern coastal streams in California and also in the Sacramento-San Joaquin River System. Steelhead are "optionally anadromous" in that some adults mature without ever going to sea. Ocean distribution is from northern Baja California north to the Bering Sea and south along the Asiatic coast to Japan. Steelhead do not always die after spawning. Although they may spawn more than once, most steelhead runs include only 10-20% repeat spawners (Behnke, 1979).

Most of the steelhead in California are of a single type referred to as fall run or winter run, depending on when they enter the stream on their spawning run. These fish spawn the same season that they enter the stream. The spring run (or summer run) steelhead has a different migration pattern. They enter the stream during the spring or summer, wait a full season, then spawn the following spring. During the summer dry months, they move far upstream and linger in the cooler deeper waters. Because so much habitat has been lost, spring run steelhead are not abundant.

The young steelhead spends 1-3 years in freshwater before smolting and migrating to the ocean. After 1-3 years in the ocean, they return to spawn in their natal stream, typically at 3-5 years of age. Most steelhead weigh less than 10 pounds at maturity, although larger fish have been taken. They are widespread in California and are the most important anadromous game fish in California (Fry 1979). Although native to western North America, the steelhead has been established worldwide and is now more abundant than ever (Behnke, 1979).

<u>Coastal Cutthroat Trout</u>

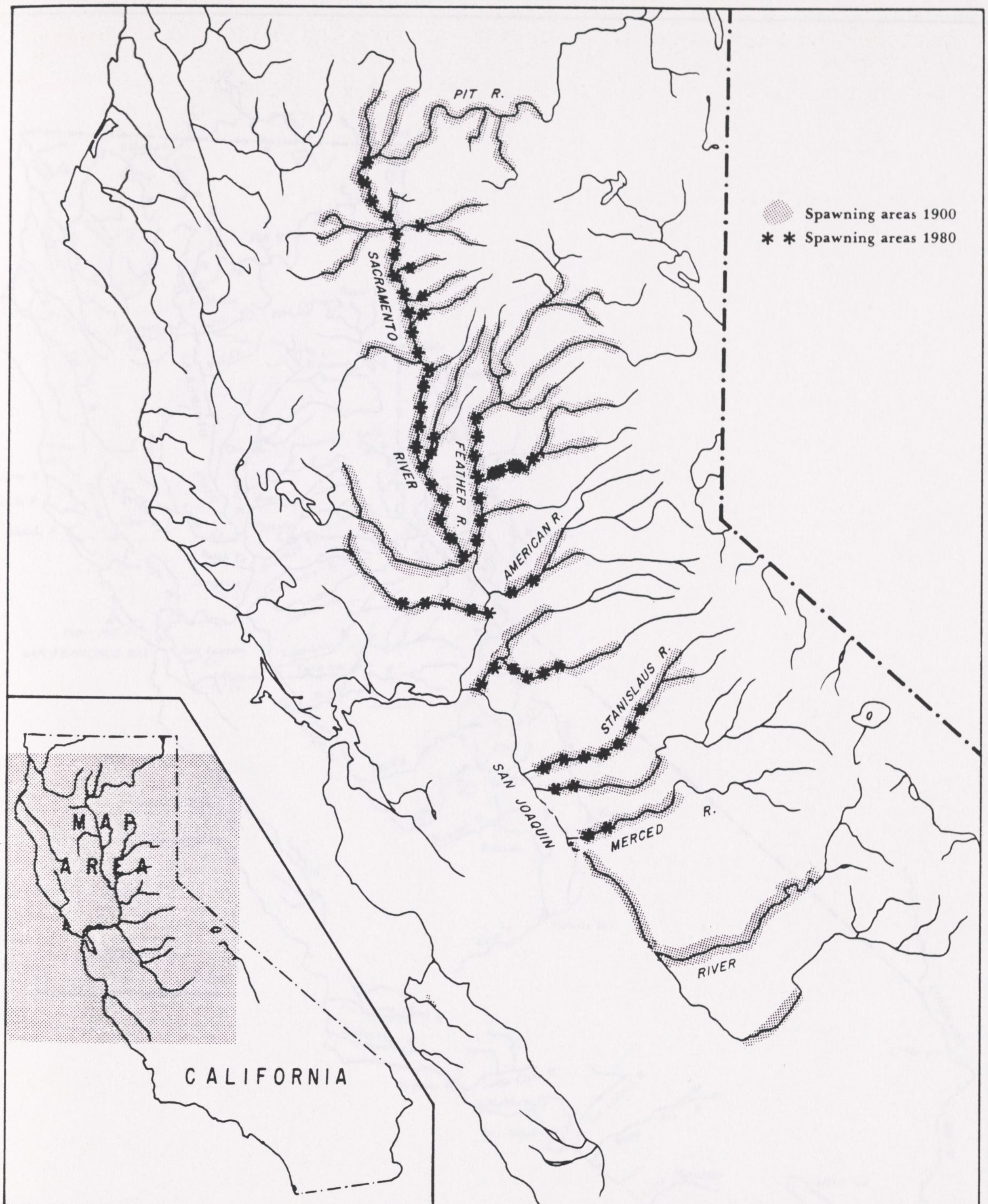
<u>Salmo</u> <u>clarki</u> <u>clarki</u> (Richardson, 1836) is an optionally

anadromous trout which occurs in northwestern California coastal streams. The southern extent of its distribution is the Eel River in California, while the northern extent is the Prince William Sound area of southern Alaska. Coastal cutthroat are usually found within 100 miles of the coast.

Cutthroat usually spawn in late winter or early spring, preferring smaller tributary streams. They remain in freshwater for 2-4 seasons, then migrate into saltwater in late spring or early summer when they are 2-4 years old. They evidently do not travel in the open ocean but rather concentrate in bays, estuaries, and along the coast. They stay at sea for only 25 months but feed intensively there on crustaceans and fish and grow quite rapidly.

The first spawning is at 3-5 years of age. The cutthroat does not always die after spawning and can live up to 10 years.

Although coastal cutthroat and coastal rainbow trout occur together, and hybridization between the two species does sometimes occur, each species maintains its own identity. An historical spatial separation has developed between the two species due to ecological differences. The coastal cutthroat trout prefers smaller tributary streams for spawning whereas the rainbow trout prefers the main channel (Behnke, 1979). The cutthroat has declined in abundance due to environmental degradation, primarily logging, but it is still the most widely distributed and abundant subspecies of Salmo clarki. Relatively few sportfishermen in California catch the coastal cutthroat due to two factors: the fish tend to be of smaller size in California than in Washington and Oregon, and the fish occur in a very small area within the state. Fishing for sea-run cutthroats requires that sportfishermen make the special effort of going to northern estuaries at the right time of year.



SOURCE:
SACRAMENTO-SAN JOAQUIN SALMON (ONCORHYNCHUS TSCHAWYTSCHA) FISHERY OF CALIFORNIA G. H. CLARK. *CALIFORNIA DEPARTMENT OF FISH AND GAME.* NO. 17, 1929. pp. 30-32

Figure A-1. Spawning areas lost to anadromous species between 1900 and 1980. Source: Lucoff, 1980.

Figure A-2. Base map of selected streams in California.
Source: Lucoff, 1980.

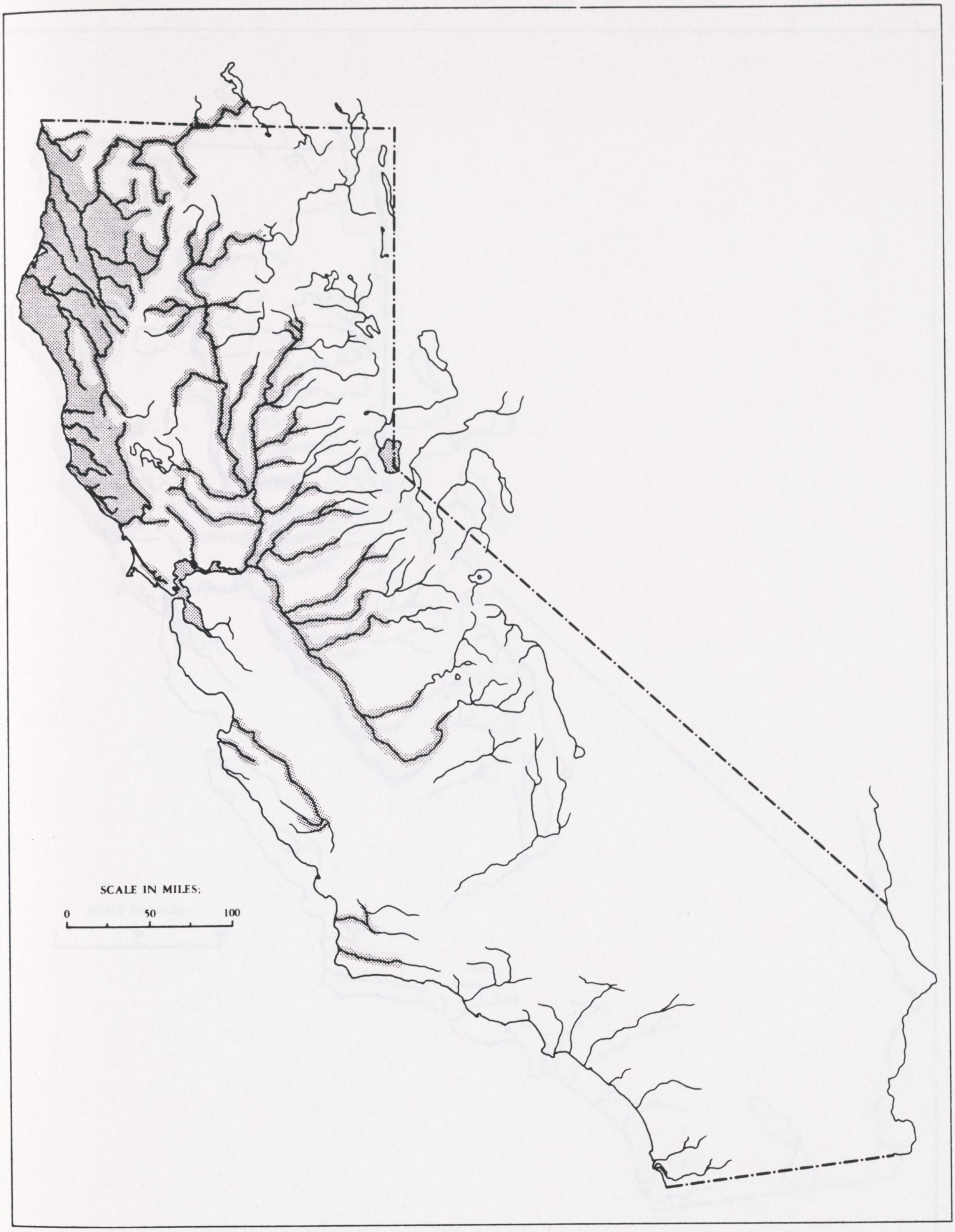


Figure A-3. 1900 distribution of chinook salmon (Oncorhynchus tschawytscha). Source: Lucoff, 1980.

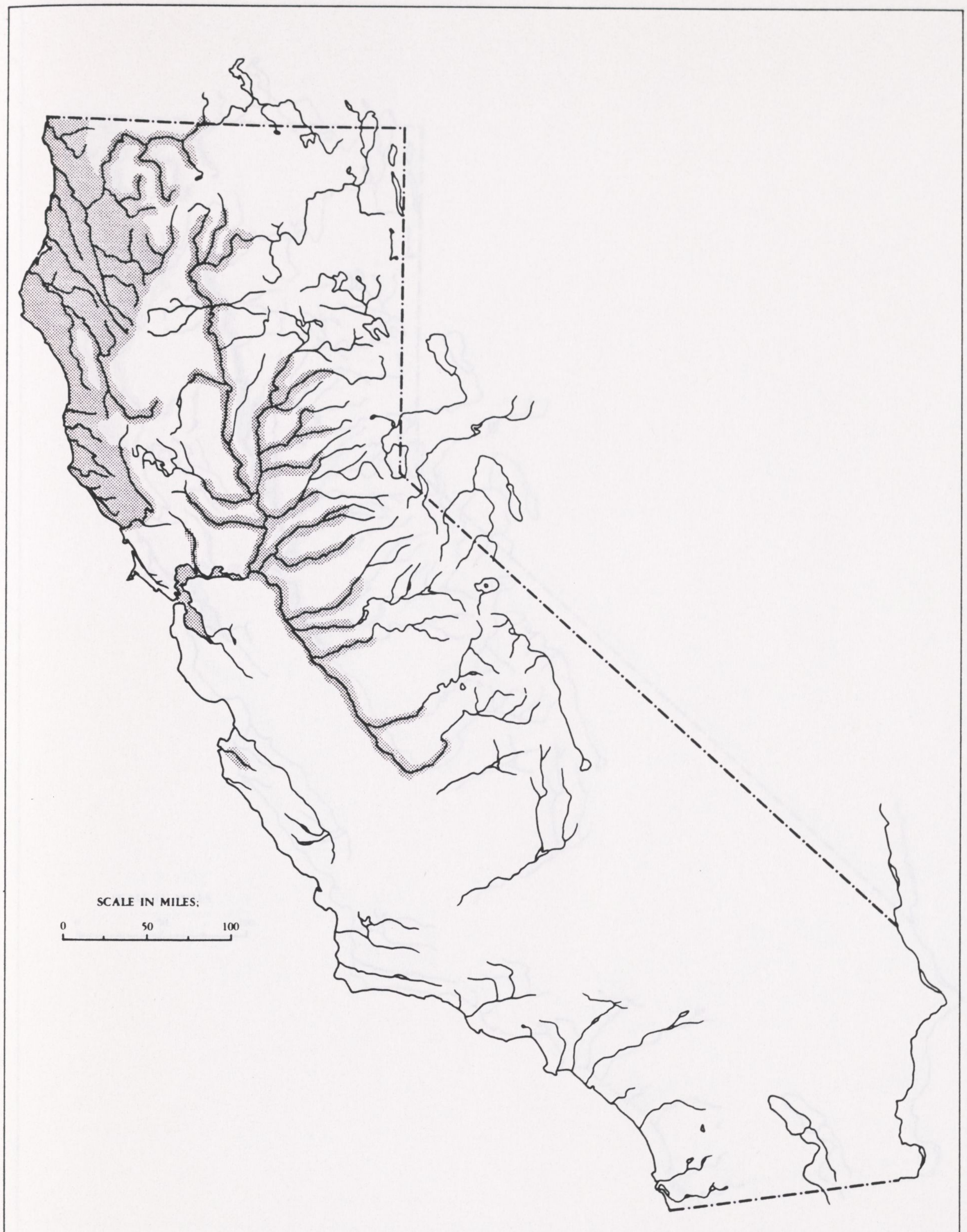


Figure A-4. 1940 distribution of chinook salmon (Oncorhynchus tschawytscha).
Source: Lucoff, 1980.

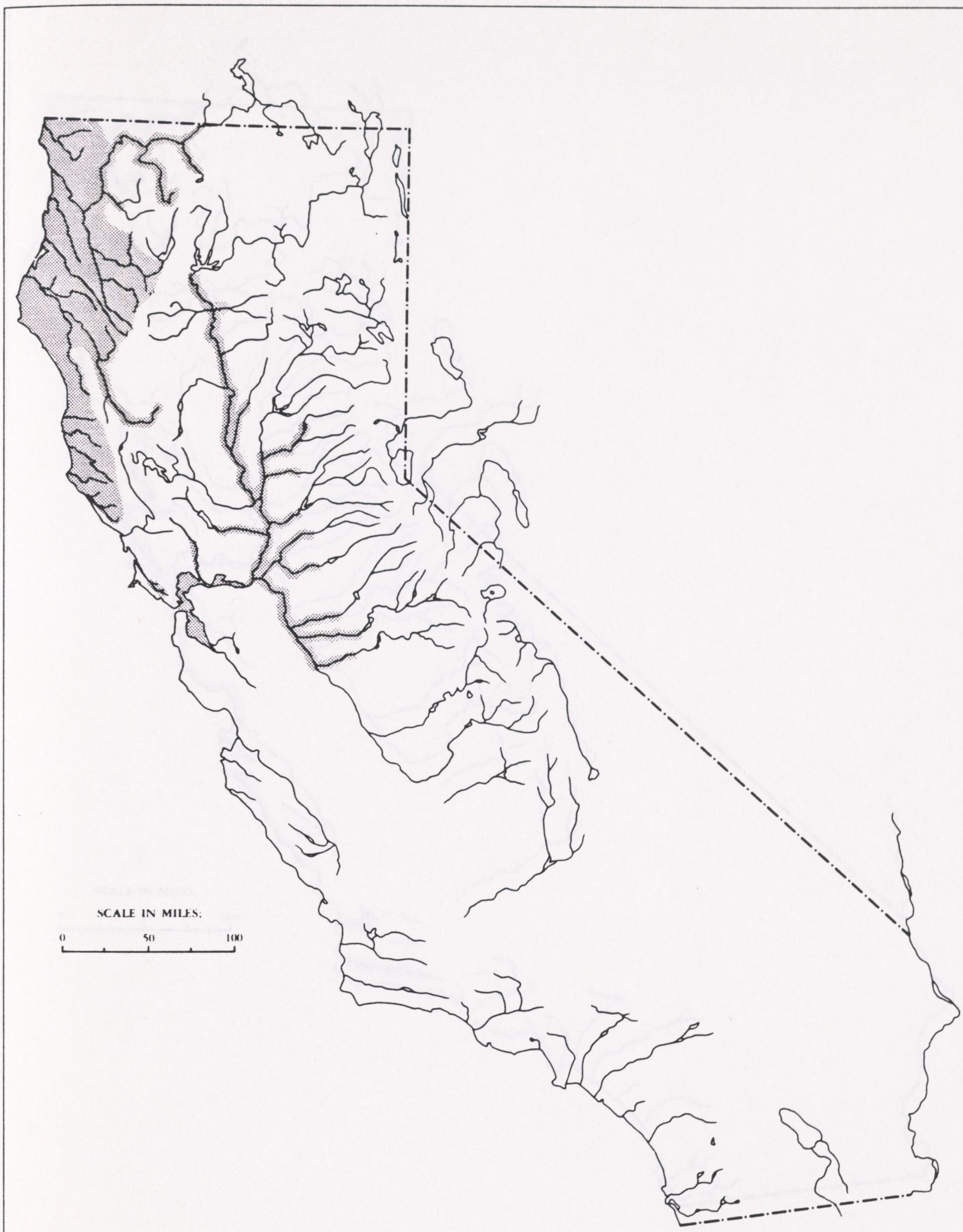


Figure A-5. 1980 distribution of chinook salmon (Oncorhynchus tschawytscha).
Source: Lucoff, 1980.

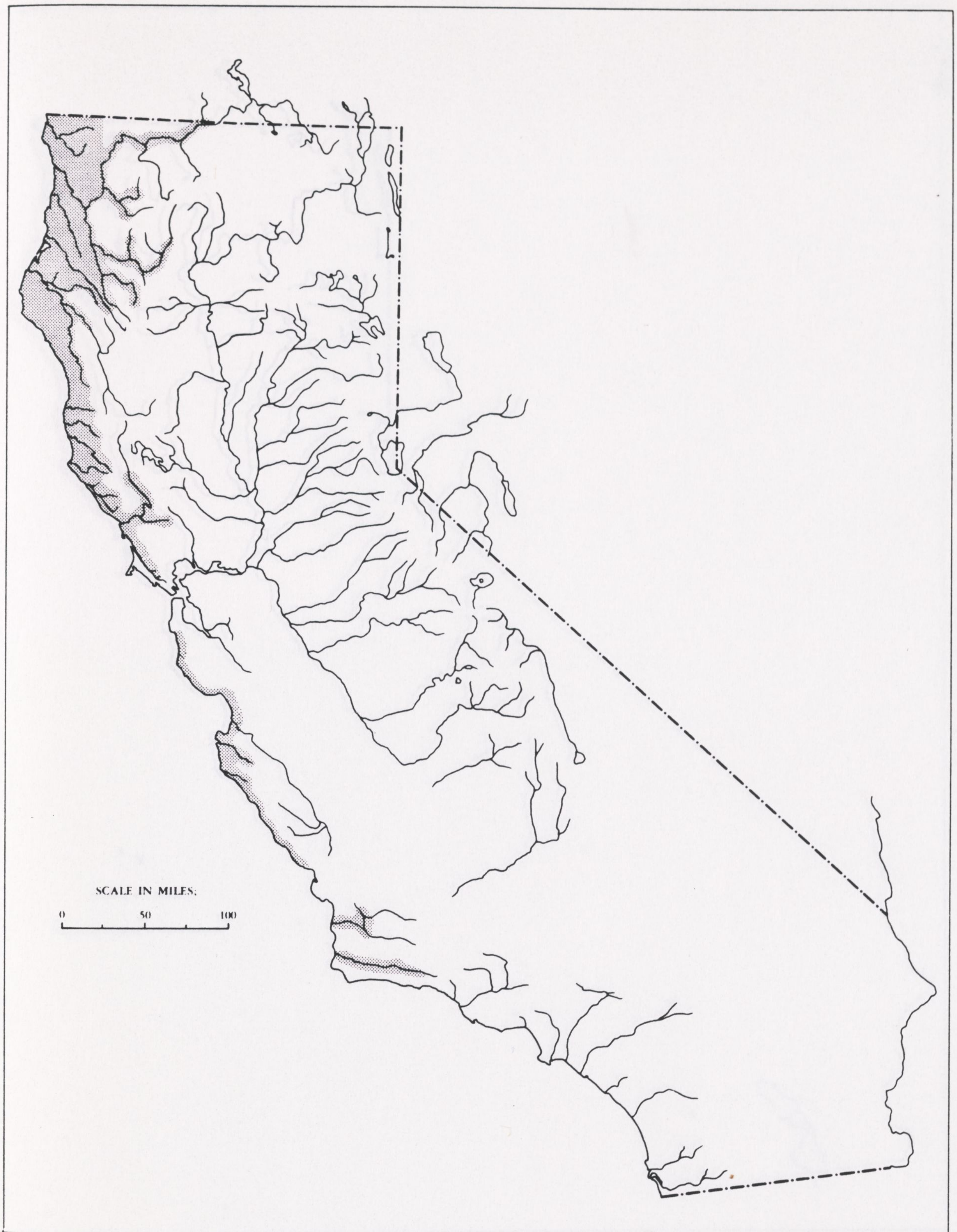


Figure A-6. 1900 distribution of coho salmon (Oncorhynchus kisutch).
Source: Lucoff, 1980.

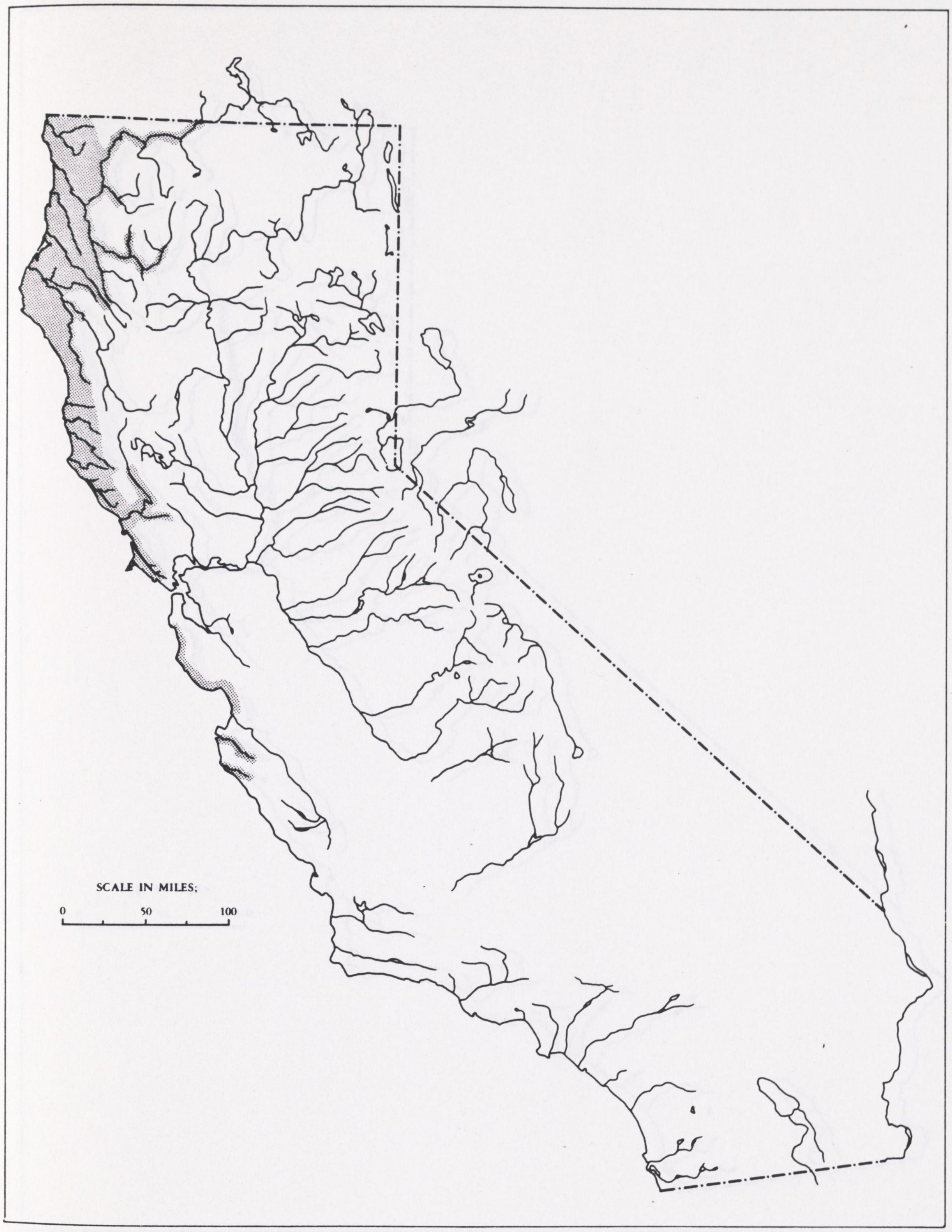


Figure A-7. 1940 distribution of coho salmon (Oncorhynchus kisutch).
Source: Lucoff, 1980.

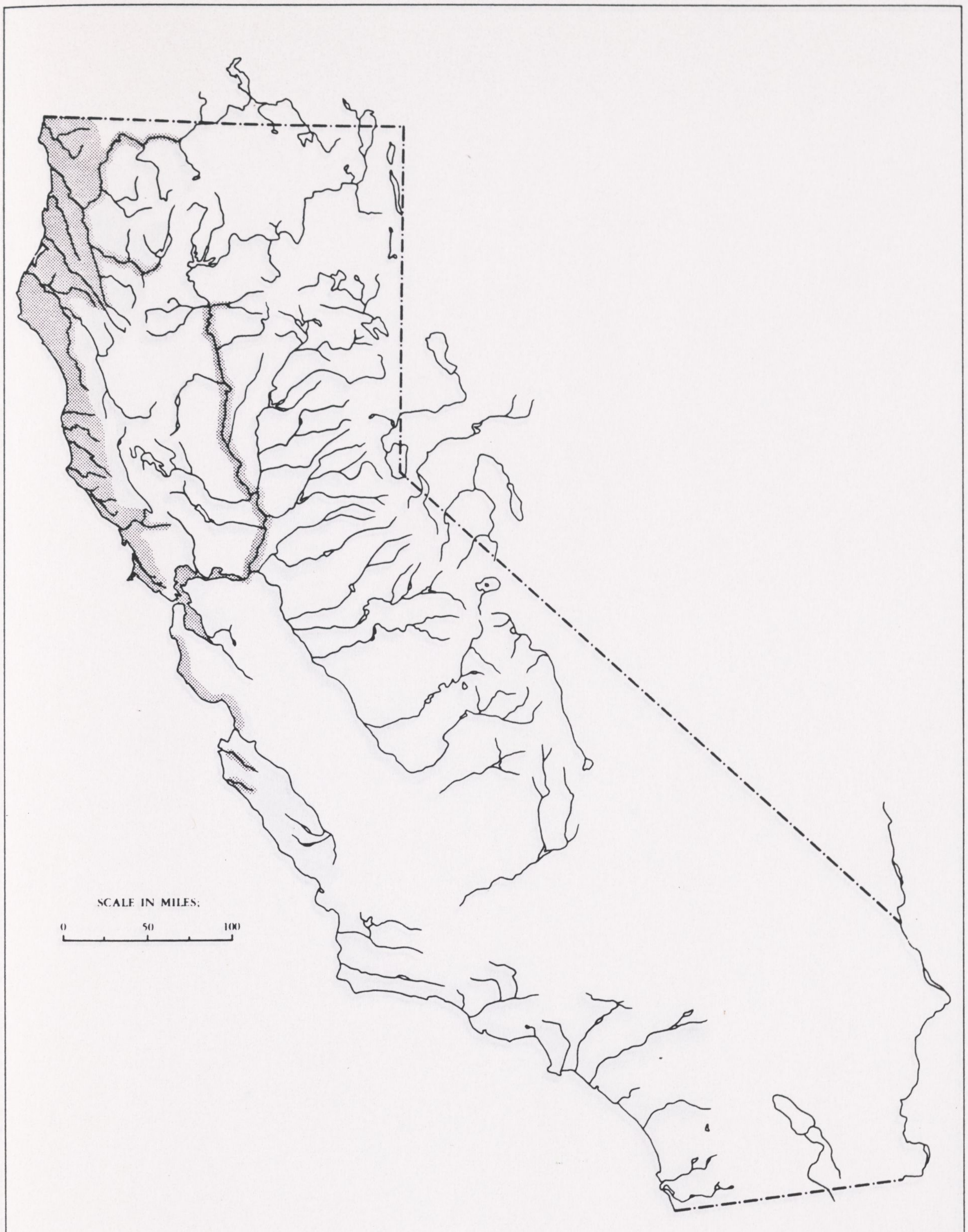


Figure A-8. 1980 distribution of coho salmon (Oncorhynchus kisutch).
Source: Lucoff, 1980.

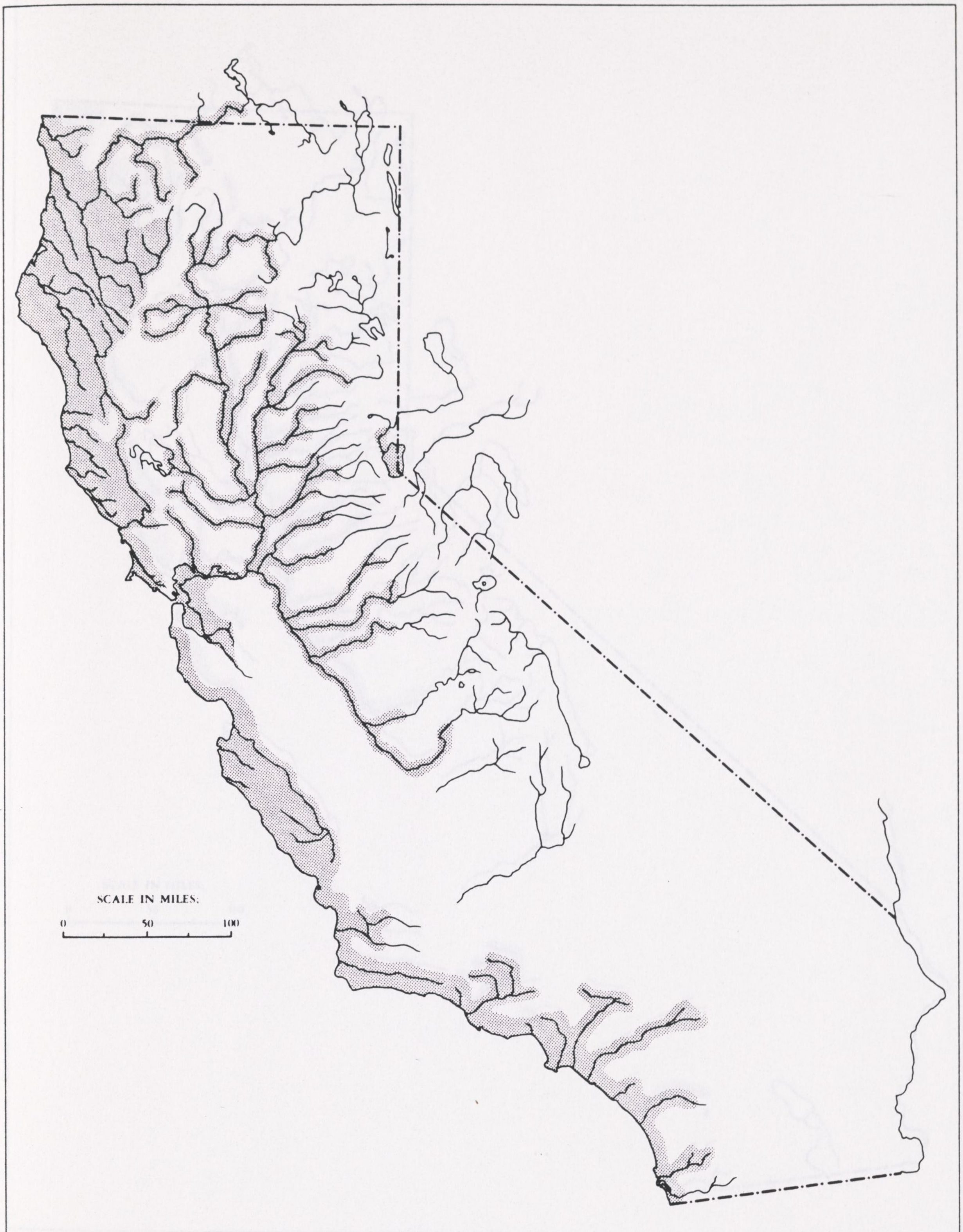


Figure A-9. 1900 distribution of steelhead trout (Salmo gairdneri gairdneri). Source: Lucoff, 1980.

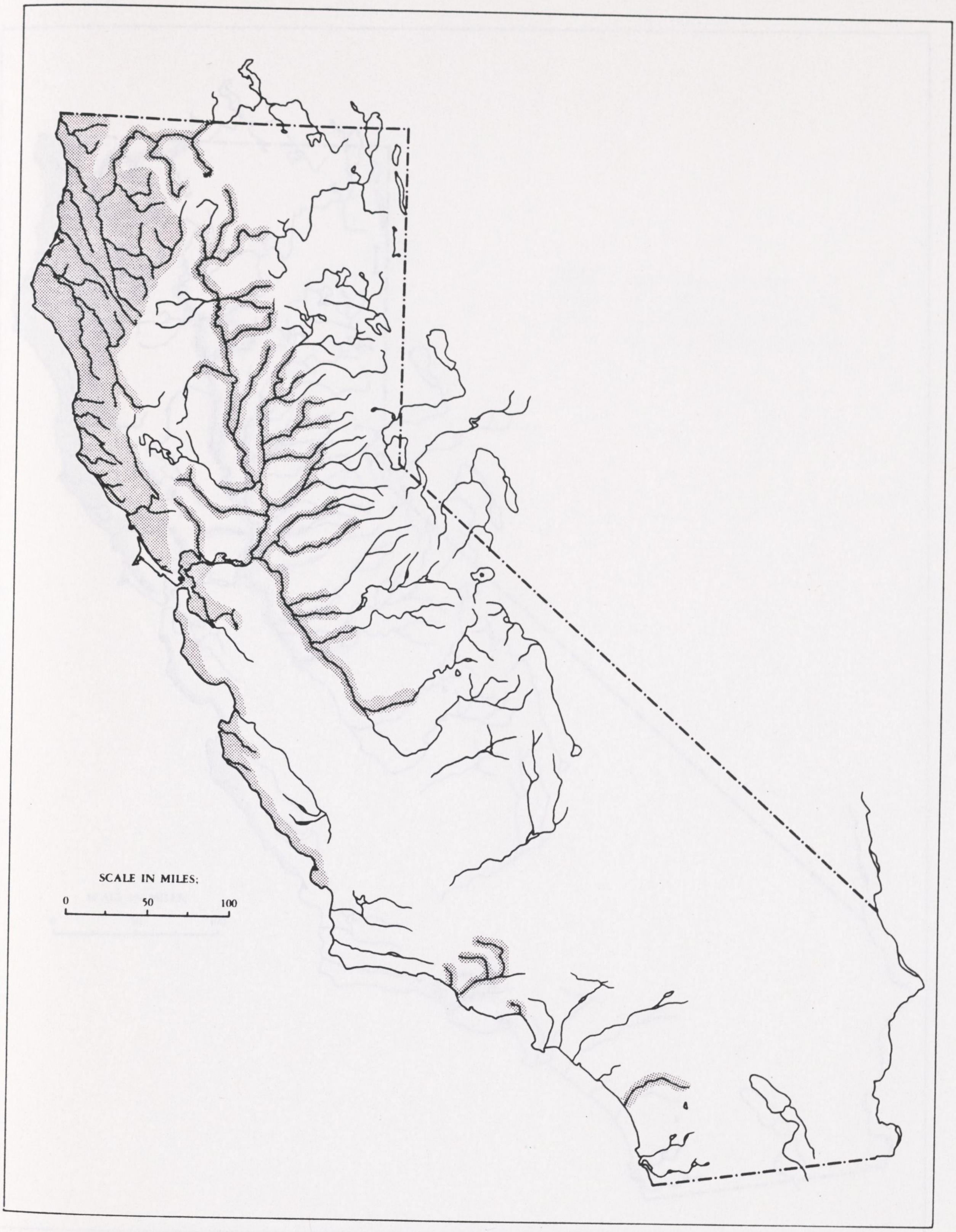


Figure A-10. 1940 distribution of steelhead trout (Salmo gairdneri gairdneri).
Source: Lucoff, 1980.

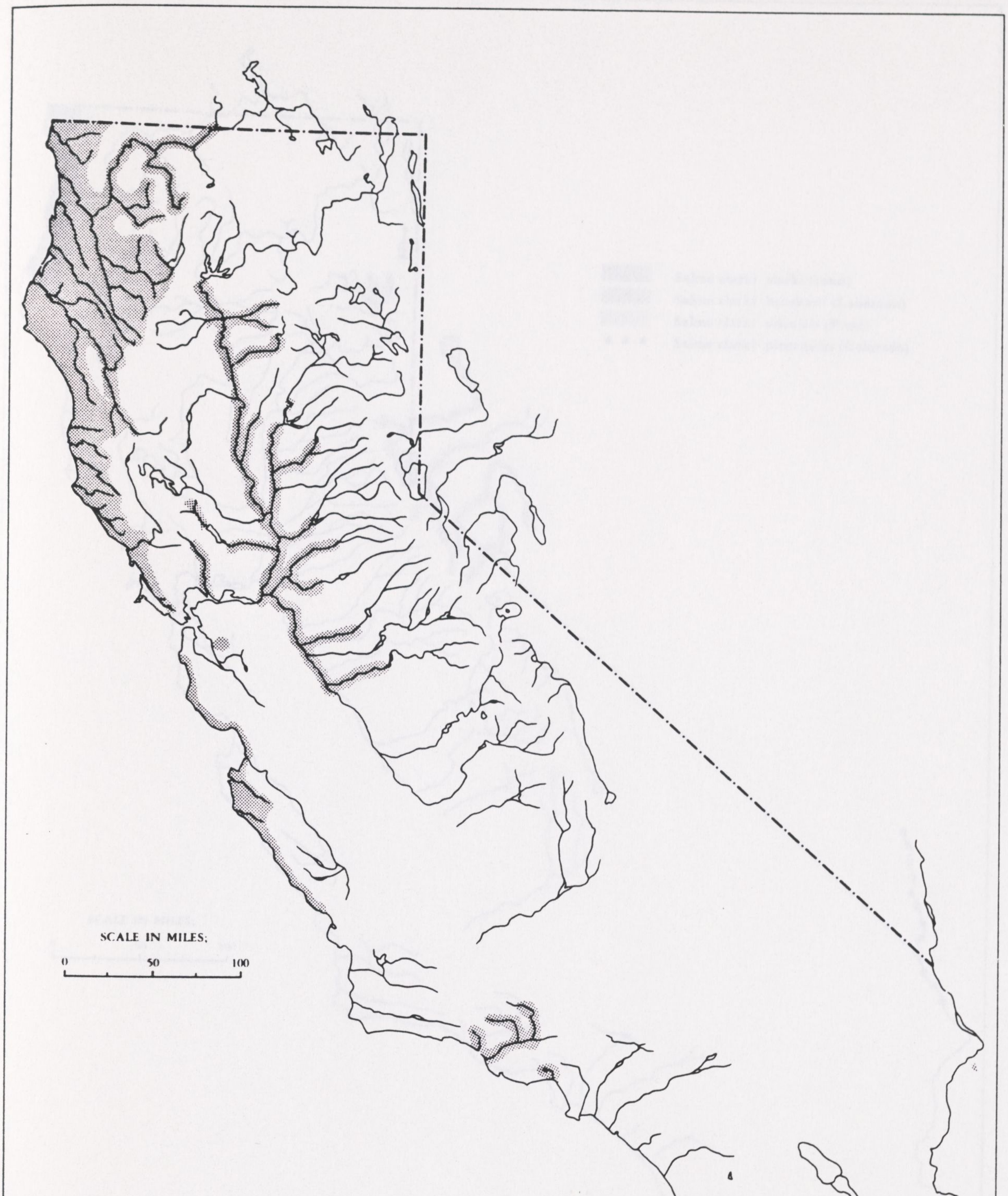


Figure A-11. 1980 distribution of steelhead trout (<u>Salmo</u> <u>gairdneri</u> <u>gairdneri</u>).
Source: Lucoff, 1980.

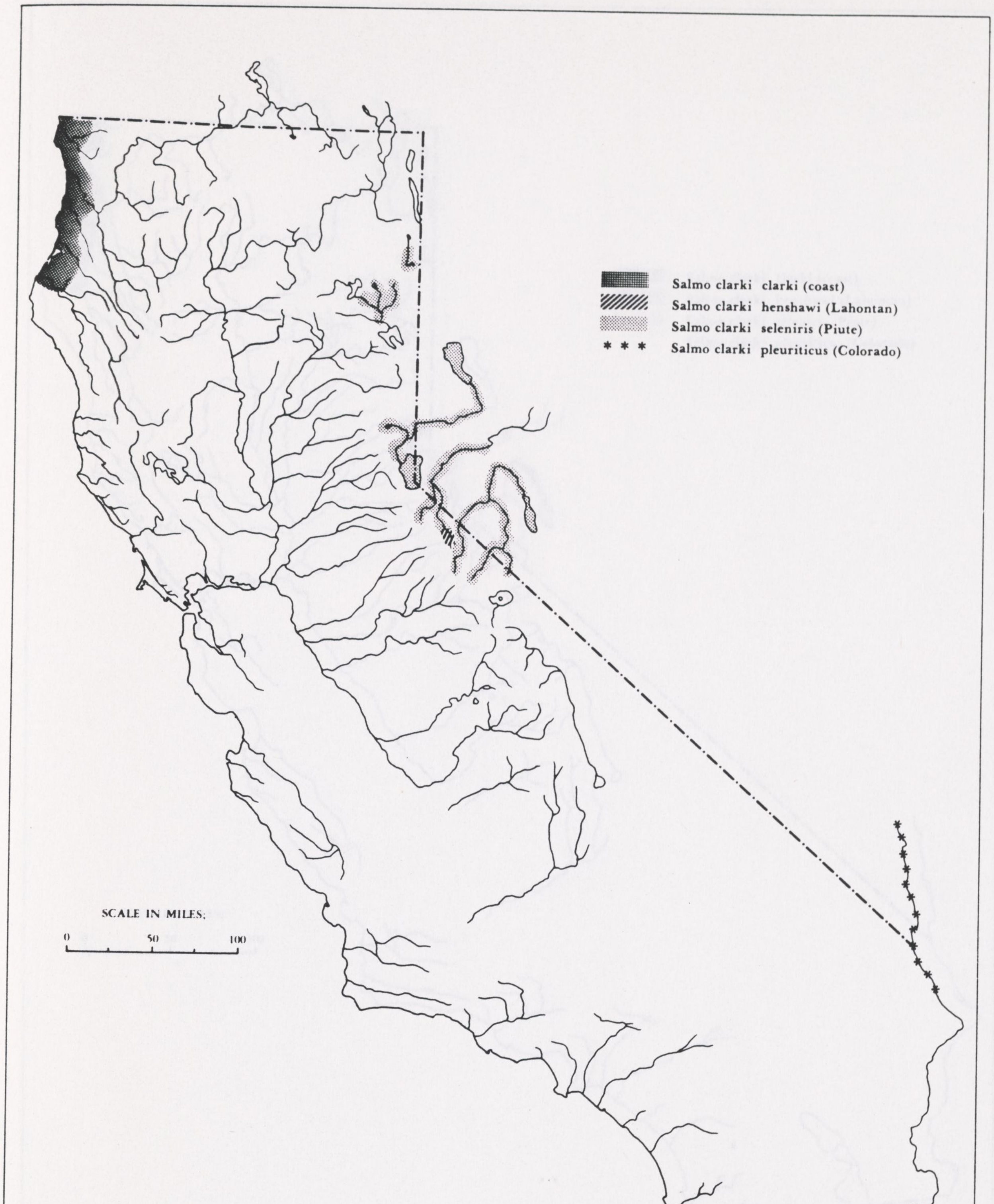


Figure A-12. 1900 distribution of coastal cutthroat trout (Salmo clarki clarki).
Source: Lucoff, 1980.

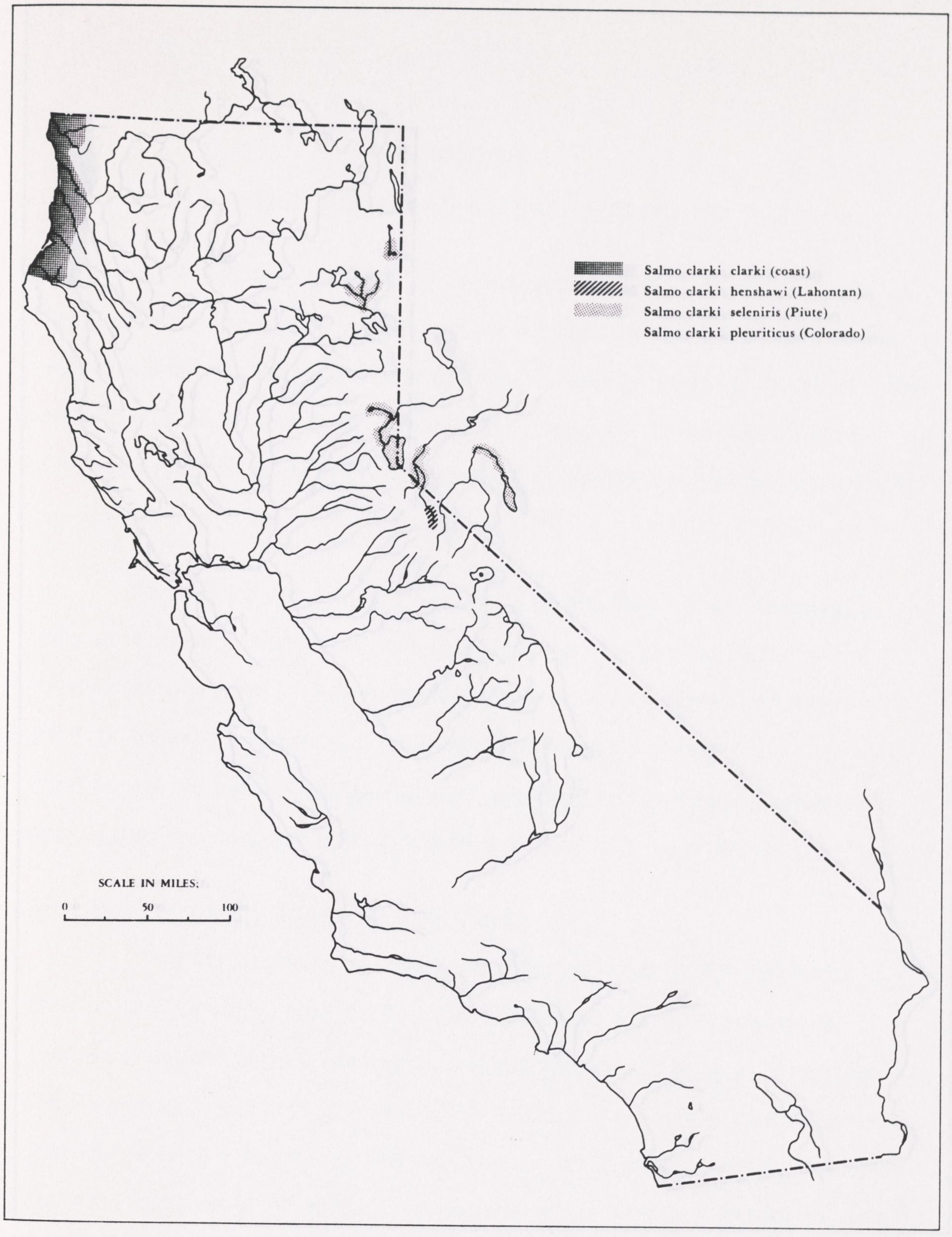


Figure A-13. 1940 distribution of coastal cutthroat trout (Salmo clarki clarki). Source: Lucoff, 1980.

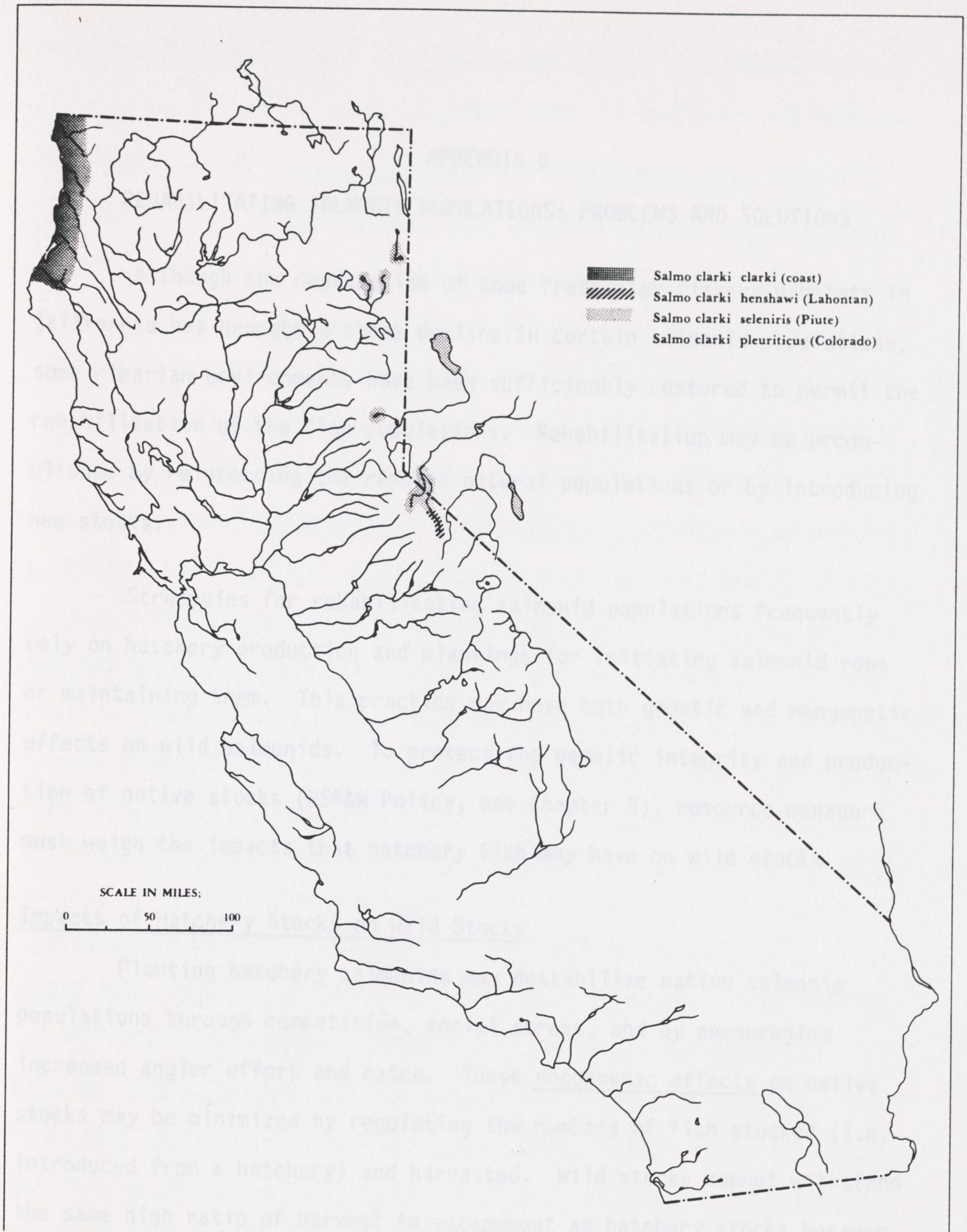


Figure A-14. 1980 distribution of coastal cutthroat trout (<u>Salmo</u> <u>clarki</u> <u>clarki</u>). Source: Lucoff, 1980.

APPENDIX B

REHABILITATING SALMONID POPULATIONS: PROBLEMS AND SOLUTIONS

Although the degradation of some freshwater fishery habitats in California has brought a steep decline in certain salmonid populations, some riparian environments have been sufficiently restored to permit the rehabilitation of the fish populations. Rehabilitation may be accomplished by reinforcing the remnant natural populations or by introducing new stocks.

Strategies for rehabilitating salmonid populations frequently rely on hatchery production and plantings for initiating salmonid runs or maintaining them. This practice may have both genetic and nongenetic effects on wild salmonids. To protect the genetic integrity and production of native stocks (USF&W Policy, see Chapter 5), resource managers must weigh the impacts that hatchery fish may have on wild stocks.

Impacts of Hatchery Stocks on Wild Stocks

Planting hatchery salmonids may destabilize native salmonid populations through competition, social stress, and by encouraging increased angler effort and catch. These nongenetic effects on native stocks may be minimized by regulating the numbers of fish stocked (i.e. introduced from a hatchery) and harvested. Wild stocks cannot withstand the same high ratio of harvest to escapement as hatchery stocks because a larger proportion of the wild salmonid population must return to spawn in order to maintain their abundance.

The genetic effects of interbreeding between hatchery and wild fish stocks may have serious and long-term impacts on the wild stocks. Fish released away from the hatchery may not home accurately to their release site upon maturation and may interbreed with wild stocks. Many published and unpublished studies which document high rates of straying of planted hatchery fish are compiled and reviewed by Lister et al. (1981). Increases in rates of straying and resultant interbreeding between wild and hatchery stocks could reduce genetic divergence and ultimately the genetic fitness of the wild stocks (Hartl, 1980). Reisenbichler and McIntyre (1977) have demonstrated the adverse impacts of interbreeding between hatchery stocks and wild stocks. During the first year of life in streams, offspring of wild fish survived better than the offspring of wild fish crossed with hatchery fish from a common stock. The researchers concluded that natural interbreeding between wild and hatchery fish may reduce the number of naturally produced smolts.

Four strategies are proposed by Nicholas, Reisenbichler, and McIntyre (1978) to minimize genetic contamination of native gene pools by hatchery stocks in streams where resource managers are concerned about maintaining natural production. (1) The introduction of hatchery-bred fish can be discontinued. (2) If this is not feasible, fish can be stocked which are reproductively isolated or which will not survive long enough to interbreed with native stocks. Reproductive isolation may be accomplished by stocking hatchery fish which spawn at different locations or at different times than native stocks. (3) Hatchery fish can also be stocked in geographically restricted regions where they will be harvested before spawning or where conditions prohibit successful spawning or egg hatching.

(4) The last strategy is to stock hatchery trout that are genetically indistinguishable from the native stocks. To achieve sufficient genetic similarity between wild and hatchery stocks, many hatchery practices would have to be modified, and annual introductions of wild germplasm into the hatchery gene pool would have to be considered. This approach would permit management of the harvest of these two stocks as one. Hatchery fish contributing to natural spawning with wild fish would not alter the gene pool while boosting natural production.

Two strategies for sampling wild fish populations for subsequent hatchery production are proposed by Krueger et al. (1981). In these strategies managers attempt to optimize the genetic diversity and adaptability of hatchery stocks to ensure their success in the natural environment. The first strategy is (1) to make collections from wild populations that represent the entire genetic diversity of the species; (b) perform all possible crosses between and within the different sources; and then (c) stock the progeny. This strategy contrasts with selective breeding by maximizing genetic variability. After stocking, natural selection will determine which genetic combinations will survive and naturally reproduce in the newly restored waters. The strategy is best used only with introductions that do not have a chance to interbreed with nearby local native stocks.

The second strategy is to sample populations from waters environmentally similar to those being rehabilitated on the assumption that they may contain preadapted genotypes. This is the best strategy to use if gene flow may occur between introduced fish and local fish populations because the local population from one environment should be little affected by gene flow due to the introduction of individuals from a similar environment with presumably similar genotypes. This strategy is best for rehabilitating many of California's anadromous fisheries, as appreciable straying has been documented from hatchery releases and planting (Frederiksen et al., 1980; Lister et al., 1981).

If the size of a relic native population is insufficient to serve as the only gamete source for fisheries rehabilitation, then it may be necessary to use supplemental germplasm from a nonnative stock. Bams' study (1976) has shown that hybrids of native and nonnative stocks may have dramatically better fitness when compared to introduced nonnative stocks. Bams' (1976) study also indicates the potential benefits from periodic reintroductions of wild salmonid germplasm into hatchery stocks. According to the Trinity River Basin Management Program (Fredriksen et al., 1980), which cites personal communication with Reisenbichler, an annual introduction of about 25% of wild gametes into the hatchery gene pool would probably keep the depressing influence of hybridization on natural spawners to an acceptable minimum. From experience with trout and carp, Moav et al. (1978) suggest that wild stocks may be genetically improved by crossing wild with domesticated breeds that produce heterotic hybrids. (See Glossary.)

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APPENDIX C

USES OF GENETIC DIVERSITY IN SELECTIVE BREEDING

In addition to its real and potential adaptive significance, genetic diversity also has practical applications in selective breeding programs to solve problems facing fisheries managers. This useful aspect of genetic diversity is operationally defined as the genetic resource (see Chapter 2). The genetic resources of anadromous salmonids are already being used effectively in the selective breeding programs of some hatcheries to raise the efficiency and quality of production.

Recent concern about the impacts of hatchery stocks on the harvest and fitness of wild stocks (Appendix B) could bring selective breeding to the forefront of hatchery procedures as a management tool for isolating these two stocks. If hatchery stocks can be bred that have a different time of return to freshwater, a different time to spawn, or a different ocean migration than those of surrounding wild stocks, then the hatchery stocks can be selectively harvested or allowed to reproduce in isolation without adversely impacting the wild stocks.

This appendix reviews the real and potential accomplishment of selective breeding of anadromous salmonids. Traits that have been successfully selected are: time of maturity and spawning, age and size at maturity, survival, i.e., percentages of return, disease resistance, and distribution of ocean catch.

Time of Spawning

Garrison and Rosentreter (1981) performed experiments to determine to what extent many traits can be altered by selective breeding. They carefully compared adult offspring from select and control groups to demonstrate the relative roles of genetics and other factors in the control of these traits. Selective breeding for early and late spawning steelhead on the Alsea River in Oregon by Garrison and Rosentreter (1981) produced families of fish that returned one month earlier and one month later than the control families. Seven years of selection for early spawning steelhead at the Skamania Hatchery in Washington produced fish that returned to spawn two months earlier than their wild counterparts (Ayerst, 1977). Eggs that are taken early in the spawning season can hatch fish that will reach smolt size for release in a single year, thus avoiding another costly year of extended rearing in the hatchery (see Appendix D). At Mad River Hatchery in California, spawning and rearing practices also favor survival of fish that are able to reach smolt size as yearlings by encouraging early spawning adults and the survival of the early-spawned eggs (Boydstun, 1977). These studies indicate that hatchery managers may potentially be able to advance the spawning time of hatchery stocks of anadromous salmonids so as to avoid natural reproduction between hatchery strays and wild stocks.

Size

The size of anadromous salmonids upon return to freshwater can be significantly altered by selective breeding. A significant difference in fork length was observed between selected large versus control (randomly selected) two-salt steelhead of the same brood year (Garrison and Rosentreter, 1981). (A two-salt fish has spent two years in the ocean before returning to freshwater to spawn.) The heritability estimate calculated for large body size in this brook was 0.27. The high value of this index suggests great promise for selective breeding of larger fish which may contribute increased economic returns to ocean fishery and salmon ranching concerns.

Age at Maturity

In addition to directly selecting for size, breeding to select for older age at maturity (delayed maturation and reentry to freshwater) also contributes larger fish to the fishery. This was the objective of hatchery managers at Skamania Hatchery in the State of Washington where they selected only the largest two-salt fish and the few three-salt fish that returned rather than the average one- and two-salt steelhead returns. Presently, a growing percentage of three-salt fish constitute the returns and returning "one-salt fish are practically non-existent" (Ayerst, 1977). With crosses among two-salt steelhead used as a comparison and a control, Garrison and Rosentreter (1981) found that crosses among three-salt steelhead produced proportionately more three-salt returns.

Survival

Survival, as measured by the percentage of returns to the hatchery, has been shown to be significantly different among strains of Atlantic salmon. Greater than 15% of some full sibling groups (families) returned to the hatchery while less than 5% survived in other full sibling groups (Carlin, 1969, from Edwards, 1978). Generally, hatchery fish have been shown to be genetically inferior to native wild stocks in traits affecting survival (Bams, 1976; Helle, 1981). Selective breeding for high survival characteristics in hatchery stocks of coho salmon has recently begun (Hemmingsen, Westgate and Conrad, 1979).

Migration

The behavior patterns of migrating fry have been shown to be adaptations to local environments, and these responses have been shown to be largely under genetic control for sockeye salmon (Raleigh, 1967; Brannon, 1967) and for cutthroat trout (Bowler, 1975). Furthermore, hybrid stock formed by reciprocal crosses of races showing opposite migrating responses to ocean current direction, displayed migrating behavior intermediate to that of donor stocks (Brannon, 1972). Selective breeding may eventually be used to determine the direction and extent of the ocean migrations of hatchery salmonids, thereby isolating hatchery stocks from wild stocks. This might allow separate management of the harvest of wild and hatchery stocks according to their independent escapement needs.

Disease Resistance

The resistance of different stocks of Atlantic salmon to vibrio disease (Gjedrem and Aulstad, 1974) and of sockeye salmon to infectious hematopoietic necrosis (McIntyre and Amend, 1978) has given rise to heritability estimates indicating that selective breeding against susceptibility to these specific diseases is possible. Other studies illustrate the potential for selective breeding by showing that distinct differences in resistance to disease exist among different salmonid populations.

Hatchery strains of chinook salmon from the Columbia River were less susceptible to infection by the parasite Ceratomyxa shasta than hatchery strains from outside this drainage (Zinn et al., 1977). A study of coho salmon of different stocks and transferrin genotypes (genotypes which exhibit different forms of a cellular enzyme, transferrin) showed that a genetic basis exists for bacterial kidney disease resistance but not for resistance to vibriosis (Winters et al., 1980b). Winters et al. do not advise selective breeding for certain transferrin genotypes since the genotypes studied may have different relative resistances to different diseases. Instead, they recommend "maintaining genetic variability in a stock to meet the demands of a variable environment."

[illegible]

hatchery fish have been shown to be genetically [illegible]

stocks in traits affecting survival (Bams, 1976; Hello, 1981).

Selective breeding for high survival characteristics in hatchery stocks of coho salmon has recently begun (Hemmingsen, Westgate and Conrad, 1979).

Migration

The behavior patterns of migration [illegible] have been shown to be adaptations to local environments, and these patterns have been shown to be largely under genetic control for sockeye salmon (Raleigh, 1967; Brannon, 1967) and for cutthroat trout (Bowler, 1975). Hybrid stocks formed by reciprocal crosses of stocks showing opposite migrating responses to ocean current directions displayed migrating behavior intermediate to those of their parents (Brannon, 1972). Selective breeding may eventually be used to determine the direction and extent of the ocean migrations of hatchery salmonids, thereby isolating hatchery stocks from wild stocks. This might allow separate management of the harvest of wild and hatchery stocks according to their independent escapement needs.

Disease Resistance

The resistance of different stocks of Atlantic salmon to vibrio disease (Gjedrem and Aulstad, 1974) and of sockeye salmon to infectious hematopoietic necrosis (McIntyre and Amend, 1978) has given rise to heritability estimates indicating that selective breeding against

APPENDIX D

IMPACTS OF SALMONID CULTURE ON GENETIC DIVERSITY

Effects of Hatchery Practices

Three major hatchery practices are likely to narrow the genetic diversity and precipitate inbreeding of artificially propagated stocks. These practices are (1) the founding event, (2) spawning unequal number of males and females, and (3) the disproportionate use of some segment of the salmon run (i.e., using only the largest fish or the earliest returning fish).

The founding broodstock of a hatchery may be insufficient in variety or number of individuals as a result of inadequate sampling from natural populations. However, according to calculations by Allendorf and Phelps (1980), the founding event is likely to account for only 2% of the loss in genetic variability.

Artificial spawning of unequal numbers of males and females is a common practice in hatcheries. In a manual for salmon ranchers, McNeil (1975) recommends holding only one male for every four females as broodstock, or only one male for every nine females if the broodstock numbers over 1000. This practice is economically attractive because many more surplus fish (males) become available for market, and fewer broodfish need be held in the hatchery to collect the same number of fertilized eggs as one would with spawning procedures that utilized a

1:1 sex ratio. The long-term effects of this practice may, however, reduce yields, since it leads to loss in heterozygosity.

The deliberate or inadvertent use of larger fish or a limited timing scheme in artificial spawning is another contributor to losses in genetic diversity among hatchery stocks. Some hatchery managers have chosen to spawn the earliest returning fish so as to allow more rearing time for their progeny (see Time of Spawning, Appendix C). Accordingly, these offspring can be stocked as yearling smolts, in contrast to the two years of rearing normally required by the offspring of wild fish or late-run hatchery parents (Ayerst, 1977). Since the success of egg-takes (measured by the collection of enough eggs to meet hatchery production goals) is often unreliable, many hatcheries start collecting eggs as soon in the spawning season as they can. If the requisite number of eggs are collected early in the season, late-returning fish may not be included in spawning procedures (Bjornn, 1977).

Genetic Drift Effects on Hatchery Stocks

Using electrophoretic methods, fisheries biologists can detect losses of genetic diversity in hatchery stocks compared with their wild relatives. Allendorf and Phelps (1980) demonstrated that the loss of genetic variation in a hatchery stock of cutthroat trout (Salmo clarki) was due to genetic drift. Genetic drift is defined as any change, either directed ("steady drift") or undirected ("random drift"), in gene frequency in a population (Rieger et al., 1968). Genetic drift, in the case of this hatchery stock, resulted in three measurable changes: (1) a reduction in the proportion of polymorphic loci, (2) a reduction in the number of alleles per locus, and (3) a reduction in average heterozygosity. Allendorf and Phelps (1980) suggest that such reductions in genetic variability may increase incidences of inbreeding, which is likely to contribute to lowered resistance to disease. In Sweden, inadvertent genetic changes and inbreeding were also identified in three hatchery stocks of brown trout that were compared electrophoretically to two corresponding natural populations (Ryman and Stahl, 1980).

Effects of Inbreeding on Hatchery Stocks

Studies have clearly demonstrated the harmful effects attributable to inbreeding (depression), such as reductions in development, growth rate, and survival. Aulstad et al. (1972) and Kincaid (1976a and 1976b) have shown reduced egg hatchings and fry survival from inbred domesticated strains of trout. Gall and Gross (1978) also show that poor fertility and small egg size were caused by inbreeding in rainbow trout. Gjedrem (1976) has estimated that every 10% of inbreeding is responsible for a 5-10% depression in growth rate in rainbow trout. Ryman (1970) reported lower survival, as measured by recapture frequency, of inbred families of Atlantic salmon that were compared to noninbred families.

Comparative Fitness of Hatchery and Wild Stocks

In stocks recently adapted to artificial culture, where inbreeding should have little or no influence, the genetic effects of artificial rearing environments can still be demonstrated. Artificially reared salmonids are genetically different from wild salmonids with respect to traits likely to affect survival in natural habitats. When compared to wild stocks, hatchery-reared salmonids may be less wary (Vincent, 1960; Moyle, 1969); may have higher mortality (Vincent, 1960; Flick and Webster, 1976; Reisenbichler and McIntyre, 1977); and less disease resistance (Flick and Webster, 1964). Reisenbichler and McIntyre (1977) have provided the most convincing evidence of genetic changes due to hatchery practices and the hatchery environment. They compared survival of wild fish to hatchery fish of the same stock. During the first year of life in streams, offspring of wild fish survived better than offspring of hatchery fish. Thus current hatchery practices produce fish that are less well-adapted to the natural environment than their wild congeners.

APPENDIX E

EX SITU DISTRIBUTION OF ANADROMOUS SALMONIDS

Ex situ distribution (i.e. outside of the native range) of four species of Eastern Pacific anadromous salmonids is depicted in Tables E-1, E-2, E-3, and E-4. The exact origin of most salmonids introduced to waters outside of their native range is poorly documented in the literature reviewed. Many introductions fail and only a few anadromous salmonid populations are self-sustaining *ex situ*.

Chinook Salmon

The introduction of chinook salmon to New Zealand from the McCloud River in California is probably the most successful example of *ex situ* establishment among anadromous salmonids and freshwater salmonids, too (Table E-1). Self-perpetuating chinook stocks now support a sport and commercial fishery in New Zealand. Despite many attempts to acclimate chinook salmon to a freshwater life cycle in the western United States and *ex situ*, New Zealand lakes have the world's only self-perpetuating freshwater stocks of chinook. The McCloud River chinook stock is now extinct in its native waters due to damming and to filling of the Shasta Reservoir. However, reintroduction of the freshwater strain of chinook from New Zealand to California might restore a salmon sport fishery in landlocked lakes and rivers like the McCloud.

Table E-1

<u>EX</u> <u>SITU</u> DISTRIBUTION OF CHINOOK SALMON

Place of Successful Introductions[1]	Native Origin	Date of Introductions	Established in Natural Waters?	Purpose of Introductions	References
Australia	McCloud River, Calif.[2]	1877 and early 1900s	Unspecified[3]	Sport fishing	FAO, 1981
Australia	Battle Creek, Calif.[4]	1963	Unspecified[3]	Sport fishing	Hatchery records[2]
Australia	Western U.S.	1967	Established[5]	Sport fishing	FAO, 1981
Chile	Western U.S.	early 1900s and currently	Established	Ocean ranching	McNeil & Thorpe, 1981
Great Lakes	Western U.S.	1960s	Established	Sport fishing	Scott, 1976
New Zealand	McCloud River, California	1876-1880	Not established	Unspecified[3]	FAO, 1981
New Zealand	McCloud River, California	1901-1907	Established[6]	Sport fishing and ocean ranching[7]	McNeil and Thorpe, 1981 Hardy, 1972

[1]Unsuccessful introductions were made to Denmark, Germany, and Argentina (FAO, 1981), and to Brazil (Joyner, 1980).

[2]California salmon eggs shipped from New Zealand.

[3]Not stated in reference.

[4]Shipment of 50,000 winter run chinook eggs from Coleman National Fish Hatchery.

[5]Non-breeding populations confined to two lakes in Victoria are maintained by hatchery production.

[6]Anadromous and resident freshwater stocks established. These are the only recorded self-perpetuating freshwater stocks in the world (Ricker, 1972).

[7]Permits have been issued for six nonpublic ocean ranching operations. Two pilot facilities operate now. Two public hatcheries operate and provide broodstock for ocean ranching (Thorpe, 1980; McNeil and Thorpe, 1981).

Chinook salmon of unspecified origin have been stocked in Australian and Chilean waters. Two lacustrine populations are maintained by a hatchery in Australia. Recently, private commercial interests have tried to establish anadromous chinook runs in Chile, and if they are successful there may be future salmon ranching and commercial fishing in Chilean waters.

Coho Salmon

There are only two examples of successful ex situ introductions of self-perpetuating stocks of coho salmon (Table E-2). Coho salmon from the Columbia River have been successfully stocked in the Great Lakes and their tributaries (Ricker, 1972). Natural reproduction of these stocks, supplemented by hatchery releases, supports a sport fishery. Records indicate introduction of coho salmon to Chilean streams by private interests may be successful since anadromous migration was completed by these stocks in 1980 (FAO, 1981). Recently, research has been conducted on the acclimatization of coho salmon to Atlantic coastal waters for possible future introductions (Joyner and Mahnken, 1975).

Many introductions have not been successful in natural or cultured waters, but the literature shows there is or has been aquaculture of coho in Cyprus, France, Germany, and Italy (FAO, 1981).

Steelhead Trout

Since the 1870s, when the first shipment of eggs left the first egg-taking station and hatchery on the McCloud River in California,

Table E-2

EX SITU DISTRIBUTION OF COHO SALMON

Place of Successful Introductions[1]	Native Origin	Date of Introductions	Established in Natural Waters?	Purpose of Introductions	References
Chile	Baker River, Wash.	1970s	Probably[2]	Ocean ranching	Joyner, 1890
Cyprus	Canada	1974	Not established	Aquaculture[3]	FAO, 1981
France	Western U.S.	1974	Unspecified[4]	Aquaculture[3]	Harache and Novotny, 1976
France	Western U.S.	1974	Unknown[5]	Accidental release from fish farm	FAO, 1981
Germany, Fed. Repub.	Western U.S.	1974	Unknown[5]	Sport fishing	FAO, 1981
Great Lakes[6]	Columbia River, Oregon & Washington	1964	Established	Sport fishing	Scott, 1976
Italy	Western U.S.	1973	Not	Aquaculture[3,7]	FAO, 1981

[1] Unsuccessful introductions were made to Argentina (Joyner, 1980) and Korea (Atkinson et al., 1973). Researchers are currently trying to acclimate coho salmon to the Atlantic coast of the U.S. and Canada (Joyner and Mahnken, 1975).

[2] Coho stocked in Chilean waters by Union Carbide Corp. A few juveniles completed anadromous migration in 1980, but it is too early to judge success (Joyner, 1980; FAO, 1981).

[3] Aquaculture is defined here as culture in confined waters (i.e., lakes, ponds, impoundments, raceways).

[4] Not stated in reference.

[5] Not known to reference.

[6] First stocked in tributary of Lake Superior (Ricker, 1972).

[7] Commercially unsuccessful so far (FAO, 1981).

rainbow trout have been introduced from its native range on the eastern Pacific seaboard to every continent except Antarctica (MacCrimmon, 1971). Of the two varieties of rainbow trout (anadromous and nonmigratory), introductions of nonmigratory trout have been much more successful. Most transplants of steelhead anadromous rainbow trout have either failed or introduced freshwater trout which have residualized, i.e., lost their original sea-going behavior and physiology.

Transplantations of steelhead trout have led to the establishment of <u>ex situ</u> anadromous runs in only two recorded countries (Table E-3), according to existing records. Repeated introductions between 1925 and 1965 have produced a small steelhead run on Prince Edward Island, Canada (MacCrimmon, 1971). A program initiated by the U.S.S.R. in 1965 successfully acclimated steelhead from the western U.S. to river basins entering the Black Sea and the Caspian Sea (McNeil, 1976; Dorosher, personal communication, 1982).

In 1883, the first successful introduction of steelhead trout was recorded from Sonoma Creek, California to lakes and rivers in New Zealand (Scott, Hewitson and Fraser, 1978). This stock has become residualized; all rainbow trout in New Zealand today are believed to have descended from this stock. Other smaller, less successful, steelhead introductions may have come from the McCloud and Shasta Rivers in California (Scott, Hewitt and Fraser, 1978). The exact origin and fate of other steelhead introductions to countries such as Argentina, Germany and Japan is unknown (MacCrimmon, 1971).

Table E-3

EX SITU DISTRIBUTION OF STEELHEAD TROUT

Place of Successful Introductions	Native Origin	Date of Introductions	Established in Natural Waters?	Purpose of Introductions	References
Argentina	Western U.S.	1904	Unknown[1]	Unspecified[2]	MacCrimmon, 1971
Canada[3]	Western Canada or U.S.	1925-1965	Established[4]	Unspecified[2]	MacCrimmon, 1971
Germany	California	1896, 1898, and 1902	Unknown[1]	Unspecified[2]	MacCrimmon, 1971
Japan[5]	California	1894, 1896	Unknown[1]	Unspecified[2]	MacCrimmon, 1971
New Zealand	Sonoma Creek, Calif.	1883	Established[6]	Sport fishing	Scott, Hewitson, and Fraser, 1978
New Zealand	McCloud River and Shasta River, Calif.	1890s	Unknown[1]	Sport fishing	Scott, Hewitson, and Fraser, 1978
U.S.S.R.[7]	Columbia River, Oregon and Dworshak Hatchery, Idaho	1965	Established[4]	Unspecified[2]	McNeil, 1976
U.S.S.R.[8]	Columbia River, Oregon and Dworshak Hatchery, Idaho	1973	Established[4]	Unspecified[2]	Doroshev, 1982, personal communication

[1]Not known to reference; may have become established as freshwater resident (i.e., nonanadromous trout).
[2]Not stated in reference.
[3]Prince Edward Island in eastern Canada.
[4]Small anadromous population.
[5]Lake Mashu, and rivers on Hokkaido Island.
[6]This stock has residualized, i.e., fish reside in freshwater, and they are no longer anadromous.
[7]Black Sea.
[8]Caspian Sea; fish transplanted from Black Sea.

Cutthroat Trout

There are recorded introductions of cutthroat trout to Denmark and Cyprus for aquacultural purposes (Table E-4), thus they are unlikely to be anadromous. The origin of these introductions is not precisely known (FAO, 1981). — poorly dn

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Table E-4

EX SITU DISTRIBUTION OF CUTTHROAT TROUT

Place of Successful Introductions	Native Origin	Date of Introductions	Established in Natural Waters?	Purpose of Introductions	References
Cyprus	Western U.S.	1980	Not established	Aquaculture and sport fishing	FAO, 1981
Denmark	Western U.S.	1962	Not established	Aquaculture[2]	FAO, 1981
Sweden	Western U.S.	1960s	Not established	Unspecified[3]	Nilsson, 1971

[1]Fish are maintained in one experimental station and stocked in one impoundment. Not anadromous trout.

[2]Fish are maintained in one trout farm where production did not justify expectations and almost ceased. Not anadromous trout.

[3]"A couple" of stocks are maintained. Not anadromous trout.

APPENDIX F

GERMPLASM INVENTORY FOR SALMONIDS IN CALIFORNIA

Conducting an inventory of native and transplanted anadromous salmonid germplasm in California is a first step toward better fisheries management (see Findings and Recommendations, Chapter 6). Accordingly, this appendix briefly documents some of the more important stock transplants in the coastal rivers and in the Sacramento River drainage.

COASTAL STOCKS IN THE SACRAMENTO RIVER

Early records of salmonids transferred from northern California coastal rivers to the Sacramento River could not be completely gathered for this assessment because of time constraints. However, some indication of the volume and frequency of transfers can be inferred from records of transplanted chinook salmon raised from eggs taken at Klamathon Station from 1920 to 1957 (Earl Lietritz, CDFG unpublished records). Forty-nine million chinook salmon fry from these Klamath River eggs were planted on nine occasions by Mt. Shasta Hatchery staff into the Sacramento River until 1937, when this practice stopped. Other early records show that 1.5 million spring chinook eggs and 1.1 million steelhead eggs were shipped from Butte Falls, Oregon, to Coleman Hatchery on the Upper Sacramento in 1941.

Recent hatchery records show that many anadromous salmonids were transplanted from the coastal rivers to the Sacramento River and its

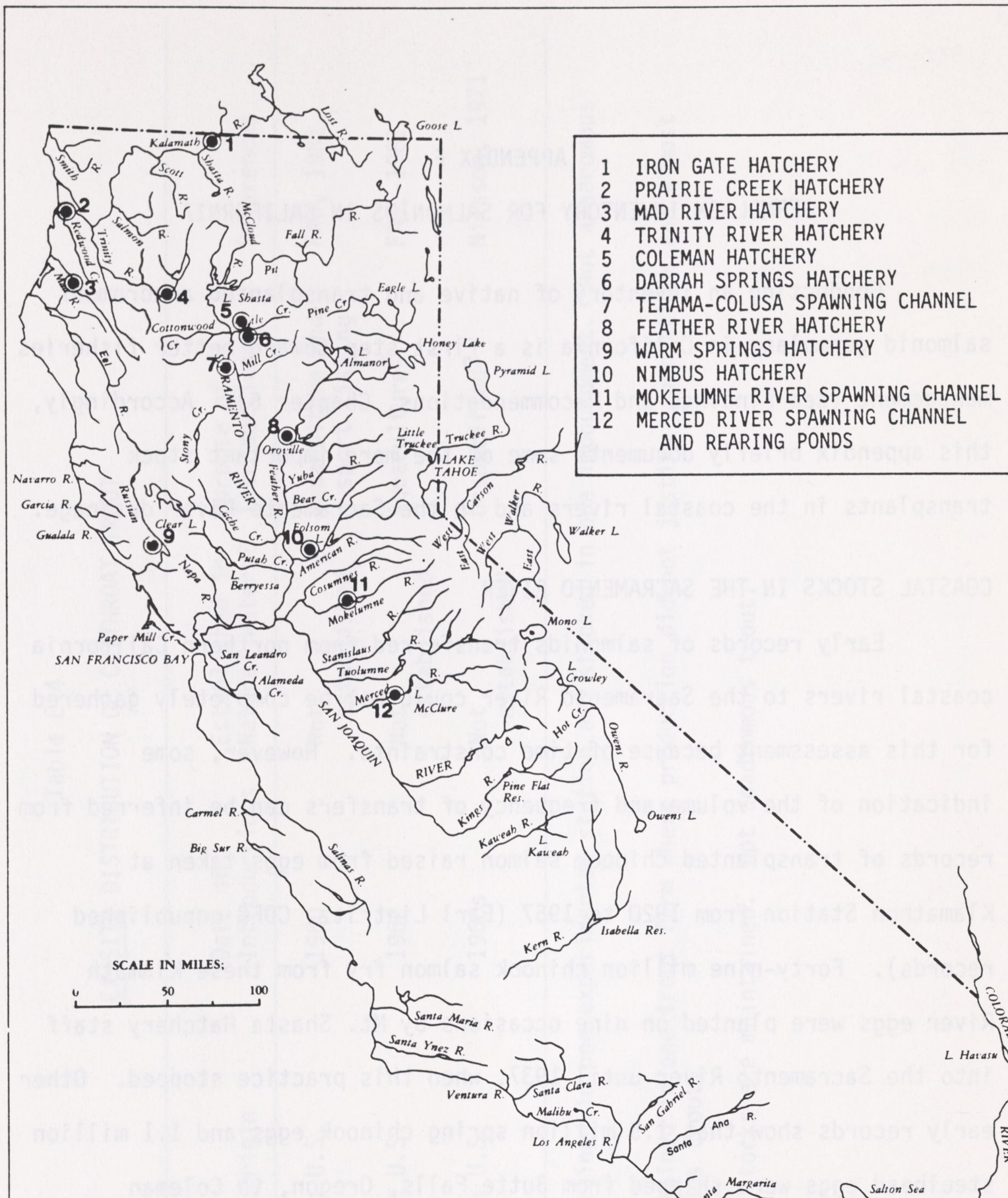

Figure F-1. Artificial propagation facilities in California.
Source: Feinberg and Morgan, 1980; Robinson, 1980; Base Map: Lucoff, 1980.

tributaries. These transplants were made in response to shrinking numbers of adult returns, paralleled by the smaller numbers of eggs taken at Sacramento River hatcheries because of the drought in the mid 1970s. During this period chinook salmon from Mad River Hatchery were planted in the Sacramento River below Red Bluff Diversion Dam, while unmarked chinook salmon fry of a Trinity River strain which were raised at Mad River Hatchery but infected with IHN were released into Battle Creek at Coleman Hatchery. These infected fish were released in the Sacramento River drainage where the disease had already spread rather than planted where they could spread the disease to many uncontaminated salmonid stocks in the North Coast rivers.

Steelhead transplants from coastal rivers to inland rivers were often employed to maintain hatchery production on the Sacramento River during the dry years of the 1970s. Untagged steelhead from Mad River Hatchery were planted in sizable lots at Red Bluff Diversion Dam and Redding on the main stem of the Sacramento River, in the Yuba River, and in small numbers at the Tehama-Colusa canal (Coleman Hatchery records). Mad River Hatchery steelhead eggs also went to Nimbus and Feather River hatcheries, and steelhead fingerlings from Iron Gate Hatchery on the Klamath River were planted at Feature River Hatchery.

Repeated unsuccessful attempts have been made to transplant coho salmon to the Sacramento River from coastal rivers where they naturally spawn. Starting in 1956, coho fry were stocked in some tributaries of the upper Sacramento River such as Mill Creek. In 1967, coho eggs from Eagle Creek, Oregon, produced 390,000 fry at Coleman Hatchery which were released into the Sacramento River. Since 1975, coho salmon eggs from Alsea River in Oregon, Green River in Washington, and Noyo River in California have been raised, and fry have been released from Merced River Fish Facility.

UPPER SACRAMENTO RIVER INVENTORY

A particular effort was made in this assessment to gather records from Coleman National Fish Hatchery and the California Department of Fish and Game Region I Office in order to document the history of fish transplants and possible transfer of stocks into and within the upper Sacramento River drainage. Aside from the aforementioned introductions of coastal salmonid stocks, fish transplanted from the lower Sacramento River are the most likely source of potential genetic introgression, disintegration of stock identity, and homogenization of the adaptive characteristics of upper Sacramento River stocks.

Records back to the 1940s show that most egg and fish transplants from the lower to upper Sacramento River have occurred in the past 10 years. Each year between 1972 and 1979, chinook eggs have been transferred from Nimbus Hatchery to Coleman Hatchery to raise and release fry into Battle Creek. Similarly, chinook fry from Nimbus Hatchery eggs have been raised by Coleman Hatchery for release at Red Bluff, Balls Ferry, and Tehama-Colusa canal. In 1977, 2.2 million chinook fry were transported from Nimbus Hatchery and released into Battle Creek, potentially introducing large quantities of new, untested germplasm into the Coleman Hatchery and wild Battle Creek spawning populations. Chinook fry from 15 million eggs from Feather River Hatchery were also recently reared and released at Coleman Hatchery, and five million chinook fry raised at Feather River Hatchery were released in Tehama-Colusa canal.

For the past 40 years, Coleman National Fish Hatchery has been the primary facility charged with maintaining anadromous salmonid runs in the upper Sacramento River. The annual reports of the Coleman Hatchery have variously described the fish planting or distribution zone as "lower Battle Creek and some portions of the Sacramento River" (1951); "upper Sacramento; various northern California streams in cooperation with CDFG" (1956); and "the Sacramento River and its tributaries" (1968). Although the distribution zone of Coleman Hatchery has expanded throughout its history, the hatchery records and CDFG Region I Office records show that some tributaries of the upper Sacramento River have not been planted and may contain only native stocks. Tributaries of the upper Sacramento River where no introductions of chinook or steelhead have been recorded are listed in Table F-1.

COASTAL RIVERS INVENTORY

Seven hatcheries operate on California North Coast rivers: Iron Gate, Trinity River, Mad River, and Warm Springs Hatcheries are operated by CDFG; Prairie Creek Hatchery is operated by Humboldt County; and Rowdy Creek Hatchery and SilverKing Oceanic Farms are privately operated (see Chapter 1). All of these hatcheries have planted streams or

Table F-1

TRIBUTARIES OF THE UPPER SACRAMENTO RIVER WHERE ANADROMOUS SALMONID SPECIES HAVE NOT BEEN INTRODUCED[1,2,3]
(listed from north to south)

Number of Introductions of Chinook	Number of Introductions of Steelhead
Cow Creek	Stillwater Creek
Bear Creek	Cow Creek[5]
Ash Creek	Bear Creek
Cottonwood Creek[4]	Ash Creek
Inks Creek	Cottonwood Creek
Paynes Creek[4]	Inks Creek
Salt Creek	Paynes Creek[5]
Dye Creek	Salt Creek
Elder Creek	Coyote Creek[5]
Thomes Creek[4]	Dye Creek
Dry Creek[4]	Elder Creek
Singer Creek	Thomes Creek[5]
Stoney Crek	Singer Creek
	Stoney Creek
	Butte Creek[5]

[1] According to California Department of Fish and Game Region 1 office records and Coleman National Fish Hatchery records.

[2] Tributaries with only one recorded introduction of chinook are Stillwater Creek, Antelope Creek, Chico Creek, and Butte Creek.

[3] Records show only one introduction of steelhead to Antelope Creek.

[4] Natural chinook spawning has been recorded within the last ten years.

[5] Natural steelhead spawning has been recorded within the last ten years.

transferred eggs or fry to other hatcheries. The distribution zone of each hatchery is roughly defined in the following discussion.

Rowdy Creek Hatchery

Rowdy Creek Hatchery plants steelhead in many places along the North and South Forks of the Smith River drainage but not yet in the Middle Fork (Art Lawn, personal communication, 1982). Eggs are sometimes transferred to Mad River Hatchery.

Prairie Creek Hatchery

Prairie Creek hatchery raises chinook, coho, and steelhead, which are planted mostly within the Prairie Creek and Redwood Creek drainages. Other waters in which steelhead have been planted are Stone Lagoon, Bull Creek, Freshwater Creek, and Little River (Steve Sanders, personal communication, 1982).

Iron Gate Hatchery

Production of anadromous salmonids by Iron Gate Hatchery compensates primarily for the loss of spawning and rearing waters above Iron Gate Dam. Consequently, most of the fish raised are released directly from the hatchery. Chinook eggs collected at Iron Gate Hatchery that are surplus to production needs are transferred most frequently to Prairie Creek Hatchery, Van Arsdale Fisheries Station on the Eel River, and Mad River Hatchery. From these eggs Mad River Hatchery raises fry which are planted in the lower Klamath River, and the other facilities use these eggs in their normal planting procedures.

Steelhead and coho salmon eggs from Iron Gate have been transferred on a few occasions to other hatcheries.

Trinity River Hatchery

Trinity River Hatchery mitigates losses of spawning habitat resulting from Lewiston Dam. Most chinook and coho releases are from the hatchery or nearby, but steelhead are planted extensively throughout the Trinity River drainage. During twenty years of hatchery production, only a Trinity River strain of chinook has been used except for one year when Klamath River chinooks were introduced (Annual Reports, Trinity River Hatchery up to 1977). Besides the Trinity River strain, coho salmon from the Eel River, Noyo River, and the Cascade and Alsea Rivers in Oregon are used in hatchery production and releases. Strains of steelhead introduced to Trinity River Hatchery are American River (Nimbus Hatchery), Eel River, Iron Gate Hatchery, Washougal and Cowlitz Rivers (both from Washington), and Rohring River, Oregon.

Warm Springs Hatchery

Warm Springs Hatchery commenced operating two years ago. It is designed to mitigate losses of coho salmon habitat resulting from the construction of Warm Springs Dam on Dry Creek and to raise chinook salmon smolts as an enhancement feature. At present, steelhead are produced from wild stocks in Dry Creek, and coho eggs come from Iron Gate Hatchery. Disease-free chinook eggs are so difficult to obtain that eggs (of a Washington strain) were brought from Wisconsin and from SilverKing Oceanic Farms in exchange for coho eggs.

SilverKing Oceanic Farms

SilverKing Oceanic Farms commercially ranches coho and chinook salmon from Davenport Landing Creek. In the past, SilverKing has raised steelhead fry and released them into San Lorenzo River.

Mad River Hatchery

Fish production at Mad River Hatchery augments anadromous fish populations in coastal streams. Consequently, chinook, coho, and steelhead eggs have been collected from many different sources for hatchery production, and fish have been planted in many different streams. The founding steelhead stocks for Mad River Hatchery production are from the South Fork of the Eel River, but steelhead fry raised from eggs from Benbow, Noyo River, and San Lorenzo River have been planted in many different streams. A list of coastal streams which have had no recorded introductions of salmonids is presented in Table F-2.

Table F-2

CALIFORNIA COASTAL RIVERS[1] AND CREEKS WHERE SPECIES OF ANADROMOUS SALMONIDS HAVE NOT BEEN INTRODUCED[2]
(listed from north to south)

Chinook	Coho	Steelhead	Cutthroat Trout
Wooley Cr.	Elk R.	Wooley Cr.	Smith R.
Elk R.	Bear R.	Elk R.	Klamath R.
Bear R.	Mattole R.	Bear R.	Eel R.
Mattole R.	Noyo R.	Ten Mile R.	
Garcia R.	Big R.	Noyo R.	
	Albion R.	Big R.	
	Garcia R.	Albion R.	
	Gualala R.	Greenwood Cr.	
	Salmon Cr.	Alder Cr.	
	Papermill Cr.	Brush Cr.	
	San Lorenzo R.	Salmon Cr.	
		Alameda Cr.	
		San Gregorio Cr.	
		Soquel Cr.	
		Big Sur R.	

[1] Rivers listed are habitat for the species indicated as depicted on the "Salmon and Steelhead Fishing Map," published in 1969 by the California Department of Fish & Game, and by Behnke, 1979.

[2] According to Mad River Salmon & Steelhead Hatchery records, and phone interviews with hatchery personnel at Rowdy Creek Hatchery and Prairie Creek Hatchery.

APPENDIX G

SALMON SPORT FISHING VALUES

Whereas data are lacking to calculate the value of salmonid sport fishing in California, three methods exist to compute that value. These methods are outlined in this appendix.

The value of California's salmonid sport fishery is its value in providing recreational fishing experiences to anglers fishing in the ocean, in the inside marine areas, and in streams. The direct or "user benefits" therefore have to be measured.

Economic theory and logic implies that net benefits to anglers be measured as the amount they would be willing to pay rather than forfeit the opportunity to fish for salmon at their chosen fishing location. Consumers' surplus is the object of measurement.

Sport fishing value will change as location, species, and fishing success change, so that any average value for a salmon or a steelhead sport fishing day or trip can be misleading.

The use of "average value per day" of sport fishing for salmon and steelhead is also misleading when estimating the value of the sport fish. The sport fishing experience for salmon encompasses the sport fish value, boating, companionship, and sight-seeing and other "goods and services" consumed by a fisherman.

This approach in economics suggests fresh ways of estimating the value of the sport fish. Such work is still in its infancy (Strand, Yang, and Norton, 1981; Lancaster, 1966; Brown, 1978).

Sound estimation of the underlying demand for salmon fishing is fundamental to reliable assessment of the value of recreational fishing, i.e., the consumers' surplus. Measurement of consumers' surplus, however, poses a problem, since the basic demand data (prices and quantities demanded) are not available, and therefore cannot be estimated directly. The relevant data to construct the underlying demand equations can only be obtained from individual anglers who are fishing for salmon or steelhead or both.

<u>Measuring Willingness to Pay</u>

Two techniques are used to measure consumers' surplus on salmonid sport fishing. The travel cost method is the most commonly used method. It requires estimation of a per capita or a per household demand function from data on trip rates as a function of costs per trip and other socioeconomic data. The demand so estimated is used to compute consumers' surplus to sport fishery at a particular site, whether it be on the ocean or on a river (Hotelling, 1949; Clawson, 1959; Knetsch, 1964).

In the other technique, sport fishermen are interviewed and asked what amount they would be willing to pay for the opportunity to participate in salmonid sport fishing at a particular site.

The Travel Cost Method

There have been a number of improvements and refinements in the methods used to accurately specify relevant variables in the Travel Cost demand equations and to measure those variables more precisely.

In the original "Hotelling method," distance is the basis of measurement. Two assumptions are made: (1) all visitors to a recreation site receive the same level of benefits and (2) individuals visiting the site from very remote areas "break even," that is, their benefits equal their travel costs. Primary benefits are designated as the saving in travel costs which accrue to visitors traveling shorter distances.

As in the Hotelling model, the Clawson variant uses a system of concentric population zones around the site, each zone having the same population. The rate of participation falls as the zones are located progressively farther from the recreational fishing site and a relationship can be established between travel costs (i.e., distance) and the participation rates.

Method of Analysis

To impute economic value, it is necessary to estimate a demand function for salmon fishing at a particular site. The function expresses a quantity purchased as a function of the price of a unit of that good and of other related variables, such as the prices of alternative goods, and individual tastes and preferences. For example,

$$Q_j = (P_{Q_j}, I, P_{Q_i}, T)$$

where

Q_j is the quantity of the good (j) in question,

P_{Qj} is the price of Qj,

I is per-capita income,

P_{Qi} is the price of a competing good (i), and

T is a measure of tastes and preferences.

When goods are sold in the market, prices and quantities may be observed and a demand function estimated directly. With nonmarket goods, such as salmon fishing in the ocean or in a stream, alternative prices and quantities cannot be observed directly. Yet we know that if higher and higher prices were charged for participating in that activity, less and less participation would result. That is, a demand curve does exist for this nonmarket good. It just happens that the price (entry fee) is zero and higher prices have not been observed.

This nonobserved demand curve may be estimated using an approach known generally as the Clawson-Hotelling method (1949, 1959) and a modification of the general approach (Brown and Nawas, 1973; Martin, Gum, and Smith, 1974; and Brown, Sorhus, and Gibbs, 1980).

The methods proceed in two stages. First, a demand curve for the entire recreational experience, including the travel experience, is developed by relating the observed quantity variable (fishing days or trips) to the actual variable costs incurred by participating in that experience. For example:

Number of trips per household = f (travel costs per trip, other costs, such as boat fuel, per-capita income, etc.)

Then, by assuming that each individual would react to an added cost (e.g., an entry fee) in the same way that he has reacted to actual costs, a second-stage demand curve for the fishing activity itself may be constructed.

For example, in the method described in detail in Martin, Gum, and Smith (1974), observations on each individual interviewed are used to estimate the first-stage curve with ordinary least squares multiple regression. The objective is to obtain unbiased, statistically significant coefficients on the variables relating costs to quantities consumed. Then, a demand curve for each individual is constructed. His individual curve is set to pass through his actual observed quantity taken at zero added cost.

The individual demand curves are aggregated to form an aggregate demand curve for salmon fishing at a site at posited increasing added costs.

Willingness-to-Pay Questionnaires

The interview approach to measuring consumers' surplus in salmonid fishing attempts to elicit directly from the salmon anglers how much they are willing to pay for the right to fish for salmon or would have to be paid to give up the right.

Davis (1964) was the first to use this approach to value recreation in the Maine Woods, and, more recently, this method has been used by Meyer (1974), Matthews and Brown, (1970), and Crutchfield and Schelle (1977). The results of these investigations are set out subsequently.

Fishermen are queried in person through the mail or by telephone about their socioeconomic status, how often they fish for salmon at a particular site, the number of fish caught, and how much more than their actual outlay they would pay for the right to fish. With these data, a function relating consumers' surplus to income, visit rates, and other variables can be estimated as follows:

Consumer surplus = $\propto(d,y,\ell)$

where d is the mean number of days or trips, y is income, and ℓ is the number of fish landed per day or per trip.

The net value of the fishing experience to the angler can be estimated from such a relationship. The net value of the sport fishing is computed by totaling the consumers' surplus for all anglers fishing at a site.

Studies have shown a significant difference between the maximum amount anglers would be willing to pay for the right to use a resource and the minimum amount they would have to be paid to give up their right. For a critique of this method and weaknesses in the Travel Cost method, see McConnell and Norton (1976).

The Travel Cost method and the Direct Interview approach, also termed the contingent evaluation method, are creditable and acceptable ways of estimating consumers' surplus or willingness to pay. The needed improvements in specification and measurement are known, and the required information can be elicited or imputed.

The U.S. Water Council, in its rules for evaluating a recreational activity such as salmon sport angling, stipulated that, in addition to the Travel Cost method and the contingent evaluation method, a third method--Unit Day Value--may be applied to estimate recreation benefits. The Unit Day Value relies on an estimate of the average willingness to pay of recreationists (arrived at by expert or informed opinion). Benefits are obtained by multiplying estimated use by this value (U.S. Water Resources Council, 1979).

There has been no attempt using any of these methods, to value California's sport salmonid fishery, although a number of researchers have attempted to estimate the value of the salmon sport fishing experience and the total net value of sport salmon fisheries in Washington and Oregon.

The following summary of net economic benefits per angler day as estimated by different researchers is taken from Brown, Sorhus, and Gibbs (1980).

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GLOSSARY

Allele: One of a pair or series of genes located in the same position on a given chromosome and affecting the same trait.

Alevin: Larval salmon and steelhead from the time of egg hatching to absorption of the yolk.

Anadromous: Migrating to ocean waters and returning to freshwater to spawn.

Broodstock: Adult fish retained for artificial propagation.

Escapement: A procedure allowing anadromous fish to escape ocean and river harvesting so that they can complete migration upriver to spawn.

Ex Situ: Outside an organism's native environment.

Fry: Juvenile salmon and steelhead at the time of yolk absorption and the initiation of active feeding.

Gene: The chemical unit of hereditary information that can be passed on from generation to generation.

Gene Flow: The spread of genes from one breeding population to others from the dispersal of gametes or zygotes.

Gene Resources: The portion of the total genetic diversity of animals, plants, and microorganisms society needs to meet its basic requirements for food, fiber, pharmaceuticals, energy, and recreation.

Genetic Diversity: The range of genetic differences among individuals or groups of organisms.

Genotype: The genetic composition of an individual.

Germplasm: Hereditary material or genes.

Heterosis: Increased superior qualities arising from the cross-breeding of genetically different plants or animals; also known as hybrid vigor.

Homing: Behavior which leads mature salmon and steelhead to return to their stream or lake of origin for spawning.

Inbreeding: Breeding through a succession of parents that are closely related.

In Situ: Within an organism's native environment.

Isozymes: Cellular enzymes.

Maximum Sustainable Yield: The greatest number of fish that can be taken without reducing the number of individuals necessary to propagate the species.

Optimum Yield: That number of fish that will provide the greatest food and recreational benefits to the nation without exceeding the maximum sustainable yield.

Outplanting: Transportation and release of fish away from hatchery site.

Phenotype: The actual characteristic appearance of an organism produced by the genotype in conjunction with the environment.

Resident: Non-migratory.

Residualization: Loss of behavioral and physiological compulsion to perform anadromous migration.

Run: Seasonal migration upriver to spawn.

Smolt: Juvenile salmon and steelhead at the time of physiological adaption to life in saltwater.

Smoltification: Physiological process that permits young salmon and steelhead to adapt to saltwater.

Stock: (n.) A species or population of fish that maintains and sustains itself over time in a defined area.

Stock: (v.) To provide; to plant or release.