OCEAN CONDITIONS AND THE MANAGEMENT OF COLUMBIA RIVER SALMON

Proceedings of a Symposium
July 1, 1999
Portland, Oregon

Edited by
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"The search for Truth is in one way hard and in another easy. For it is evident that no one can master it fully or miss it wholly. But each adds a little to our knowledge of Nature, and from all the facts assembled there arises a certain grandeur"

Aristotle (384-322 B.C.)

"The management system has not yet developed any mechanism for responding to the uncertain state of nature due to changing ocean conditions"

Hilborn, R. 1987, North American Journal of Fisheries Management 7 (1): 1-5

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PREFACE

For many years, scientists have been researching the complex interactions between the ocean climate and different runs of anadromous salmonids. Until recently, however, their observations and the tremendous amount of information generated through their work have done little to alter conventional management perspectives in salmon management. Not surprisingly, the protracted time lag between scientific advances and their incorporation into policy decisions is a recurring weakness -- not just of salmon management programs, but of natural resource administration efforts in general. The end result fosters much frustration and poor policy choices.

In the case of managing Columbia River Basin salmon resources in the context of a variable marine environment, this gap between scientific progress and policy recently seems to have narrowed significantly. For instance, concepts such as the El Niño Southern Oscillation or inter-decadal scales of environmental variability are no longer limited to a handful of researchers and academicians. Instead, government and society increasingly are aware of sound ecological principles. This new perception invites us to embrace a holistic view of the entire ecosystem experienced by migratory salmon of the Columbia River Basin. This thrust is illustrated by the efforts of the Northwest Power Planning Council to integrate the vast salmon ecosystem through science and policy. Similar perceptions were part of the rationale when the U.S. Congress amended the 1980 Northwest Power Act, in September 1996, to integrate scientific and policy elements into fish and wildlife decision-making. Clearly, the acknowledgement of a broader scope of interest by regional decisionmakers responsible for managing salmon is not the end point. Rather, we are increasingly aware of the complexities before us and recognize we are at the beginning of our learning curve.

The *Symposium on Ocean Conditions and the Management of Columbia River Salmon*, sponsored by the Council on July 1, 1999, was just one of the many efforts to make sensible and educated progress toward our broader view of salmon management. This event was convened to underscore and discuss contemporary regional perceptions about the interaction between salmon and a variable ocean environment. Understanding this interaction is fundamental to generating a revised list of salmon recovery issues and to realizing how they may be addressed by our management actions.

To illustrate this point, consider the prevailing perception just a few years back. At that time, decision-makers essentially dismissed the ocean environment and focused management attention on the vast extension of the Columbia River Basin, with a multitude of resources --such as salmon-- and ecological processes interacting within a finite geographic area. In a sense, the physical boundary imposed by the wall of Bonneville Dam represented the edge between where humans experience salmon most frequently and the unknown area downstream. Perhaps the abandonment of this limited scale of observation is one of the most significant changes in regional perception. We now recognize that Bonneville Dam is not a boundary but, rather, that there is a continuum between the Columbia River, its estuary – where fresh water contacts sea water, the plume – the extensive discharge of the Columbia that dilutes surface waters of the nearshore Pacific, and the remainder of shelf and oceanic areas extending from northern California to the Gulf of Alaska.

Another change in perception leads us to a slightly different view of the life cycle of salmon. As insignificant as it may sound, our perception evolved from understanding this life cycle to include a "fraction spent at sea" to a more holistic view where the marine residence of salmon becomes much more prominent. As a corollary, this marine portion "added" to the salmon life cycle brings with it a whole new host of factors and processes which vary, as we can anticipate, in broad scales of space and time. Understanding these scales of variability will help us identify problems, opportunities, and priorities.

The Council has endorsed two concepts consistent with these new perceptions. Both are captured in an issue paper completed by the Council in 1997. The first concept consists of a recognition that the estuary and plume are important ecological environments for salmon, and that natural events, river management actions and local actions critically impact them. This is to say, for example, that if we concentrate on the area of the Columbia River estuary we begin to visualize many of the processes and mechanisms altered or disrupted as the result of local changes and decades of interventions in the freshwater system elsewhere in the basin.

The second concept is one that promotes salmon life-history diversity. This survival strategy is the natural mechanism that evolved in salmon in response to changing conditions. A wide array of life histories provide alternative pathways to survival, growth, and reproduction, all of which define the "fit" of individuals to their environment and shape different populations over evolutionary time. We argue that it is necessary to modify and adjust those management actions that restrict the natural expression of salmon life history diversity.

The day-long symposium convened on July 1 was our attempt to seek professional input from a select group of experts who included leading authorities in the fields of climatology, oceanography and fishery sciences, to expand many of the arguments, emphasize fundamental principles and provide a more detailed account of current regional thinking. We also benefited from the presence of some of the top resource administrators in the region, who proposed some provocative questions on how to incorporate current scientific understanding about the variability of conditions in the marine environment into salmon management. Representatives of federal, state, and tribal entities, members of the public, and private interests attended the event. The collective concerns, contributions, and perceptions of all of those who attended the symposium are recorded in these proceedings. Together, we began to improve our perceptions and to tailor our management response to the challenges ahead.

In closing, I want to extend my personal gratitude to the speakers at the symposium, members of the panel, and the audience for their interest and participation. Also, I want to express my appreciation for the excellent quality of help provided by members, professional and administrative staff of the Northwest Power Planning Council in making this symposium a success.

Gustavo A. Bisbal, Ph.D.
Northwest Power Planning Council

SYMPOSIUM AGENDA

OCEAN CONDITIONS AND THE MANAGEMENT OF COLUMBIA RIVER SALMON

When: **July 1, 1999** – 9:00 a.m. to 4:00 p.m.

Where:
The Governor Hotel
Ballroom
611 SW 10th Avenue at Alder
Portland, Oregon
Phone: (503) 224-3400

Sponsor:
Northwest Power Planning Council
Phone: (503) 222-5161 – (800) 452-5161

9:00-9:15	**Opening and welcoming remarks** Todd Maddock, Chairman, Northwest Power Planning Council Donna Silverberg, Facilitator
9:15-9:45	**Consideration of ocean conditions in the Council's Fish and Wildlife Program.** Chip McConnaha and Gustavo Bisbal, Northwest Power Planning Council
9:45-9:55	**Questions and answers**
9:55-10:25	**Climate effects on salmon populations.** George Taylor, Oregon State University
10:25-10:35	**Questions and answers**
10:35-10-45	*BREAK*
10:45-11:15	**Sources and effects of variability in the Columbia River estuary and plume.** Ed Casillas, National Marine Fisheries Service
11:15-11:25	**Questions and answers**
11:25-11:55	**Sources and effects of variability in the Northeast Pacific Ocean.** Richard Beamish, Canada Department of Fisheries and Oceans
11:55-12:05	**Questions and answers**
12:05-1:00	*LUNCH BREAK*
1:00-1:30	**The transition between ocean science and policy.** Daniel Bottom, Oregon State University
1:30-1:40	**Questions and answers**
1:40-2:25	**Management strategies I: Ocean conditions and management of the freshwater system.** Panel/Council/audience discussion
2:25-2:35	*BREAK*
2:35-3:20	**Management strategies II: Ocean conditions and "the four H's".** Panel/Council/audience discussion
3:20-3:50	**Closing remarks.** Robert Francis, University of Washington
3:50-4:00	**Questions and answers**
4:00	*Adjourn*

WELCOME

Good morning, everyone. My name is Todd Maddock, and I am the chairman of the Northwest Power Planning Council. On behalf of the Council, which is sponsoring the symposium today, I am pleased to welcome you here.

This is a unique event and a unique opportunity for the Council. While it is unusual for the Council to host this type of event, we welcome the opportunity to listen to the presentations and interact with the scientists.

For the last several years, the Council has been concerned about the potential of the ocean environment to impact salmon and steelhead from the Columbia River Basin. As well, since 1996 it has been part of our legal mandate to take ocean conditions into account when we make funding recommendations to the Bonneville Power Administration for projects that implement our Columbia River Basin Fish and Wildlife Program.

We recognize that there is much debate about the impact of the ocean on the survival of salmon and steelhead, and I am pleased to recognize, on behalf of the Council, that today we have an impressive group of experts who will address the issue. I am looking forward to hearing what they have to say, and I would like to point out that this afternoon there will be an opportunity to interact with the scientists.

So with that, I would like to introduce Donna Silverberg, who will facilitate the presentations this morning and our discussions this afternoon.

Todd Maddock
Chairman
Northwest Power Planning Council

Consideration of Ocean Conditions in the Management of Salmon[1]

Gustavo A. Bisbal and Willis E. McConnaha
Northwest Power Planning Council
Fish and Wildlife Division
Portland, Oregon

Introduction

On September 12, 1996, the U.S. Congress enacted the first and only amendment to the Northwest Power Act of 1980 (Northwest Power Planning and Conservation Act, section (4)(h)(10)(D) 1996). The original federal law authorized the states of Idaho, Montana, Oregon and Washington to form the Northwest Power Planning Council (the Council) and called for the Council to develop the Columbia River Basin Fish and Wildlife Program (NPPC 1994). The program addresses the restoration of fish and wildlife affected by hydroelectric development in the Columbia River Basin. The recent amendment directed the Council to "...consider the impact of ocean conditions on fish and wildlife populations..." during the implementation of its program. Consideration of ocean conditions has its most direct impact on anadromous fish populations, such as salmon and steelhead. In this paper, we will suggest how the consideration of ocean conditions can be incorporated into salmon management, especially as it relates to the Council's mission in the Columbia River.

During their anadromous life cycle, Pacific salmon utilize riverine and stream environments, but spend most of their lives at sea. Management of salmon populations, however, has typically stressed manipulations of elements in the freshwater phase of this cycle. In general, the forces and processes affecting salmon in the marine environment have been largely ignored (Hare and Francis 1995). The ocean has been regarded as a virtually inexhaustible pasture for juvenile fish produced through actions taken in the freshwater environment (Pearcy 1992). Hatcheries and other approaches in fresh water have been implemented to compensate for habitat deterioration, to increase numbers of fish produced and to smooth out natural fluctuations in abundance (Lichatowich 1997). Failure to maintain adult salmon abundance through these controlled actions indicates that ocean conditions are, in fact, highly variable and major determinants of the fate of entire fish runs. For some, the pendulum has shifted to the conclusion that management actions during the freshwater phase of salmon life are relatively futile in the face of the mortality and variability experienced by salmon during the marine phase of their life.

In this paper, we suggest the need for a more holistic view of the salmon ecosystem that encourages a new perspective on the importance of ocean conditions and their inclusion in the management of salmon. Both ocean and freshwater conditions – and their variability – are now accepted as integral components of the salmon ecosystem (NRC 1996; Williams et al. 1996). We now have a greater appreciation for the impact of the ocean on salmon abundance and the degree of variation in the marine environment. Throughout their life cycle, salmon negotiate environmental variability by having a broad array of biological characteristics within and between populations. This diversity provides different options for salmon to cope with the

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[1] This paper is an abbreviated version of Bisbal, G.A. and W.E. McConnaha. 1998. Consideration of ocean conditions in the management of salmon. *Canadian Journal of Fisheries and Aquatic Sciences* 55(9):2178-2186.

mortality they experience during their life cycle in general, including their marine residence. Because management actions taken in fresh water can restrict biological diversity, consideration of ocean conditions in the management of anadromous fish will require relaxation of those constraints that lead to environmental and biological simplification.

Interaction between salmon and environmental variability

Many factors can potentially affect the growth and survival of salmon at sea. Physical events, such as extreme environmental conditions, and biological interactions like competition and predation can result in substantial variability in salmon recruitment (Pearcy 1992). In addition to natural fluctuations of environmental conditions, salmon encounter elements introduced by man. These impacts are particularly acute in the estuary and river plume. Human actions can affect estuarine and coastal-ocean conditions through pollution, river operations, hatcheries, harvest or habitat changes. The response of salmon to such environmental challenges differs according to important biological features including life stage, body size, age, growth rate, and previous exposure to specific conditions. Extensive contributions by several authors provide ample information on the factors and sources of variability that challenge salmon as they enter the ocean (Sherwood et al. 1990; Pearcy 1992; Beamish and Bouillon 1993; Weitkamp 1994; Mantua et al. 1997).

Variation within the marine environment is particularly important in determining the success of individuals, populations and species of anadromous salmonids, because they spend most of their life in the ocean. Salmonids can be quite plastic in their response to environmental change and can accommodate this variability by a relatively high degree of genotypic and phenotypic diversity (Adkison 1995; Healey and Prince 1995; Thompson 1991). Within salmonids, features such as spawning, dispersal, morphology, maturation, and patterns of growth are all life-history traits that define the "fit" of individuals to their environment. Each life history represents a suite of characteristics that defines the episodes of birth, reproduction and death of individuals, and the dynamics of populations over evolutionary time.

Variation in life histories represents different biological solutions to intrinsic environmental variability. In a natural ecosystem, life history strategies evolve through natural selection, operating under anatomical, behavioral and genetic constraints, to match key characteristics of the environment. When confronted with variable environmental conditions, however, no one solution is always optimal. Hence, depending on the particular environmental template (sensu Southwood 1977) encountered by individuals, certain life histories are more successful than others and convey a reproductive advantage and increased fitness (Thompson 1991). The environmental template varies in time and space and determines the range of possible life histories needed to maintain fitness through time (Southwood, 1977).

Human interventions add important hurdles to the ability of salmonids to maintain their biological diversity and, hence, their ability to withstand environmental variation. Anthropogenic forces may act as agents of artificial selection (Sheridan 1995), favoring some life-history traits over others, and can modify the generalized anadromous life cycle of Pacific salmon. Fish husbandry practices, for example, can select against behaviors and morphologies that may be advantageous in the wild, but that are less conducive to the operations and goals of hatchery programs (Reisenbichler 1997). Harvest, hydroelectric dam operations, flow manipulations and many other human-driven perturbations can act synergistically with variable environmental conditions to alter the biological structure of salmonid populations. Under favorable environmental conditions, salmon populations show a higher tolerance to human perturbations. When environmental factors are restrictive, the relative importance of human factors increases and the capacity of salmon populations to tolerate external disturbances becomes very limited (Fogarty et al. 1991).

Intensively regulated freshwater systems tend, in general, to reduce environmental variation (Stanford et al. 1996). Floods are reduced, banks are stabilized and biological components are adjusted to fit within the needs of a heavily engineered river redesigned through human technology. For example, in the Columbia River, a variety of actions are taken to enhance survival of juvenile fish during their downstream migration. These include seasonal flow augmentation, controlled spill at hydroelectric dams and physical transport of fish around dams in barges and trucks (Ebel et al. 1989). Many of these actions are designed to force a particular biological configuration that minimizes the conflict with other human uses of the river. Because these actions are expensive, their implementation tends to be optimized on the basis of juvenile fish abundance rather than on the natural diversity of salmon life histories. Based on the relationship between the habitat template and ecological strategies (Southwood 1977), simplification of the environment and its variability also should result in a decrease in biological diversity (Stanford et al. 1996).

The interaction between environmental variability and biological diversity is illustrated in Figure 1. Environmental variability is depicted on the left as a template (Southwood 1977) with variously shaped indentations representing combinations of spatial and temporal environmental conditions encountered by salmon over the course of their life cycle. This variability promotes the development of adaptive mechanisms that maintain relative fitness in salmon populations and shapes the evolution of life history traits (Thompson 1991). Different life histories are represented by correspondingly shaped pieces on the right. As an adaptive mechanism influencing reproductive success and fitness, the correspondence between the life histories and the environmental template must ultimately embrace the entire life cycle. The environment at each life stage, however, is realized by salmon at different scales and offers its own unique set of factors and circumstances (Levin 1992). Thus, it is possible to imagine a different template for the environment encountered at each life stage. For purposes of this discussion, the templates in Figure 1 illustrate the variability in the ocean environment encountered by populations of juvenile salmon entering from the freshwater (in this case the Columbia River). Five general scenarios are discussed below, focusing on variation in ocean conditions, life histories, and their significance to salmon survival.

Figure 1A represents an ideal scenario where favorable ocean conditions provide adequate survival and growth opportunities to a broad range of salmon life histories. Due to the complex and dynamic nature of the environmental template, however, even "favorable" conditions can be better described as some average state tracked by the bulk of available life histories. In this ideal case, variation in the shape of the template results in varying degrees of match and mismatch between some life histories and the environmental template. Different life histories may be favored according to random circumstances and decadal or longer environmental cycles. Therefore, the evolution of a rich mosaic of life history strategies provides salmon with their characteristic resilience to a variable environment.

Figure 1B depicts an extreme condition where the environmental window of biological opportunity is severely narrowed, perhaps as a result of an El Niño episode or other climatic event. While some of the available life histories fit the template, many others are disfavored, resulting in decreased salmon abundance. In fact, the persistence of some life histories may be in jeopardy; however, as the environmental template varies again, these life histories may reappear to take advantage of new opportunities. Over time, a biologically diverse array of life histories exists to accommodate adverse environmental demands.

As discussed above, human interactions with the ecosystem tend to reduce biological diversity. This makes the natural mechanism for incorporating environmental variability less effective. This situation is depicted first in Figure 1C where a reduced set of life histories fits segments of the environmental template. The outcome of this scenario is probably a reduced abundance relative to the situation in Figure 1A or even 1B, although artificial augmentation can bolster abundance under favorable conditions. However, some might conclude that any reduction in fish abundance is simply a necessary sacrifice towards progress and point to the apparent success of mitigation efforts directed at the reduced set of populations. A strategy of this kind, however, may prove risky and result in serious ecological imbalances, as illustrated in the next two scenarios.

For example, it is possible that a much reduced set of life histories can thrive during a period of generally unfavorable ocean conditions if there happens to be a fortuitous fit between the available life histories and the ocean conditions (Figure 1D). Then the end result parallels the outcomes described for Figure 1C. The apparent success of a management strategy that focuses on customizing fish populations to the assumed "normal" ocean condition, masks the serious risks of environmental variation.

If the environment shifts away from the situation depicted in Figure 1D, then the limited set of life histories may fail to fit the template of ocean conditions (Figure 1E). This mismatch translates into a disastrous recruitment collapse. Because there are no alternative life histories to exploit the prevailing environment, abundance declines, perhaps precipitously. Some populations can be extirpated, and, without a rich source of biological alternatives, recolonization can be slow or non-existent.

Taking ocean conditions into consideration

The question of how ocean conditions can be taken into account for salmon management revolves around how we view the relationship between marine and freshwater environments and their relative significance to salmon. Figure 2 illustrates three different possibilities for this relationship, each of which results in an alternative approach to salmon management. While no individual or entity necessarily ascribes fully to any of these hypothetical views, elements of one or more of them form the basis for many salmon management decisions in the Columbia River Basin and elsewhere. These explanations for – and proposed responses to – the fluctuations in salmon abundance have polarized numerous interest groups, administrative entities, and segments of the public involved in the architecture and implementation of salmon recovery programs.

A. Freshwater Dominance

The first view (Figure 2A), which characterizes traditional salmon management for most of this century, suggests that fluctuations and declines in salmon abundance are largely the result of deterioration of the freshwater environment due to development activities. While acknowledging that a large part of the mortality that occurs over the course of the salmon life cycle takes place in the ocean, the implied assumption is that the ocean is a relatively stable environment where salmon mortality affects a constant proportion of smolts entering the ocean. It then follows that fluctuations in the production of adult salmon can be dampened and declines can be reversed through the manipulation of the smolt output (Bottom 1997). From this "freshwater dominance" perspective, management actions in fresh water areas above the estuary have a direct impact on overall salmon production. According to this argument, a management course that relies heavily on artificial production and technological innovations, for instance, is generally correct. Hatcheries, hydroelectric operations and harvest are managed to provide a standard "product" with the focus of increasing the number of juvenile fish entering the ocean. Augmenting the number of juveniles released from hatcheries is the strategy of choice to increase numbers of fish available for harvest or returning to the river, independent of variation in ocean conditions (Bottom, 1997). Ironically, continued declines in fish runs do not provide the much needed evaluation of the strategy, conceptual criticism or rejection of program activities. Instead, they seem to provide the necessary justification for a more aggressive implementation of the current technological fixes (Meffe 1992; Stanford et al. 1996; Lichatowich 1997).

B. Marine Dominance

The second view pervading the political environment of salmon management ascribes most of the variability in salmon abundance to conditions in the marine environment (Figure 2B). In many ways, this is the opposite of the first view. This "marine dominance" perspective views the ocean as the ultimate controller of fish populations. In this scenario, environmental changes in the ocean control the number of fish, and the freshwater environment is reduced in importance.

Because many sources of mortality affecting salmon during their freshwater phase are under management control, compared to very few in the marine environment, both the efficacy of freshwater actions as well as the importance of salmon mortality during their seawater residence are reevaluated under this view. Failure to observe simple cause-and-effect relationships between augmented smolt abundance in fresh water and eventual returns of adult fish suggests that variation in the abundance of salmon runs can be attributed to factors outside human control. It then follows that freshwater actions may assist downstream migrants and returning adults, but are relatively less important in the face of large and variable ocean conditions. The significance behind this argument is that if changes in the ocean climate dominate changes in salmon biomass, then actions to improve conditions in the river or its tributaries are relatively futile, particularly in years when ocean conditions are unfavorable. This view could lead to the conclusion that recovery efforts and funding for them may be wasted because ocean conditions negate the effect of any improvements in the freshwater environment.

C. Holistic

The first two perspectives view the freshwater and marine environments as distinct and separable habitats. Fundamentally, they differ in regard to the relative importance placed on either area as determinants of salmon abundance. In recent years, the continued decline of salmon from the Columbia River has called into question the wisdom underlying both of these management arguments. More recent thinking about ecosystems and their importance to species of interest, such as salmon, as well as a greater understanding of the ocean, leads to a third conceptual alternative (NRC 1996; Williams et al. 1996). Under this view, freshwater and marine areas are integral components of a larger ecosystem within which salmon exist (Figure 2C). Hence, the abundance of salmon reflects the overall condition of the entire ecosystem and variation in both the freshwater and marine environments. This view reflects a greater appreciation of the ecological context of fisheries management (Bottom 1997). Variation in the environment, including ocean conditions, is a natural feature of the ecosystem to which salmon have adapted through a diverse array of biological traits. The shift of management focus toward the entire salmon ecosystem, recognizes that even though the ocean is variable, management actions – particularly those in freshwater systems – are critical in promoting the conservation of this diversity over time (Lawson 1993).

This "holistic" view of the ecosystem can be summarized in the following points:

1. The ocean is not a constant environment. Ocean conditions and carrying capacity vary and can be limiting.
2. Freshwater and marine environments are not independent. There is evidence that variations in the two environments are linked via large-scale atmospheric processes and that both are integral parts of the salmonid ecosystem.
3. The estuary is an important transition between these two portions of the ecosystem. Conditions in the estuary can be an important determinant of early ocean survival of salmon.
4. Environmental variability is an inherent feature of the ecosystem of salmon. Salmon accommodate this variability through a similar variety in life history traits.

These new understandings have significant implications for the management of salmon. The environmental and functional fragmentation of the salmon ecosystem, expressed in the first two views, lead to management approaches that have proven to be too narrowly focused. When the entire ecosystem of salmon is recognized as the organizing principle behind a balanced management framework, the sources of environmental and biological variability, and the spatial and temporal scales involved acquire new significance. This leads to a comprehensive management approach where different parts of the salmon ecosystem are integrated for implementing adaptive management strategies.

The proposed management response

Although the causes of salmon mortality in the marine environment are difficult to study, our understanding of how ocean conditions affect long- and short-term variation in salmon populations has increased over the last several years. In the northeastern Pacific, in general, and the more localized realm of the Columbia River estuary and discharge plume, both natural phenomena and human interventions have modified environmental conditions and their rate of change. Although salmon tolerate a wide range of environmental conditions and disturbances, many factors may be lethal or cause physiological stress. The integration of these factors into management policies is based on our perception of the whole salmon ecosystem - a wide area that spans marine and freshwater domains.

Based on an understanding of the mechanism salmon use to cope with environmental variation (Figure 1) and an holistic view of salmonid ecosystem (Figure 2C), fish and wildlife managers may employ two primary approaches to influencing salmon survival in the ocean. The first approach is through the improvement of estuarine and nearshore conditions. The Columbia River estuary and nearshore plume are important to salmon production, particularly because of their impact on survival of juvenile fish making the transition to the ocean environment. Like many estuaries, these areas have been, and continue to be, negatively affected by upstream flow regulation, construction of dams, and local habitat change. Hatchery operations may also result in ecological imbalances, competitive interactions and competition for food and space by smolts during their estuarine and plume residence.

Based on these points, consideration of ocean conditions could include evaluation of flow regulation, river operations and habitat management in regard to their impacts on the estuary and nearshore marine areas. For example, efforts in the Columbia River to restore the seasonal hydrograph through release of stored water during the spring have generally been conceived as a way to assist downstream migrating salmon and steelhead (e.g. NPPC 1994). A more holistic view of the salmonid ecosystem suggests a broader biological role for flow including estuarine habitat and food web development and establishment of a river plume that approximates the condition under which Columbia River salmon evolved. Flow regulation to affect estuarine and nearshore areas may require volumes and schedules different from those used for upriver biological purposes. Estuarine habitats lost to past efforts to stabilize riparian areas and land reclamation can be reclaimed. In several Northwest rivers, for example, estuarine habitat has been re-established by breaching dikes to allow normal tidal flooding of estuarine areas (Simenstad and Thom 1996). The key role of these areas in the critical freshwater-marine transition suggests the need for examination of these possibilities in the Columbia River as well.

The second management approach available to resource administrators, is to address environmental variability – whether freshwater or marine – through the preservation of life-history diversity in salmon, a natural survival mechanism that evolved in response to changing conditions (Thompson 1991). Fluctuations in the ocean climate are an integral component of the overall environmental variability encountered by salmon. Salmon and steelhead in the Columbia River and elsewhere accommodate environmental variability through the development of a wide range of biological traits and behaviors that have been selected to permit survival within this ecosystem. However, management actions often restrict the natural expression of salmon life-history diversity. Actions that target limited time periods (e.g., restricted flow augmentation, spill, transportation and hatchery release schedules), select for particular physical characteristics of the fish (e.g., harvest and hatcheries), or reduce complexity of habitats (e.g., reduction of seasonal flows and channelization), can restrict biological diversity. For instance, the current operation of bypass systems at dams, smolt transportation, flow augmentation and spill, generally occurs within a relatively short time period from about April 15 to July 31, in the Snake River, and from May 1 to August 31 in the Columbia River (NPPC 1994). However, the juvenile fish migration extends appreciably before and after this period. Some bypass measures select for some physiological and morphological conditions over others (Muir et al. 1990). To the extent that these actions enhance passage conditions for the majority of the migrating population, they select against life histories that migrate outside this window of time or are not captured by the actions. The result is a focusing of the migration within a narrow time interval and a selection against the wide range of migration strategies that might occur naturally. Therefore, a major option for taking ocean conditions into account involves ensuring that restoration strategies are designed and evaluated in regard to their potential to restrict or enhance the natural expression of biological diversity in salmon populations.

The hypothetical scenarios described in Figure 1 have significant implications for the management of salmon, specifically those that limit salmon diversity. It is possible to take advantage of favorable ocean conditions and dampen negative ones by addressing potential settings of the ocean environment in a proactive, rather than a reactive or even a resigned, manner. An appropriate management response to environmental variability in general, and ocean variability in particular, is to relax anthropogenic pressures that inhibit or restrict development of a natural range of biological diversity.

From this premise, a primary means for taking ocean conditions into consideration in salmon management in general, and for the implementation of the Council's program in particular, it to evaluate recovery actions and their impact on biological diversity. Hatchery practices, for example, should need to minimize selection that restricts or skews the distribution of biological diversity. The role of hatcheries within a functioning salmonid ecosystem needs to be developed to allow populations to express diversity levels that enhance long-term survival (White et al. 1995). In the Columbia River, the use of smolt transportation, flow augmentation, spill and other juvenile migrational aids should be managed to provide benefits to the entire spectrum of migrants rather than the central majority of the run. Restoration efforts need to move from the paradigm of management for the average biological condition to management for the range of potential biological variation (Williams et al. 1996). Common to these scenarios is that biological diversity is not "fixed" or engineered in a mechanical sense but is allowed to increase to the appropriate level by relaxation of anthropogenic constraints. The appropriate level of biological diversity is not static, if indeed it is even quantifiable or predictable, but varies according to short and long term trends in the environment.

In the debate over innovative approaches to salmon management, it is questioned whether current capabilities to forecast changes in the marine environment are sufficient to adjust management decisions (Pulwarty and Redmond 1997). In general, resource managers are concerned with anticipating ocean and atmospheric conditions to manage their coastal waters and resources. The advent of modern remote sensors and electronic instrumentation has expanded significantly the ability to sample ocean conditions, fish distributions and ecosystems over multiple scales of space and time. Based on this progress, it has been argued that the impacts of future atmospheric and oceanic conditions on salmon populations could be modeled and, to some degree, predicted (Simpson 1994). With sufficient predictive power, it might be argued that hatchery releases and other practices could be managed in real time to maximize the fit between biological traits and the environment (Figure 1). However, the accuracy and precision of these predictions still require much improvement before management decisions can be implemented according to forecasts of ocean conditions (Walters and Collie 1988). Furthermore, a potential danger associated with this is continuation of the implicit belief that we can engineer biological systems to simultaneously meet the goals of multiple use, sustainability, and fish and wildlife as well. Predictive power aside, practical difficulties associated with managing production areas often located several hundred miles upriver from the ocean and the need to manage and protect the remaining wild populations and genetic resources, argue against the hope that fish might be engineered in response to real-time environmental predictions. While new technologies can be useful tools for ecosystem managers, caution should be exercised to avoid a "predict-and-control" approach as a surrogate to implementing sound ecological principles (Stanley 1995).

The ideas presented in this article argue against the default notion that salmon management activities are futile in the face of variable ocean conditions. If attention is focused on that portion of the marine environment that includes the estuary and near-shore plume at the mouth of the Columbia River, then there are important ways to directly address ocean conditions through the restoration of estuarine habitats. Specifically, we call for a significant re-assessment of management strategies that directly affect these environments. We further suggest that ocean conditions be taken into account by promoting the naturally evolved strategy that salmon use to accommodate environmental variability. We propose that policy directives and management actions be geared to estuarine habitat restoration and to promoting the conservation of salmon biological diversity. Improving the understanding of these actions and the ways they force biological changes in salmon life histories can enhance the management of Pacific salmon. Certainly, restoration of habitats and modification of actions and strategies to foster development of a natural expression of life history diversity within Columbia River salmon will likely conflict with other uses of the river and involve potentially costly tradeoffs. Thus, the management questions confronting policy-makers require an understanding of the impact of ocean and freshwater factors on salmon and a willingness to devise necessary adjustments to meet these challenges.

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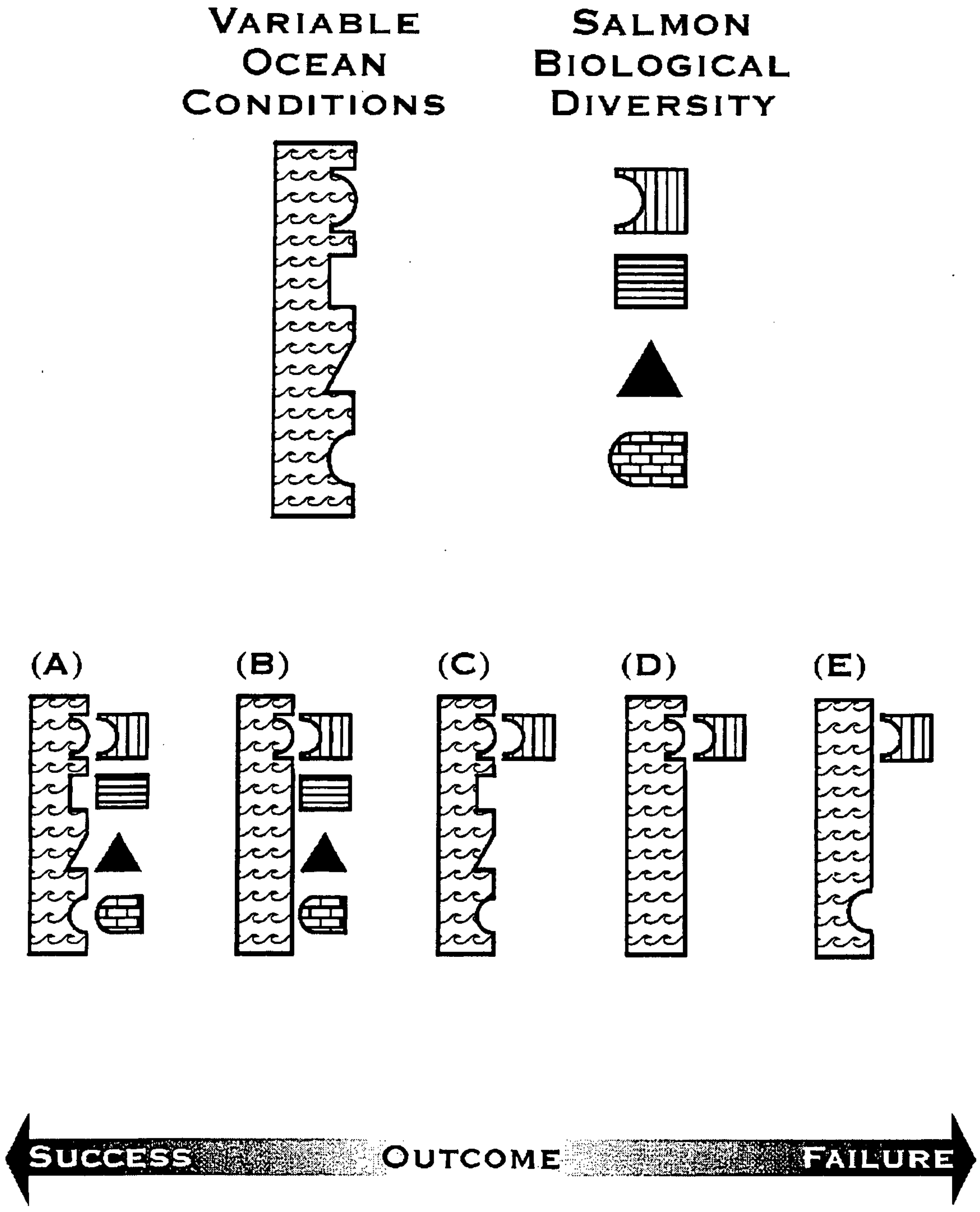


Figure 1. Interaction between ocean conditions and salmon life-history diversity. Five possible scenarios (A-E) illustrate the relative definition of failure and success of salmon management as determined by the fit between different salmon life histories (shapes on the top right) and the variability in ocean conditions (template on the top left).

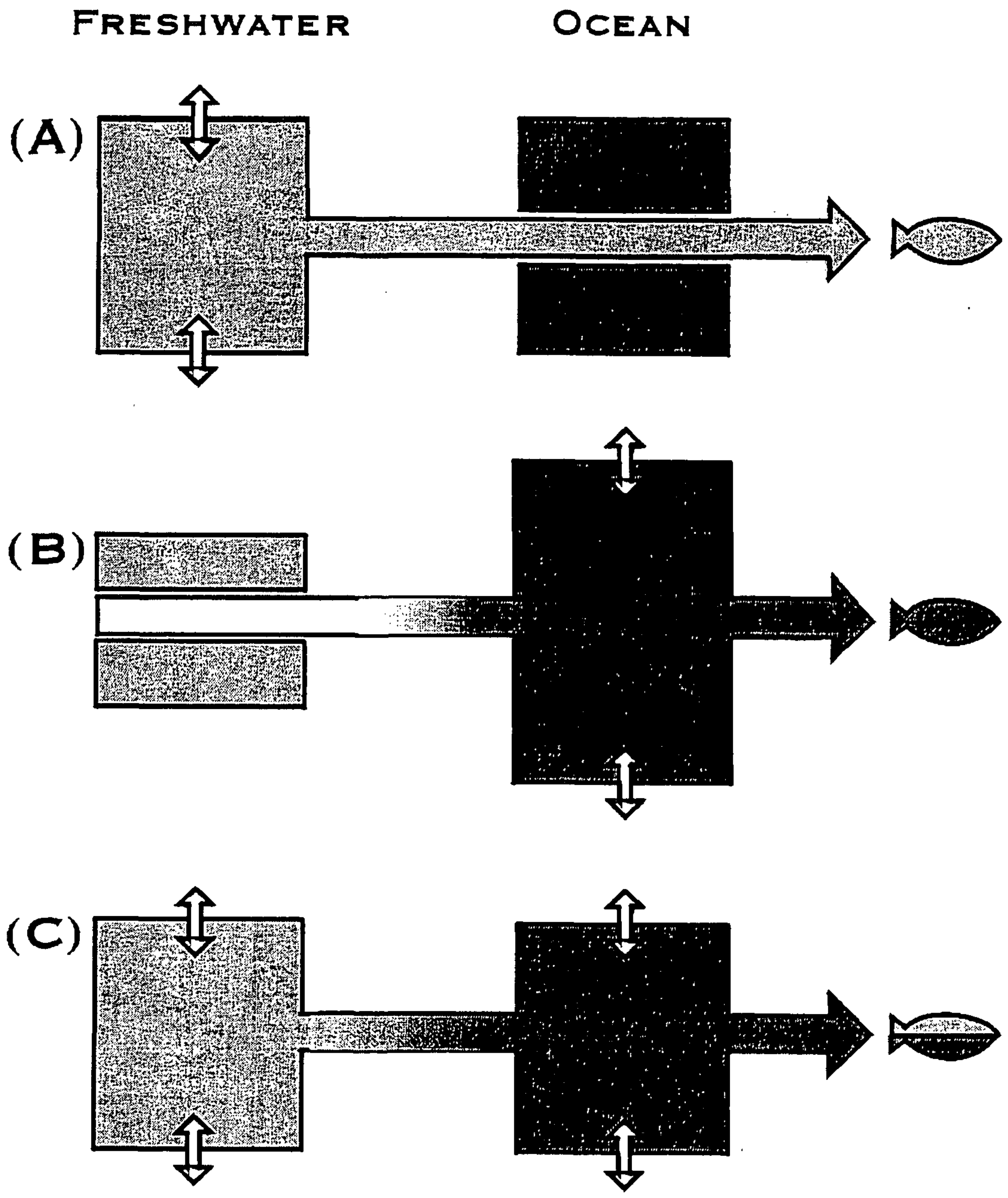
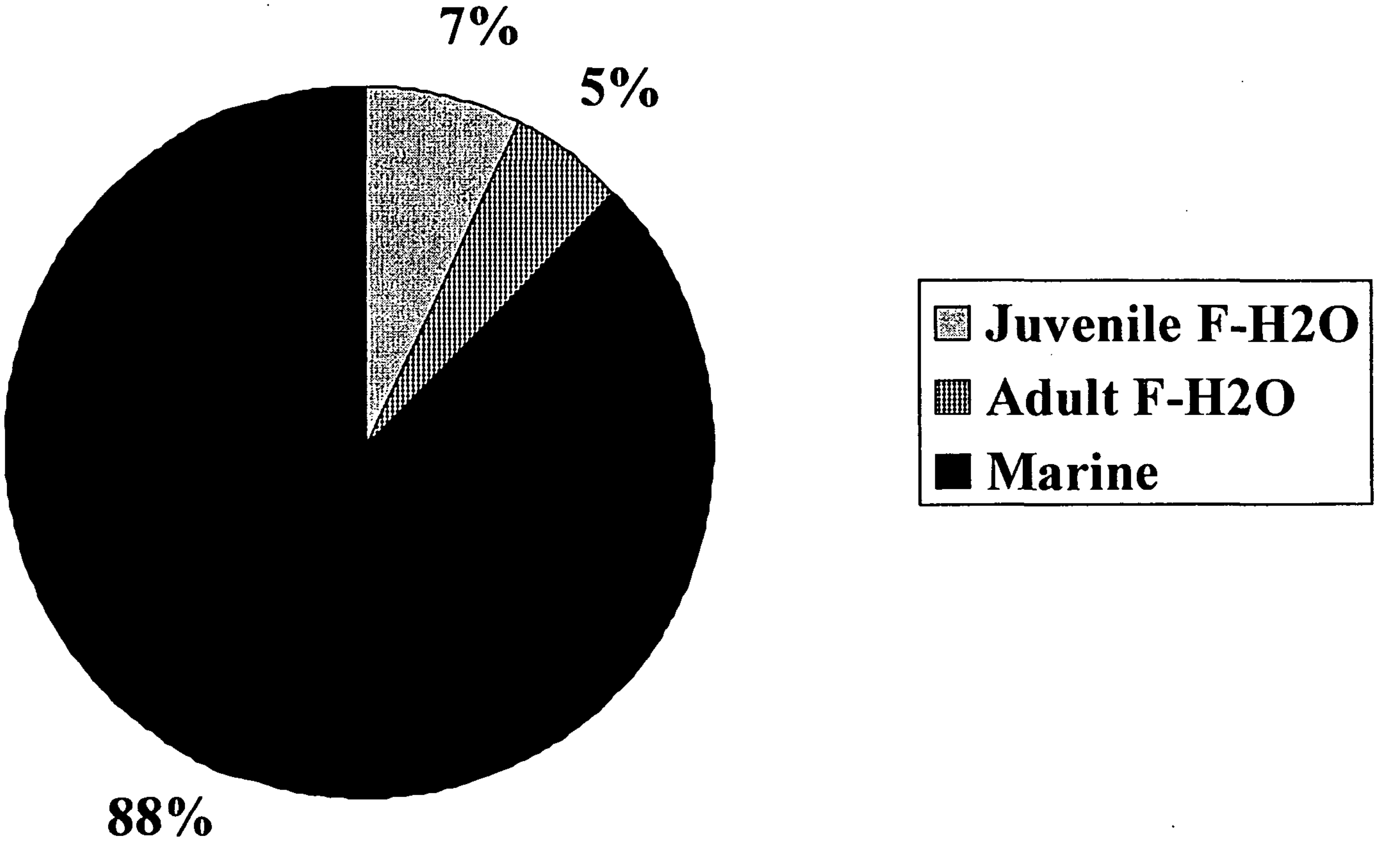


Figure 2. Different theoretical perspectives on the relative impact of freshwater and ocean environments on salmon production: A) Freshwater dominance, B) Marine dominance, and C) Holistic. In each case, the box on the left represents the freshwater environment, while that on the right represents the marine environment. The horizontal arrows through the boxes illustrate movement of juvenile salmon during their life cycle, from fresh water to the ocean. Vertical arrows on either the freshwater or marine boxes indicate were adjustments may occur in order to affect the number of fish returning. These adjustments can be natural, in the form of environmental variability, or human-caused, resulting from management actions to increase numbers of fish, or other activities that reduce their abundance.

Additional illustrations displayed during Chip McConnaha and Gustavo Bisbal's oral presentations

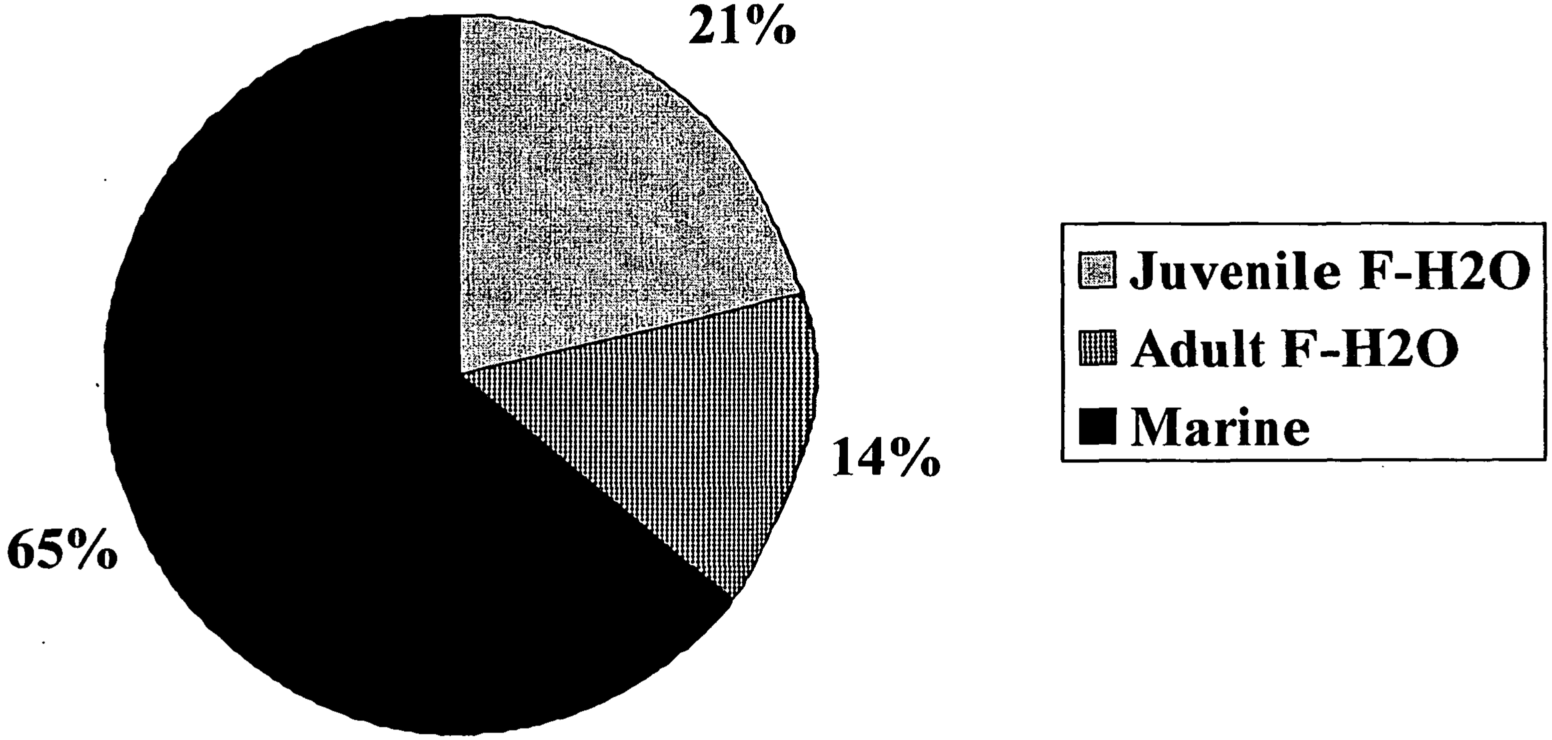
Ocean-type Chinook

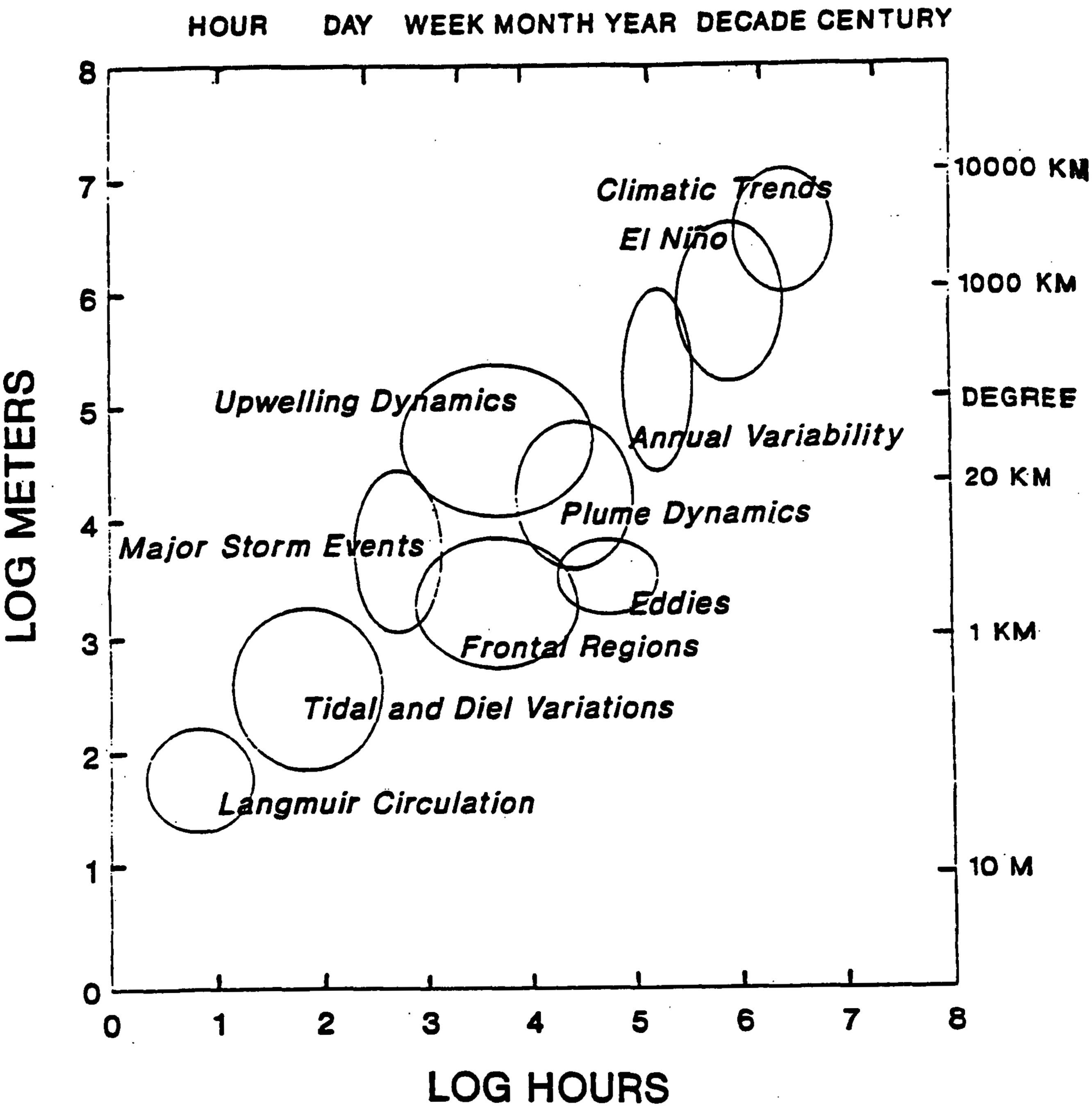
Life stage allocation by major habitat type



Stream-type Chinook

Life stage allocation by major habitat type





Time and space scales of physical variability in the ocean environment which may affect juvenile salmon.

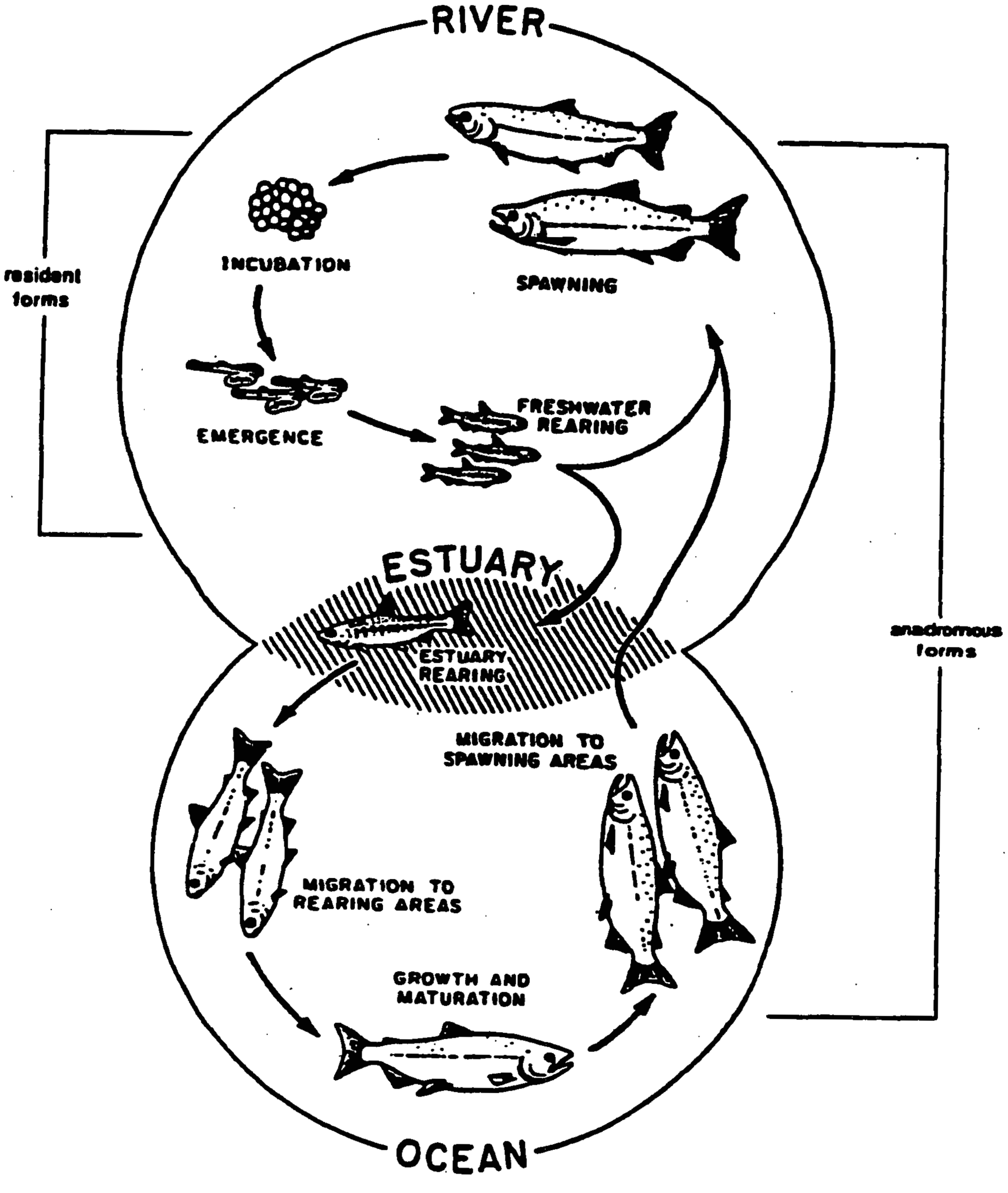
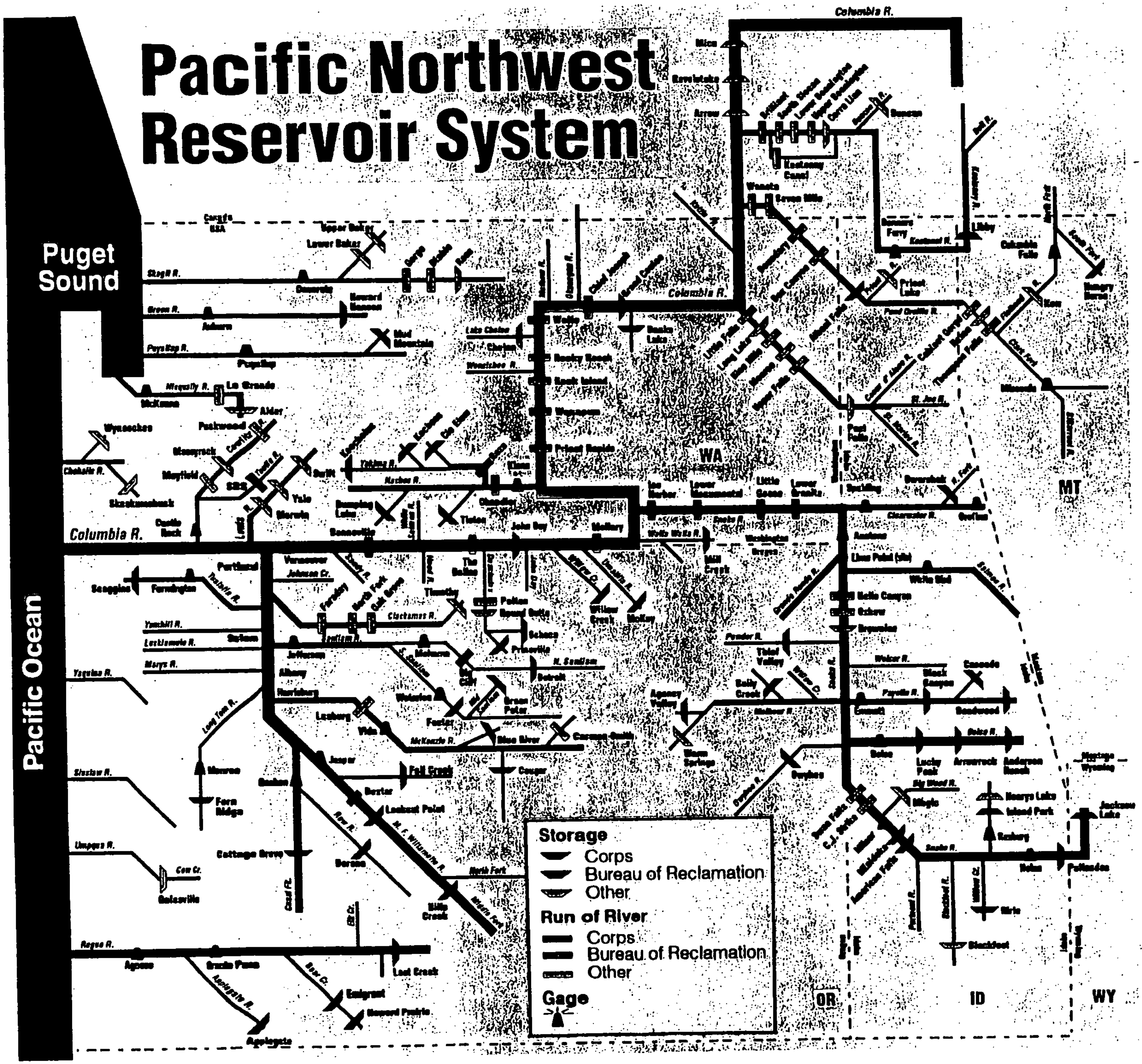


Figure 4-1. Generalized salmonid life cycle, showing freshwater and ocean components. Modified from Nicholas and Hankin (1988). Reproduced with permission from the authors.

Pacific Northwest Reservoir System



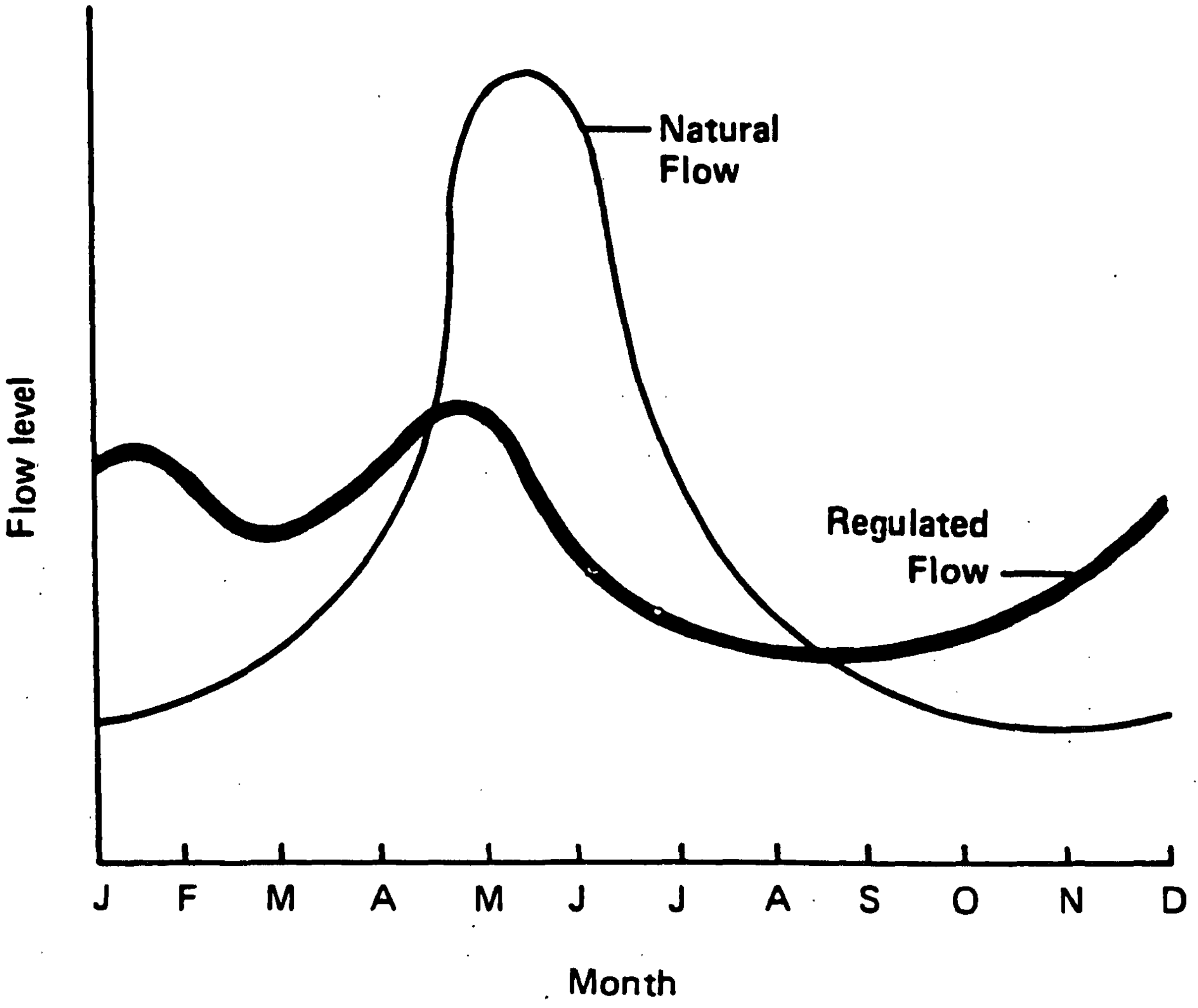


FIG. 2. Generalized effect of reservoir operations on mainstem Columbia River flows near The Dalles, Oregon. Tributary storage of water and mainstem production of hydropower eliminated the spring peak runoff that once transported juvenile salmonids downstream to the Pacific Ocean.

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Comparison of Estuarine Characteristics at Present and Pre-1870s.

From Sherwood et al. (1990)

Character	Pre-1870s	Present
Inputs from upriver (million t C year $^{-1}$)		
Phytoplankton	9,000	61,400
Detritus	73,000	147,000
Zooplankton	25	102
Area covered by tidal swamps and marshes (ha)		
Tidal marshes	6,548	3,723
Tidal swamps	12,149	2,813
Carbon equivalents of tidal marshes (million t C year $^{-1}$)	62,600	11,300
Macrodetritus production from marshes and swamps (million t C year $^{-1}$)	20,000	3,600
Estimated populations of primary consumers pre-1870s		
Wetland herbivores	12-138 times	present levels
Infaunal detritivores	12 times	present levels
Relative importance of foodweb pathways		
Pelagic microdetritus-based pathway	Low	High
Benthic macrodetritus-based pathway	High	Low
Detritus export to the ocean (million t C year $^{-1}$)	80,000	159,200

Long-term Climate and Ocean Trends and Salmon Populations in the Pacific Northwest

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Declines in salmon populations in the Northwest have occurred despite many decades of management attempts, and untold millions of dollars. Many of the management strategies focused on a single aspect of the problem, such as overfishing, habitat restoration, or water diversions. Recently a more comprehensive "ecosystem based" approach has been initiated, one that considers a multitude of factors for salmon enhancement. This paper describes some aspects of what may be considered the "backdrop" for salmon survival: climate and ocean conditions in the Northwest and the North Pacific.

There is increasing evidence that salmon populations in the northeast Pacific are significantly influenced by long-term climate and ocean changes. An examination of the historic records for salmon and environmental variables shows variations over a number of time scales. A better understanding of the lengths and causes of these "cycles" will enable decision-makers to make more informed choices regarding salmon recovery strategies.

Precipitation variations

In the Northwest, temperature and precipitation data go back about 100 years. During that time there have been four relatively distinct climatic periods. These are illustrated in Figure 1, which shows annual precipitation (departures from the long-term average) for the Oregon Coast. All stations west of the crest of the Coast Range were averaged together to get a single value each year, and every year's value compared with the long-term average. The Water Year (October through September) was used so that all months from a single winter remained in the same data set.

The four climatic periods were:

1896-1914 Generally wet (and cool)
1915-1946 Generally dry (and warm)
1947-1975 Generally wet (and cool)
1976-1994 Generally dry (and warm)

Note that the last four years, all of them wetter than average, more closely resemble those that prevailed during the wet and cool periods. The 1998-99 season is the fifth consecutive wet year. In any given climatic period, not all the years are dry or wet, but a high percentage (roughly 75%) follows that pattern. For example, in the 1915-1946 period there were 22 dry years and only 10 wet ones. Consecutive dry years were common (indicating drought periods). The wet period immediately following had 21 wet years versus 7 dry ones, and consecutive dry years never occurred. Droughts were nonexistent during the latter period, although there were several major floods.

Some of the data from single stations show variations, which are somewhat different from the multi-station averages in Figure 1. Figure 2 shows annual precipitation at Portland since 1910. While the overall trends are similar to those in Figure 1, there is also evidence of shorter-term variations; in essence, there are 10-year cycles within 50-year cycles.

Ocean currents

It is becoming apparent that surface currents in the northeast Pacific are subject to long-term variations that coincide with the climate variations described above. Since 1946, the Bakun upwelling index, a numeric value based on surface wind speed and direction, has been calculated. Figure 3 shows spring (April-June) values of the Bakun index. Note the high values (strong upwelling) in earlier decades, and generally negative values since 1979.

It appears that the surface current variations result not from local changes but rather from basin-wide variations involving the entire North Pacific. Several scientists have suggested that the position and strength of the Aleutian Low is a key element in North Pacific current variation. During some years (Figure 4, top), the Low is very deep, and strong cyclonic (clockwise) flow around the Low causes surface winds to be generally from the southwest across the northeast Pacific. This results in a strong deflection of surface water to the north, towards Alaska, and relatively weak flow to the south (the California Current). Historically, such periods appear to have been more common during the decades when the Northwest has been warm and dry.

On the other hand, there are years (and decades) when typical wind flow across the North Pacific is from the west of west-northwest, due to a weak or nonexistent Aleutian Low. The bottom half of Figure 4 illustrates this situation. During such conditions, more of the surface water is diverted southward, enhancing the California Current and reducing flow into the Gulf of Alaska. This type of wind/current flow has been much more common during the wet-cool periods in the past.

Since stronger upwelling produces more favorable offshore conditions for salmon, and since salmon thrive onshore during generally wet periods (when river flows are high and water is cool), these correspondences of precipitation and ocean currents cause great variation in the potential for salmon survival. During the generally dry, warm periods, when upwelling is poor, survival potential would appear to be quite low compared with the alternate periods when cool, wet conditions correspond to stronger upwelling. Let us now examine the salmon records to verify whether this is so.

Salmon returns

Anderson (1995) has studied the effects of climate and ocean conditions on salmon. Figure 5, which was reproduced from that document, compared the "Pacific Northwest Index" (PNI) to Columbia River spring chinook salmon returns going back to 1940 (earlier data are not available). PNI provides a numeric value representing precipitation and temperature; note the similarity with Figure 1. The correlation between spring chinook and PNI is very strong, and indicates that salmon return increase during cool, wet periods and decline during warm, dry ones.

While there are undoubtedly human-induced effects on the fish (including dam construction and habitat destruction), Figure 4 indicates that the expected "survival potential" described in the previous section is indeed reflected in salmon returns.

While stocks in the Northwest have shown low numbers in recent decades, Alaska salmon have had a tremendous boom period. Climatologists have known for many years that weather patterns in Alaska and the Northwest are out-of-phase: wet periods in the Northwest tend to be dry in Alaska, and vice-versa. The El Niño-Southern Oscillation appears to be the major reason for this flip-flop. Interestingly (and perhaps not surprisingly), salmon returns in the Northwest and Alaska are similarly out of phase. In Figure 6, also from Anderson (1995), Columbia and Alaska salmon are shown to be out of phase, with the abundant 1950-1975 period in the Northwest corresponding with a very poor salmon period in Alaska. When Northwest stocks declined in the 1970's, Alaska's were soaring.

Mantua et al. (1996) identified the phase differences between Northwest and Alaska salmon stocks using observational data back to the early 1940s. They also quoted from the Pacific Fisherman Journal to demonstrate that the two areas have been out of phase throughout the century:

> *Pacific Fisherman 1915*
> *"Never before have the Bristol Bay [Alaska] salmon packers returned to port after the season's operations so early."*
> *"The spring [chinook salmon] fishing season on the Columbia River [Washington and Oregon] closed at noon on August 25, and proved to be one of the best for some years."*
>
> *Pacific Fisherman 1939*
> *"The Bristol Bay [Alaska] Red [sockeye salmon] run was regarded as the greatest in history."*
> *"The [May, June and July chinook] catch this year is one of the lowest in the history of the Columbia [Washington and Oregon]."*
>
> *Pacific Fisherman 1972*
> *"Bristol Bay [Alaska] salmon run a disaster."*
> *"Gillnetters in the Lower Columbia [Washington and Oregon] received an unexpected bonus when the largest run of spring chinook since counting began in 1938 entered the river."*
>
> *Pacific Fishing 1995*
> *"Alaska set a new record for its salmon harvest in 1994, breaking the record set the year before."*
> *"Columbia [Washington and Oregon] spring chinook fishery shut down; West coast troll coho fishing banned."*

ENSO

It is well known that the El Niño Southern Oscillation (ENSO) has a profound effect on climate in the Northwest. Most of the time, El Niño or "warm" events produce dry, mild winters in the

Northwest, while La Niña or "cool" events coincide with wet, cool winters. El Niño winters are characterized by strong Aleutian Lows, while La Niñas are more conducive to westerly or northwesterly winds across the North Pacific, so it can be postulated that ENSO is the cause of the wind and current scenarios shown in Figure 4.

While El Niños and La Niñas occur with about the same frequency over the historical record (the most reliable records go back about 150 years), there have been periods with far more El Niños, and others with more La Niñas. The period from 1975-1994, for example, was dominated by El Niños (six, versus only one true La Niña), whereas the 1947-74 years had more La Niñas. There may be a mechanism that varies over several decades that causes changes in frequency of ENSO phases, and thus in local climate and ocean conditions. Let us examine the most significant cyclical variations in the earth-atmosphere-ocean system to see if we can identify the causes of these variations.

The Global Connection

In the last decade, a great deal of research has focused on global-scale variations in ocean currents and their effects on climate conditions. Gray and Landsea (1993) described the global thermohaline circulation, or "conveyor belt," as a slow, steady movement of warm water from the Pacific, Indian and south Atlantic into the tropical and north Atlantic (see Figure 7). When this "conveyor" is active, the Atlantic warms and the Pacific and Indian oceans cool. During inactive periods, the reverse occurs. A warmer Atlantic should coincide with greater numbers of hurricanes and greater precipitation around the Atlantic rim, including the Sahel region of west Africa. A warmer Pacific would be linked to increased numbers of El Niño events, and thus generally dry conditions in the Northwest, while a cool Pacific should correspond to more La Niñas and wet, cool conditions in our region.

Table 1 is a "scorecard" of variations in hurricanes, precipitation and ENSO over the last century. The matchup with the previously cited periods in the Northwest is quite consistent, and suggests that the "conveyor" effect may be a major reason for the variations seen in our region. The fact that several of the parameters in the table changes suddenly about five years ago, just when the Northwest entered what has been a very wet period, adds further credence to this hypothesis.

Cyclical Variations

There are a number of cyclical or quasi-cyclical variations which are known to affect the atmosphere and oceans. Table 2 lists some of them. It is probable that a combination of the variations shown, as well as others of longer length and some not yet identified, produce the regional climate-ocean variations shown earlier.

Implications for Decision-Making

Over time, our understanding of the role of periodic variations in climate and ocean conditions will improve. Eventually we may even be able to predict these changes in advance. In any case, it is clear that these environmental variables have played a major role in salmon survival rates in this century.

Also apparent is that management/enhancement strategies will be more effective if this environmental "backdrop" is considered. A strategy that works quite well during periods of favorable climate and ocean conditions, such as occurred in the 1950s and 1960s, may be a dismal failure in the dry, warmer regime. In addition, the evaluation of the success of salmon management should consider these environmental conditions. What might be deemed a very poor year for salmon returns might in actuality be a successful one if it occurred during truly unfavorable climate/ocean conditions. On the other hand, a slight increase in salmon might not be cause for celebration if it occurred during a truly outstanding climatic year. Rather than simply report salmon returns, we must evaluate them in light of what the potential returns might have been.

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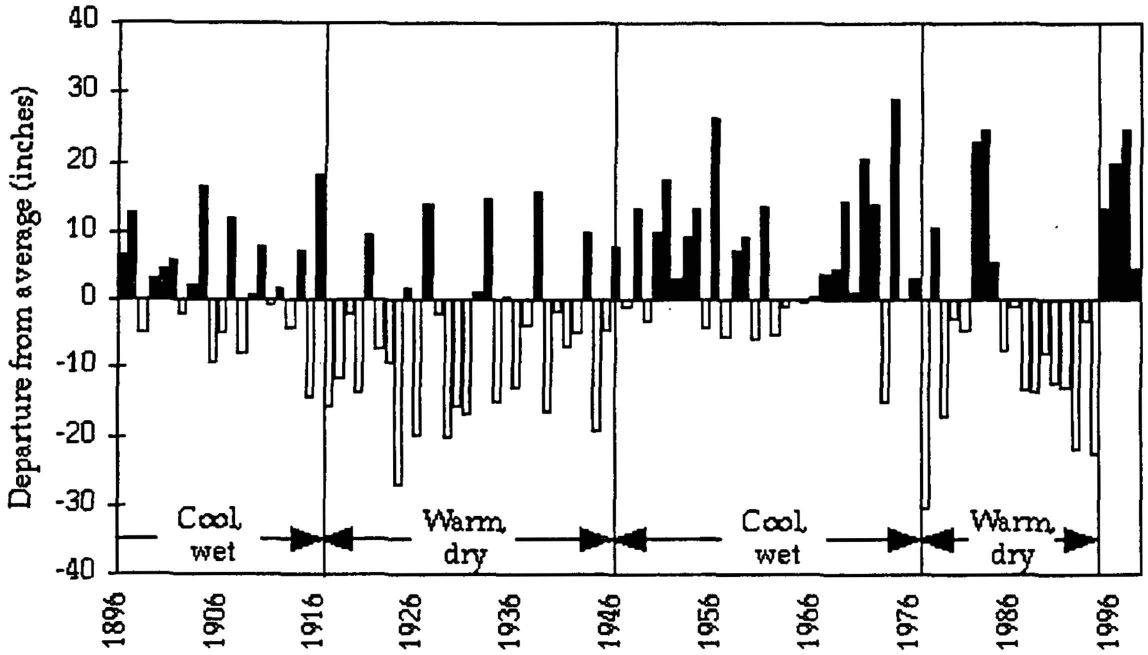


Figure 1. Water Year Precipitation (Oct.-Sept.), Oregon Coast climate division, 1896-1998, showing annual departures from 103-year average.

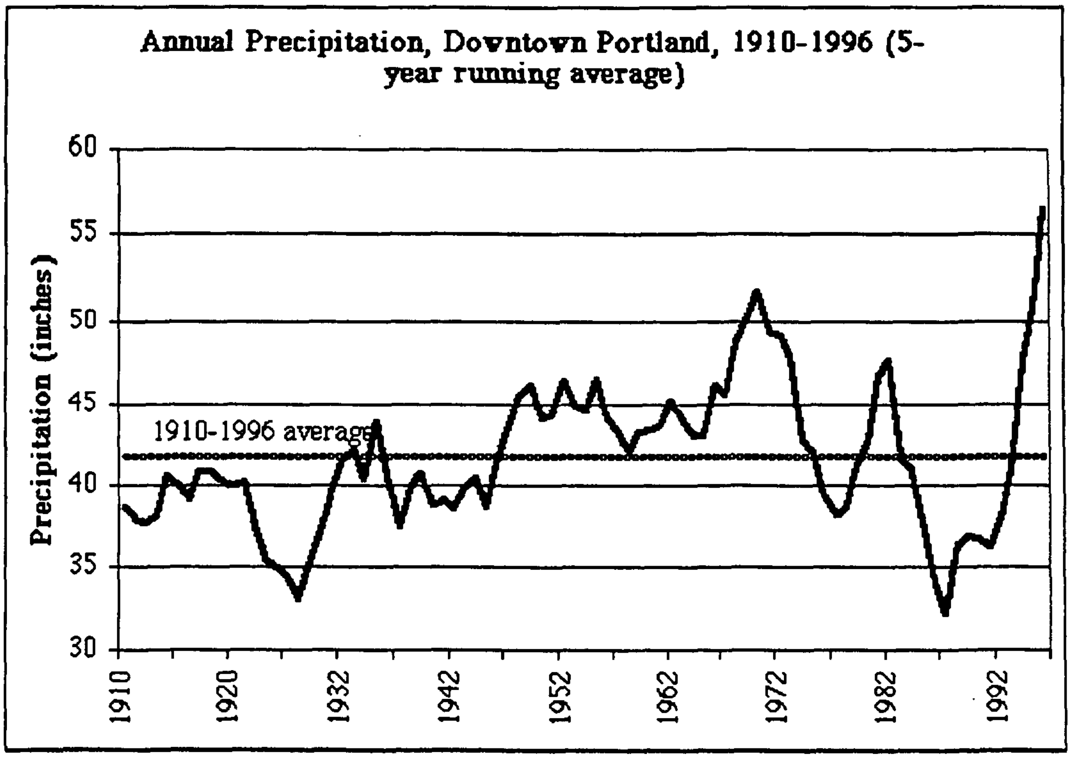


Figure 2. Annual precipitation, downtown Portland, 1910-1996 (5-year running average).

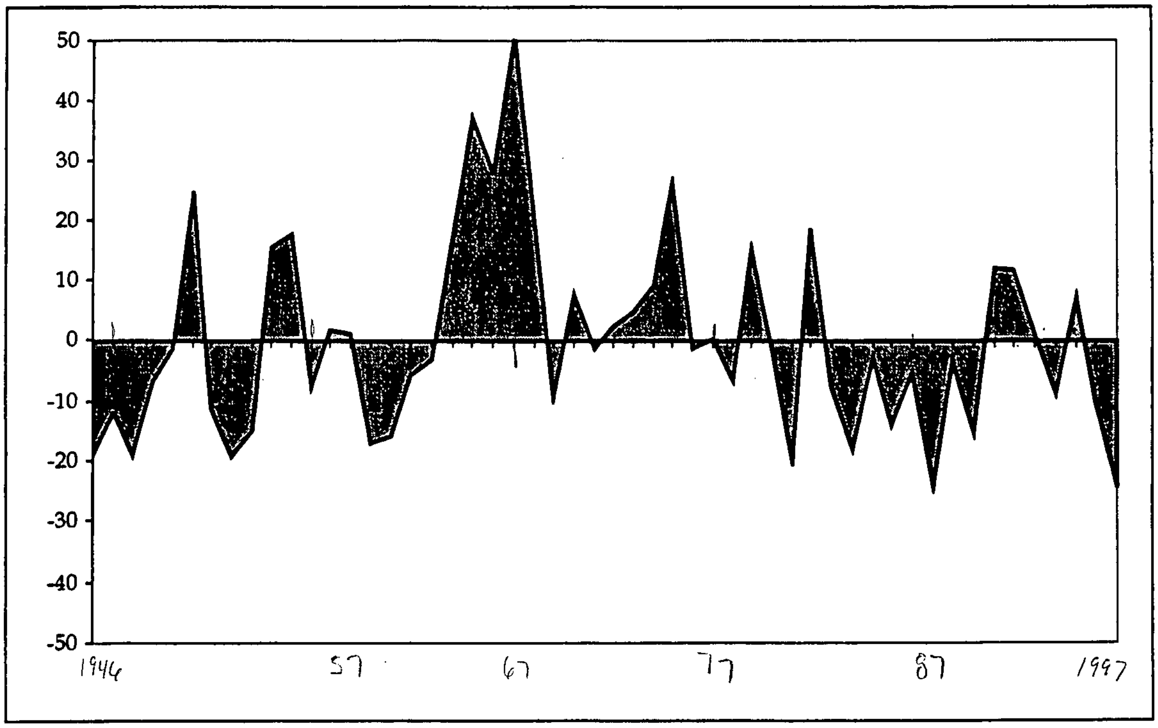


Figure 3. Bakun upwelling index, April-June average, at 45° N, 125° W.

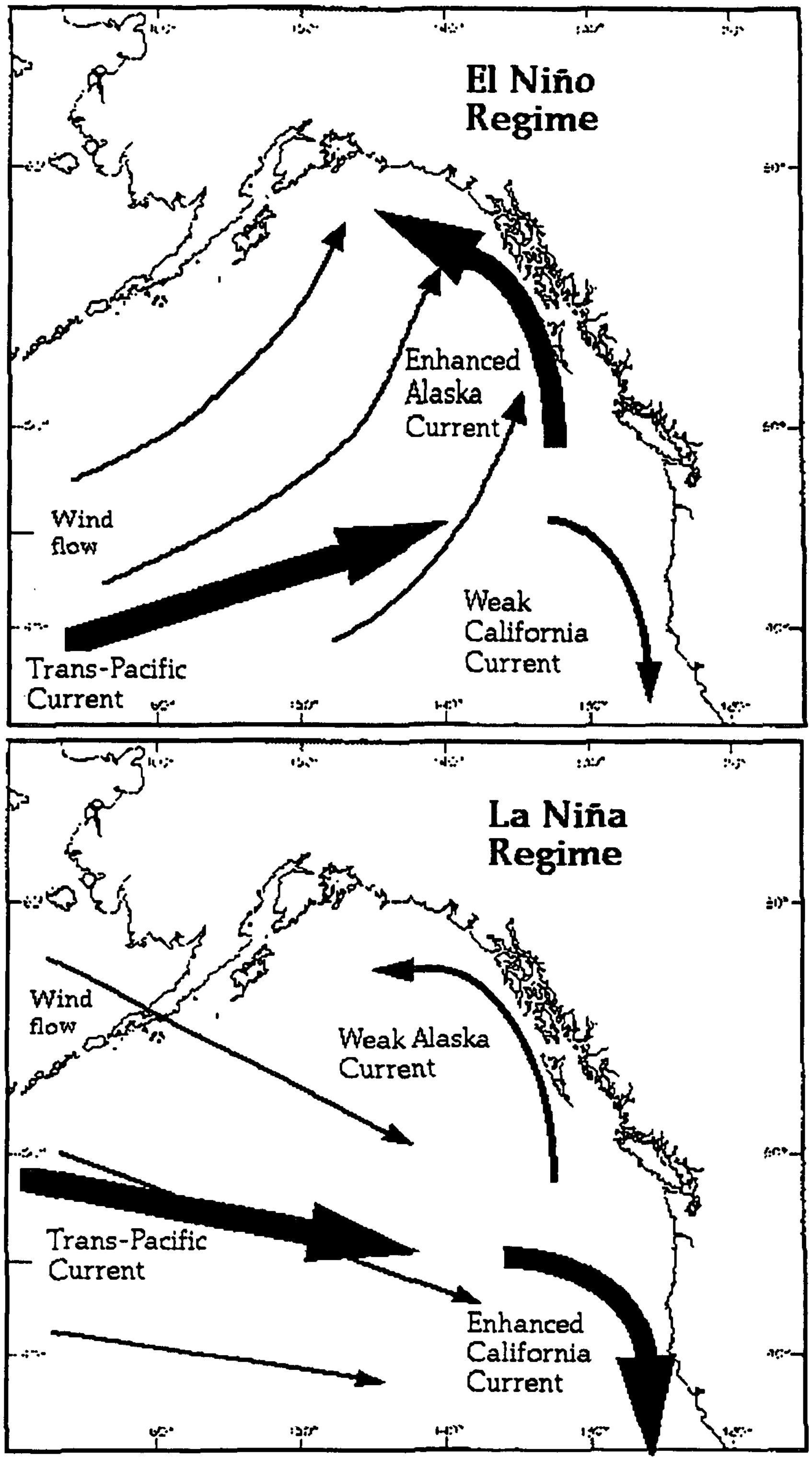


Figure 4. Typical wind direction (small arrows) and surface currents (large arrows) during different types of conditions. (Top) strong Aleutian Low, southwesterly winds, strong Gulf of Alaska Current, weak California Current; (Bottom) westerly or northwesterly winds, west-to-east trans-Pacific Current, strong California Current, weak Alaska Current.

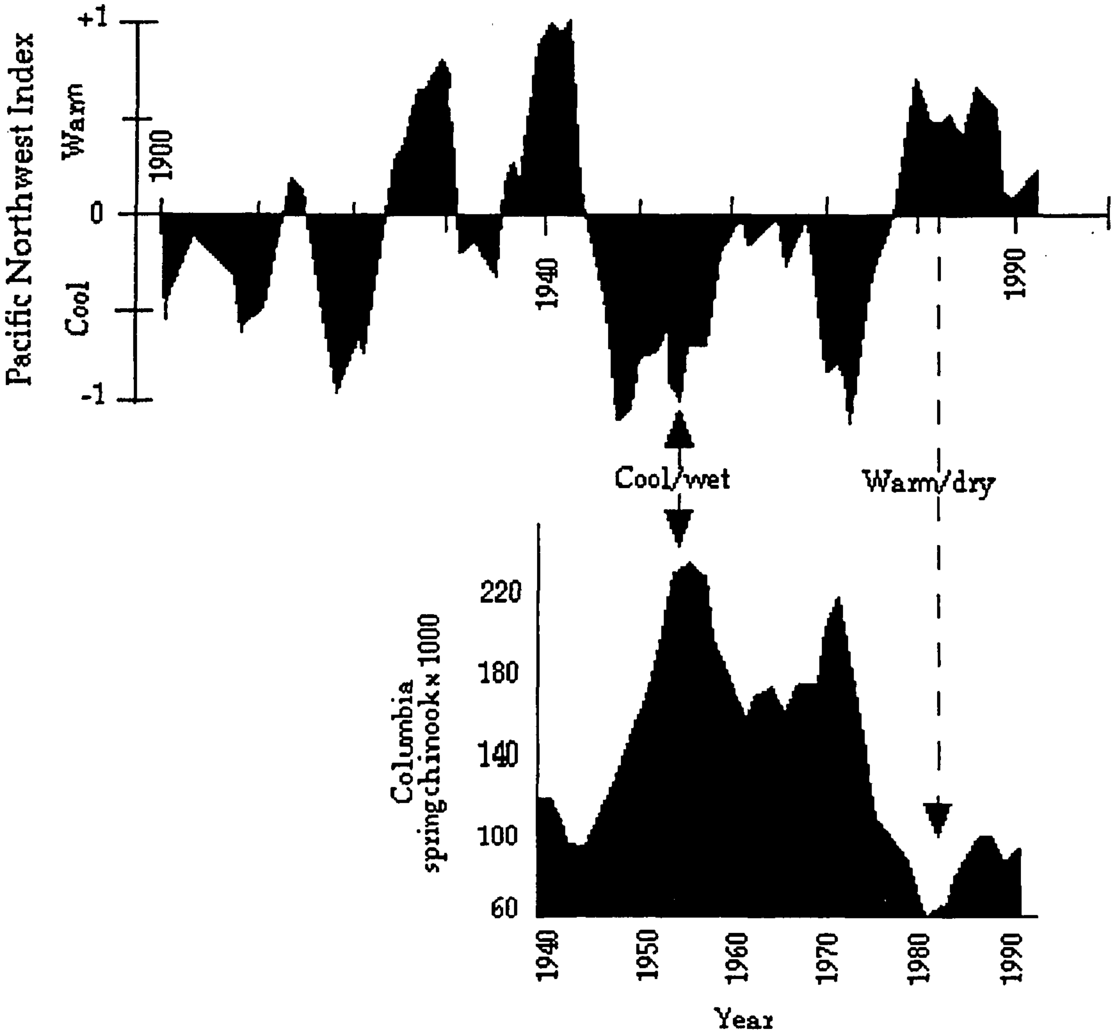


Figure 5. The correlation between the Pacific Northwest Index (PNI) and abundance of Columbia River bright spring chinook salmon (5-year running averages), reproduced from Anderson (1995).

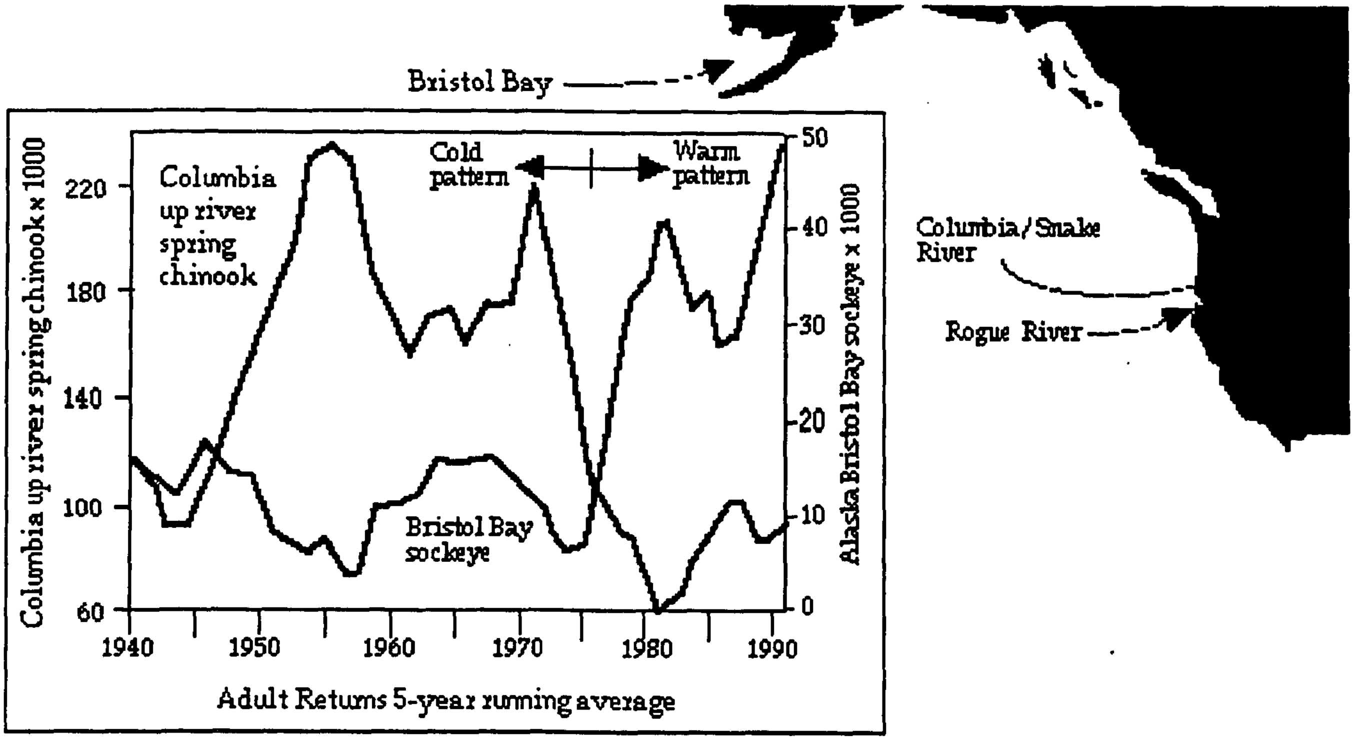


Figure 6. Comparison of Columbia River spring chinook and Bristol Bay, Alaska sockeye salmon counts since 1940 (reproduced from Anderson 1995).

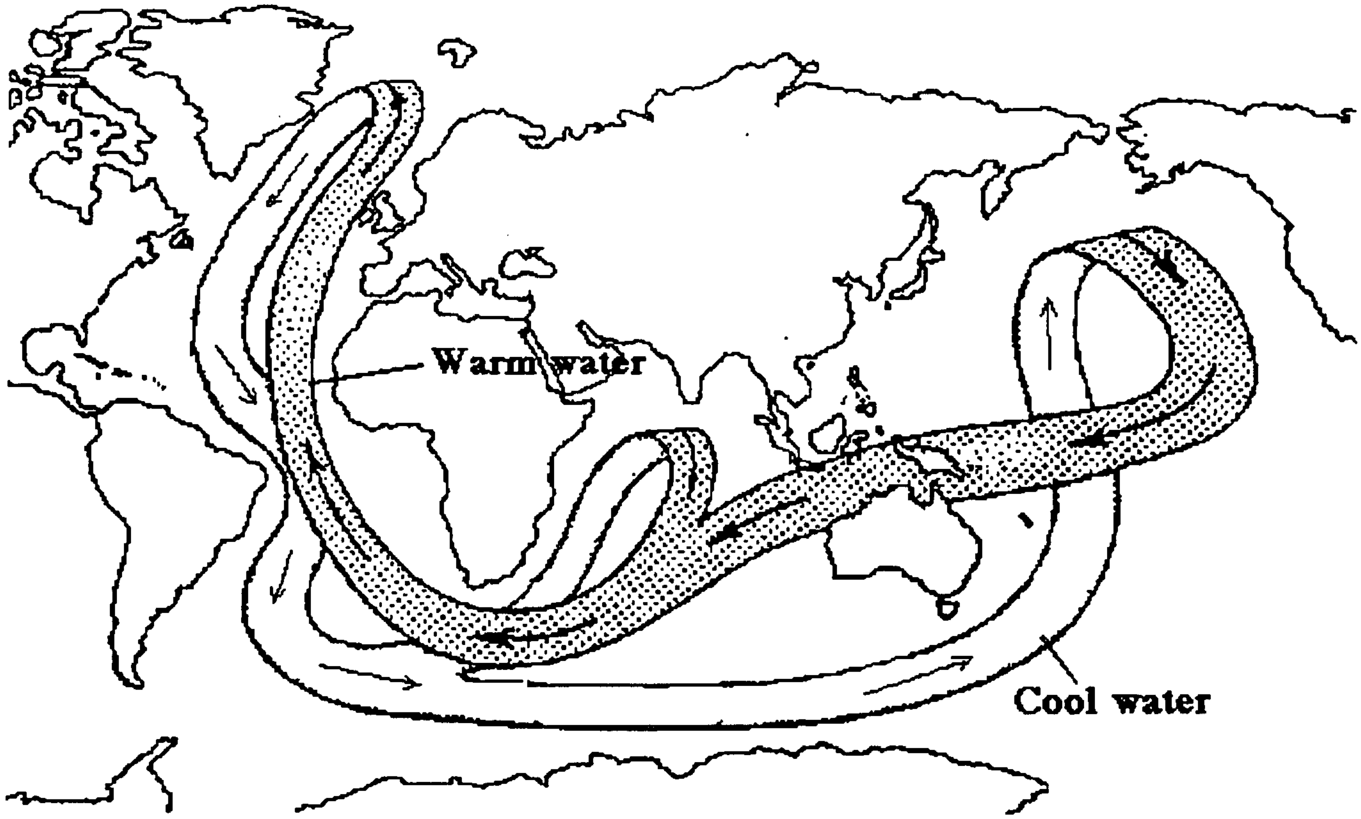


Figure 7. Schematic of the global thermohaline circulation, or "conveyor belt" (adapted from Gray and Landsea 1993).

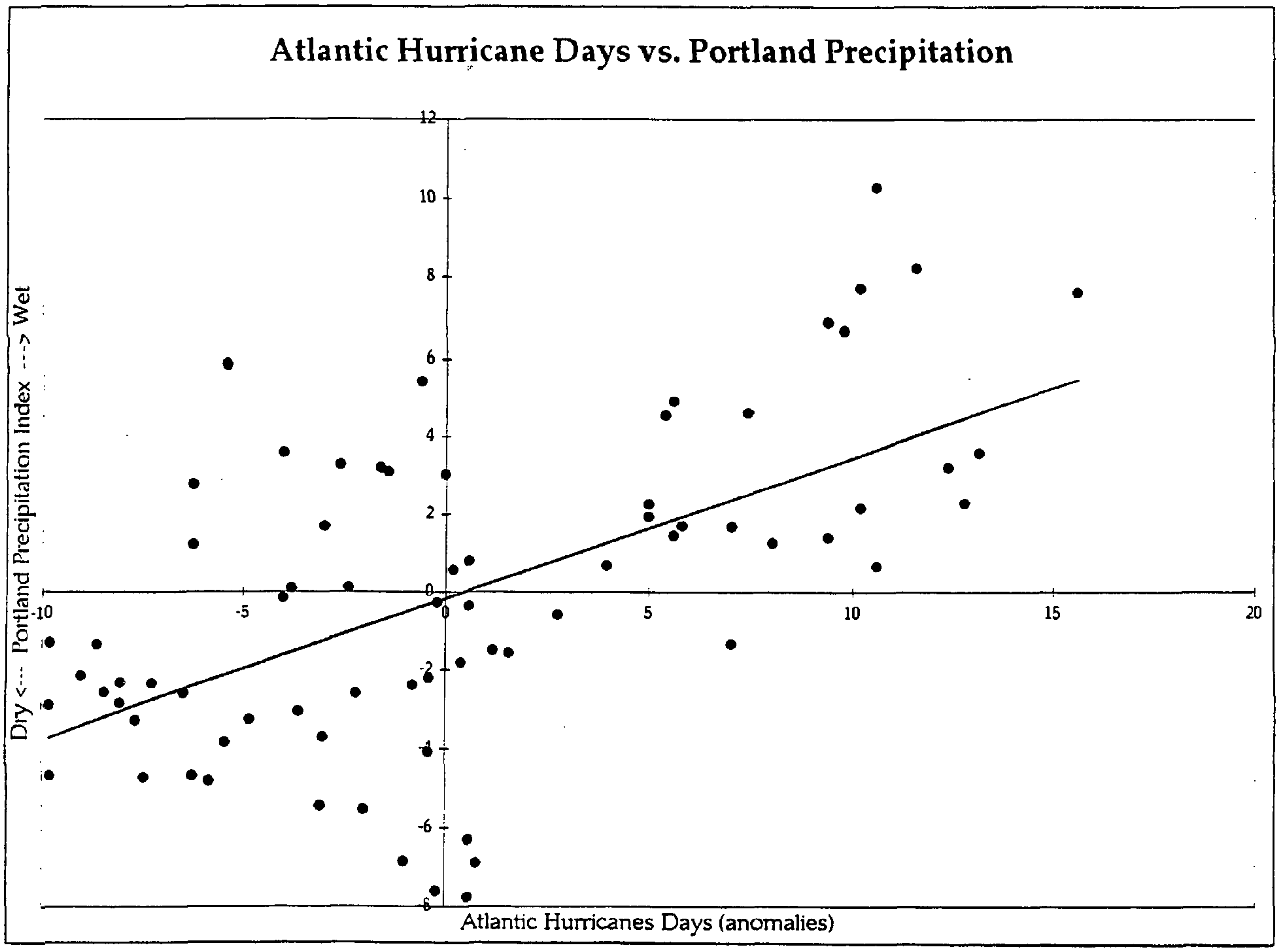
Table 1. Evidence for multi-decadal shifts in weather and ocean conditions worldwide, including precipitation in the Pacific Northwest (PNW). These patterns are consistent with apparent changes in the global thermohaline circulation, or "conveyor belt."

Parameter	1890-1917	1918-1945	1946-1974	1975-1994	Since 1994
Atlantic hurricanes	Many	Few	Many	Few	Many
Sahel rainfall	Very wet	Average	Very wet	Very dry	Average
El Niño events	Few	Many	Few	Many	One, but 3 La Niña years
Global air temps	Decrease	Increase	Decrease	Increase	?
PNW precipitation	Wet	Dry	Wet	Dry	Wet
Conveyor belt	Strong	Weak	Strong	Weak	Strong

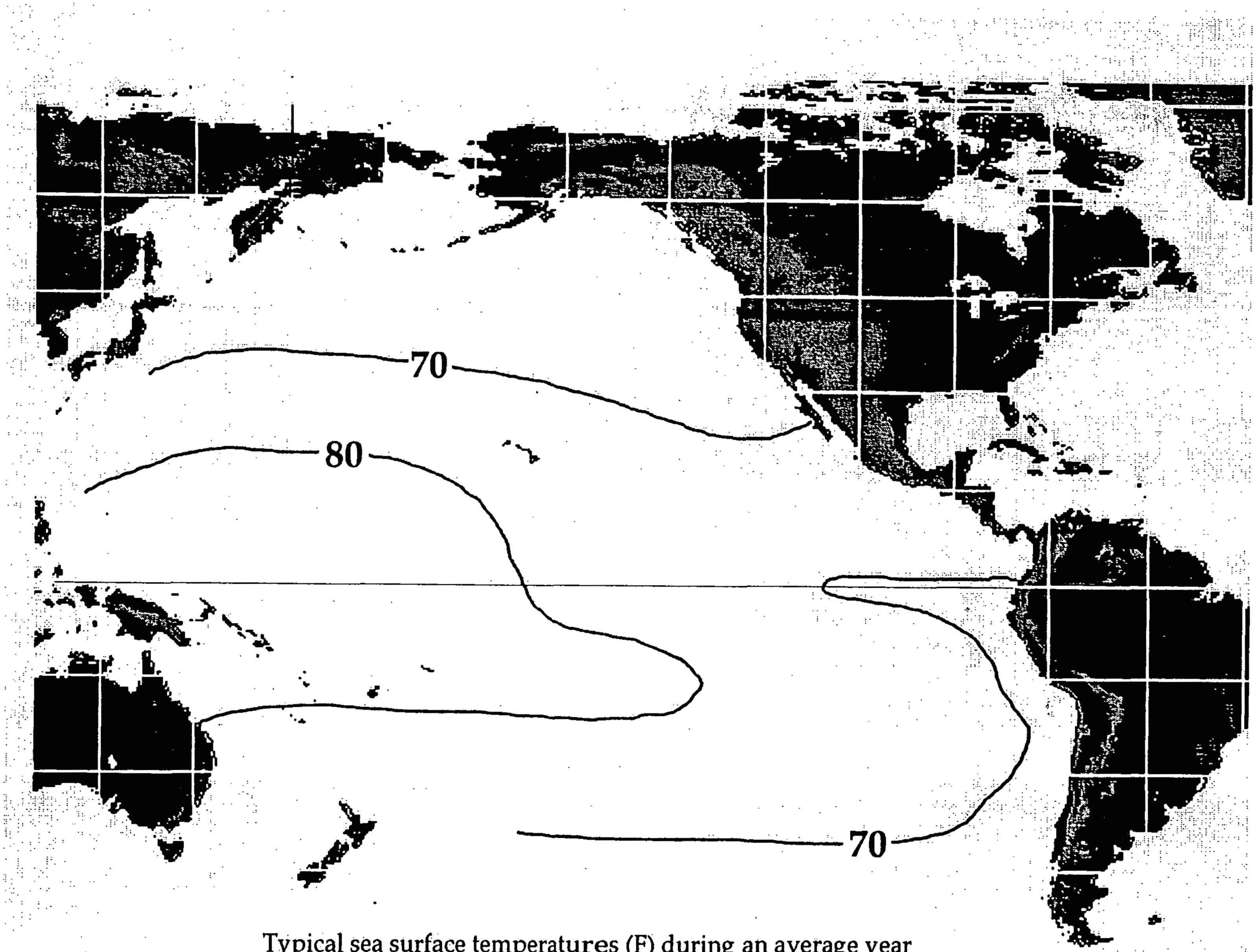
Table 2. Some of the major short-term cycles in the atmosphere and oceans.

Cycle	**Length**	**Effect**
Seasonal	1 year	Seasons
Quasi-biennial	2.2 years	Shift in wind direction in the tropical stratosphere appears to cause changes in ENSO and other factors
ENSO	1-3 years	Worldwide climate effects and changes in entire Pacific
Sunspots	11 years	Changes in solar radiation, and thus temperatures
Lunar tides	18.6 years	Not fully understood
Sun's magnetic field	20-27 years	Shorter cycles appear to cause greater atmospheric warming than long cycles

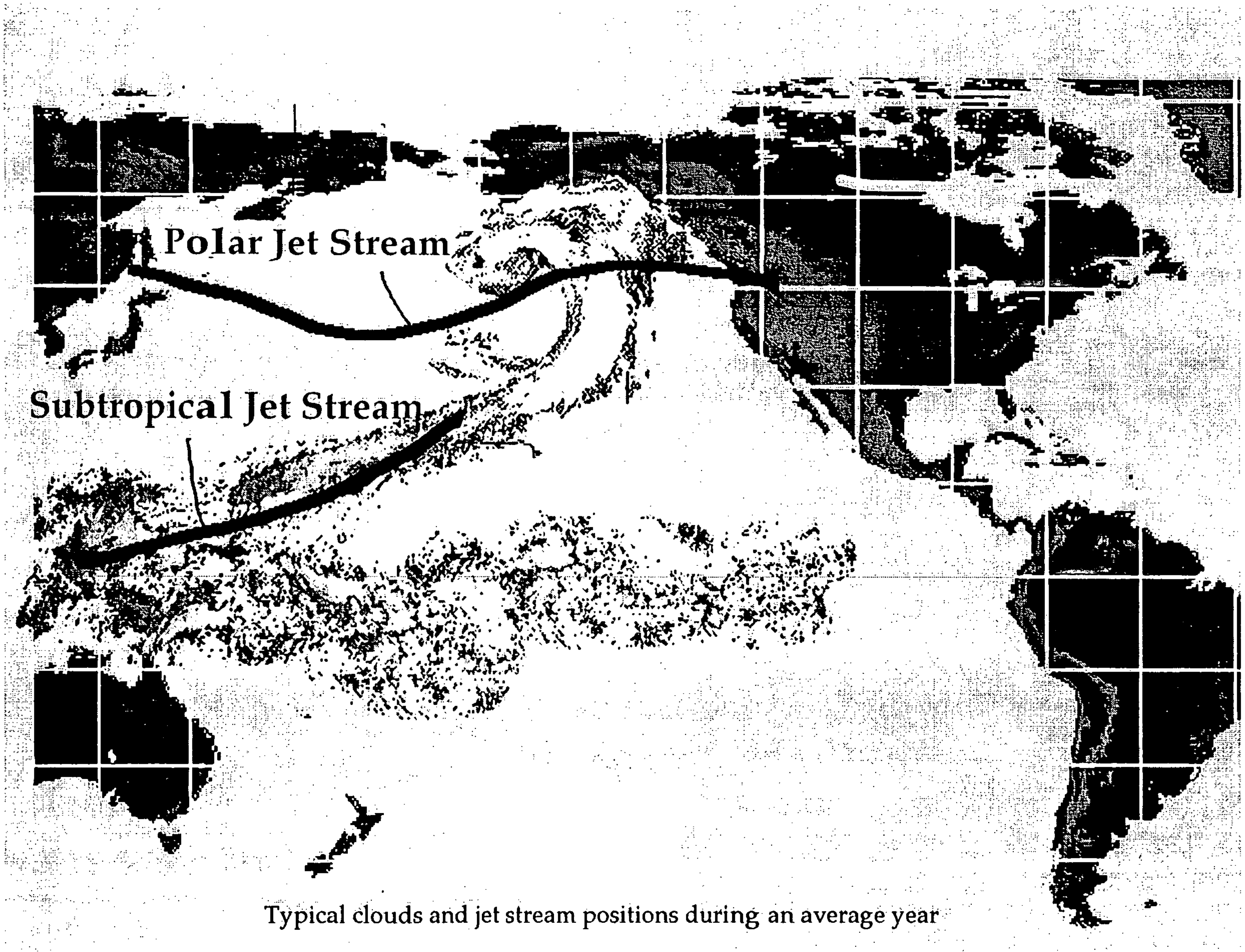
Additional illustrations displayed during George Taylor's oral presentation



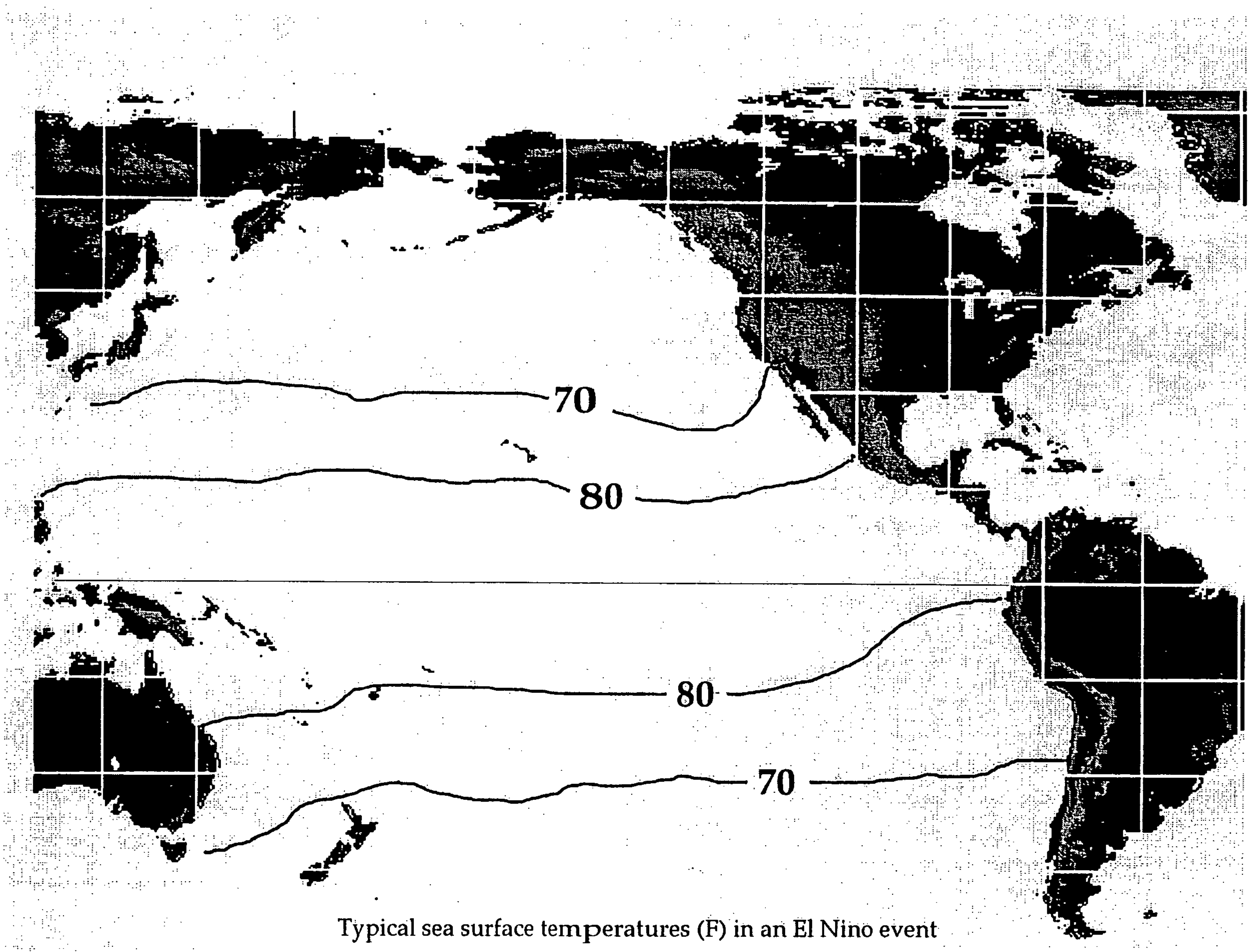
Atlantic Hurricane Days vs. Portland Precipitation



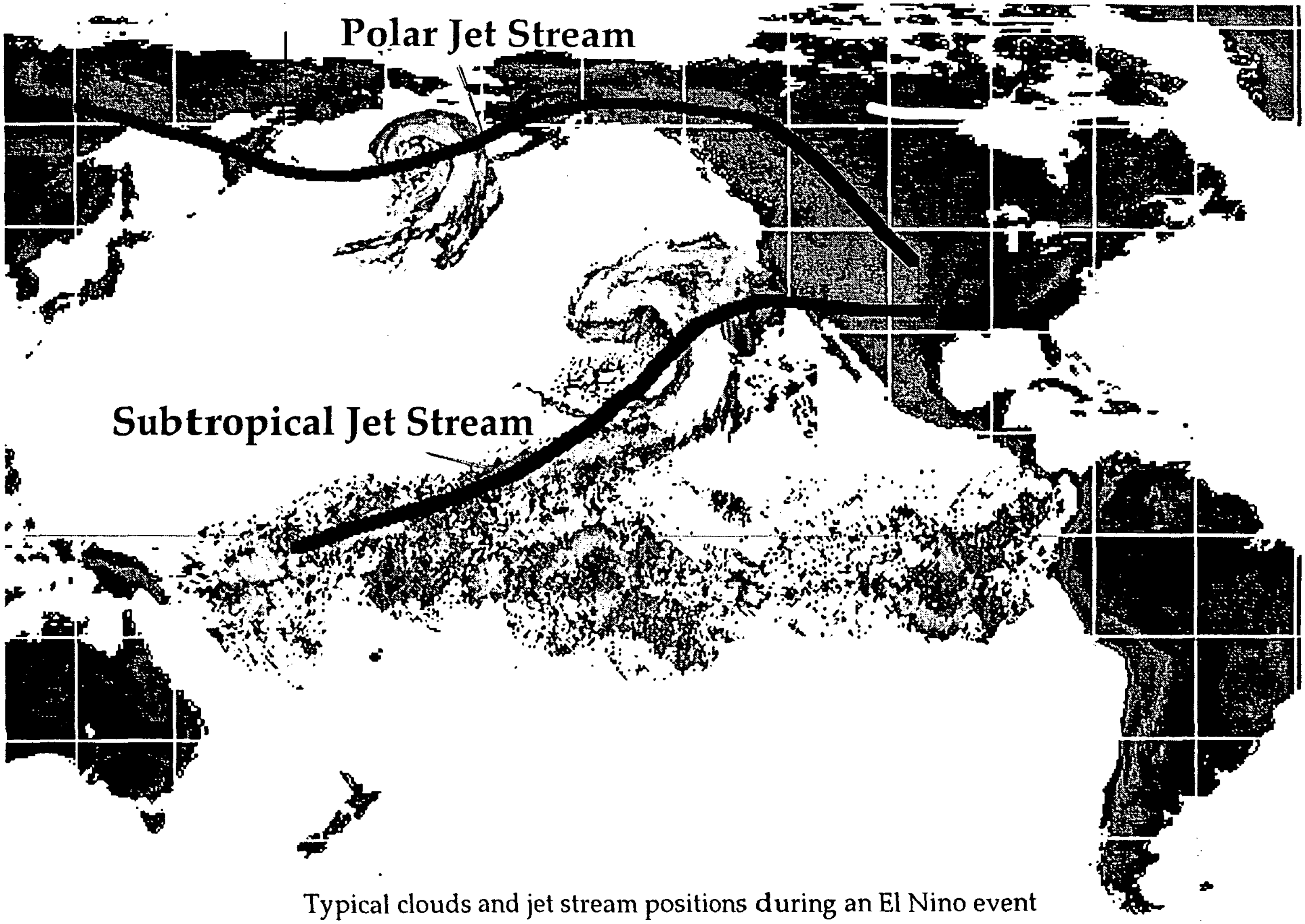
Typical sea surface temperatures (F) during an average year



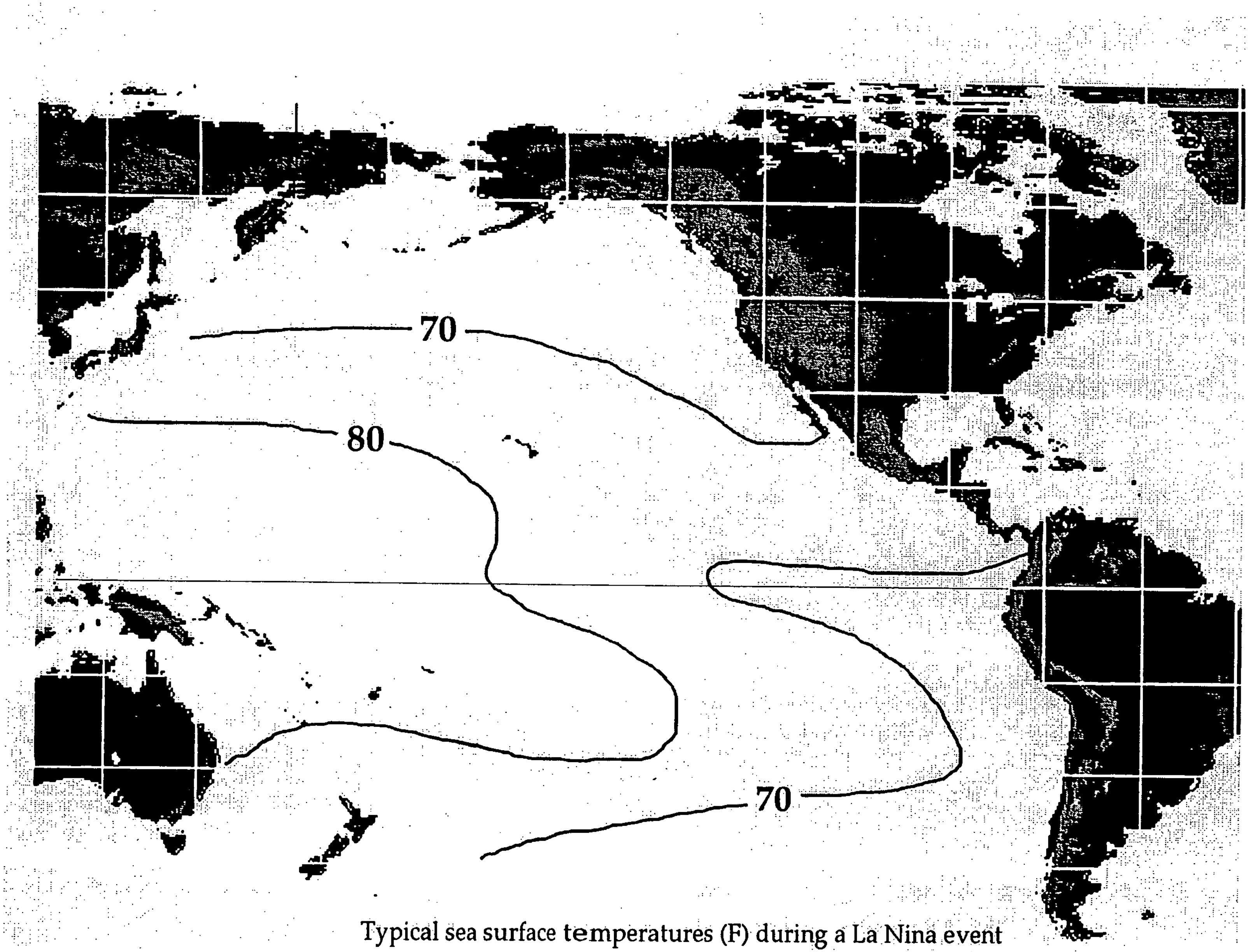
Typical clouds and jet stream positions during an average year



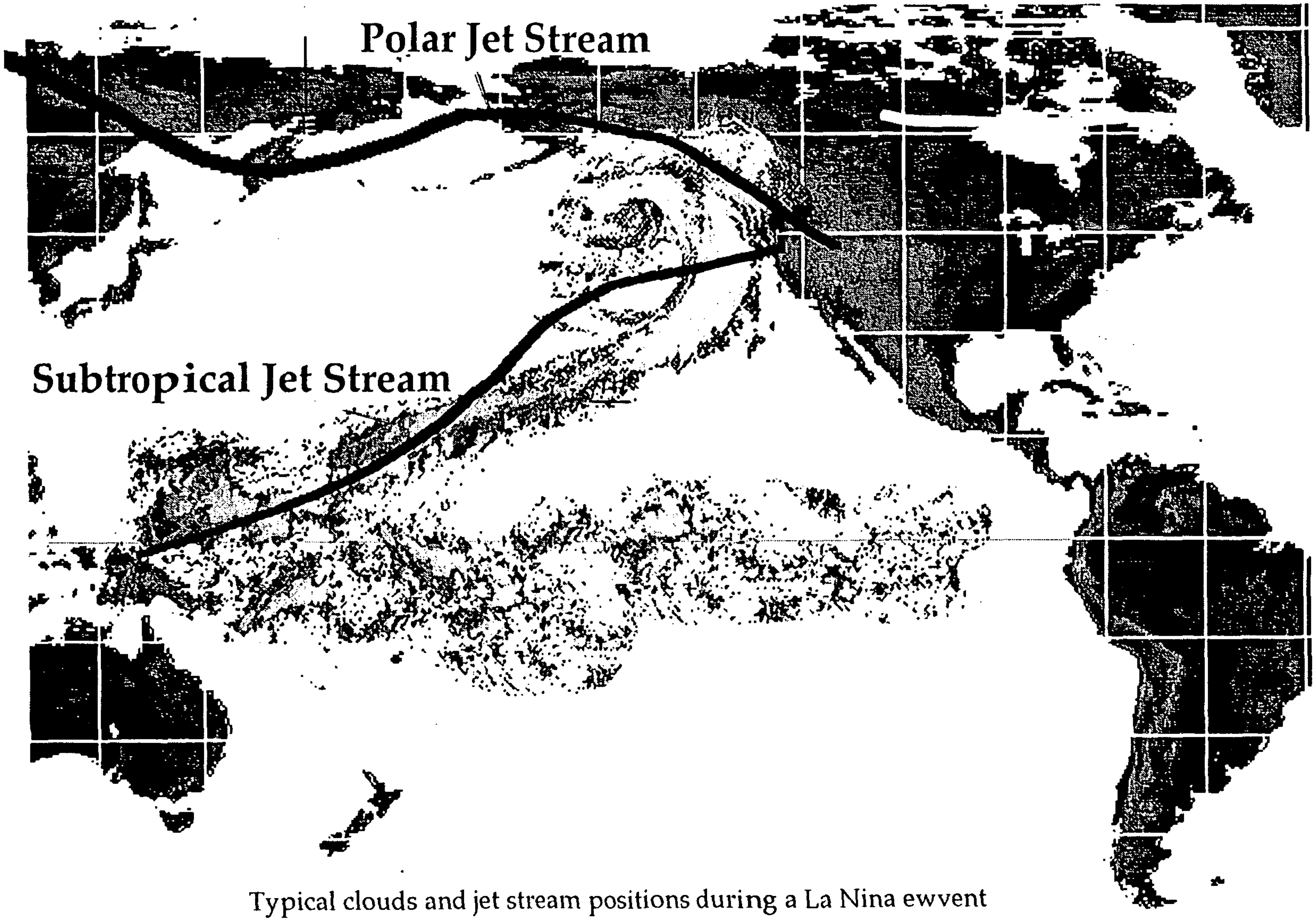
Typical sea surface temperatures (F) in an El Nino event



Typical clouds and jet stream positions during an El Nino event

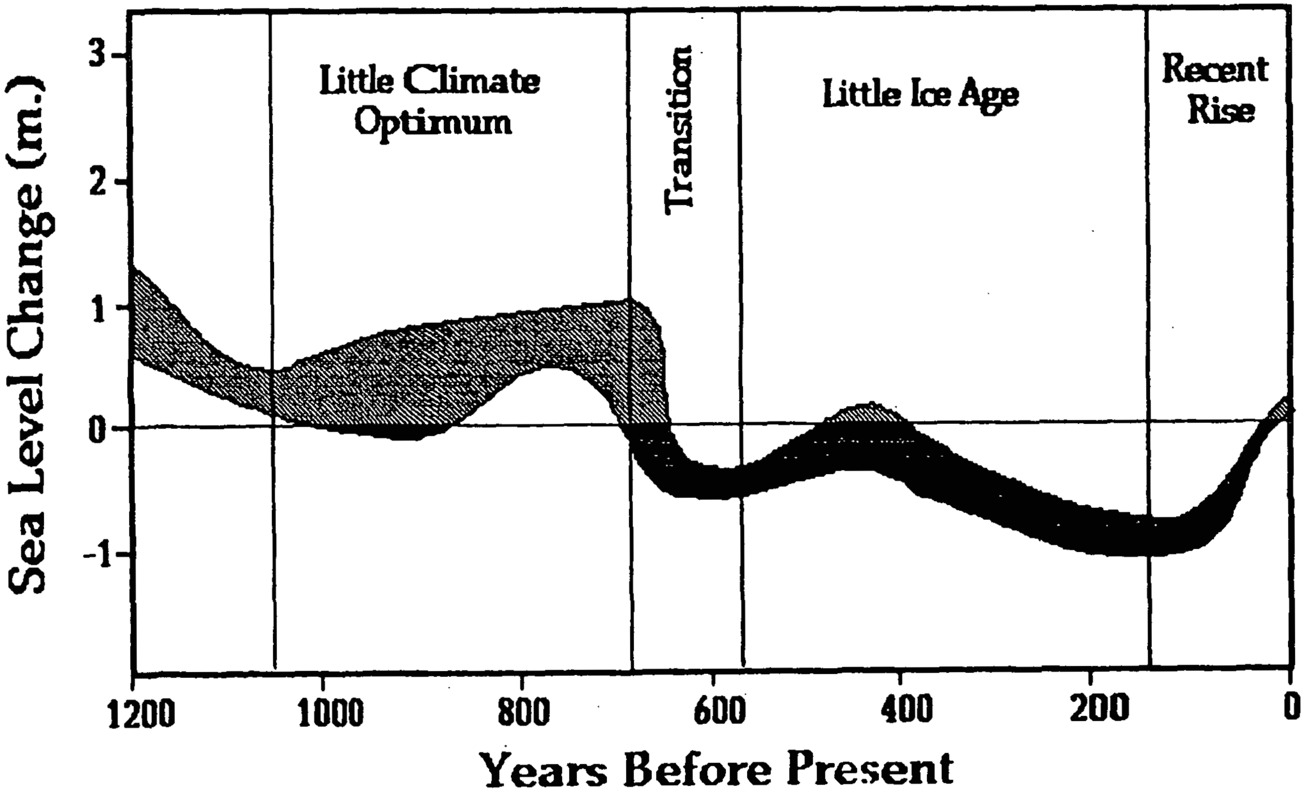


Typical sea surface temperatures (F) during a La Nina event



Typical clouds and jet stream positions during a La Nina ewvent

Pacific Sea Level over the Last 1,200 Years



Role of the Columbia River Estuary and Plume in Salmon Productivity

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Introduction

There has been a common assumption that the size of the oceans confers stability in oceanic processes. Although seasonal differences were recognized, the biological resources of oceans were considered stable and limitless. However, recent efforts documenting the existence of regime shifts (Beamish et al. 1999) and common and recurring weather phenomena such as El Niño and La Niña, and their respective impacts on fisheries, have forced a reevaluation of this basic premise. There is now improved understanding of the link between marine fisheries and climate (Francis and Hare 1994; Mantua 1997). Much effort is trained on identifying important climate indices that drive changing weather patterns, including the Pacific Decadal Oscillation (PDO), ENSO (El Niño Southern Oscillation) events, the Aleutian Low Pressure (ALP) index, and the Pacific Northwest Index (PNI), as examples. Despite improved knowledge, the efforts to understand the impacts of ocean conditions on salmon survival have been minimal. When salmon production has dropped, it has generally been attributed to the degradation of freshwater habitat. However, an evaluation of survival records for the major salmon species of the Northeast Pacific now shows mortality rates in the freshwater and ocean environments (egg to smolt *vs*. smolt to adult) are essentially equivalent (Bradford 1995). Thus change in salmon survival can be attributable to either or both habitats. Because climate changes affects physical oceanic characteristics (fronts and eddies, upwelling intensity, temperature of the water, etc.), features important to fishes, it is easy to understand how the climate and ocean links could directly affect salmon production. At the very least, assessment of restoration efforts in freshwater to rehabilitate salmon runs will need to consider ocean conditions to properly value the success of any incremental improvement of freshwater habitats.

Local Ocean Conditions Are Important

What is the spatial scale we need to consider in understanding the role of the ocean in salmon productivity? Certainly large ocean features are important when considering large aggregate populations, such as Pacific coast salmon stocks. However, the local marine environments may be equally important. Several lines of evidence support this contention. Peterman et al. (1998) and Pyper (1999) assessed variation in survival rates, length-at-age 4, and age-at-maturity for nine stocks of Bristol Bay sockeye salmon from northern Alaska, and 16 stocks of Fraser River sockeye salmon in southern British Columbia. They argued that yearly variation in any of these parameters, relative to the stock averages, were a reflection of enhanced or sub-optimal environmental conditions. Further, yearly co-variation, when stock indices were compared, indicated they were experiencing similar environmental conditions. Predictably, significant co-variation within Bristol Bay and Fraser River stocks for each of the parameters was identified. More importantly, significant co-variation in length-at-age and age-at-maturity between Bristol Bay and Fraser River stocks was identified. This finding is consistent with the mixing of these two stocks in the Gulf of Alaska through much of their marine life. However, although significant co-variation in survival rates existed within stocks, no significant co-variation was identified between Fraser River and Bristol Bay sockeye; that is, Fraser River and Bristol Bay stocks were not experiencing similar environmental factors that affected survival. They concluded that much of the difference in survival rates is attributable to conditions in the first summer in the marine habitat. Local marine environmental conditions where salmon stocks originate greatly affected survival. A second line of evidence is derived from the positive relationship between abundance of precocious (jacks) males and adult survival rates (Pearcy 1992). Precociousness is a function of environmental conditions; higher growth rates translate to increased proportion of jacks (Friedland 1996). Because of the speed of returning jacks (coho jacks, for instance, return to spawn after only 3-4 months in the ocean), they cannot migrate far from their rivers of origin as some of their larger adult counterparts. This finding suggests the local marine environmental conditions greatly affect survival and year-class success for outmigrating stocks of juvenile salmon. Understanding local marine conditions and their influence on survival and health of outmigrating juvenile salmon should help in identifying important features that benefit or suppress growth, recovery, and resilience of specific salmon stocks.

Within the local marine environments, do we consider the entire coastal domain, or do salmon appear to seek specific marine habitats. If so, what are the features? Identifying important attributes that salmon seek could assist in developing appropriate monitoring plans. One of the best lines of evidence of habitat selection by salmon comes from temperature preferences identified for salmon in the Gulf of Alaska (Welch et al. 1995; 1998). Salmon were found in specific oceanic habitats that were delineated by an upper and lower boundary temperature limit. Further, these limits varied with the season, increasing through the summer and were the lowest during the winter. It is clear that not all the ocean presents itself as usable and acceptable habitat for salmon. Environmental conditions can clearly be envisioned that increase or decrease the quality and amount of habitat that may be preferred by salmon. Similarly, not all salmon are found together, suggesting species-specific habitat requirements that need to be identified.

Columbia River Plume

Salinity preferences may be an attribute to further identify and exploit, as suggested by Favorite (1969). Salmon are found in the less saline surface layers of the Northeast Pacific Ocean of the Subarctic Domain which is bounded to the south by the vertical structure (34 ‰ isohaline) of saline waters of the Transition Zone. Locally, the Columbia River plume may represent a habitat of less saline marine waters that is critical to salmon survival. The freshwater/saltwater interface is also considered a critical habitat. When coupled with our current inability to partition the contribution of the estuary factors alone from the marine environment, evaluating the contribution of the Columbia River estuary and the plume to salmon survival, recovery, and resilience may prove useful in assessing their overall contribution to Columbia River stocks. This concern is supported by recent studies assessing the importance and impact of the Fraser River plume to salmon. Beamish et al. (1994) found that the plume of the Fraser River affected survival of coho, and chinook salmon, with low flow years typically supporting higher productivity and salmon survival than high flow years. The mechanisms by which the Columbia River estuary and plume affect juvenile salmon survival have not been quantified, but likely include provision of food, refuge during transport away from coastal predation, and improvement of estuarine conditions for subyearling fish. Since the Columbia River estuary and plume have been significantly altered from historical conditions and hatchery stocks may be affected differently than natural stocks, the system's altered state likely contributes to the overall reduction of salmon. The impact of hydrosystem effects on reducing spring river flow and suspended particulate matter transport on salmon production in the estuarine and coastal plume environment may be large, as flows in most years may now be sub-optimal for salmon production.

Sources and Extent of Variability in the Columbia River Plume

The extent, propagation, and impact of the Columbia River plume on salmon productivity are affected by two dominant factors, one marine driven and one freshwater driven. The Coastal Upwelling Domain, which the plume enters, is part of the California Current (CC) system (Bakun 1996). The CC is a broad, slow, meandering, equatorward-moving flow that extends from the northern tip of Vancouver Island (50° N) to the southern tip of Baja California (25° N), from the shore to several hundred miles from land. In offshore waters, flows are southward all year round; however, over the continental shelf, southward flows occur only in spring, summer, and fall. During winter months, flow over the shelf reverses, and water moves northward as the Davidson Current. The transitions between northward and southward flows on the shelf bear the terms "spring transition" and "fall transition," because they occur in March/April and October/November, respectively. A deep, poleward-flowing undercurrent is found at depths of 100-300 m over the outer shelf and slope in spring, summer, and fall. This current seems to be continuous at least from Southern California (33° N) to the British Columbia coast (50° N).

Coastal upwelling is the dominant physical force affecting advection and production in the Coastal Upwelling Domain. Upwelling off Washington and Oregon occurs primarily over the continental shelf during the months of April-September, but can occur year round off Northern California. Upwelling also occurs in offshore waters through the action of Ekman pumping and through surface divergence in the centers of cyclonic eddies. The result of these several upwelling processes is a high biomass of both phytoplankton and zooplankton. Production is seasonal with periods of high and low productivity bounded by the spring and fall transition.

It is important to note that coastal upwelling is not a continuous process. Rather, it is a cyclic phenomenon, with favorable northerly winds blowing for periods of 1-2 weeks, interspersed by periods of calm or wind reversals. Interannual variations in the length and number of upwelling events lead to variations in the level of primary and secondary production, thus the overall level of production during any given year is highly variable. Any process that leads to reduction in the frequency and duration of northerly winds will result in decreased productivity. The most extreme of these processes is El Niño, which disrupts coastal ecosystems every 5-10 years. Understanding how this variation (on a daily, monthly, seasonal, yearly, and longer time scale) translates to a change in Columbia River plume environments and its impact on survival potential of salmon species is a critical variable that needs to be considered.

Variability in productivity of the California Current and its interaction with the Columbia River plume occurs at varying climatic time scales, each of which must be taken into account when considering recruitment variability and fish growth. For example, the North Pacific experiences dramatic shifts in climate on a 30-40 year frequency, caused by eastward-westward jumps in the location of the Aleutian Low in winter. Shifts occurred in the 1920s, 1940s, and most recently in the winter of 1976/1977. One dramatic effect of these shifts (called regime shifts) is that large changes in biological productivity are seen in the Subarctic Pacific/Gulf of

Alaska and the California Current, and they are opposite in trend. Under the present regime (known as a "warm regime"), zooplankton biomass in the southern sector of the California Current has declined by an order of magnitude whereas zooplankton biomass in the Subarctic Pacific has increased at least two-fold (Brodeur and Ware 1992). Salmonid abundance has never been higher in the Subarctic Pacific and never lower in the California Current. In contrast, during the past (cool) regime which extended from the 1940's through the mid-1970s, salmonid stocks were low in the Subarctic and high in the California Current. Groundfish species are also affected. Declining body weight of Pacific hake began near the regime shift and directly translates into reduced fishery yield. Declining recruitment for Dover sole and bocaccio rockfish in some areas also roughly coincides with the regime shift (Bakun 1996).

Since the early 1980s, the California Current has been experiencing an increased frequency of El Niño events, with large El Niño events occurring every 5-6 years: 1976-77, 1982-83, 1986-87, and 1991-92. Another large event occurred during 1997-98. Prior to 1982, El Niño events seldom reached as far north as Oregon. Since 1992, the Oregon and Washington coasts have been experiencing almost continuous El Niño-like conditions during summer (i.e., reduced upwelling and warmer ocean conditions in general). Whether these conditions will have a long-term effect on the fisheries of the Pacific Northwest has not yet been investigated. Changes in recruitment seem likely, however, with the decline in coho salmon survival since the onset of warm ocean conditions in 1992 a noteworthy example.

The shape and extent of the Columbia River plume is also controlled by the amount of freshwater flowing out of the Columbia River. Not only the flow or amount of water may be important but also the amount of sediment affecting turbidity, and the amount of nutrients fueling estuarine and oceanic productivity may be important to salmon growth and survival. Historical changes in flows of the Columbia River have been observed. Flow regulation, water withdrawal and climate change have reduced the average flow and altered the seasonality of Columbia river flows and sediment discharge, and have changed the estuarine ecosystem (NRC 1996; Sherwood et al. 1990; Simenstad et al. 1990; 1992; Weitkamp et al. 1995). Annual spring freshet flows through the Columbia River estuary are ~50% of the traditional levels that flushed the estuary and carried smolts to sea, and total sediment discharge is ~1/3 of 19th Century levels. Decreased spring flows and sediment discharges have also reduced the extent, speed of movement, thickness, and turbidity of the plume that extended far out and south into the Pacific Ocean during the spring and summer (Barnes 1972; Cudaback and Jay 1996; Hickey et al. 1997). Pearcy (1992) suggests that low river inflow is unfavorable for juvenile salmonid survival despite some availability of nutrients from upwelling, because of: a) reduced turbidity in the plume (increasing foraging efficiency of birds and fish predators), b) increased residence time of the fish in the estuary and near the coast where predation is high, c) decreased incidence of fronts with concentrated food resources for juvenile salmonids, and d) reduced overall total secondary productivity based on upwelled and fluvial nutrients. Reduced secondary productivity affects not only salmonid food sources but focuses predation by other fishes and birds on the juvenile salmonids.

Characterizing the importance of the Columbia River plume to salmon will depend on identifying the attributes that are critical to salmon survival. Whether the important attributes are purely physical (e.g., a turbid environment) or biological (e.g., enhanced prey availability) in nature remains to be determined. It is likely the benefit of the plume will be derived from both physical and biological attributes that are powered by variation in the marine environment that the plume enters into and the quality and amount of freshwater flowing out of the Columbia River. Further, it is likely that the benefits will not be expressed in a linear manner, but more a dynamic interaction with no one combination of attributes working to benefit or suppress salmon production on a predictable frequency scale.

Columbia River Estuary

Estuaries appear to be uniquely important to salmon survival. Two separate studies in the early 80s (Emmett and Schiewe 1997) have shown that estuaries confer enhanced survival to salmon. In both cases, juvenile smolts (in one instance coho, and in the other, chinook smolts) were collected and released in the river, in the estuary, in the transition zone outside the estuary, and in the ocean. Both studies were repeated for multiple years. In both cases, smolts released in the estuaries consistently provided more to the fisheries or returned at higher rates than smolts released outside the estuaries. Interestingly, one of the studies, conducted in the Columbia River, showed that releasing smolts in the Columbia River plume was just as beneficial to survival. In another example, examination of adult returns from transportation studies conducted at Lower Granite Dam in 1990 showed that PIT-tagged adult salmonid returns varied dramatically through the seasons. Smolts transported and released below Bonneville Dam (at the head of the Columbia River estuary) during the early part of the migration season apparently had much lower survival than those transported during the later part for both hatchery and wild fish (Matthews et al. 1992; Hinrichsen et al. 1997). What is remarkable is the transition from a lower to a much higher survival rate occurred during a one-week transition period. The short time frame for the transition suggests that the events affecting survival are local, very likely within the estuarine domain. What have not been determined in any of these studies are the specific attributes of the estuary that confer enhanced survival to salmon.

What are the benefits of the Columbia River estuary to salmon productivity? Estuaries provide critically important habitats for numerous marine and anadromous fish and shellfish. Biologically, the estuaries of the PNW are perhaps most recognized as a transition habitat for salmon in their migrations to and from seawater. Although coho and stream-type chinook salmon, steelhead, and cutthroat trout spend relatively little time in estuaries (<6 weeks), ocean-type chinook salmon can reside in estuaries for up to 2 months or more. The influence of estuaries extends well beyond the immediate land boundaries of the coast, and the important linkages between estuaries and the nearshore ocean environment are greater than commonly recognized. Estuaries, for example, represent a means by which energy resulting from the action of climate (weather) on land masses is transmitted to the ocean. In addition, estuaries support important trophic interactions affecting a variety of marine species. For example, the planktonic larval stages of many estuarine invertebrates provide a major food source for many pelagic marine fish species. The nearshore ocean environment is continuously influenced by rivers (large or small) and their estuaries, and this influence can extend far beyond the coast for large river systems such as the Columbia and Sacramento/San Joaquin Rivers or for large bays such as Grays Harbor, Willapa Bay, Puget Sound, and San Francisco Bay. Humans have impacted estuaries in literally hundreds of different ways that have led to habitat destruction, habitat simplification, and loss of ecological function. Further, although urban lands make up only 2 to 3% of the land base of the West Coast, greater than 70% of the human population lives near estuaries or river and stream corridors that flow into estuaries. Most of these urban areas are located on historical wetlands, where drainage requirements have eliminated more than 90% of these productive aquatic habitats.

Sources and Effects of Variability in the Columbia River Estuary

The role of the Columbia River estuary in supporting or enhancing salmon survival may be diverse. The estuary may simply serve as a conduit to the ocean, transporting fish from the river to the ocean allowing them to complete their life cycle. Most important attributes affecting the outcome would be actual flow rates, timing of flow, and turbidity, as mentioned previously. This represents a practical role for the estuary. However, the Columbia River estuary may contribute in other ways. The estuary may represent an extension of the freshwater habitat of salmon, expanding the available habitat for rearing (Wissmar and Simenstad 1998). Obviously the number of salmon that could potentially be supported within the Columbia River system is increased if parts of the estuary served this role. Apart from contributing space or transporting fish, processes within the estuary can also affect survival of salmon. The impact of Caspian tern predation in the Columbia River estuary on salmon is clearly a recent example of concern. The outcome is that fewer salmon leave the estuary compared to the number that enter. Finally, estuarine processes may not directly affect salmon, but incur effects that are delayed. To this end, estuarine processes can directly benefit or negatively impact salmon. The outcome, with respect to survival, is manifested later, depending on conditions they encounter outside the estuary. Evidence of negative impacts has certainly been documented (Emmett and Schiewe 1997) and one can envision how improved availability of food, supporting enhanced growth, can make ocean survival more likely. With fish, as with all animals, increased size confers an enhanced survival potential. The actual role played by the Columbia River estuary is currently unknown, but likely incorporates components of all those listed above. Understanding the contribution will require a more comprehensive evaluation of the use of the estuary than we currently have.

The specific attributes in the Columbia River estuary that may be critical to salmon are varied and influenced by both external and internal forces. If these critical features could be identified empirically, then modifications could properly be targeted to restore or preserve these features. What are the characteristics of the estuarine features that possibly enhance salmon survival? Physical properties of estuaries that likely affect salmon include amount of flow and flow patterns, the degree of turbidity, as indicated previously, and the hypsometric curve. It is easy to see how climate, in the form of rainfall, could affect these features on a number of temporal scales (e.g., seasonal, yearly, decadal). There are, however, other physical variables of the estuary that may be critical. These include habitat types, influenced by landscape structure, the diversity of habitat types within the estuary itself, and the availability and amount of low velocity habitats. These could provide refuge and feeding habitats, particularly low velocity habitats, for salmon during critical migratory or residency periods. Food web structure within the estuary may also be important (Wissmar and Simenstad 1998). These are clearly influenced by the amount and type of nutrients and the type of organic matter sources that feed into the estuary. The impact of nutrient quality and quantity on prey availability and the timing and abundance of secondary productivity could certainly influence survival of juveniles. The Columbia River Data Development Program (CRDDP) studies, conducted in the 80s showed that a majority of the resident and outmigrating salmon had food in their stomachs. Factors that alter the food availability dynamics at the various scales of concern are likely to affect salmon survival. In addition, all of these elements contribute to the overriding ecological interactions that affect survival. Foremost of these are intra-specific and inter-specific competition, which are influenced by the abundance of salmon entering the estuary as well as the proportion of wild (naturally-produced) and hatchery-reared salmon. Finally, the biodiversity of the estuarine community confers benefits that are difficult to quantify, but certainly reflect on the quality of the estuarine habitat in general. The relative contribution and importance of all these elements, as with the role of the estuary, needs to be clearly identified before the impact of changes in the Columbia River estuary can be properly characterized. This has yet to be done empirically.

Do climate and ocean conditions affect estuarine condition directly or through the action of freshwater? Clearly a case can be made that the lower portion of the estuary is affected by ocean conditions. However, the upper portion of the estuary is more likely affected by freshwater inputs. As described previously, the evidence for change historically in terms of flow and climate in the Columbia River basin support the contention that the current day estuary is not the same (Sherwood et al. 1990). To the extent that understanding climate factors and their impact on estuarine conditions need to be addressed, clearly the modification of the Columbia River estuary by human-induced changes to the dynamics of the Columbia River flows is probably most dramatic. The human impact has likely affected the ability of the system to provide a diverse and acceptable habitat more so for salmon than any other factor in current historical terms. Nevertheless, both anthropogenic and natural factors need to be considered as driving factors affecting the beneficial use of the estuary by salmon. This is in contrast to the interaction of the Columbia River plume with the California Current, which is primarily driven by natural factors.

Management Issues

Should management of the Columbia River system incorporate the entire ecosystem important to salmon rather than concentrate on urban impacts on freshwater habitats? The answer is an unqualified yes, but the question is how. If the estuary and plume represent important habitat for critical periods in the salmon life cycle, we need to address the impact of the hydropower system, habitat, hatcheries, and harvest beyond the freshwater phase. For example, modification of the habitat by river flow amounts, timing of flow, as well as sediment input may be detrimental to the diversity of salmon life histories that occur in these areas. Clearly this would be affected by climate. But we need to examine the human-induced impact placed upon the Columbia River estuary and plume that are dynamically affected by natural forces. The integration of such an evaluation may provide insights into potential magnification of unforeseen problems simply because we artificially limit where and how we view the extent of the problem. Clearly if we ignore the dynamics and importance of the Columbia River estuary and plume environment to salmon stocks, our management success will be limited. One avenue that should be pursued is to improve our monitoring of the estuary and plume environment. The characteristics of the monitoring program at this stage should incorporate evaluation of the physical structure of the plume in relation to the ocean environment (e.g., strength of upwelling events, ocean temperatures, the timing of the spring transition) and characteristics of the biological environment (prey availability, condition of juvenile salmon during the summer period). Modification of the monitoring effort should take place as the important attributes affecting survival of salmon become better identified and articulated.

Conclusion

Both the freshwater and marine phases of salmon life history contribute significantly to survival. Further, the near coastal habitat, where salmon first enter the ocean environment appears to be a key area to recruitment success. This implies that the Columbia River estuary and plume may represent critical habitat for Columbia River basin salmon stocks. It is clear that natural oceanic and climatic forces affect the estuary and plume environment. In addition, consideration of human-induced changes to the estuarine and plume environment should be incorporated into any management plan that hopes to sustain or recover depressed salmon stocks of the Columbia River basin.

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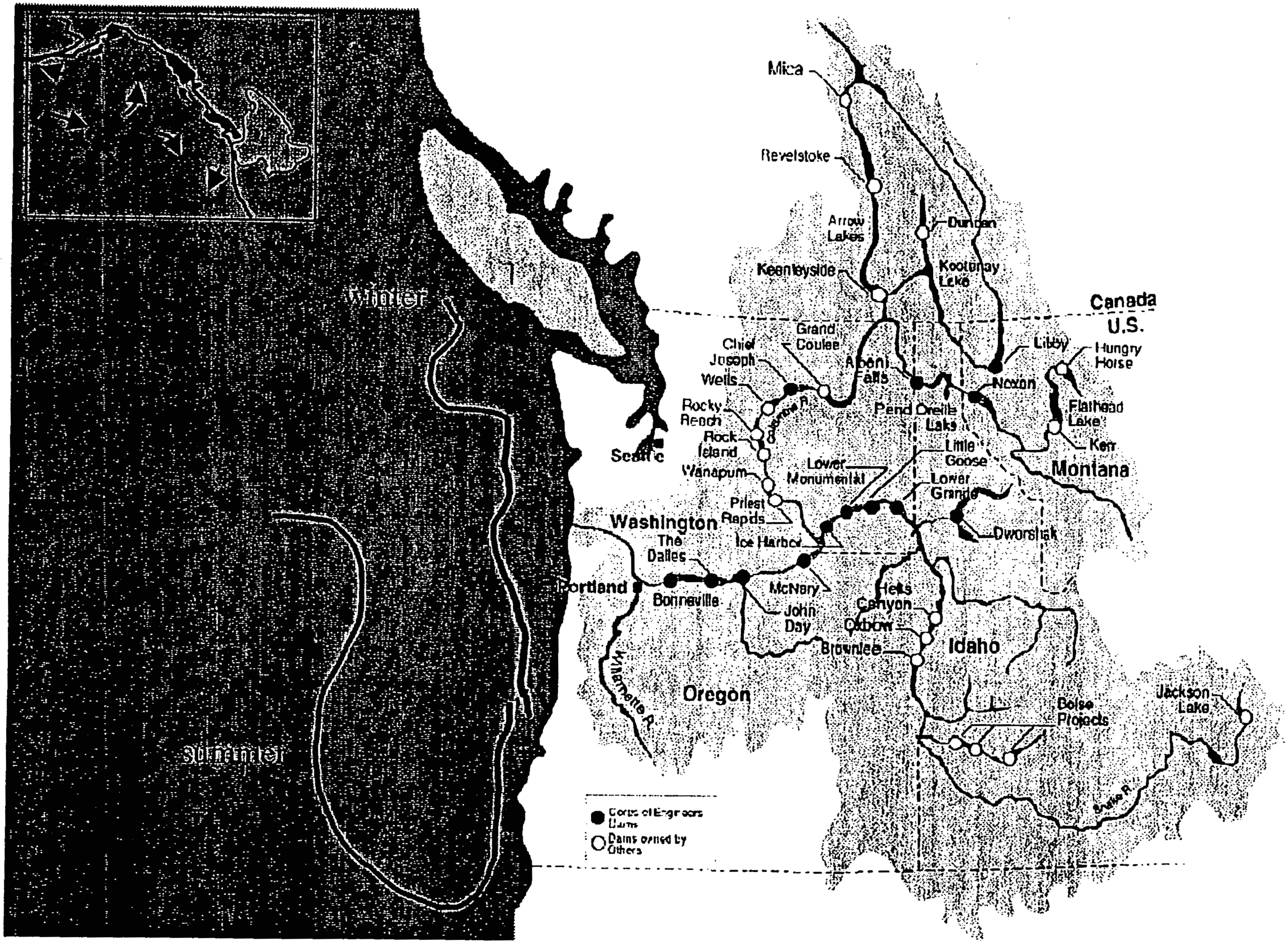
Additional illustrations displayed during Ed Casillas' oral presentation

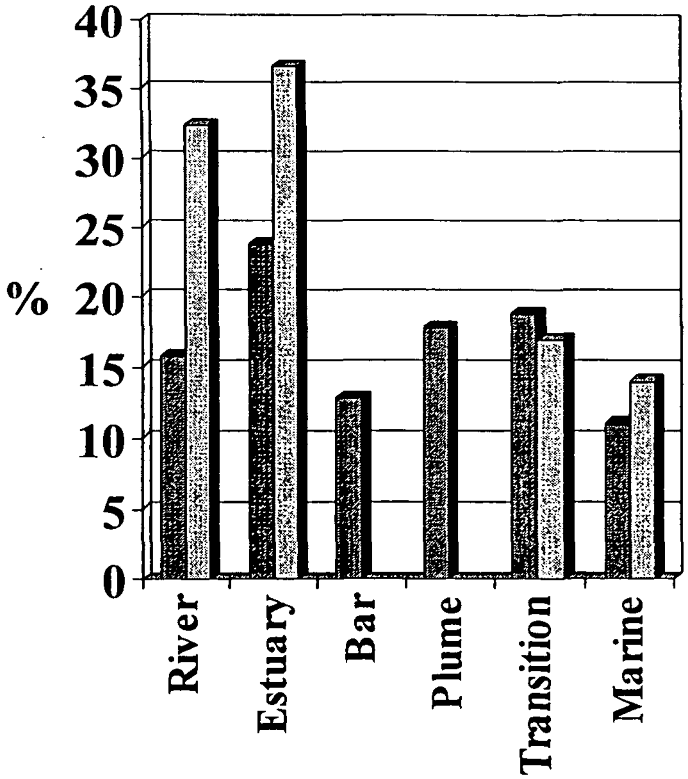
Columbia River Plume Role?

- Refuge from predators; turbidity important
- Transport from estuary & coastal waters away from predators
- Water mass boundaries - concentrates food resources
- Nutrient input affects primary & secondary productivity providing food resources and relaxing predation pressures on juvenile salmon

Columbia River Plume: Sources of Variation

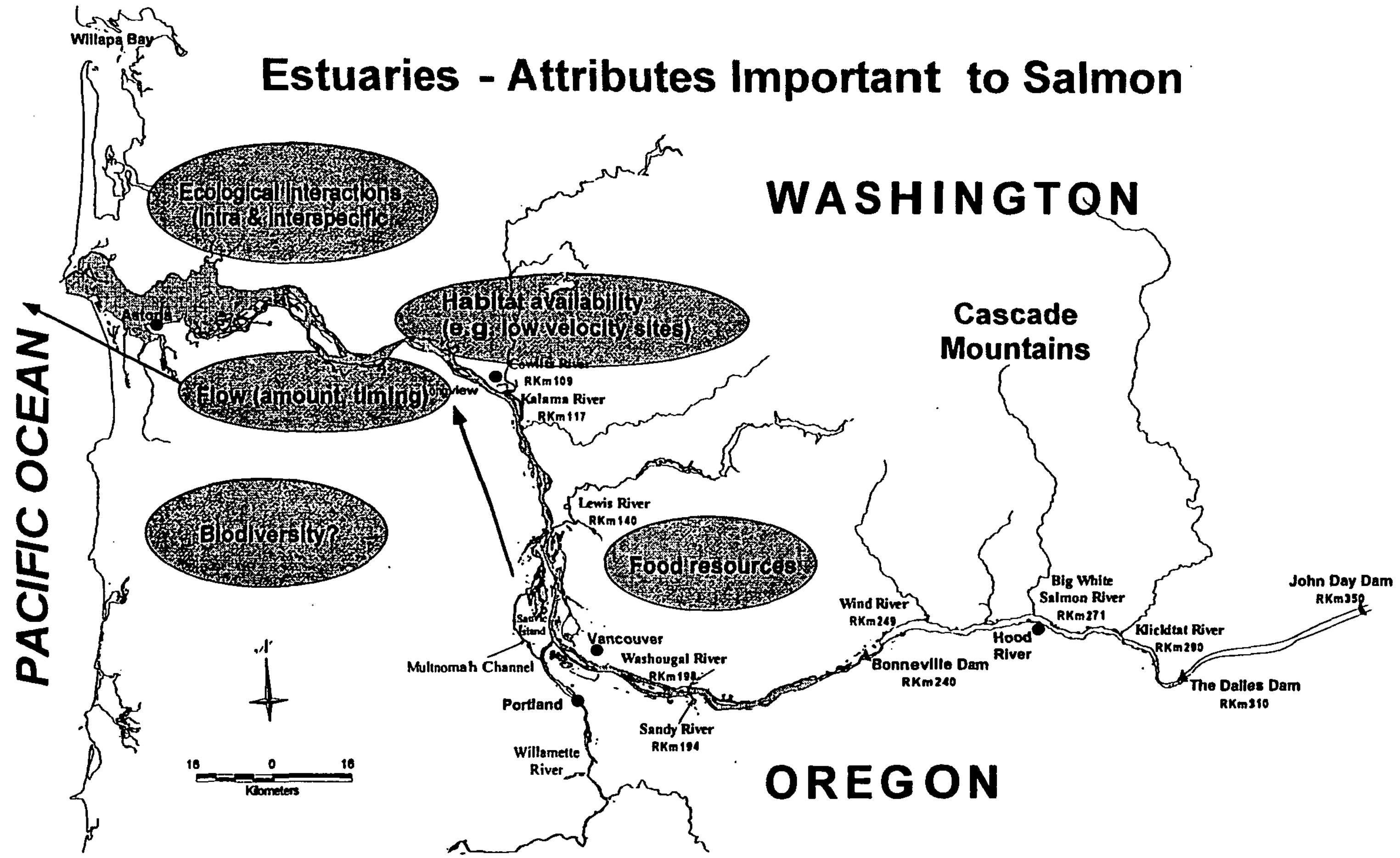


Estuaries: Are They Important to Salmon Survival?



- Columbia River & Campbell River, Canada
- 3 to 5 years of data
- Estuaries almost always ranked highest in contribution

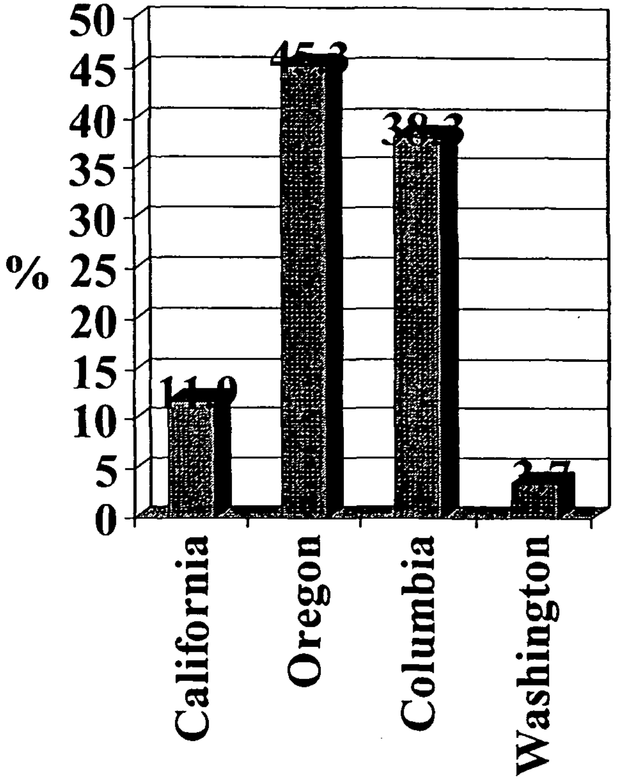
Estuaries - Attributes Important to Salmon



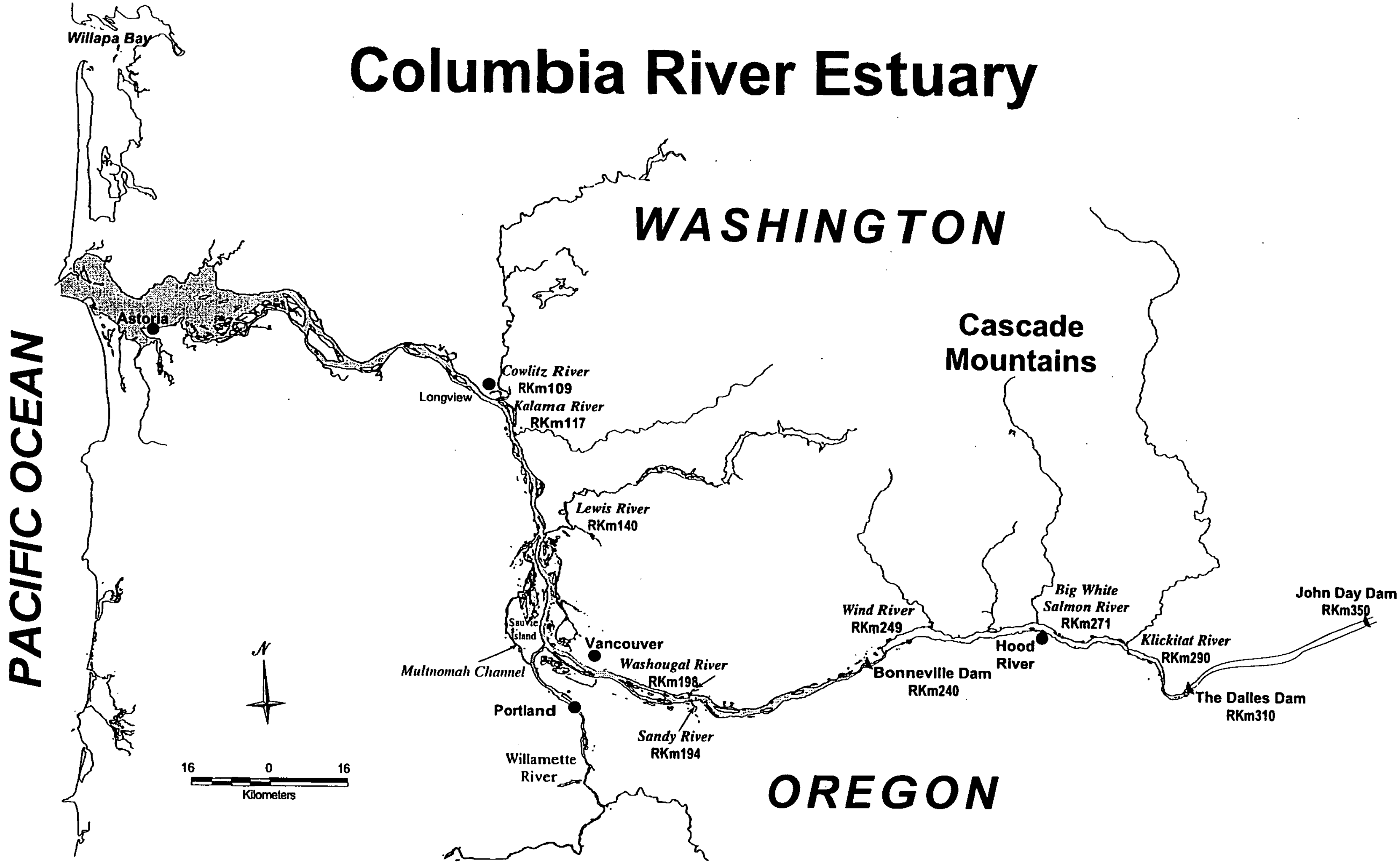
The Columbia River estuary is depicted in blue shading, extending from the ocean entrance to Bonneville Dam.

Chinook Stock Composition

- September 1998
- Samples from Oregon and Washington marine waters including the plume
- Based on genetic allelic frequency analysis



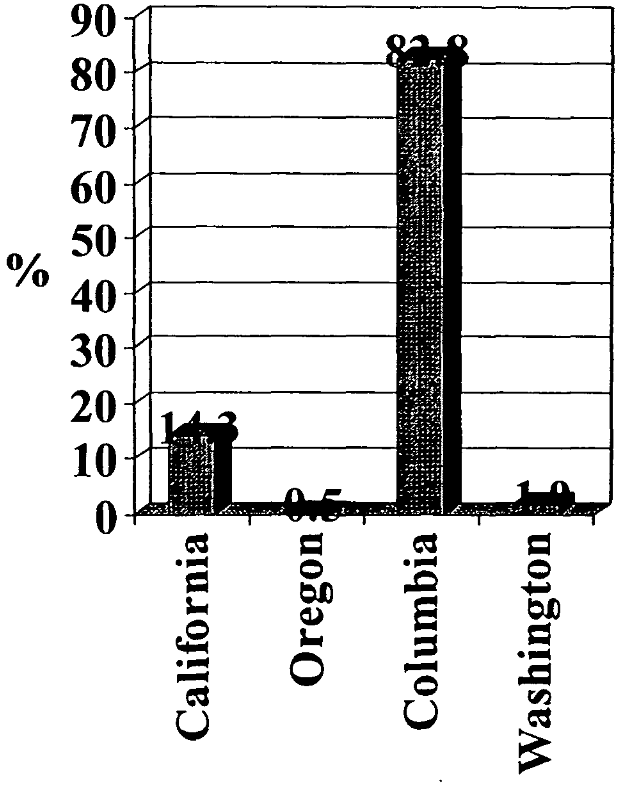
Columbia River Estuary



The Columbia River estuary is depicted in blue shading, extending from the ocean entrance to Bonneville Dam.

Chinook Stock Composition

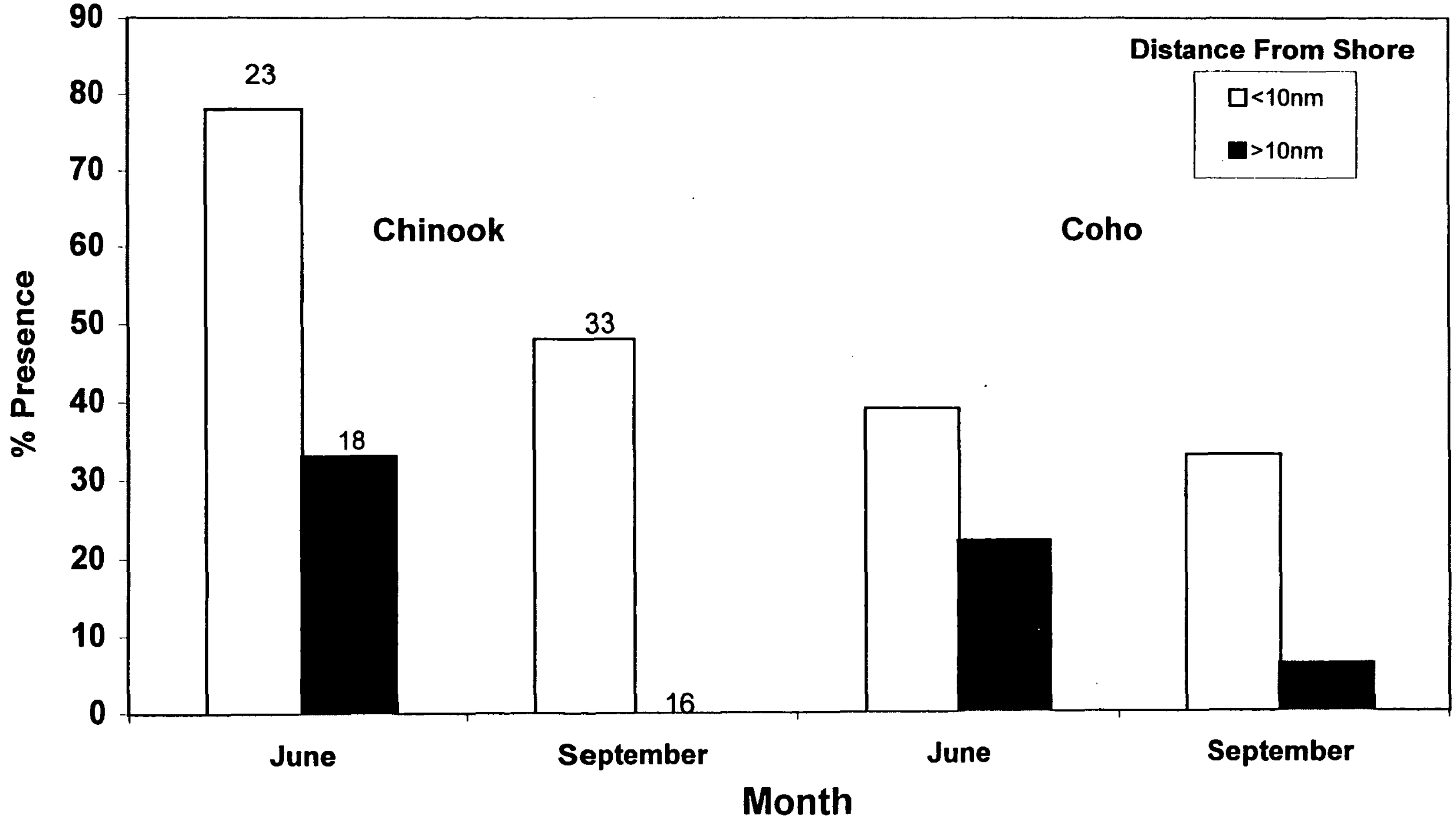
- June 1998
- Samples from Oregon and Washington marine waters including the plume
- Based on genetic allelic frequency analysis
- Fraser chinook present at ~1%

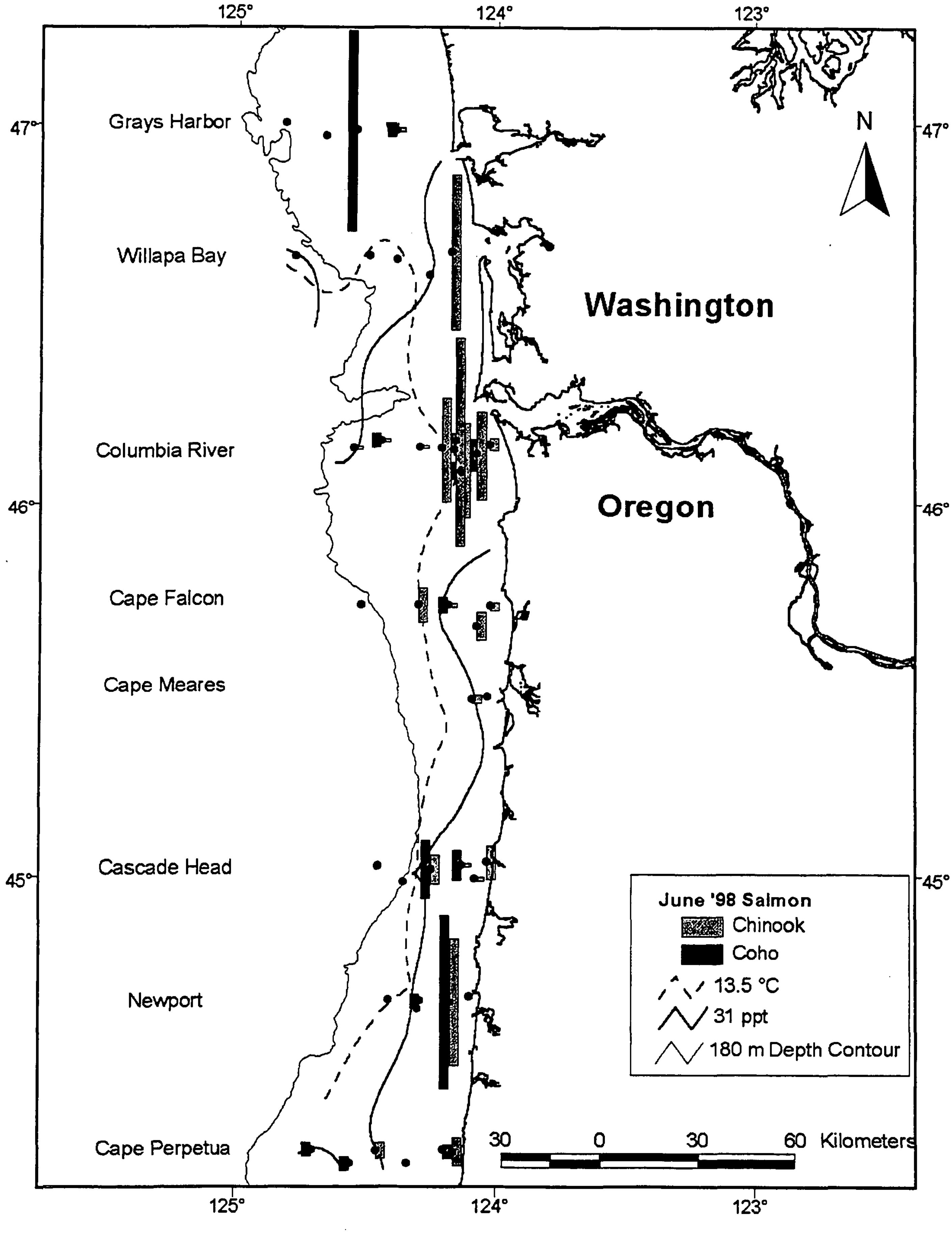


Ocean Features & Presence of Juvenile Coho Salmon – Historical Record

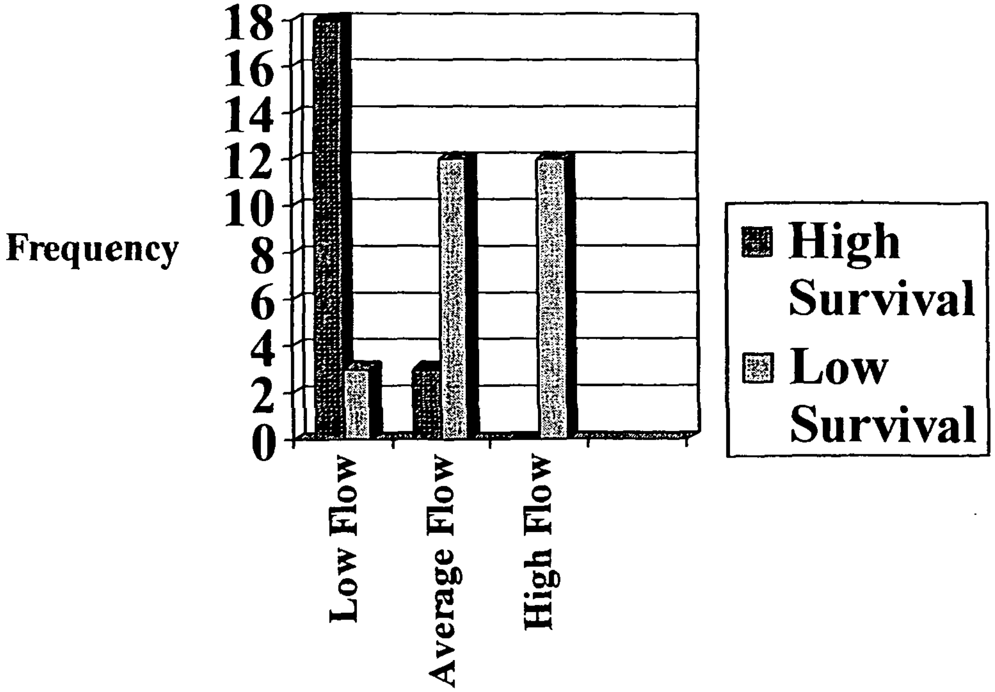
Ocean Trait	Year			
	1981	1982	1983	1984
Low temp/Low salinity	71%	79%	100%	72%
Low temp/High salinity	0%	57%	50%	29%
High temp/Low salinity	46%	100%	44%	57%
High temp/High salinity	50%	50%	50%	0%

Habitat Influence on Presence of Juvenile Salmon (1998)-
Columbia River Plume



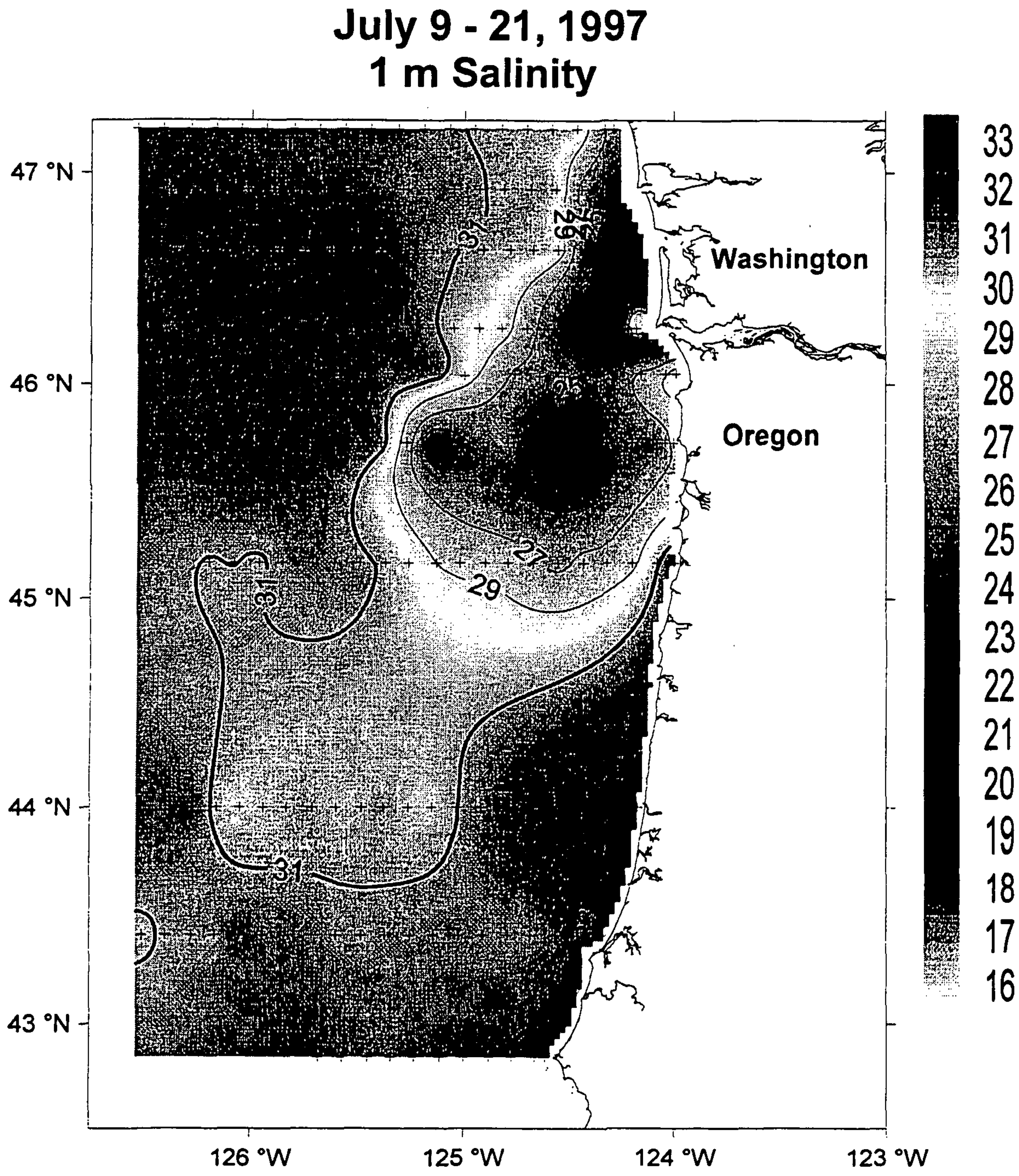

125°
124°
123°
47°
46°
45°
N
Grays Harbor
Willapa Bay
Washington
Columbia River
Oregon
Cape Falcon
Cape Meares
Cascade Head
Newport
Cape Perpetua
June '98 Salmon
▨ Chinook
■ Coho
13.5 °C
31 ppt
180 m Depth Contour
30
0
30
60
Kilometers

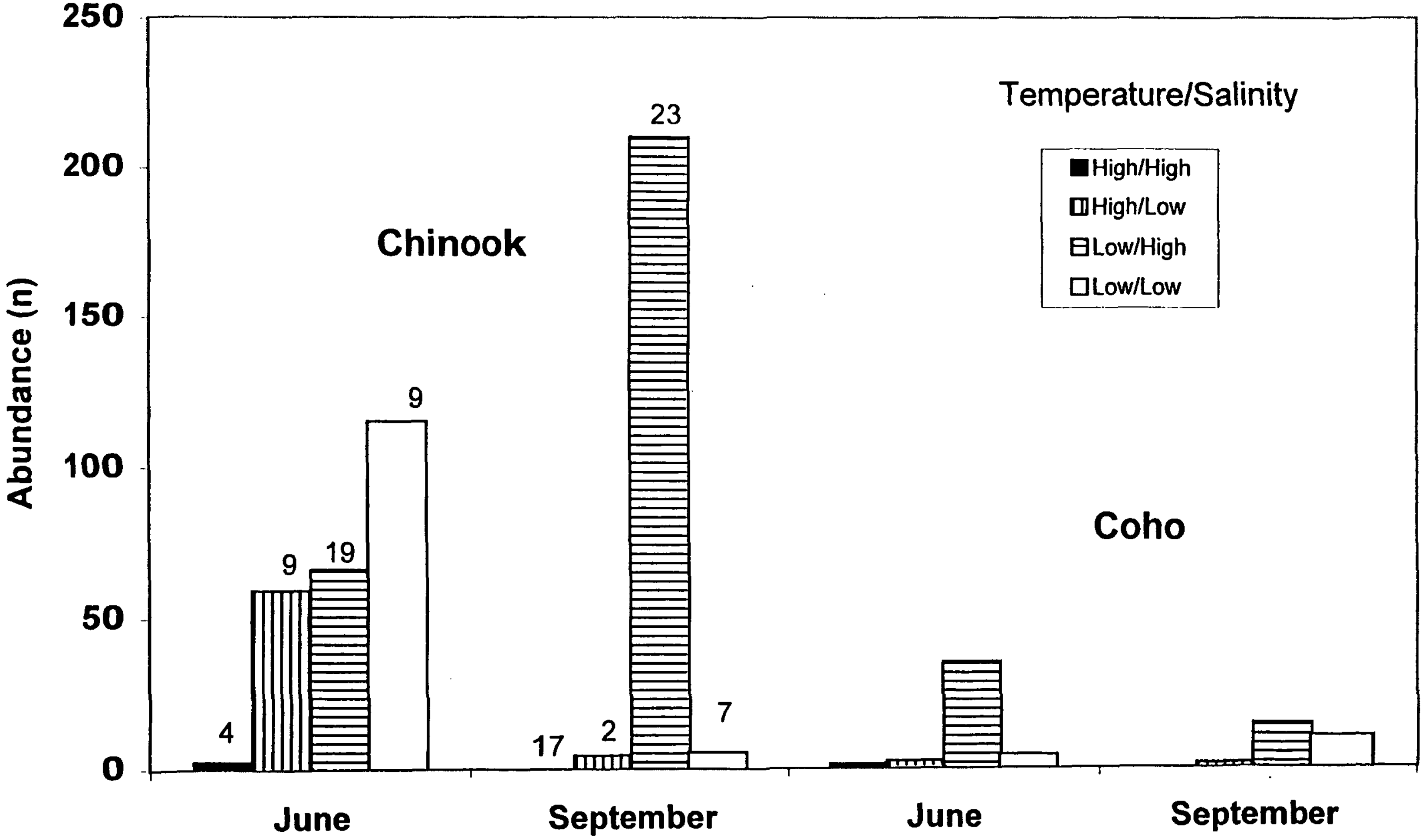
Fraser River Flow & Salmon Production


Chinook Salmon

- Beamish et al. CJFAS, 1994
- Flow discharge anomalies related to salmon production
- Impact on early marine survival
- Coho & chum salmon show same relationship

Columbia River Estuary & Plume





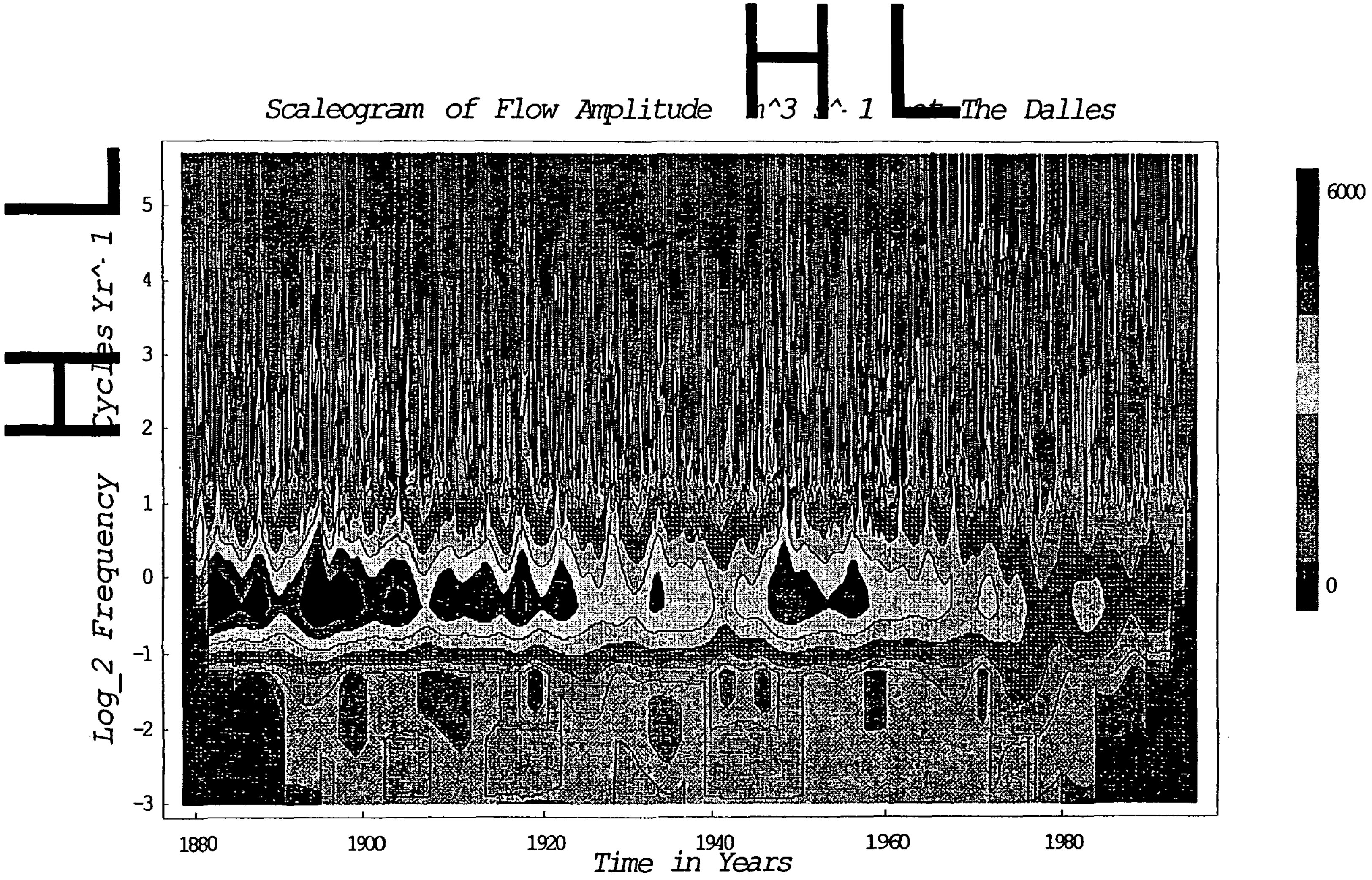
Abundance of Juvenile Salmon with Respect to Coastal SST (Low <13 C) and Salinity (Low <31 ppt) - Columbia River Plume (1998)

Ocean Features & Presence of Juvenile Chinook Salmon – Historical Record

Ocean Trait	**Year**			
	1981	1982	1983	1984
Low temp/Low salinity	100%	79%	100%	59%
Low temp/High salinity	29%	50%	50%	33%
High temp/Low salinity	17%	0%	19%	64%
High temp/High salinity	0%	0%	23%	0%

CR Plume Study Plan

- Assess plume characteristics - model
- Physical characteristics - SPM & salinity
- Prey field - zooplankton & forage fish
- Associated fish community
- Fish predator dynamics
- Juvenile salmon (coho & chinook) distribution, abundance, growth & health

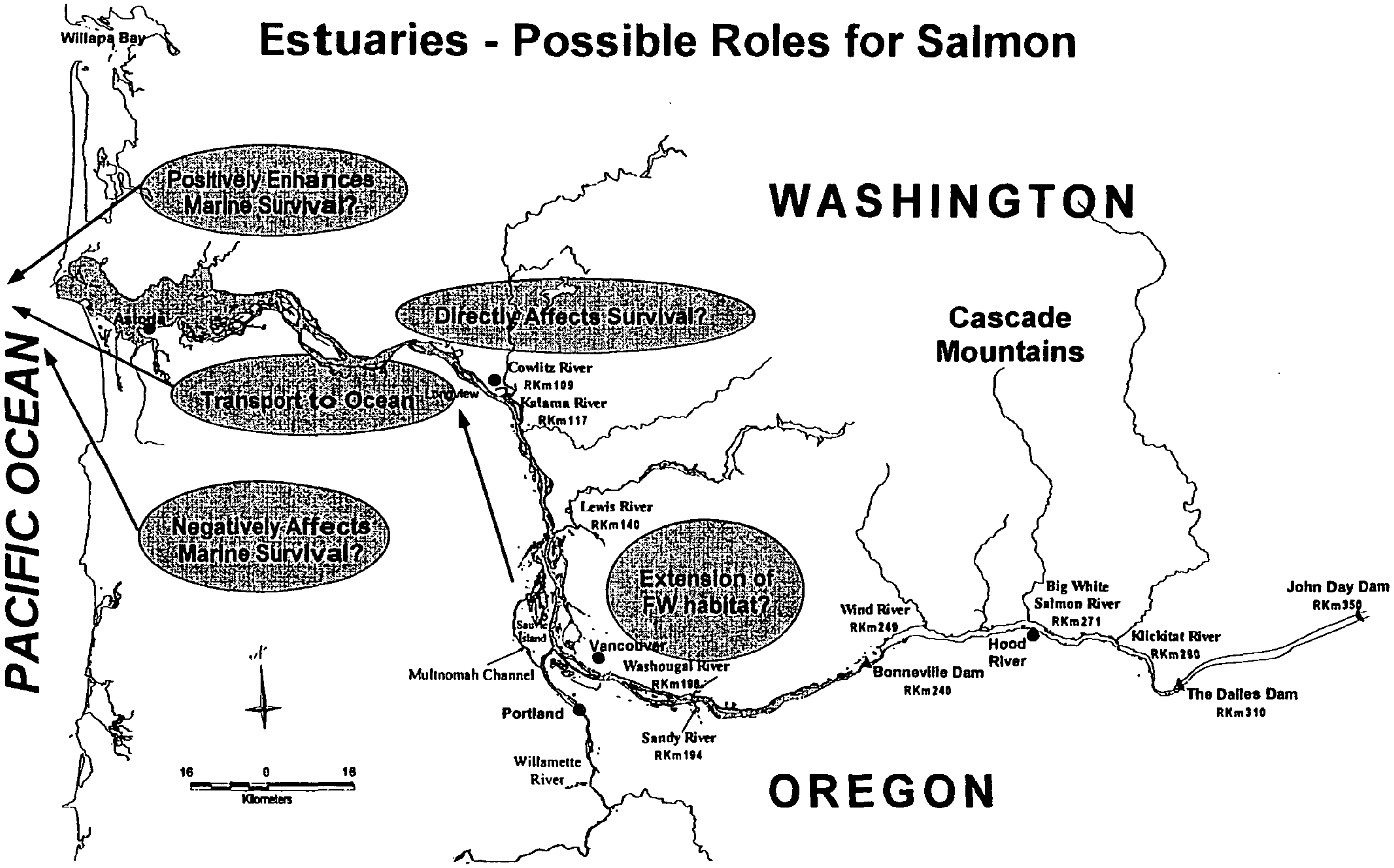


Amplitude of Columbia River Yearly Flow Fluctuations at the Dalles, OR, 1878-1996 (Jay)

Conclusion

- FW & SW phases important
- Local ocean conditions affects survival
- CR estuary & plume likely critical habitat
- Natural/anthropogenic modifications to the ecosystem suggest management considerations need to extend beyond the river

Estuaries - Possible Roles for Salmon



The Columbia River estuary is depicted in blue shading, extending from the ocean entrance to Bonneville Dam.

Climate, Salmon, and Preparing for the Future

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Introduction

Knowledgeable and wise people are impressed with how little we actually know. One only has to stand at the sea shore to be reminded of the complexity of the relationships among plants, animals, and their environment. As fisheries managers we can be overwhelmed by this complexity or we can look for simplifications. In fisheries management science we traditionally simplify the complexities. It is important to remember that we do this because we need to remind ourselves that our assessments are based on uncertainty. The advice that comes from these simplifications is useful but it is only one part of the process required for successful stewardship. It is the process that aggregates all of our information that provides the best stewardship. New information about salmon comes from studies of their relationship with climate and it is the importance of this new information that is considered in this report. It is essential that we learn more about the impacts of climate as the warming of our planet is particularly threatening to salmon in both their freshwater and marine habitats.

What salmon tell us about the impacts of climate

As a species, Pacific salmon are approximately one million years old. This means that they have survived 4 major ice ages, 4 warming periods, the extinction of 35 different genera of mammals including woolly mammoths, camels, lions, and sabertooth cats. Even wild horses became extinct in areas where salmon are found today. We marvel at the salmon's stunning ability to find their way back from the ocean to their place of birth, but we sometimes forget that they have colonized new freshwater habitats in the same manner as less desirable animals and plants have recently moved into our environment. We know that there is approximately 90 to 98% mortality from eggs to entry into salt water. There is also an almost unbelievably high mortality in salt water. In the past few years we have observed ocean mortalities of 99.5% for chinook in the Strait of Georgia and in Puget Sound, 98% for coho throughout their entire southern distributions and about 90% for sockeye from the Fraser River. Despite these high mortalities, stocks of salmon continue to survive. This is not strictly correct because several stocks have been identified as lost, and over a thousand stocks have been classified as at risk of extinction (Slaney et al. 1996; Nehlsen et al. 1991). However, we believe that the loss of these stocks resulted from the added mortalities of fishing or freshwater habitat loss, not from natural causes.

Recently we have become aware of natural fluctuations in the abundance trends of salmon. The abundance trends of salmon are amazingly similar to fluctuations in Pacific sardine abundances off South America, North America, and Asia (Fig. 1) indicating that something of large scale such as climate may be a common cause of the synchrony. We know that sardine catches have fluctuated in abundance for centuries (Baumgartner et al. 1992), leading to the speculation that salmon abundance has also fluctuated naturally (Beamish et al. 1999a). Recently, it has been possible to measure the natural fluctuations of salmon populations using stable isotopes (Finney 1998). When sockeye salmon return to fresh water to spawn, they contain a form of nitrogen that only comes from the ocean. This marine form, or nitrogen 15, is deposited in the lake sediments and provides a way of looking at past fluctuations in abundance. Finney (1998) observed clear trends in the pattern of deposition, which was interpreted as a natural fluctuation in abundance for about 400 years prior to any commercial fishing. Low abundance was noted in the mid-1500s, the early 1700s, the early 1800s, and in the mid- to late 1900s. It is interesting that the salmon returns to the Fraser River were so low in 1827 that there were reports of starvation among natives during the winter. Thus, it is possible that the early 1800s was a period of generally low salmon abundance. Larger abundances were noted in the early 1500s, the late 1500s, the early to mid-1600s, the late 1700s and the mid-1800s to the early 1900s. We also know that the abundance trends in salmon change quickly and in synchrony with large scale climate shifts that we call regimes (Fig. 2, Mantua et al. 1997; Beamish et al. 1999a). Pacific salmon also respond to climate related impacts by changing ocean migratory patterns (McKinnel et al. 1998), changing final body size (Ricker 1995), and changing their horizontal distribution (Welch et al. 1998). It is clear that climate is an important component of the population dynamics of Pacific salmon.

Pacific salmon evolved from a freshwater existence to an anadromous life history (Neave 1958). The retention of the freshwater stage over the past million years indicates that there is value in returning to fresh water to reproduce. The production of a large number of juveniles in fresh water and the exceptionally large marine mortality is an indication that the marine habitat is harsh for salmon. Beamish and Mahnken (1998; 1999) proposed that salmon reproduce in fresh water as a safe refuge for their young. This ensures that there is a diversity of genetic traits and life history types available for the salmon population when it enters the harsh ocean habitat. There is an abundance of food in the ocean, but the large ocean mortalities spotlight the costs of moving into this habitat. We may not be able to control the marine habitat, but we can recognize its influence on the biology of salmon. The occurrence of natural trends in abundance is clear evidence that the carrying capacity in the ocean changes. The variation in abundance of returns that we see today is a result of ocean habitat changes as well as from the impacts of fishing. The natural fluctuations prior to commercial fishing indicate that salmon have an evolved ability to survive extreme changes in their environment. The fact that some fish from each stock, always come back despite the large amount of marine mortality, tells us that a mechanism exists that "buffers" salmon from the randomness of death at sea. In some way, Pacific salmon have evolved not only to survive the uncertainties of the ocean habitat, but also to ensure that a few representatives of each stock always return.

Evidence of a linkage between salmon productivity and climate

Understanding the process that ensures the return of salmon is essential for our stewardship of salmon. It is essential because we intervene in the evolved, precisely tuned mechanisms that allow salmon to compete successfully with other organisms. It is also our responsibility because we have been trusted to spend the earnings of many people in our efforts to protect salmon and salmon fisheries. It was the desire to do the right thing and our lack of understanding of climate impacts that convinced us that hatcheries were a solution to management problems. Hatcheries made sense because we believed that the reduced abundances of salmon resulted from human impacts. We overfished or we prevented successful spawning. We believed that this error could be corrected by avoiding the high freshwater mortality, which we viewed as wastage, rather than having any evolutionary value. Furthermore, because we believed that the ocean carrying capacity was much larger than currently being "used" by salmon, we thought that we could produce more fish for harvest if we "planted more seeds" in this vast ocean pasture. Now that we know that the productivity of this pasture changes, we need to be more careful with the seeds we sow. Hatcheries have a role in management and our experiments with hatcheries provide us with an excellent way of studying marine impacts on salmon (Coronado and Hilborn 1998), but we need to reconsider the role of hatcheries in times when reduced ocean survival is limiting total returns.

The marine survival of coho in the Strait of Georgia, Puget Sound, and of Oregon follows a pattern that corresponds to large scale changes in climate. After 1989, the ocean survival of the aggregate of stocks in these three areas all declined dramatically (Beamish et al. 1999b). The other change occurred in 1977, a well-known period of climate change (Ebbesmeyer et al. 1991; Mantua et al. 1997; Minobe 1997; Beamish et al. 1999a).

Although there was a change in the trends of survival in the three areas after 1977, the change was not the same as it was after 1989. The reasons for the different responses are not known, but the differences emphasize the importance of looking for specific responses within any given ecosystem when regimes shift. The climate change associated with these shifts can be illustrated using the Aleutian Low Pressure Index (ALPI) (Beamish et al. 1999a). The ALPI is a measure of the intensity of winter winds in the Subarctic Pacific. The intensity of winds, in turn has been linked to changes in production (Brodeur and Ware 1992; Sugimoto and Tadokora 1997; Lagerloef 1995; Polovina et al. 1995). The Aleutian Low Pressure Index shows virtually the same fluctuating trends as other indices such as the Pacific Decadal Oscillation (Fig. 2). The Pacific Decadal Oscillation (Mantua et al. 1997) is a measure of sea surface temperature change, but it also represents changes such as annual flows from large rivers. The Pacific Circulation Index (PCI) (King et al. 1998) is an index of the general Pacific atmospheric circulation in the winter (December-March). The index was developed by categorizing the atmospheric processes over the North Pacific into zonal (west), meridional (northwest) and easterly (southwest) wind patterns. The positive trend in the PCI indicates a period of below average meridional and above average zonal or easterly processes. The changes in circulation trends in the PCI are similar to the trends in the other climate/ocean indices in Figure 2 and therefore are linked to both ocean changes and salmon abundance trends. It is important that there is such a close relationship between the wind related indices, the sea surface temperature dominated Pacific Decadal Oscillation and salmon production as it demonstrates the linkage between atmospheric circulation, ocean processes and biological responses. Other indices of climate change in the Arctic (Thompson and Wallace 1998) and in the North Atlantic have some similar trends to the Pacific indices. Hurrell (1996) has shown that there is a linkage between the trends in the atmospheric pressure based North Atlantic Oscillation Index and the surface air temperatures in Europe. The relevance is that we are learning that there are long-term trends in climate that are related to the measures that we use to characterize fish production.

The ALPI changed in 1977 and 1989 (Fig. 2). The change in 1989 was from a period of extreme low pressures (stormier winters) to a period of average pressures. It is important to remember that ALPI is an index of change and the actual changes in a particular ecosystem and their impacts on a particular species would need to be determined. The relevance of the reduced marine survival of coho after 1989 is that the marine habitat for coho changed and that the ocean could not support as many coho as it did previously. We do not believe that this is simply a percentage change in survival. Thus, adding more coho would not be expected to improve future adult returns. However, proving that adding more coho would not lead to production of larger adult returns is a difficult scientific problem without doing the experiment, which is also complicated. When the ocean carrying capacity is reduced, it is also possible that adding more coho from hatcheries may reduce wild coho abundance (Sweeting et al. 1999; Solazzi et al. 1990).

Beamish et al. (1997) showed that the rate of increase of the total Pacific catch of three species of Pacific salmon from the mid-1970s through to the mid-1990s was similar. However, the catch of chum salmon was estimated to be 84% hatchery fish, pink was 23% hatchery fish, and sockeye was approximately 5% hatchery fish. Thus, the addition of hatchery fish did not appear to alter the rate of increase during the favourable ocean regime in the 1980s (Fig. 3).

The linkage between changes in climate/ocean environment and the natural regulation of abundance has been proposed to be through the amount of growth during the summer (Beamish and Mahnken 1998; 1999). They considered that the abundance of salmon is regulated naturally in the ocean in two principal stages. There is a large mortality shortly after salmon enter the ocean. This early marine mortality is predation based and may be related to size. During the summer, the young salmon compete for food with other individuals of the same species and with other species. Climate impacts may alter the total amount of food produced and the abundance of competing individuals. According to the hypothesis of Beamish and Mahnken, Pacific salmon and coho salmon in particular must grow to a minimum size by the late fall in order to survive the severe conditions during the winter. If they do not reach a critical size, they are not physiologically able to survive. In some cases, juveniles revert back to a parr like appearance that ultimately ends in death (Mahnken et al. 1982). This second mortality is a physiologically based death. Because the amount of total mortality is related to competition, it is expected that some fish will always grow to the critical size by the critical time of the year. In this way, some individuals of each stock will always return. In the future, Pacific salmon abundances would be expected to continue to fluctuate over 10 to 30 year periods in response to natural changes in climate. These persistent trends in abundance would change abruptly in response to shifts in climate as they have in the past. Beamish et al. (1999a) recently speculated that a common event is responsible for these long-term shifts and that the common event is associated with large scale energy redistributions within the Earth and its atmosphere. Such a fundamental mechanism would be important as its discovery would provide a basis to forecast changes in the trends in the dynamics of local marine ecosystems.

A Russian index of the general circulation of the atmosphere in the Northern Hemisphere is called the Atmospheric Circulation Index ACI (Beamish et al. 1999a) and is the European equivalent of the PCI. The ACI, like the PCI, is an attempt to simplify the dominant direction of the westerly winds on an annual time scale. When the ACI is compared to the measured change in the daily rotation of the solid part of the Earth or length of day (LOD) expressed as an average annual change, there is an amazing, inverse relationship (Fig. 4a). The PCI also has a close inverse relationship with the length of day (Fig. 4b). It may take time to sort through the possible explanations for the linkages between Earth rotation and ecosystem productivity, but it is a relationship that may show that the complexities of ecosystems are linked through a common factor.

There have been some important changes in the trend of the Aleutian Low in the 1990s. After the period of intense lows from 1977 to 1989, there was a period of average lows from

1989 until 1998. It is the period of average lows that has been associated with the synchronous decline in the marine survival of coho. In the last two years, the Aleutian Low has been intense and average. We suspect that this is the beginning of another change in trend that we speculate may be to more extreme fluctuations. An obvious question is how marine survival of coho will be affected. Our answer, unfortunately, is that we do not know. We do know that fishing impacts will remain important, but they no longer should be considered in isolation of the effects of the ocean environment.

The next crisis

Another important climate change is global warming. There is no dispute about the warming of the planet (Fig. 5). There is ample documentation of warming trends and there is no serious debate among credible scientists about the warming trend. There is debate about the cause of the warming. It is intriguing that the Northern Hemisphere surface temperature trend looks more like the trend in the climate indices than the build up of CO_2, which is the main contributor to global warming. This suggests that the warming is a result of both natural trends and CO_2 increases. There is a tendency to try to separate natural climate change from the global warming impacts before we consider the consequences. It is a serious mistake for fisheries managers to become mired in the debate about the reasons for the current warming. We need to go no farther than the certainty that the planet is warming. It is not that the debate is unimportant, but rather it is that we need to act immediately to address management issues related to the warming. The impacts will be in fresh water and the ocean and the impacts will relate to temperature effects and ecosystem effects. One common sense response to the impacts of global warming is to respect the ability of wild salmon to adapt to extreme environmental change. The evolved ability of salmon to survive the extremes of one million years of ocean habitat change is stored in the genetic make-up of salmon. If we believe in evolution, we believe that surviving extreme changes in the environment is the reason different species exist. In other words, the genetic traits of wild salmon are the most effective adaptation to the inevitable extreme changes in climate. Thus, when conditions in the ocean are less favourable as indicated by the recent low marine survival, we need to ensure that wild stocks are protected. It may be our preservation of the naturally evolved genetic ability to survive extreme environmental events that enables salmon to remain in their more southern habitats.

In periods of low marine survival or low carrying capacity, we need to modify our expectations of having high abundances. If we accept lower abundances as a reality, we can address the issue of the importance of wild salmon. We need to change our objective of sustaining historic high abundances of salmon to protecting the evolved ability of wild salmon.

Change is part of the make up of all living things. We are in a period of very profound and obvious change in our climate. We have a responsibility to recognize this change and adapt our thinking and our management of salmon (Bisbal and McConnaha 1998). The desire to do the right thing for salmon has always been embedded in the culture of Pacific Rim peoples. The difficulty is that as we learn more about the factors that affect salmon such as climate, we also realize how much more there is to learn. Recognising that we will always be learning, I recommend we do the following to prepare for the future. I hope that it makes sense to you:

1. Protect freshwater habitat as a safe refuge for spawning and for baby salmon to grow.
2. Respect the marine habitat of salmon because most salmon do not survive the complexity of factors that can cause their death.
3. Recognize that the life histories of the various species of wild salmon have evolved to adapt to a wide range of natural conditions which means that if salmon were left alone they could solve their own survival problems.
4. Be concerned that we have not left salmon alone.
5. Be even more concerned that we have intervened in the natural regulation process while understanding very little about the natural mechanisms that affected survival.
6. Fishing should not prevent a stock from replenishing itself, but knowing what the safe level of fishing should be will always be a challenge.
7. Be careful of advice that tells you that you can rebuild salmon with computers.
8. Accept that climate affects the survival trends in salmon.
9. Believe that the planet is warming and the climate is changing, but do not delay responding while experts debate if the cause is from our production of greenhouse gas or natural trends as it is probably from both.
10. Recognize our uncertainties and speak openly about what you know and don't know as expectations will become more realistic and people will like fisheries biologists better.
11. Remember that everyone cares for salmon, it is the interpretation of our ignorance that creates conflicts.
12. Expect the unexpected, prepare for change as do all animals, and believe that the future survival of salmon is a measure of our ability as a species to live in balance with other species.

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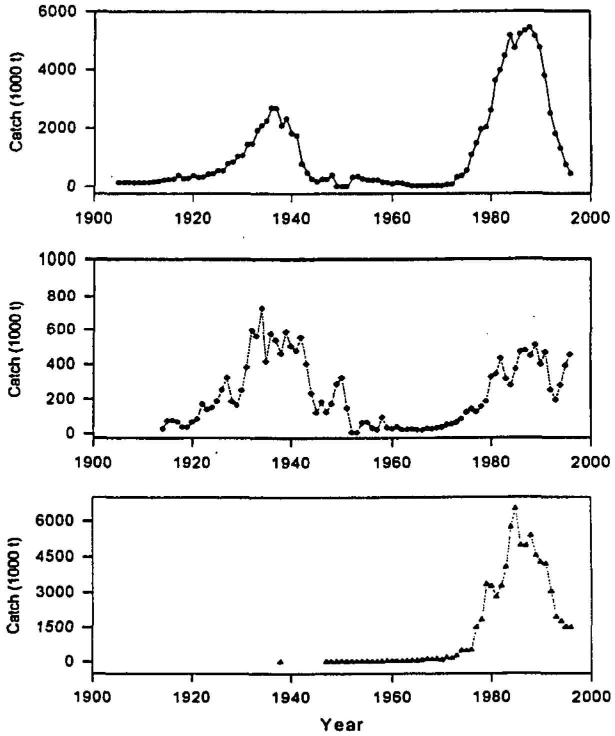

Figure 1. Catch of sardines (1000 tonnes) from the three major stocks in the Pacific Ocean (updated from Kawasaki and Omori, 1988). Note the synchrony in catch trends.

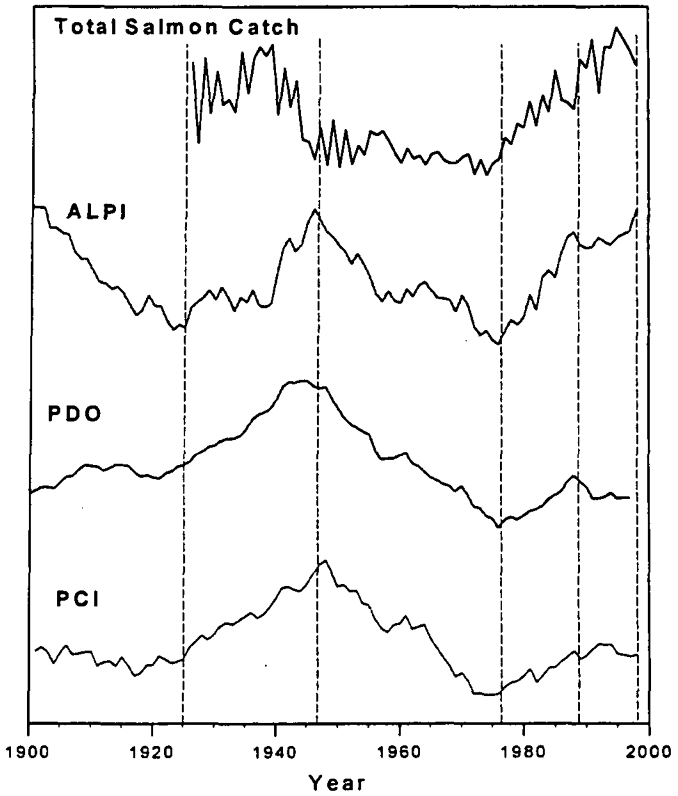

Figure 2. The relationship among three indicators of climate over the North Pacific and the total, all nation catch of pink, chum and sockeye salmon (approx. 90% of catch of all species of salmon). The salmon catch is unsmoothed and the Aleutian Low Pressure Index (ALPI), the Pacific Decadal Oscillation Index (PDO), and the Pacific Circulation Index (PCI) are in the CuSum form (Beamish et al. 1999a). The vertical dashed lines represent regime shifts: 1925, 1947, 1977, 1989 and possibly around 1998.

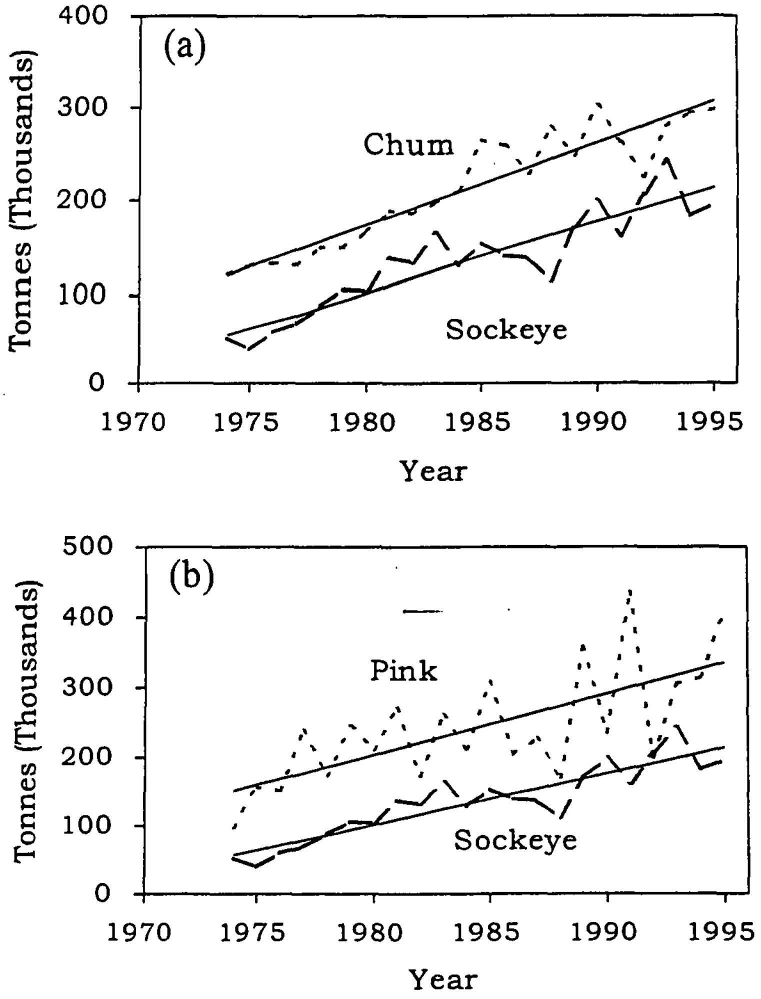

Figure 3. A comparison of the total all nation catch of chum salmon and pink salmon to sockeye salmon.

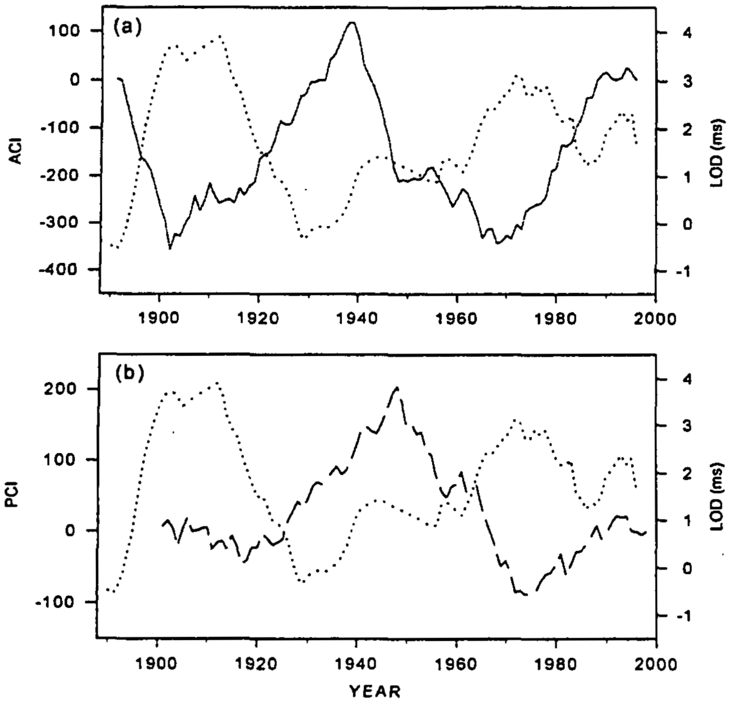

Figure 4 a, b. The relationship between the index of atmospheric circulation (a) ACI (solid line) and (b) PCI (dashed line) to the measured average annual change in the rotation of the solid Earth or length of day (LOD, milliseconds, dotted line). The relationship shows that the change in the index of the dominant, annual direction of the westerly winds is inversely related to the average annual rotational velocity of the solid part of the Earth. The implication is that the relationship may represent patterns of energy transfers between the solid earth and the atmosphere.

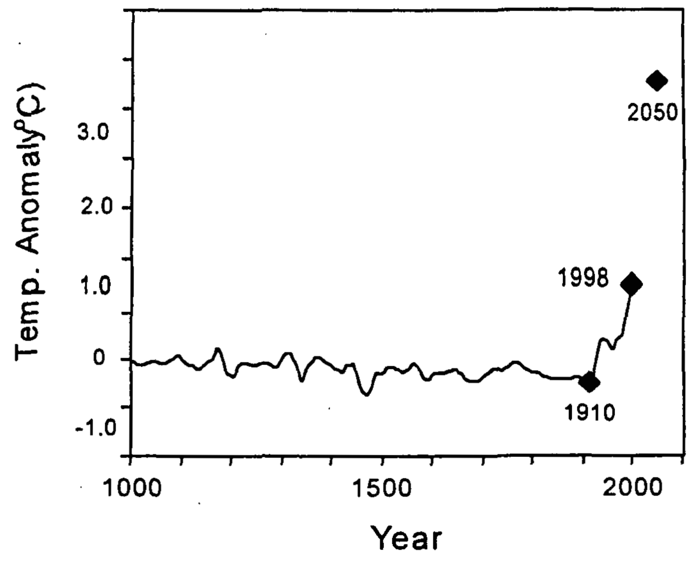

Figure 5. The 1000 year estimated average Northern Hemisphere surface temperature anomalies from Mann et al. (1999), with the predicted temperature for the year 2050 from global climate change models. Instrument data begins in 1902. Data from 1000 to 1902 reconstructed from tree ring measurements and a smoothed 40- year average.

Managing for Salmon as if the Ocean Mattered

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Introduction

The topic of this symposium—the effects of the ocean and climate on salmon production—marks a dramatic break with traditional ideas in fisheries conservation. Through most of its history, fisheries science has assumed that salmon populations are in a stable balance that is maintained by biological interactions in freshwater. According to this idea, nature produces a vast excess of salmon eggs and fry each year, which are subjected to "density-dependent" mortality from competition, predation, and disease. Left undisturbed, each salmon population presumably reaches a stable threshold or "carrying-capacity" level that is determined by the most limiting resource in the environment, typically thought to be the amount of food or habitat available during the earliest juvenile stages.

Upon this density-dependent and freshwater foundation, fisheries science constructed a framework of ideas that has long guided salmon conservation in North America. Included in this framework are the following principles and assumptions:

- **Nature produces a predictable surplus of salmon for harvest.**

Since density-dependent factors limit the production of each brood of salmon, any spawners returning above the minimum number required to seed the available freshwater habitat will be "wasted" if they are not harvested. Because populations are in a perfect balance with their available resources, the annual surplus available for harvest can be precisely calculated from equilibrium population models.

- **The goal of management is to remove limiting factors to salmon production.**

The stable balance of populations with their environment allows resource managers to manipulate salmon and their ecosystems to achieve management goals. By controlling the sources of freshwater mortality, the harvestable surplus can be increased to claim for people what would otherwise be "wasted" in nature. Large estuarine and marine environments, which cannot be readily controlled and are presumably neutral factors in salmon production, for all practical purposes can be ignored.

- **The effects of management manipulations are ecologically benign.**

Natural systems, as evidenced by the stable balance of populations, are like machines with separable and replaceable parts. These parts can be modified or substituted to more efficiently produce salmon without adversely affecting the ecosystems that support salmon.

- **Management success is measured by salmon abundance.**

The goal to increase salmon production and yield dictates that abundance measures (e.g., total pounds and numbers of fish harvested or annual return of spawning adults) are the key indicators for evaluating management results. Differences in the geographic origin or behavior of local populations (e.g., run timing, duration of estuarine rearing, age of returning adults, etc.) are irrelevant to the total quantity of salmon produced.

- **The appropriate scales for understanding salmon are defined by the jurisdictional boundaries of the agencies that manage salmon.**

The jurisdictions of government agencies determine the geographic extent of their interests in salmon. These proprietary interests, in turn, dictate the relevant scales of information each agency needs to properly manage salmon.

Recent evidence that Columbia Basin salmon production may be controlled by changes in the atmosphere, ocean, and estuary undermine these traditional assumptions. The results show that salmon populations are not in a steady-state equilibrium, that annual returns are not entirely determined by freshwater conditions, and that salmon variability is at least partially explained by remote physical factors that can affect survival independent of the density of fish. Moreover, the vast scale and uncertainty of oceanic and atmospheric processes call into question traditional harvest and hatchery programs that depend on steady-state population models and artificial control of freshwater environments. The presenters at this symposium raise important issues that require changes in the way we think about salmon and how we might go about conserving them. Here I briefly summarize the history of ideas about the ocean and salmon, new information and ideas presented at this symposium, and the implications of these results for salmon conservation in the Columbia River Basin.

Changing Views of the Ocean

Throughout the history of resource management, ideas about the importance of the ocean to salmon production have evolved slowly to accommodate new understanding of salmon biology and changing attitudes toward fishery regulation. This history of thought can be characterized in three major stages (Figure 1):

The Ocean is Irrelevant (1870s to 1920)

During the second half of the nineteenth century, state and federal fish commissions were established to address concerns about the decline of fisheries in New England and to promote new hatchery technology that promised to make the nation's most valued food fishes widely available to all citizens (Bottom 1997). Hatchery development was consistent with a prevailing cultural ideal that promoted efficiency and control of natural resources for human benefit. The desire to increase fish production emphasized the freshwater phase of salmon life history where limitations to survival seemed readily apparent and could be artificially controlled. The success of hatcheries, though unsubstantiated, seemed self evident because 70 to 90% of the eggs survived in a hatchery environment compared with only a few percent or less in nature. These results led to wildly optimistic claims of potential hatchery benefits based on the untested assumption that total fish production would increase in direct proportion to the number of eggs that were saved by raising them in a controlled environment (Lichatowich et al. 1996; Bottom 1997). The presumed success of hatcheries, in turn, supported a policy by the U.S. Fish Commission to make fish so abundant that harvest regulations would be unnecessary (Goode 1886).

During this period, estuarine and ocean environments were not considered relevant to salmon management. Before the turn of the century, little was known about the ocean life of salmon species, which were generally assumed to rear within a few miles of the mouths of their local streams until they matured (Lichatowich et al. 1996). The high natural mortality of eggs and fry and the ability to control these effects, focused exclusive attention on the freshwater phase of salmon life.

After 1900, experience with marine fisheries, particularly in the North Atlantic, convinced many biologists that overfishing was becoming a serious problem (McEvoy 1986). In the Pacific Northwest, these concerns raised some doubts that salmon abundance could be maintained through hatchery production alone (Higgins 1928). New fishing technology increased the efficiency of salmon harvest in the Columbia River, and boats outfitted with gasoline motors began to establish troll fisheries in the ocean. By 1920, as many as 2,000 trollers worked the mouth of the Columbia River (Smith 1920 cited in Lichatowich et al. 1996). These changes expanded the distribution of fisheries into adjacent coastal waters, a development that would have far-reaching implications for future conservation efforts. Concerns about overharvest and the need for better information to support conservation stimulated early research on the migrations of salmon (Gilbert 1912). But resource managers remained steadfast in their belief that hatcheries could maintain or increase fish production. Within a framework of presumed freshwater population control, estuarine and ocean factors simply had little meaning.

The Ocean is Benign (1920s to 1970s)

By the turn of the century, public anxiety over the effects of unrestrained economic development became the focus of new conservation policies of the Progressive Era. Progressive ideals emphasized the principle of scientific management by experts to insure efficient production and equitable allocation of natural resources. These ideas were widely accepted in fisheries conservation by the 1930s (Larkin 1977) as fish and game regulations expanded and data collection increased to provide a scientific basis for management. New tagging studies documenting extensive ocean migrations by salmon and the movement of salmon fisheries offshore meant that the ocean was indeed becoming relevant to fisheries management. But despite new information about salmon life history, interpretations of salmon production continued to rely on traditional freshwater assumptions. The ocean was like a vast, inexhaustible pasture designed to accommodate all those salmon that survived the rigors of freshwater life.

A major focus of scientific management during this period was the improvement of hatchery technology to more fully control salmon mortality in freshwater. Throughout this period, fish runs in the Columbia River steadily declined. But despite the failure of hatcheries to maintain salmon abundance, hatchery production continued to expand (Lichatowich et al. 1996). With the construction of mainstem dams on the Columbia River, new hatchery programs were established to mitigate effects. Continued research after World War II yielded substantial improvements in fish nutrition and disease prevention and allowed fish to be reared to a yearling ("smolt") stage before release. Throughout this rapid expansion of hatchery programs, the productivity of the estuary and ocean seemed unlimited; fishery managers simply assumed that the vast ocean reservoir downstream could absorb any desired quantity of salmon smolts released from Columbia River hatcheries.

By the 1920s, understanding the fluctuations of economically important species had become a primary focus of many subdisciplines of ecology including fishery science (Kingsland 1995). The entire science of population regulation developed from a new conceptual framework that viewed species as collections of populations rather than as a single homogenous and unchanging group (Mayr 1982). Studies of Atlantic herring and other marine fishes (Heincke 1898 and Hjort 1914) had revealed a geographic structure of populations within species that accounted for year to year fluctuations in abundance. Prior to this understanding, variability in the landings of many marine species were assumed to result from changes in the distribution of a single species group across its geographic range (Sinclair 1988). The population ideas that first developed out of studies of marine fishes were similarly applied to anadromous salmon. By the 1930s, studies had confirmed the "home stream theory," which held that salmon return to their natal streams to spawn (Lichatowich et al. 1996). These results revealed a complex geographic structure of populations within salmon species. Rich (1939) thus described in detail the importance of protecting local breeding populations of salmon as the fundamental units for conservation of species.

Biologists immediately recognized that the population structure of wide-ranging marine and anadromous fish had a critical meaning for fisheries management: Harvest of a population in one part of its range would affect the same population across the rest of its distribution (Sinclair 1988). In the late 1920s, chinook salmon tagged from the Columbia River in ocean waters west of Vancouver Island demonstrated the international conflicts that could arise when a population harvested at sea had spawning grounds in another country (Lichatowich et al. 1996). When Willis Rich (1939) later summarized the stock concept for Pacific salmon, he warned that any conservation efforts within the Columbia River could be negated by the activities on distant ocean fishing grounds. Thus, interest in the ocean life of salmon first developed around the definition of property rights and the allocation of migratory fish that crossed state and national boundaries.

Ironically, this same understanding of population structure that raised concerns about harvesting salmon in the ocean had little influence on thinking about ecological effects of the ocean on salmon production. The discovery of dominant year classes in marine fish populations had clearly demonstrated that ocean conditions during early life stages could account for year-to-year fluctuations in their production (Sinclair 1988). But an important distinction was made when population ideas were applied to anadromous fish: If conditions during early life stages are most important to recruitment success, then the critical factors in salmon production must remain in freshwater. W. F. Thompson (1919) concluded that "The salmon is a highly localized anadromous species, for which artificial propagation is carried on very extensively, and its fresh water life is perhaps more critical than its marine. It is therefore not comparable to purely marine species." Willis Rich (1928) proposed a research program for the International Pacific Salmon Investigation Federation that included "for the sake of completeness" research on various biological factors influencing the marine survival of salmon. He noted, however, that "since [these factors] are not, apparently, subject to any control by man, these problems do not appear . . . to be of prime practical importance." Thus, the "practical" purpose of management—to control salmon production—and the assumption that freshwater was the critical limiting environment (and conveniently, an environment that could be controlled) were mutually reinforcing ideas.

The idea of a constant and benign ocean environment for salmon became formalized in the sustained-yield concept, which proposed an objective, scientific methodology for setting harvest levels. Although biologists were very familiar with the concept by the 1930s, the theory was not developed fully until the work of Beverton and Holt in 1957 (McEvoy 1986). Stock/recruitment models began from the assumption that abundance of a fish population is regulated primarily by density-dependent factors during early life stages. Maximum Sustained Yield was based on a logistic growth curve developed from animal populations held under constant food supply and environmental conditions (Barber 1988; Botkin 1990). It assumed that natural populations reach a stable equilibrium level (carrying capacity) set by available resources in the environment as defined by the logistic curve. In practice, however, spawner-recruit relationships using empirical data relied on many years of observation to show an "average" relationship between population size and the resulting recruitment. Thus, rather than contribute to a better understanding of the effects of environmental change, population models assumed that change was insignificant by averaging conditions over the period of observation (e.g., Cushing 1995). Population models legitimized the benign ocean.

The Ocean is Dynamic (1980s to 1990s)

Within the last two decades, traditional ideas about the ocean and salmon production have undergone a dramatic change in the Pacific Northwest as a result of regional fishery collapse, the increasing risk of extinction of many populations, and new information about the effects of variable ocean conditions on salmon survival. The view of the ocean as a stable and tranquil pasture for salmon has been replaced with the idea of a dynamic, unpredictable, and sometimes hostile ecosystem.

As recently as the 1960s, the assumption of freshwater control of salmon production seemed well supported by the apparent success of new hatchery technology. As Oregon coastal and Columbia River hatcheries began producing large numbers of yearling coho salmon, both the survival rate of hatchery fish and the total return of adult salmon measurably increased (Figure 2). But after 1976, coho populations unexpectedly collapsed despite continued increases in hatchery output, providing the first convincing evidence that mortality factors outside the freshwater environment could be responsible for fluctuations in salmon abundance (Bottom et al. 1986). Successful prediction of adult returns from the previous year's run of precocious males (jacks) further indicated that survival of juvenile coho salmon sometime during their first six months in the ocean could control the production of an entire year class of adult salmon (Gunsolus 1978).

For the last twenty years, scientists have been documenting ocean effects on salmon production involving physical processes over a wide range of spatial scales. Oregon researchers first examined local upwelling processes (Gunsolus 1978; Scarnecchia 1981), which were known to increase nutrient levels and biological productivity at about the time salmon smolts first enter the ocean. Nickelson (1986) found a positive correlation between the percent survival of hatchery coho salmon released off Oregon and average upwelling intensity during the spring and summer. In recent years, the importance of large-scale climatic changes have become obvious as a result of unusually frequent El Niño activity in the tropics, including two very strong events in

1982-83 and 1997-98. During the 1982-83 event, researchers documented range extensions of marine fishes, birds, and plankton (McClain and Thomas, 1983; Pearcy et al. 1985; Mysak 1986); reduced reproductive success of Oregon seabirds (Graybill and Hodder 1985); and reduced size, fecundity, and survival of adult coho salmon off Oregon (Johnson 1988). These and other climatic effects create an entirely different view of the Pacific Ocean as an interconnected, basin-wide ecosystem in which the background conditions (e.g., species composition, circulation patterns, and biological productivities) continually shift among geographic regions in response to the global heat budget (Barber 1988). Wholesale shifts in the ecological condition of regions around the North Pacific, in turn, alter the environmental context of local salmon populations, whose paths of entry into the ocean are fixed by the location of their home streams.

Factors Affecting Salmon Production

This symposium summarizes recent results that further support the idea that the ocean and estuary are dynamic ecosystems that can produce year-to-year and decade-to-decade variations in salmon production. Among the important findings in this discussion are the following:

Estuary and Plume Effects

- **Estuarine rearing may improve ocean survival of salmon**

Estuaries provide important habitats for juvenile salmon for rearing, adaptation to salt water, and refuge from predators. Size at migration as influenced by estuary rearing conditions may be an important factor affecting salmon survival in the ocean. For example, although 5 different life history types were identified among chinook salmon poulations in Sixes River (Oregon), those juveniles that reared in the estuary for an extended period in late summer and grew to a relatively large size before their ocean migration accounted for 90% of the returning adult spawners (Reimers 1973).

- **The relative benefits of estuarine rearing may vary from year to year**

Manipulation experiments have been used to compare the survival of different groups of chinook salmon that were given or denied access to the Campbell River estuary (British Columbia) before they entered the ocean (e.g., Levings et al. 1989). An intriguing part of this research is that only two of three brood years of chinook salmon showed higher survival as a result of estuarine rearing, suggesting that the relative importance of estuaries to salmon production may vary from year to year as a result of environmental changes. These findings support the notion that estuarine rearing may be just one of a variety of alternative life-history strategies that salmon have acquired to minimize the risk of brood failure in a variable environment.

- **Nearshore environmental conditions during the first few weeks of ocean life may be critical to salmon survival**

The recruitment success of each year class of salmon appears to be established sometime soon after the juveniles enter salt water. Nearshore conditions within the Columbia River plume therefore may be critical to salmon production.

- **The specific mechanisms affecting salmon survival in the Columbia River estuary and ocean are poorly understood**

Understanding the mechanisms of estuarine and marine survival in the Columbia River Basin is limited by the lack of research on basic salmonid ecology within these environments. The inability to readily distinguish wild from hatchery fish complicates assessment of the effects of hatchery production on natural patterns of residence, migration, and habitat use by juvenile salmon in the estuary and plume.

- **Flow regulation in the Columbia Basin has altered the seasonal hydrograph with effects on salinity, density, and sediment transport**

Impoundment of summer flows and releases during the winter by Columbia River dams alter the physical properties and distribution of the plume. The shift in seasonal hydrograph has decreased the volume of Columbia River water transported off the Oregon coast during summer and increased the volume off Washington in winter with effects on salinity distributions north and south of the Columbia River mouth (Williams et al. 1996). Substantial decreases in spring freshet flows from the Columbia River may reduce concentrations of nutrients and food resources in the plume, decrease turbidities, and increase predation pressures to the detriment of salmon survival.

- **Flow and hatchery release schedules have reduced established patterns of salmon migration and rearing in the Columbia River estuary**

By dampening seasonal fluctuations in the hydrograph, dam operations have reduced the diversity of freshwater habitats and variety of flow conditions available to salmon. At the same time, hatchery production and release strategies have been narrowly programmed to fit the schedules of water releases through the dams. River operations thus constrain the historical diversity of rearing behaviors and concentrate salmon migrations through narrow "windows of opportunity" prescribed by the management system (Williams et al. 1996). Such changes may limit the flexibility of Columbia River salmonids to withstand variable estuarine and ocean conditions.

- **Creation of impoundments and removal of tidal wetlands may have enhanced pelagic food chains and reduced detrital sources that support Columbia River salmon**

Loss of vegetated wetland habitats has reduced emergent plant production and availability of macrodetritus in the estuary to the detriment of food chains that support salmon (Sherwood et al. 1990). At the same time, impoundments created by the mainstem dams have increased phytoplankton production and sources of microdetritus available to pelagic food chains. The tremendous expansion of American shad populations in the Columbia River is consistent with this apparent shift in estuarine food chains.

Ocean and Climate Effects

- **Climatic processes at a Pacific Basin scale can have an overriding influence on local and regional biological production**

Changes in global atmospheric circulation, ocean currents, and thermal regimes that can last for decades may set broad limits of salmon productive capacity. Although managers certainly cannot control these large-scale processes, natural variability must be understood to correctly interpret the response of salmon to management actions in the Columbia Basin. The capacity of local populations to realize the full productive potential of any particular climatic state will depend in large part on local habitat, harvest, and hatchery decisions.

- **The Pacific Basin ecosystem does not move toward a steady state**

Changes in the ocean basin ecosystem undermine assumptions of a steady-state background upon which biological interactions take place. The factors affecting salmon production include both density-dependent and density-independent processes. Variability of the Pacific Basin ecosystem suggests that equilibrium population models are not very useful for making long-term conservation decisions.

- **Climatic changes affecting salmon are often nonlinear and unpredictable.**

Decades-long shifts in ocean and climate regimes occur unexpectedly. The unanticipated decline in Oregon salmon production that began after 1976 (Figure 2), for example, coincided with a large-scale shift in oceanic regime. Sufficiently conservative standards of salmon protection are necessary even during a high productivity state to maintain the genetic and life-history diversity needed to withstand subsequent productivity troughs.

- **Shifts in climate regime change the carrying capacity "rules" for salmon**

Changes in climate regime alter the distribution of species, structure of marine food chains, and physical processes. Salmon populations that enter the ocean during different climatic regimes therefore experience an entirely different suite of physical and biological interactions. It should not be surprising, therefore, if simple correlations between salmon production and selected variables (e.g. upwelling, temperature, etc.) established for one climatic state no longer apply during another.

- **Biological responses in different regions of the North Pacific oscillate out of phase**

Atmospheric and oceanic processes in the North Pacific create opposing regional patterns of productivity in the central North Pacific and the California Current region (Oregon, Washington, and California). However, managers should be cautious in assuming that recent decreases in salmon production in the central North Pacific necessarily indicate a return to decades of improving salmon survival off Oregon. It is unclear, for example, how the predicted warming of global climate from steadily increasing concentrations of atmospheric carbon dioxide might alter future productivity oscillations in the North Pacific.

- **Stream flows and temperatures are affected by the same large-scale processes that control ocean circulation and productivity.**

It is not possible to partition the freshwater, estuarine, and ocean factors that affect salmon in part because these environments are embedded within the same regional and global climate systems. In Oregon, stream and ocean conditions that affect salmon survival tend to oscillate in phase with one another: the same climatic conditions that produce warm ocean temperatures and low coastal productivity often coincide with periods of low precipitation, reduced stream flow, and increased river temperatures (Greenland 1994).

- **Unique local geography and disturbance histories may establish different biotic potentials and responses to large-scale climate change.**

Although there is considerable synchrony in patterns of marine survival for southern stocks of salmon (e.g, British Columbia, Washington, Oregon, California), unique geographic influences and local population behaviors may produce complex patterns of environmental change and salmonid response within this broad region. For example, the direction of storm tracks and effects of varied topography on patterns of rainfall and snowmelt may yield different environmental and populations responses to the same regional climate.

Is the River Irrelevant?

The fact that large-scale climatic changes may regulate regional patterns of salmon production has led some people to argue that protection and restoration of freshwater habitats will provide little benefit to salmon. Like some management approaches that ignore the ocean in favor of the stream (because it is not practical to *control* the ocean), some now claim that the river has become irrelevant (because variability in the ocean is the critical limiting factor)(Figure 1). Opposing management views of river versus ocean dominance flow from the same conceptual framework, which defines resource management as *the active removal of production constraints within the single most limiting environment of the salmon life cycle*. This view is a simple extension of Leibig's Law of the Minimum, which holds that food or nutrients in least supply control the productivity of a population. In this version of Leibig's Law, the entire environment where the apparent limiting factor occurs becomes the one critical area of management concern above all others. Thus, some argue that the stream environment becomes inconsequential to salmon production if recruitment variations can be associated with ocean conditions.

Solazzi et al. (in review) recently completed stream restoration experiments in several Oregon coastal basins that illustrate some of the flaws in this argument. In the Nestucca River Basin, the number of yearling coho migrants substantially increased in a treatment stream (East Creek) after it received extensive habitat improvements throughout a 2.4 kilometer reach. The treatments, which were designed to improve the quality of overwinter habitat for coho salmon, included construction of 23 dam pools, 8 off-channel rearing ponds, and additions of large wood. Following habitat restoration, the number of coho migrants leaving East Creek increased relative to the number of migrants in the adjacent reference stream (Moon Creek), which received no habitat improvements (Figure 3). Whereas the mean number of salmon migrants in the reference stream steadily declined to near extinction levels during the post-treatment period, the mean number doubled in East Creek following habitat improvements. Moreover, these changes were the direct result of improved overwinter survival of coho salmon. Following treatment, mean overwinter survival for salmon in East Creek increased by 250% (0.11 to 0.39) while the background mean survival in the reference stream declined from a mean of 0.19 to 0.10 (Solazzi et al. in review). These results illustrate that by increasing smolt output, appropriate stream restoration activities may help buffer populations from the additional mortality that also occurs in the estuary and ocean. In fact, not only is the quality of freshwater habitat relevant to salmon conservation, it becomes all the more important during periods when the ocean exerts strong control over salmon populations by decreasing the rate of marine survival.

A principal problem with the conceptual framework of traditional salmon management is that it assumes that the environments at each salmon life stage are separable and independent. Yet the capacity of salmon to reproduce depends upon the connectivity of an entire chain of aquatic habitats from headwater streams to estuary and ocean. The rate of return from a particular brood depends on the cumulative mortality across all these habitats and life-history stages. But this cumulative mortality is not a simple sum of independent mortalities at each successive life-history stage. Mortality from egg to adult and the "carrying capacity" of the environment for salmon are properties of the larger freshwater-estuarine-marine ecosystem (Figure 4). For example, extreme flows, habitat quality, and other factors that contribute to mortality in freshwater determine the ranges of size, times of emigration, and physiological condition of the surviving juveniles that migrate downstream. Slightly different migration times through the estuary and ocean, in turn, may be advantageous in different years, depending upon variations in the timing of coastal upwelling, near-shore ocean temperatures, the location of the Columbia River plume, and so on. Thus, selection pressures at each life stage, which determine the biological characteristics and migration times of the surviving population of migrants, may be as important to the subsequent survival of salmon in the ocean as are the particular environmental conditions within the ocean itself.

Implications of Estuarine and Ocean Variability for Salmon Conservation

Although resource managers cannot control environmental variations in the estuary and ocean, this does mean that they can afford to ignore them. First, the failure to account for natural fluctuations may lead to unwarranted conclusions about the success or failure of restoration efforts. Changes in climate may cause substantial increases or decreases in fish abundance unrelated to management efforts. Many population increases that fishery managers originally attributed to hatchery programs, for example, were in fact the result of environmental changes that naturally increased salmon survival (Bottom et al. 1986; McEvoy 1986; Lichatowich and Nicholas in press). Second, estuary and ocean dynamics that regulate salmon productivity require management responses involving all other aspects of the salmon life cycle that are under human control (Williams et al. 1996). Conservation decisions that are appropriate under one ocean and climate regime may not be appropriate under another. For example, harvest levels must be adjusted to account for changes in survival during periods of low ocean productivity. Furthermore, opposing cycles of salmon abundance between the Central North Pacific and the California Current region (off Washington, Oregon, and California) underscore the importance of stock-specific management of fisheries. Even during periods of high salmon survival off Oregon, harvest limits must ensure that Columbia Basin stocks are not overexploited by northern fisheries trying to compensate for coincidental decreases in Alaska and British Columbia stocks.

Diverse life histories of salmon provide resilience to species in a fluctuating environment. For example, northern and southern coastal chinook stocks in Oregon exhibit different ocean migration patterns such that all fish may not be equally vulnerable to an El Niño event or local upwelling collapse. Similar migratory differences may explain the substantial decline of tule fall chinook stocks during the 1982-83 El Niño compared with other stocks from the Columbia Basin that had a more northerly ocean distribution (Johnson 1988). Loss of freshwater habitats, regulation of river flows, and the shift to large-scale production of very few hatchery stocks have all reduced the diversity of salmon life histories in the Columbia River basin and may limit the variety of migratory pathways of salmon into the estuary and ocean. Thus, management manipulations that alter population structure, life histories, or habitat diversity in freshwater may directly alter the capacity of salmon to withstand fluctuations in the estuary and ocean (Williams et al. 1996). Efforts to "stabilize" conditions in freshwater through flow regulation or hatchery programs, for example, may unwittingly eliminate behaviors that buffer salmon production in a variable estuary and ocean.

There are two principal strategies that resource managers can adopt to better accommodate variability in the estuary and ocean and support salmon recovery:

- **Restore and maintain life-history diversity among salmon populations**

A primary goal of restoration in the Columbia Basin should be to promote the greatest possible re-expression of life-history diversity among salmon populations. The impact on salmon diversity of existing management programs for habitat, harvest, hatcheries, and flow regulation should be explicitly evaluated. This review should include an assessment of the potential effects of hatchery programs on historical salmonid migrations, residence times, and habitat use in the estuary and Columbia River plume. At the same time, new restoration activities should be designed to expand flow variations and the variety of quality habitats needed to support diverse salmon life histories. Stream habitat restoration should encompass both tributaries and mainstem areas. Williams et al. (1996) recommend use of water storage and natural runoff to re-establish peak spring flows as a strategy for restructuring and revitalizing mainstem habitats (Williams et al. 1996). Restoration of the spring freshet plume could have additional downstream benefits in the estuary but these potential effects should be evaluated. Within the estuary, tideland marsh and swamp habitats should be restored through dike and tidegate removal to re-establish productive marsh-channel rearing areas and to promote macro-detrital production.

- **Develop an integrated monitoring and research program that incorporates the entire chain of salmon habitats**

Monitoring and research activities in the Columbia River basin should include the estuary and nearshore ocean to evaluate salmonid food webs, growth and residence times, and habitat use. This work should be developed as part of a larger monitoring/research design to provide basic information about salmonid ecology throughout the salmon life cycle and to monitor effectiveness of recovery efforts throughout the basin. Key physical and biological variables should also be identified and monitored to provide indicators of estuarine and near-shore variability needed to guide management activities in the rest of the basin. Finally, research is needed to examine whether specific patterns of salmonid migration and habitat use in the estuary and plume can be linked to specific tributary habitats and stocks upriver. These results would guide habitat protection and restoration efforts upriver toward the areas needed to maintain diverse life histories in the estuary and nearshore ocean. By protecting upstream-downstream habitat linkages, managers can insure that the available habitats and productive capacities of the estuary and Columbia River plume are fully utilized. From this perspective, the diversity of patterns of salmonid use expressed in the estuary and plume could become a system-wide indicator of the success of restoration activities throughout the basin.

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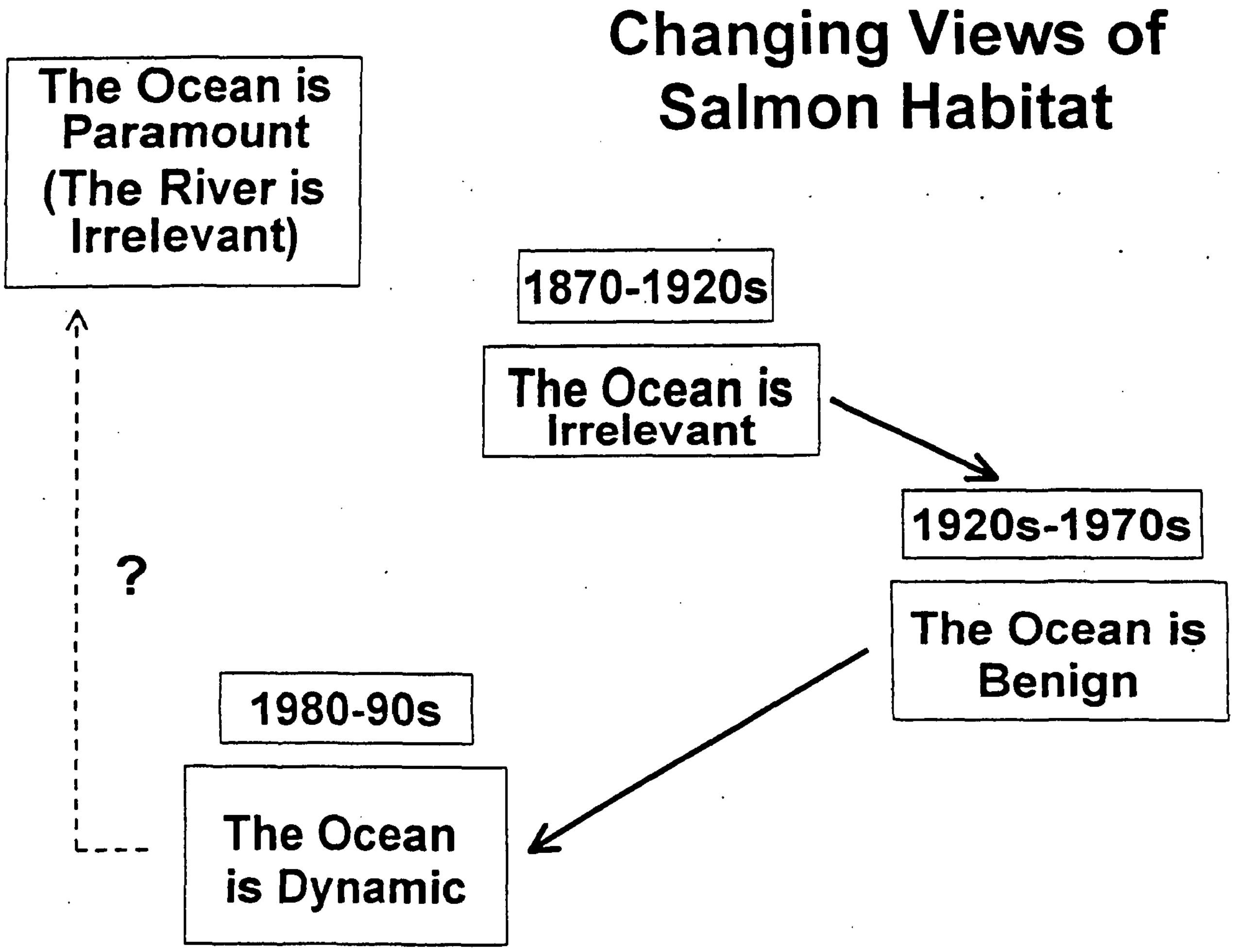


Figure 1. The evolution of ideas about the ocean in salmon management (see text).

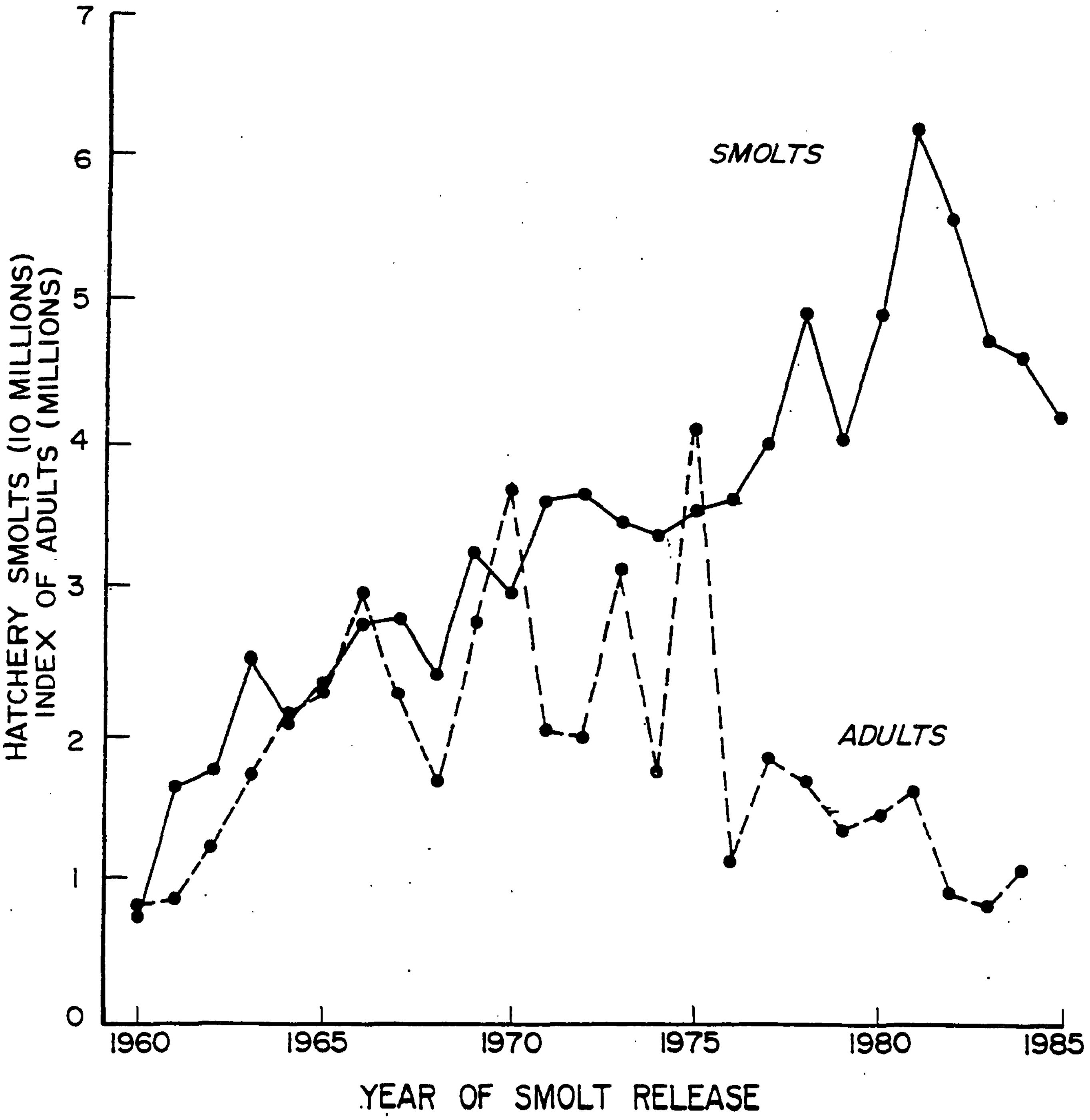


Figure 2. Numbers of hatchery coho salmon smolts released and estimated abundance of hatchery and wild adults produced the following year in the Oregon Production Area (from Nickelson 1986).

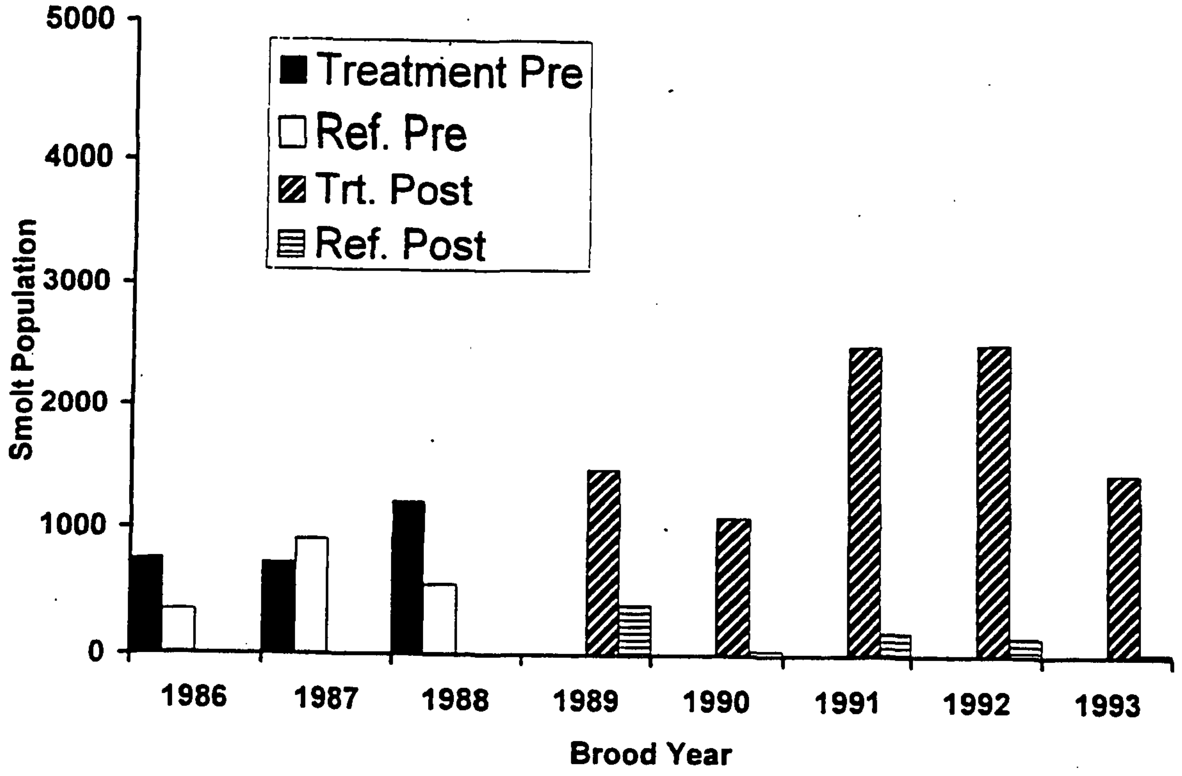


Figure 3. Pre- and post-treatment populations of coho salmon yearling migrants in treatment (East Creek) and reference (Moon Creek) streams in Nestucca River basin, pre- and post-treatment. (Data from Solazzi et al. In Review).

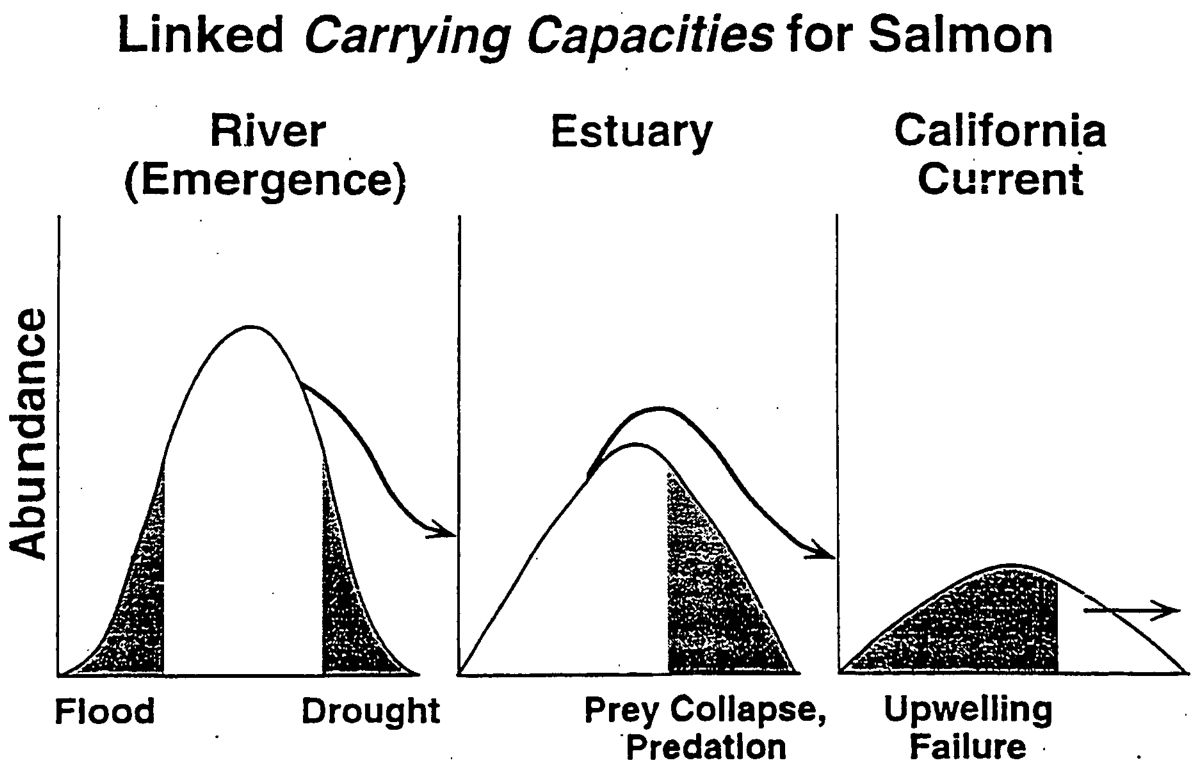


Figure 4. Diagram illustrating survival linkages between salmon life stages. Selection processes in one environment dictate the time of migration, physiological condition, or other characteristics of the surviving fish. These characteristics, in turn, influence the capacity of the population to withstand the environmental conditions that are found at the next life stage and time period, and so on.

Additional illustrations displayed during Daniel Bottom's oral presentation

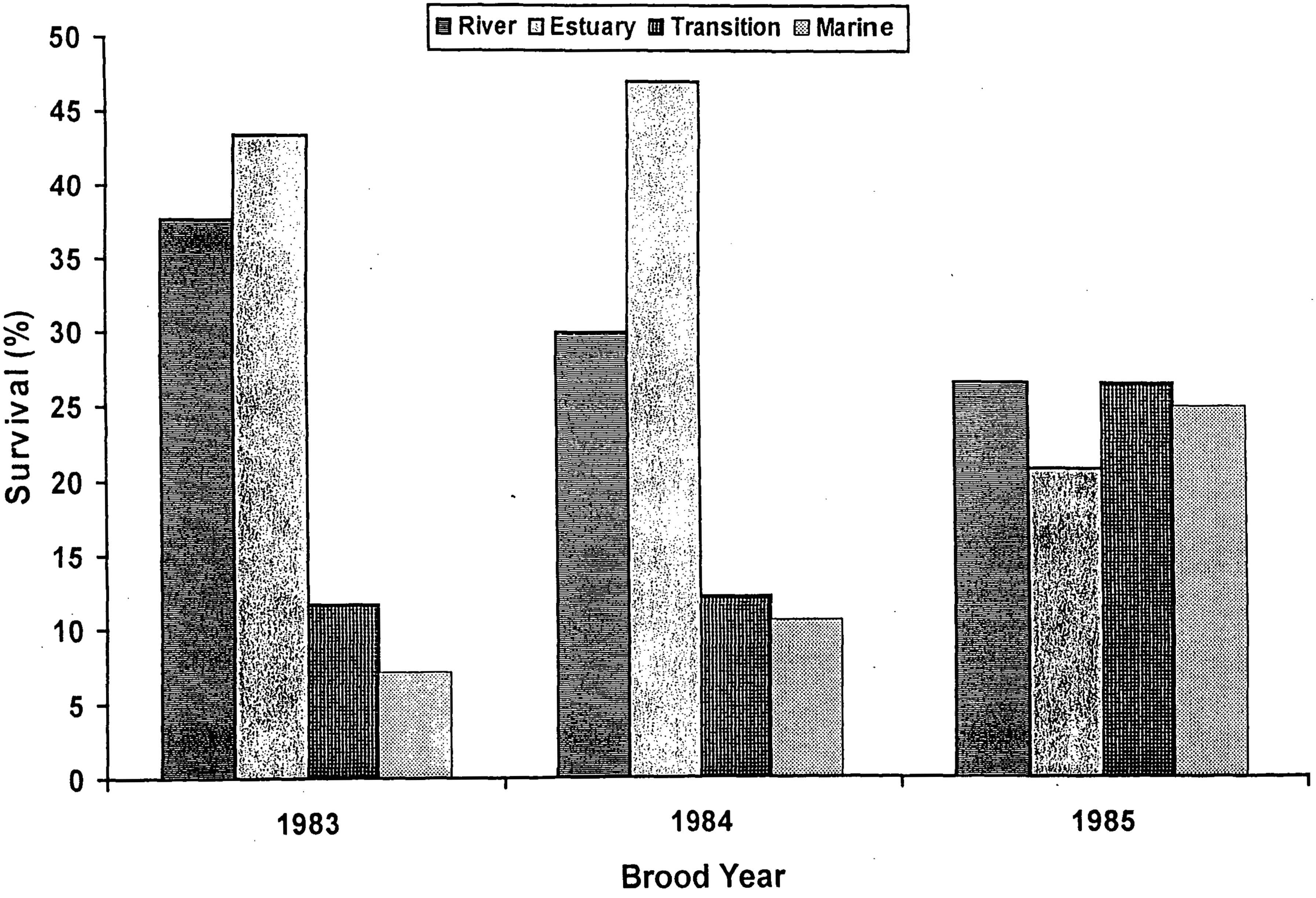
Conceptual Framework of Traditional Fisheries Management

- Fish populations are in a stable equilibrium
- Salmon populations are regulated by density-dependent factors in fresh water
- Management removes "limiting factors"
- Management changes are ecologically benign
- Management success is measured by abundance
- Political boundaries define the relevant scales for understanding salmon

Estuary and Plume Effects

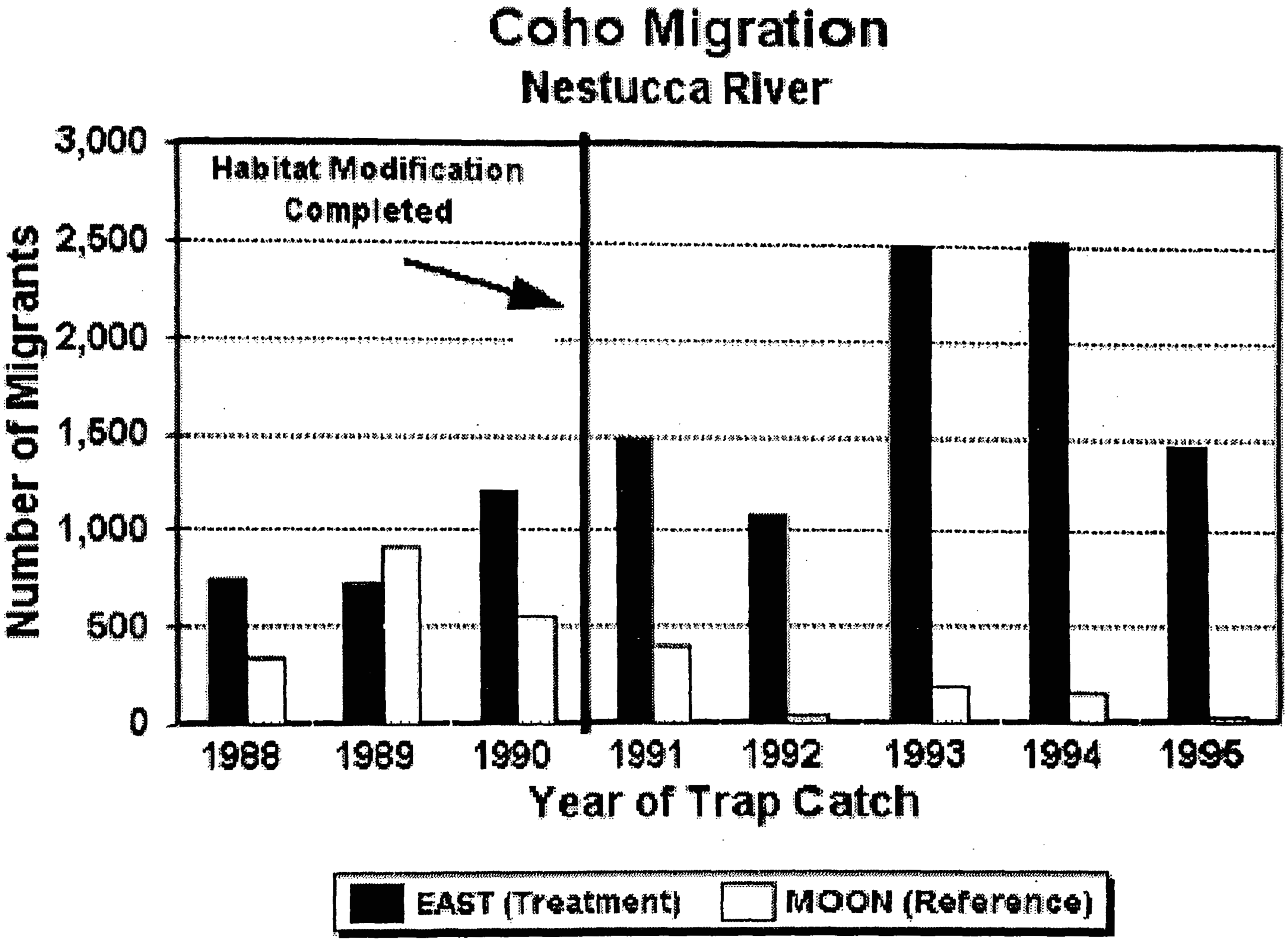
- Estuarine rearing may improve ocean survival of salmon.
- The relative benefits of estuarine rearing may vary from year to year.
- Near shore environmental conditions during the first few weeks of ocean life may be critical to salmon survival.
- The specific mechanisms affecting salmon survival in the estuary and ocean are poorly understood.

ESTUARINE DEPENDENCY (SURVIVAL) OF CHINOOK SALMON ON THE CAMPBELL RIVER ESTUARY (Levings et al. 1989)



Human Influences on the Estuary and Plume

- Flow regulation has altered the seasonal hydrograph with effects on salinity, density, and sediment transport.
- Flow and hatchery release schedules have reduced established patterns of salmon migration and rearing in the estuary
- Creation of impoundments and removal of tidal wetlands may have enhanced pelagic food chains and reduced detrital sources that support salmon.


Coho Migration
Nestucca River
Number of Migrants
3,000
2,500
2,000
1,500
1,000
500
0
Habitat Modification
Completed
1988
1989
1990
1991
1992
1993
1994
1995
Year of Trap Catch
EAST (Treatment)
MOON (Reference)

Ocean and Climate Effects on Salmon

- Processes at a Pacific Basin scale can have an overriding influence on biological production.
- The Pacific Basin Ecosystem does not move toward a steady state.
- Climatic changes affecting salmon are often nonlinear and unpredictable.
- Shifts in climate regime change the carrying capacity rules for salmon.

Ocean and Climate Effects on Salmon

- Biological responses in different regions of the North Pacific oscillate out of phase.
- Stream flows and temperatures are affected by the same processes that control ocean circulation and productivity.
- Unique local geography, disturbance histories, etc. may establish different biotic potentials and responses to climatic change.

Management Implications

- Freshwater, estuarine, and marine life stages of salmon are not independent
- Conservation efforts chosen under one climatic regime may not be appropriate under another.
- Opposing cycles of production in different Pacific regions underscore the importance of stock-specific management
- Global warming is a serious risk to southern stocks of Pacific salmon.

Conservation Strategies

- Improve estuarine habitats that support juvenile salmon.
- Restore/maintain life-history diversity
    - Expand ranges of natural variation
    - Evaluate management effects on diversity
- Develop an integrated monitoring/research program for the entire chain of salmon habitats
    - Develop physical/biological indicators of estuary and ocean conditions
    - Investigate stock-specific patterns of habitat use

Changes in Size at Maturity of Salmon Before and After the Ocean Regime Change of 1976-77: Management Implications

John H. Helle
National Marine Fisheries Service
Alaska Fisheries Science Center
Auke Bay Laboratory
Juneau, Alaska

Salmon catches increased greatly in Alaska after the ocean regime change of 1976-77 (Fig. 1). Catches in most years during the mid 1980s to mid 1990s in Alaska exceeded the large catches in the first half of this century. I think most biologists working in the 1950s, 1960s, and early 1970s never expected future salmon catches in Alaska to surpass those banner catches of the teens through the mid-forties.

About the same time as the regime change (and this was a coincidence because nobody had recognized the regime shift until later), interest in pink and chum salmon hatcheries was rejuvenated This new interest was the result of a breakthrough in hatchery technology -- the substrate incubator. This new incubator provided critical physical support for alevins. Japanese chum salmon hatcheries had been using physical support for alevins in their alevin rearing channels since at least the 1940s. Both wild and hatchery stocks in North America as well as Asia enjoyed enormous increases in marine survival following the regime change. However, even if the North American hatchery contribution were subtracted, the catch of wild fish in the 1980s and 1990s would still have greatly exceeded those early century catches.

Along with the dramatic increase in catches of salmon in Alaska in the late 1970s and early 1980s the size at maturity started to decline. This decline continued through the early 1990s. The decline in size was as dramatic as the increase in abundance (Fig. 2). Four-year-old chum salmon at Fish Creek, near Hyder, Alaska, in the early 1990s declined in weight by about 46% compared to the same age fish in the early 1970s. Four-year old chum salmon at Quilcene National Fish Hatchery in Hood Canal, Washington also showed a sharp decline in size from the early 1970s through the early 1990s (Fig. 3). Similar declines in size at maturity were recorded in Japan. Catches of chum salmon in Asia following the regime change increased more than catches in North America during the same time (Fig. 4).

While size at maturity declined, age at maturity increased following the enormous increases in abundance in both North America and Asia. We do know that North American and Asian stocks of chum salmon intermingle on the high seas. These changes in size and age at maturity associated with large increases in salmon abundance provide evidence for an inverse relationship between body size and abundance of salmon in the North Pacific Ocean. This evidence suggests that carrying capacity for salmon on the high seas may be limited under certain conditions. And, these changes in size at maturity were not just limited to chum salmon. Most stocks of all species of Pacific salmon showed reductions in size after 1980.

Most biologists attribute the enormous increases in salmon survival in Alaska following the regime change to improved conditions in the early marine experience and in freshwater. We do know that coastal waters were warmer after the mid- 1970s and offshore waters cooler. We

also know that final size at maturity, at least in chum salmon, is determined during the last t
years at sea.

So, what have we learned from the regime change and all the associated changes in size, age and abundance that we can use in salmon management and run predictions? One, maybe we can learn to recognize ocean regime changes. Fish Creek chum salmon show a significant increase in size at maturity starting in 1995 (Fig. 2). Quilcene chum show a significant increase in size at maturity starting in 1994 (Fig. 3). However, the abundance of chum salmon did not show a significant decline in 1994 or 95 or 96 (Fig. 4). The negative relation between size at maturity and abundance that was clear during the 1980s and early 1990s was not evident in these years. Therefore, conditions on the high seas for growth must have changed or improved. And, in most years, trends in sea surface temperatures in the central North Pacific Ocean and coastal areas tend to be opposite. So, are we in the midst of another ocean regime change? Are we switching from warmer coastal waters to cooler coastal waters? North American chum salmon catches have remained at high levels during 1994-98. Japanese catches did drop in 1997 and 1998 however, they remain at historic high levels (Fig. 4).

Another bit of evidence that suggests that we are in the midst of an ocean change is that 3-year old chum salmon are starting to show up again in southeast Alaska during the past four years. Age composition of chum salmon in southeast Alaska has been skewed toward 4-and 5-year old chum along with a small increase in 6-year old chum salmon since the mid-1980s. Six-year old chum salmon were rare south of Prince William Sound during the 1950s through the mid-1980s.

Why the emphasis on chum salmon? I think chum salmon are an excellent "barometer" of ocean conditions. They respond to changes in ocean conditions and competition by changing their age and size at maturity and these changes are relatively easy to monitor. Chinook and sockeye salmon may also change their age and size at maturity but their freshwater life history is more complex than that of the chum salmon. Pink and coho salmon apparently have little opportunity to change their ocean age.

While Alaska and Asia were blessed with very beneficial ocean conditions for salmon survival during the mid-1970s through the mid-1990s, ocean conditions off California, Oregon, Washington, and southern British Columbia were generally not good for salmon production. It has been suggested that marine conditions for optimal salmon production are opposite between Alaska and the Pacific Northwest. Then, if ocean regimes are cyclical, marine conditions in the Pacific Northwest may improve if conditions in Alaska deteriorate. So, we may be in the midst of improving conditions in the Pacific Northwest?

What other evidence is there that ocean conditions may be improving for salmon production in the Pacific Northwest? Chum salmon runs were very strong from central British Columbia to Puget Sound, Washington in 1998. This fact may not show on the catch statistics because they were not fished in relation to their abundance because of low prices. Chinook salmon returns during the past several years have improved to southern Oregon and northern California. Chinook salmon from about Newport, Oregon, on south have a different marine migration pattern than do chinook salmon from Newport on north. From Newport north chinook salmon make a "right-hand turn" and migrate along the coast northward and westward. South of Newport chinook apparently go south and westward before they go north? So, does this mean that marine conditions are improving in the southern areas? If so, can we expect marine conditions to deteriorate in the North Pacific off of Alaska? There certainly is some indication that salmon production in parts of Alaska is changing, particularly in the most northern areas in the Bering Sea. Bristol Bay sockeye salmon returned in 1997 and 1998 in numbers much below predictions. Chum and chinook salmon returning to western Alaska, especially the Yukon River in 1998, were definitely below expectations and subsistence and commercial users suffered. A test fishery for Bristol Bay sockeye salmon operated by the University of Washington's Fisheries Research Institute reported that June 1999 sea surface temperatures off Port Moller are the coldest since 1971. The winter of 1971-72 was a record cold winter in Alaska. That could mean delays in adult salmon arrival and maybe not good conditions for the juveniles leaving Alaska streams in that area?

If conditions are improving for marine survival of salmon in the Pacific Northwest, is the freshwater habitat ready to produce large runs again? During the highly favorable marine conditions off Alaska after the regime change - mid-1970s through mid 1990s - the freshwater habitat was only mildly affected by urbanization and conflicting land use policies. That just is not true for the Pacific Northwest. Is the salmon habitat in streams and rivers of the Pacific Northwest of sufficient quality to take advantage of improving ocean conditions for the young salmon that make it to sea? What has been the impact of straying and competition from many years of hatchery "mitigation" on wild stocks of salmon? Is the genetic diversity of the remaining wild salmon populations sufficient to generate large diverse increases in salmon abundance if the ocean environment improves? The habitat issues are simpler to deal with than the more subtle genetic issues. Habitat restoration has shown some promising opportunities recently. But, time is short. How long do the favorable ocean conditions last if they are cyclical?

One of the lessons from the last 30 years that is clear to me, is, that it is especially during times of poor ocean conditions that we need to pay close attention to the health of the salmon's freshwater habitat and impacts of hatcheries on wild stocks. We need to maximize the quality and numbers of our freshwater output of salmon during the lean ocean years to make sure that we do not lose the resource or lose the opportunity to recover the resource during periods of favorable ocean conditions.

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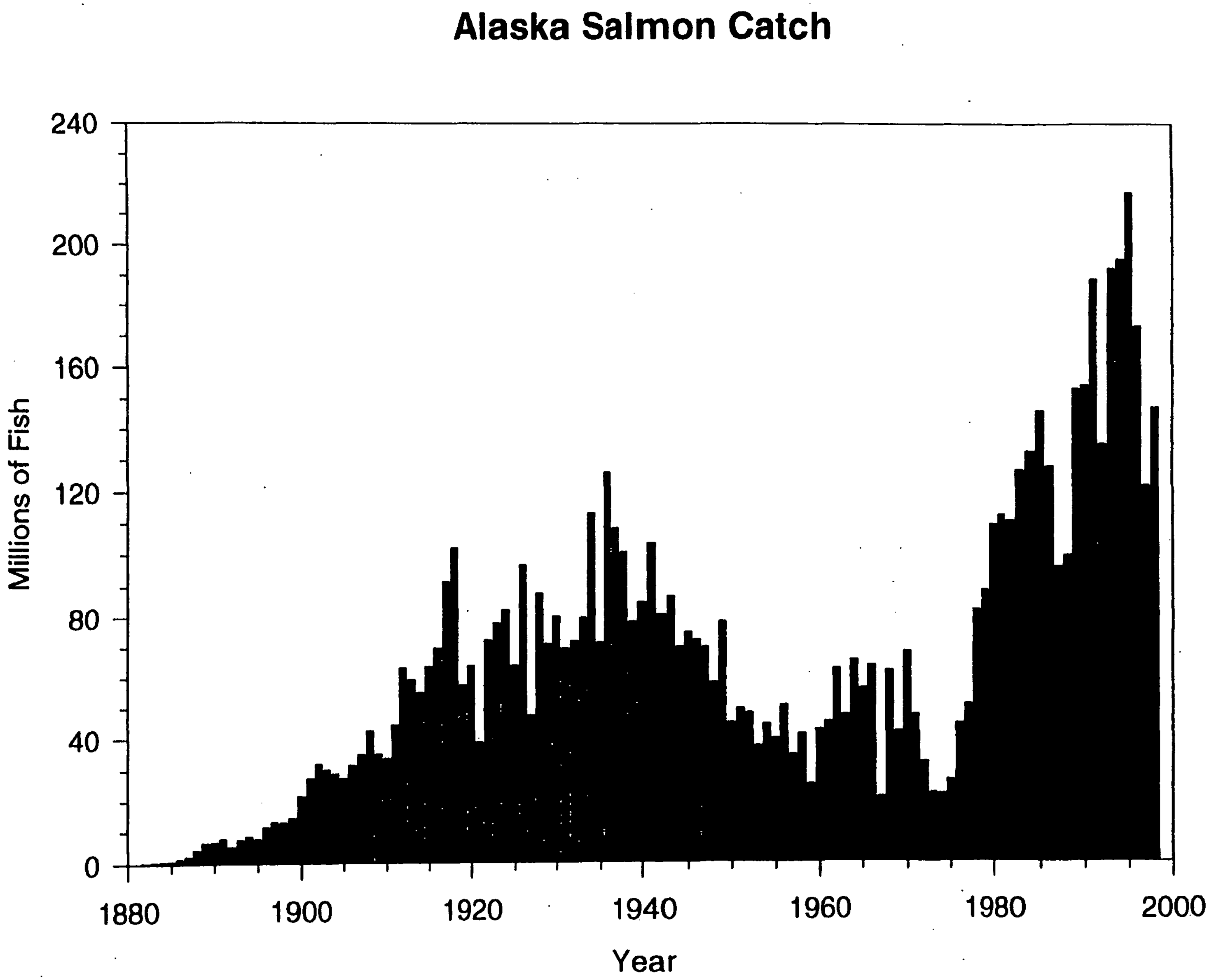

Fig. 1. Catch of all species of salmon in Alaska from 1880 through 1998 (data from Alaska Department of Fish and Game).

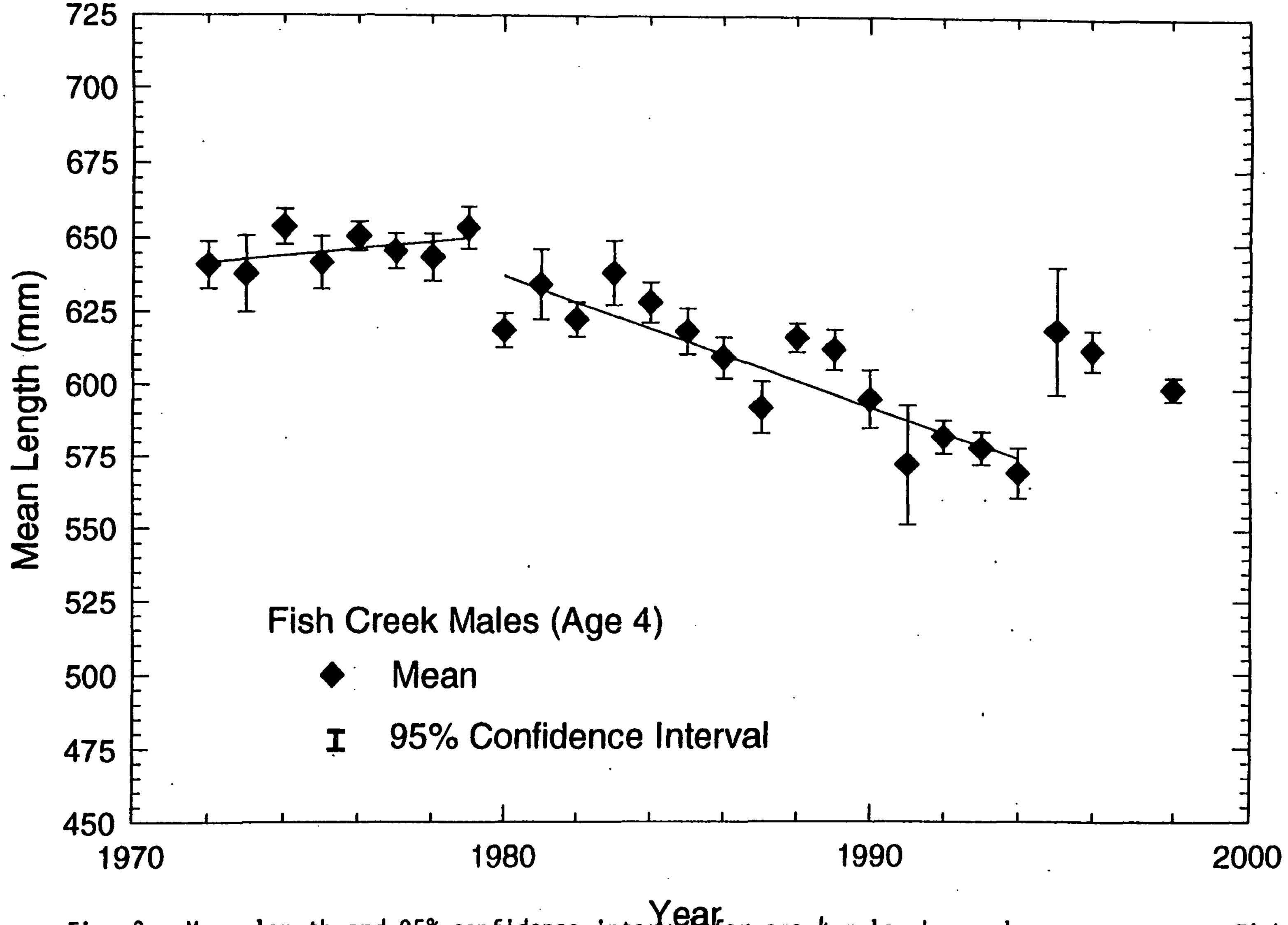

Fig. 2. Mean length and 95% confidence interval for age-4 male chum salmon spawners at Fish Creek, 1972-98. Length measurement is mid-eye to end of hypural plate. Escapement in 1997 was insufficient to obtain samples.

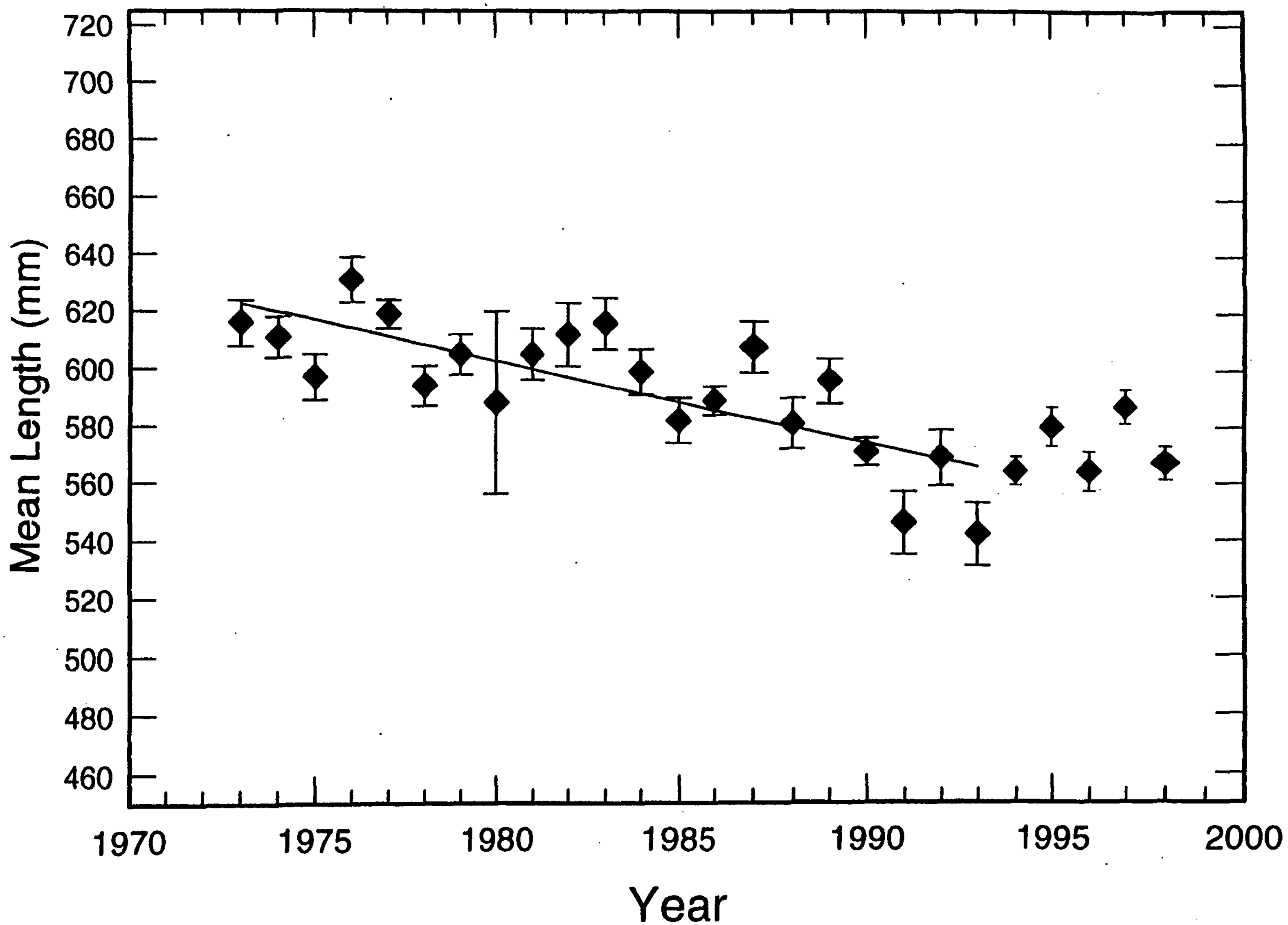

Fig. 3. Mean length and 95% confidence interval for age-4 male chum salmon spawners at Quilcene National Fish Hatchery, 1973-98. Length measurement is mid-eye to end of hypural plate.

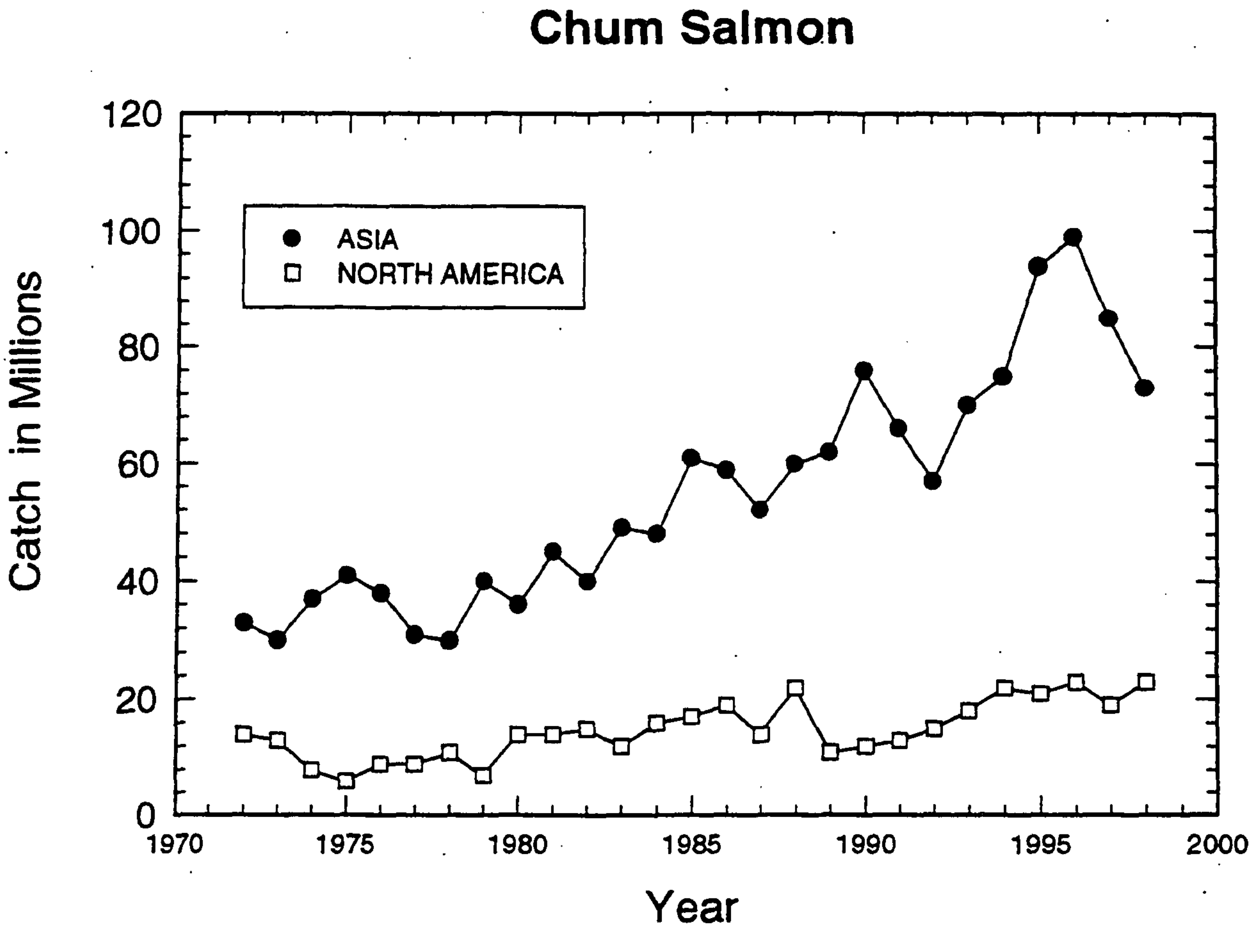

Fig. 4. Commercial catch of chum salmon in North America and Asia. Data from D. Rogers, Fisheries Research Institute, University of Washington, Seattle.

Ocean Variability and Population Diversity – A Match Made in Heaven
Closing Remarks

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There are two objectives to this short paper. First I will summarize my view of the most salient conclusions reached in the afternoon panel discussions. And second I will summarize my own views on the significant management implications that arise from consideration of what we know about the effects of ocean conditions on salmon populations. Actually it turns out that both of these objectives converge around two words and a figure. The two words are variability and diversity. And the figure is from Bisbal and McConnaha (1998 – Figure 1) and shows how salmon have evolved diverse population structures in order to deal with, among other things, variable and uncertain ocean conditions. And clearly salmon population diversity is directly related to the availability of healthy, complex and connected freshwater and estuarine habitat. More about this later.

It is clear that ocean conditions have a significant impact on the overall production of all species of Pacific salmon, and that climate and ocean variability act at a number of time and space scales (e.g. seasonal, annual decadal time scales and global, regional and local space scales) to affect salmon production dynamics. Emmett and Schiewe (eds.) (1997) provide a good recent summary of what we think we know in this area. In fact it is becoming quite clear that interdecadal climate has forced major shifts in the basic structure of coastal marine ecosystems. The most studied and notorious of these incidents occurred with the 1977 NE Pacific climate regime shift (e.g. see Miller et al. 1994; Mantua et al. 1997; Francis et al. 1998). Recent studies have shown that interdecadal changes in atmospheric circulation affect the structure of the upper ocean (Miller et al. 1998) and, in turn, the timing (Mackas et al. 1998) and magnitude (Brodeur et al. 1996; Roemmich and McGowan 1995) of the oceanic biological production process. This, in turn, can affect major reorganizations of the coastal marine ecosystems (Anderson and Piatt pers commun.) which have such a significant impact on salmon production.

Unfortunately, the scales we understand least about (seasonal and annual time scales; local space scales) are the ones that appear to be most important to salmon management, at least as it is presently practiced. And so it is very difficult if not impossible to "engineer" salmon management to match anticipated ocean conditions. And so, what can we do? I think that Bottom (1995) really hits the nail on the head when he urges that we adopt an ecosystem view towards salmon management. Thus rather than try to circumvent essentially unpredictable natural variations through the use of technology, or ignore it through the use of deterministic predictive models, we should "embrace environmental variation as an essential organizing property of living systems." The purpose of conservation, and I would add fishery management, is not to "improve" nature by eliminating variability; it is to protect the interrelationships that allow populations and communities to sustain themselves in a changing world.

We only need to look as far as salmon populations themselves to see how this is done. For millenia, salmon have had to deal with the kinds of changes recently thrown at them by the ocean. And they have done this by evolving a diversity of life history strategies such as mixed year classes, extended smolt migration periods, lengthy adult spawning migrations and other strategies to hedge their bets against the uncertain freshwater, estuarine and ocean environments they are confronted with. And thus within metapopulations (e.g. Columbia River coho salmon), a diversity of genetically hard-wired behaviors provide the key buffers to the climate-driven uncertainties that must be confronted on a year to year and decade to decade basis.

In this context, management should focus on maintaining the diverse metapopulation "parts" of the whole. In this view, resilience is directly related to diversity, and diversity is directly related to the availability of healthy and complex freshwater and estuarine habitat. And to say that an ecosystem is "healthy" is to say that the overall system maintains sufficient complexity and flexibility to protect its self-organizing qualities (Norton 1992; Francis 1997). It must have the capacity to respond to change. In this context, "management must have as its central goal the protection of the system's creativity" (Norton 1992).

Once again in the words of Bottom (1995) - what I call the Bottom Line - "the emphasis on ecosystems reflects a growing awareness that we cannot maintain even our most carefully managed resources apart from the biophysical context that created them." And so I want to reemphasize my main point here: in order to preserve the capacity of Pacific salmon to respond to variable ocean conditions, we must preserve and restore intact and connected freshwater and estuarine habitat. Once this point is firmly institutionalized, the salmon will do the rest.

It seems to me that there are four things that can be done by managers to insure that this ecosystem worldview to salmon management is incorporated.

1. Do everything possible to preserve wild salmon population diversity through the conservation and restoration of freshwater and estuarine habitat. Degrading or eliminating pieces of the habitat leads to a simplification and destabilization of the salmon metapopulation structure of a region.

2. Avoid fishing practices that are selective towards specific metapopulation components. Francis (1997) points out that in the case of Bristol Bay sockeye, nature has dealt the system at least as much variability, in both the short (annual) and long (decadal) term, as the (apparently) sustainable fishery has been able to remove at its peak. And thus with its freshwater and estuarine habitat in virtually pristine condition, the Bristol Bay sockeye ecosystem has evolved and maintained the capacity of absorbing significant levels of ocean-induced variability over multiple time scales, even in the presence of the largest single species salmon fishery on the planet. One should note that Alaska fishery managers make every effort to spread the fishery out over as broad an array of system components as possible.

3. Manage hatchery programs to avoid negative impacts on wild stocks. In particular this requires the management and control of the release of hatchery fish as well as their harvest. In general, fishery managers need to develop ecologically based performance standards and monitoring programs to insure that the risks of hatchery programs are minimal (Bottom 1995).

4. Conservation and management must be based on sound science. This seems obvious but is often ignored in the rush to satisfy short-term political agendas. As Bottom (1995) points out, "prudent ecosystem conservation is not the same as quantitative prediction. It is a deliberative process of informing both citizens and decision-makers so that they can choose wisely despite the many ecological and cultural uncertainties involved in any management choice." Holling (1993) argues that there are at least two "streams" of science. In the first stream, the machine metaphor for nature pervades. Management is oriented to smoothly changing and reversible conditions, and operates under the view that one needs to know before taking action. In the second stream, which Holling (1995) argues is more appropriate for approaching ecosystem issues, the view is that knowledge will always be incomplete. And so in order to be a science for management, uncertainty and surprise must become an integral part of a sequence of actions, one dependent on the results of how the system responded to those that have come before (Francis 1997). This, then, is a science which openly acknowledges indeterminacy, unpredictability, and the historical nature of resource issues. The scientific problems faced by taking an ecosystem view are not amenable to solutions based on knowledge of small parts of the whole, nor on assumptions of constancy or stability of fundamental relationships - ecological, economic or social. In this context the focus best suited for management policy is "actively adaptive designs that yield understanding as much as they do product." (Holling 1993).

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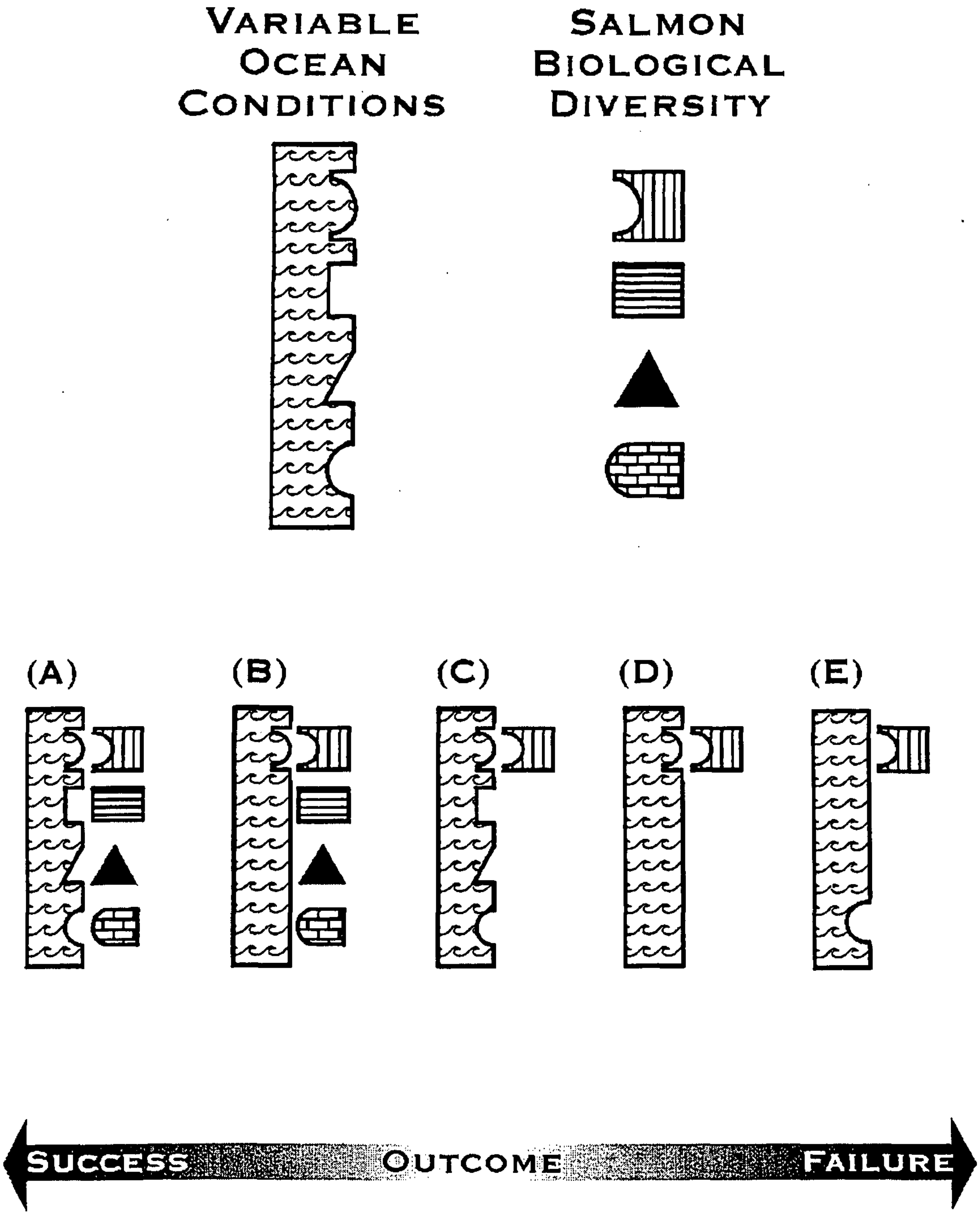

Figure 1. Interaction between ocean conditions and salmon life-history diversity. Five possible scenarios (A-E) illustrate the relative definition of failure and success of salmon management as determined by the fit between different salmon life histories (shapes on the top right) and the variability in ocean conditions (template on the top left)(From Bisbal and McConnaha 1998)

OCEAN CONDITIONS AND THE MANAGEMENT OF COLUMBIA RIVER SALMON

PANEL PARTICIPANTS

(In alphabetical order)

Brian Allee	*Columbia Basin Fish and Wildlife Authority*
Richard Beamish	*Department of Fisheries and Oceans*
Eric Bloch	*Northwest Power Planning Council (Oregon)*
Daniel Bottom	*Oregon Department of Fish and Wildlife*
Ed Casillas	*National Marine Fisheries Service*
Larry Cassidy	*Northwest Power Planning Council (Washington)*
Donna Darm	*National Marine Fisheries Service*
Mike Field	*Northwest Power Planning Council (Idaho)*
Robert Francis	*University of Washington*
Jack Helle	*National Marine Fisheries Service*
Phil Roger	*Columbia River Inter-Tribal Fish Commission*
George Taylor	*Oregon State University*
Donna Silverberg	*Facilitator*
Jeff Kuechle	*Note recorder*

OCEAN CONDITIONS AND THE MANAGEMENT OF COLUMBIA RIVER SALMON

TRANSCRIPT OF PANEL DISCUSSION

I. Management Strategies I: Ocean Conditions and Management of the Freshwater System.

How do we put the scientific information presented today into a context that helps policymakers and resource managers – what does, or should, this science mean to the people on the ground? Silverberg asked the panel.

Larry Cassidy said that, earlier today, the Nestucca example was discussed; you mentioned two tributaries, and treatment vs. non-treatment... define treatment for me, Cassidy said. Treatment was the experimental treatment, Dan Bottom replied -- the restoration of the habitat, then the measurement of the output of fish from that system -- the fish that survived the winter, then outmigrated. In your discussion, Cassidy said, you mentioned that one of your resolutions was to have management in a more conservative way – how would you define that? First of all, we believe the "pinch periods" are really critical to determining the survival of fish, Bottom replied. If you look at the history of our management of this fishery, as we have passed through the various regimes, we seem to have lost productive capacity. During the last regime, the peak of good conditions was lower than the one before. One interpretation of that fact might be that, through habitat loss and the loss of stocks, we are no longer carrying enough fish through the "pinch periods" to provide the same production potential the next time conditions improve. We need to find ways to carry those stocks through the hard times, Bottom said; that may mean being more conservative during the more productive periods. We may need to re-evaluate our management policies, in terms of their effects on diversity.

[Editor's note: Dan Bottom has indicated that further information on the Nestucca River study can be accessed at http://osu.orst.edu/Dept/ODFW/freshwater/salmonidhab/nestucca/index.html]

Next, Mike Field noted that, in listening to today's presentations, he was struck by how much information is out there -- climatic, biological etc. Where is the coordination happening for this effort, between agencies within the U.S., and between U.S. and international agencies? Also is there a central clearing-house for this information? We coordinate these ocean studies very tightly with our Canadian counterparts, as well as with the group working in California, Jack Helle replied. As far as a clearing-house for the information, that is more problematic; while the scientific part of this effort is being carefully coordinated, I'm not sure that science is finding its way into the hands of the public and the decision-makers. We are experiencing some funding problems, despite the fact that we're doing some very exciting and productive work, Helle said.

What would be the best vehicle for such a clearing-house? Field asked. Are you talking about availability between scientists, or to policymakers? Bottom asked. For everyone, Field asked – how can we get access to all of the research that's being done? Just read the newspapers, Robert Francis replied – hardly a week goes by that I'm not contacted by one reporter or another; articles are being published in both the popular and scientific presses. I'm not sure there needs to be a central clearinghouse, he said; I think you just need to stay aware of what's going on. There is more coordination between entities on this effort than on any other scientific effort I've ever been involved with, Francis said. George Taylor observed that, in the last five to 10 years, there have been more and more of these multidisciplinary studies, because of the difficulty of finding a single source of funding. We all see the same problem from different perspectives, he said; there is strength in this type of diversity of background and perspective.

Donna Darm said that, from her perspective, the message from today's workshop is both encouraging and frustrating. It is encouraging because, for some stocks on the brink of extinction, it suggests that there may be some relief on the horizon. It is frustrating because it also creates a refuge or an excuse to those who resist change; for example, one of NMFS' main concerns has been the restoration of freshwater habitat. NMFS' message has consistently been that, unless there are major changes, in many parts of the Pacific Northwest, in the way we use land and water and manage growth, we will see stock extinctions. When we talk about ocean conditions, there are those in the region who seize upon that information to say it's not the freshwater habitat that is the problem -- it's the ocean. My question is, how should we talk about the importance of the interaction between freshwater habitat and production and ocean habitat and production? she asked. More narrowly, how should we focus our research and monitoring on the interaction between freshwater production and ocean production? she asked.

Francis replied that there is growing information that the ocean environment has a significant impact on salmon. It's obvious that we can't engineer our way out of this problem very easily. We need, therefore, to look at how the salmon have "engineered their way out of it," which has been to evolve a very complex population structure; this allows them to deal not only with variability, but also with change. They have taken advantage of the diversity of freshwater environments to evolve complex and diverse life-history strategies, which allow these fish to deal with the variability in both the freshwater and the ocean environments. It seems to me that now that we understand that the ocean has a huge impact, we need to strengthen our efforts to restore healthy, connected freshwater and estuarine environment, so that these metapopulations can deal with change and thrive, Francis said.

Helle responded to Darm's first question by saying that, when ocean conditions are bad, we must be especially conservative in our management of freshwater habitat. If ocean conditions are bad, the tendency is to say human efforts make little difference, because the fish are just going to die anyway -- in my opinion, that's when we need to be very careful about what we do in the freshwater habitat. Helle noted that there is a tendency to view the salmon as essentially freshwater creatures, when in fact they spend 90% of their life in the ocean; he drew an analogy between the salmon life-cycle and a North Dakota farmer who experiences chaos and danger on a vacation to New York City. In a way, it's an apt analogy, Helle said – that's exactly what happens to the salmon when they come into the freshwater environment.

Richard Beamish noted that all animals reproduce in an environment that is safe for their young; salmon reproduce in freshwater for that reason. The freshwater environment ensures that there is a diversity of genetic traits, so that there is optimal survival when these animals enter the harsher environment, which is the ocean. In order to ensure that some salmon always come back, in light of the fact that ocean mortality is estimated at 90%-99%, salmon need the genetic diversity they acquire by surviving in freshwater, Beamish said. In other words, despite the impact of the ocean environment, the freshwater environment is an absolutely vital part of the life-history of these fish – it ensures both successful reproduction and the genetic diversity that allows these animals to survive in a harsh marine environment.

You asked about the importance of the interaction between the freshwater and the ocean, Bottom said. There are two places where that interaction occurs, which really aren't separable. One is at the level of the physical process; the other is the migrations of the salmon themselves, which maintain the links between those habitats by virtue of their movements. What we do in freshwater sets the stage for how these fish are going to survive in the next step of their life-cycle, said Bottom; if we believe upwelling is critical, for example, if our upstream management actions select against the early portion of a given run, the later migrants might completely miss that important window. The survivors carry a history with them, through every link in the life-cycle chain, and if we artificially select against portions of a given run, then our freshwater management actions can have a significant impact on these stocks.

Eric Bloch said that, aside from education for education's sake, the practical purpose this is all leading to is the development of a management plan for the restoration of anadromous stocks in the basin. Before we can develop a plan, we need to agree on a management philosophy. You have presented a great deal of scientific information today which suggests at least some of what that management philosophy should be, said Bloch. For example, Dr. Bottom mentioned the concept of "conservative" management, and I was curious about how he would apply that, in a practical sense. Also, Dr. Beamish has suggested that, if they were left alone, salmon might be able to solve their own problems -- again, what does that suggest, in terms of practical management philosophy?

Bottom replied that, historically, salmon stocks in the region have been managed based on prediction; once we run our models and generate numbers, we have a tendency to hang our hats on them. Stock-recruitment curves are a prime example; when we start to believe our models, that's when the problems begin. The real question is, can we develop a philosophy based on hedging our bets, rather than predictions, so that we maintain our options in case we're wrong? When the Oregon land use goals and guidelines for estuaries were developed, for example, a conscious decision was made to maintain a diversity of estuary types. The plan set aside some estuaries for conservation, some for development, and some to remain in their natural state – in other words, they chose an approach that didn't rely on prediction, but covered all of the available options, in case management mistakes were made. That's a philosophical approach that could also pay dividends in the salmon arena, Bottom said.

Beamish said that, in his opinion, overall, around the Pacific, we do a pretty good job of managing salmon. We may have gotten off-track somewhat during the '80s, he said, primarily because we thought we knew more about the salmon than we actually did. We have to live with what we did during those decades, said Beamish; I think the management philosophy we need to move toward is one that protects wild salmon, and recognizes that we never really were in charge in the first place. Given the fact that we still have to live with a great deal of uncertainty, it is the process that becomes the deciding factor.

Ed Casillas commented that introducing a holistic component to the management scheme is also very important; that's what we're talking about here today -- a more balanced approach to how we view the world. We can't focus on a single facet of this problem while excluding all of the others, he said. Also, engineering our way out of these problems is not a practical approach; engineering solutions alone are not going to get us where we want to go; we need to recognize, at this point, how little we really know for sure.

Brian Allee observed that, from the point of view of managing the salmon resource, it is disturbing that funding apparently is a problem with this effort. If we're going to develop predictive indices for the ocean and estuarine environments, and develop a management plan that might allow us to decrease our reliance on hatcheries based on the ocean environment, how can we do that in the absence of a steady, well-funded ocean and estuary research effort? Allee asked. My question, basically, is how do we manage these populations, using the information you've been able to acquire to date?

Helle replied that the stability of funding for this type of scientific effort is critical right now, and the climate for long-term research funding continues to be very poor. If you're studying chinook salmon, for example, it takes 12 years to evaluate two broods, which tells you very little in the larger scheme of things. We have to have more long-term funding stability, in order to do long-term monitoring. In recent years, because of changing ocean conditions, scientists have gotten together in ways they never have before; there is now a tremendous exchange of information and resources between oceanographers, biologists, climatologists and others. We're all fighting the same thing – the need to find stable funding sources for long-term investigations. Helle said.

Phil Roger noted that in 1995, the Tribes produced their plan for the restoration of salmon in the Columbia Basin. I'm heartened to hear many of the same ideas that plan presented echoed here today, Roger said; in particular, recognition of the interconnectedness between ecosystems and life-stages, and the idea that, if we give them a chance, the salmon will find their own way out of this morass, and find a way to persist. With respect to the Nestucca information, Roger said, the information was very interesting; habitat restoration is one of the strategies a lot of people can buy into without controversy. Can you give us some more details about the magnitude of the problem on the Nestucca – the number of stream miles involved, and whether adult returns have reflected the increase in juvenile production?

We have indices of returning spawners, but we don't have a trap which would give us accurate adult counts, Bottom replied -- we have trends which seem to reflect an increase in adult production, but I haven't personally seen this data, so I can't say for sure. What I can say, Bottom continued, is that we are developing a series of index sites up and down the Oregon coast, where we will be looking at smolts out of a system and adults returning back to those systems. It will be our first opportunity to compare freshwater and ocean survival for wild fish over the long term, Bottom said.

How much do we have to invest, and what are we going to get out of our investment? Roger asked. These are fairly sizable investments, Bottom replied – there is a lot of construction involved.

[Editor's note: Dan Bottom has indicated that further information on the Nestucca River study can be accessed at http://osu.orst.edu/Dept/ODFW/freshwater/salmonidhab/nestucca/index.html]

II. Management Strategies II: Ocean Conditions and the "Four Hs."

Silverberg provided a brief introduction to this section of the discussion, recapping the main points made during the last session. She noted that this section of the panel discussion is designed to get at a more specific question: What should be done with regard to the four Hs? What management changes should be made in response to the information presented today?

Cassidy said that one of the issues he wrestles with continually, in looking at the breathtaking amounts of money we spend on restoring the salmon, is, how do we spend those funds to produce the greatest public benefit? Most of your studies are focused on chum, pinks and sockeye, while most of the concern in my state is on chinook, coho and steelhead. How do we change that, Cassidy asked, and wouldn't that be a wise step?

Helle replied that chums and pinks are rewarding to study because of their short (two-year) life-cycle – you get information back fast, and because chums have virtually no freshwater rearing history. They do all of their growing in the marine environment, which makes them an excellent barometer of ocean conditions, he said. You get answers more quickly, which may apply to the other species as well. Coho are very difficult to study, because, in Alaska, at least, they don't enter the river to spawn until October, November or December; at that point, most researchers are more interested in writing up their results from the earlier portion of the season than they are in fighting the elements to do another study – starting in October, the storms come in one after another off the North Pacific, which makes field conditions extremely challenging, to say the least. However, said Helle, I agree with you that we need to spend more effort on chinook and steelhead, and I think that's something that has gotten better in the past few years.

Casillas noted that his study is focused on chinook and coho, and chinook are also being studied in Alaska. There is also Canadian research on chinook, coho and steelhead, he said; we would like to do more work on steelhead in the ocean, but we really don't have a good handle on where they go – they are very dispersed and hard to find. GLOBEC is also starting a five-year program to study coho and chinook off Southern Oregon and Northern California, beginning next year, Casillas added.

Field asked whether there is any hope, given the fact that salmon are highly adaptive, that they might be able to adapt themselves and thrive in a changed hydrosystem, and the kind of management regime we have in place now. Obviously we still have a spring freshet, he said, but peak flows in the Columbia system aren't anywhere near what they were before the dams were built.

The short answer is, I don't know, Casillas replied. There are many factors that drive survival and productivity, obviously; flow being one of them. We're still trying to understand the role of flow in the big picture, he said; if we were to improve flows somehow, it is likely that other elements and variables could work against that improvement, such that the outcome would still be the same. We're trying to understand the importance of flow, then develop a suite of alternatives we could employ to improve conditions for salmon.

But can the salmon adapt to the management regime that is currently in place in the Northwest? Field asked. It's unlikely -- the adaptive mechanism of salmon is measured on a geologic scale, not a scale of years, Casillas replied. Bottom added that, in a sense, the salmon have adapted, and we're seeing those life-histories that are able to live with the system as it is currently configured and operated do better. Temperature conditions are another case in point -- they have eliminated certain life-histories already, and what we're left with are those few life histories that can adapt to the conditions we currently have.

Next up was Darm, who noted that there are now about two million annual adult returns to the Columbia system, compared to perhaps 16 million historically. This is true despite the fact that about the same number of juveniles are now leaving the system as did in historic times; the suggestion, then, is that, during times of low ocean productivity, such as we've seen over the past 20 years or so, there may be a limit to the carrying capacity of the estuary and ocean. Taking that further, it has been suggested that, through hatchery production, we may be overloading the carrying capacity of the estuary and ocean, and detrimentally impacting the survival of wild fish by overloading the system with hatchery fish competing for the same resources, Darm said. Dan Bottom has noted that climatic patterns affect conditions in both the freshwater and the marine environment, which suggests that there may be some regulatory mechanism that affects both freshwater and ocean productivity. How likely is it that we have done some harm to the survival of wild fish in the estuary and the ocean by overloading their carrying capacities with hatchery fish? Darm asked. Also, does it make more sense to try to predict what ocean conditions may be like, and adjust our hatchery production accordingly, or does it make more sense to impose a conservative cap on our hatchery production, given the fact that our ability to predict those ocean conditions is limited?

I'm afraid you may be right, Beamish replied. We no longer believe that the carrying capacity is limited by the number of juveniles; what that means is that you need to reconsider your hatchery management. That doesn't mean you close all of the hatcheries down; it simply means that you need to look carefully at what you're trying to achieve, given our current understanding of the factors that are regulating abundance. With respect to your question about wild salmon, what you need to do is find out what the percentages of hatchery and wild salmon are in your areas. In British Columbia and the Strait of Georgia, for example, we estimate that the percentage of hatchery coho and chinook is 75%-80%; somehow, we've gone from a very small percentage of hatchery fish to a very high percentage of hatchery fish. To me, that means there is some sort of interaction, Beamish said; I think the interaction is in the ocean, but I can't explain how it works.

Helle noted that there are two aspects to the hatchery production question -- you can, as Donna has suggested, overload the carrying capacities of the estuary and ocean. There is also the genetic aspect of hatchery production -- if you transplant non-native stocks, they tend to stray; if you use indigenous stocks, you minimize straying. Basically, my concern is that straying could be having a major impact on the wild stock genetics in the Northwest, Helle said -- I'm not against hatcheries, in the right situation, but I also think they can do a lot of damage if they're not used properly.

Next up was Bloch, who observed that research is a sort of stepchild, in some ways, but it is also an essential component to a wise management strategy. We've talked about developing an integrated monitoring and research program to look at every link in the salmon habitat chain, he said, asking the science panelists to identify one critical research need to help the salmon managers.

Francis agreed that research is a management strategy; we need to take bold actions that require management decisions. It seems to me that, in order to experiment at the ecosystem scale, so that we're not just fine-tuning bits and pieces, we need to work in partnership with management, he said.

Beamish said his one research project would be the ability to identify wild salmon. If the question is for a larger area of research, it would be the movement to larger, ecosystem management.

Bottom said his suggestion would be the fundamental issue of how much the fish use the estuary. The same questions apply to the marshes as well -- we don't know how much those systems are being used as rearing habitat for salmon, he said.

Taylor said we need to continue to learn about the cause-and-effect relationships between El Niño and the Southern Oscillation Effect; we also need to take the next step to an operational approach, and talk boldly about how forecasting skills can help us manage the system better.

Casillas said his priority would be the ability to get out in the field and look directly at what is going on, and the support from management to do that. We can't answer all of these questions at the computer, he said; we need the ability to go out in the field and see what's going on. In other words, we need the support for the kind of research that is required – we need critical thinkers from different disciplines out there in the field, with the support to bring a variety of expertise to bear on the problem.

Helle suggested that the availability of stable funding for long-term research is a critical need, as is the need for field stations doing long-term observations on various species. We were doing that, beginning in the 1930s in Alaska, he said, but we gave up on it, because of lack of funding. There are too many graduate students that are being trained at the computer now, he said – we need to get people back into the field, doing long-term, hands-on studies.

Next, Brian Allee asked whether any of the panel members are bold enough to predict when we might see a turnaround in ocean conditions in our part of the world. Also, with regard to the management actions involved in sequencing smolt releases from barges and hatcheries, can we develop a protocol or index to help manage the system to optimize survival?

Taylor said he has publicly suggested, as early as 1995, that we are now entering a cooler, wetter period that would last for the next 20-25 years. In other words, he said, maybe conditions already are changing – they look pretty good this year.

With respect to your second question, said Beamish, we really don't understand the mechanisms of ocean survival and mortality very well -- we don't understand how salmon regulate their abundance naturally, which makes it difficult to say what we can do to optimize ocean survival. It could be that the large releases of chum salmon are causing survival problems for coho.

Next up was Roger, who noted that managers tend to take positions that they think are risk-averse. Often, decisions won't be made and status quo will be preserved if the risk is perceived as too high. Despite the fact that natural systems are much noisier than laboratory conditions, can you give me a sense of what degree of accuracy you might expect from the field studies you propose?

There are different ways to take risks, Francis replied. There are two types of errors you can make when you're trying to do inference: you can reject a hypothesis when it's true, or you can accept a hypothesis when it's false. In taking a more holistic perspective, we alter the kinds of risks we're willing to take from the first type to the second. When you're dealing with conservation issues, which can have very long-term consequences, we have to pay a lot more attention to minimizing the second type of error, Francis said.

Bruce Suzumoto from the Public Power Council observed that it appears, from what he's heard at this conference, that ocean conditions have at least as much to do with the survival and recovery of salmon as the freshwater environment. Yet the spending on studying ocean conditions is only a fraction of the amount spent on freshwater recovery measures. What do the panel members think should be done about that?

Cassidy replied that he had written a note to himself earlier in today's session, to the effect that there's nothing we can do about ocean conditions. I don't know the answer to that question, Cassidy said; it's one of the most difficult issues we have to address.

There are two aspects to that question, Roger said -- one is from a salmon managers' perspective; the ocean is out there, but there isn't much we can do about it. In an ecological sense, we need a better understanding of ocean conditions on salmon survival; however, I'm not sure what level of resolution we need for that answer. We also need to think about the funding aspect – how can we coordinate activities better, so that the amount that is being spent is spent as effectively as possible?

Field noted that, as managers, we have a responsibility to move into research that will allow us to understand what's going on in the estuary and the ocean. If we look at only one aspect of the life-cycle, he said, we haven't really done our job, and I think that's something you'll see the Council push for more vigorously in the near future – more research in the estuary and ocean.

There isn't much we can do about ocean conditions, said Darm; however, there are things we can do in the estuary, and I think that's where we should put our resources, because all of the fish in the Columbia system use the estuary. My agency has focused much of its effort on freshwater habitat, and not very much on habitat in the estuary – I think what we've heard today suggests that that is an important place to focus our resources.

SYMPOSIUM SPEAKERS

PROFESSIONAL QUALIFICATIONS

(In alphabetical order)

RICHARD J. BEAMISH, C.M., PH.D.

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Personal Married, two children, born 1942 Toronto, Canada

Education Ph.D. University of Toronto, Zoology, 1970.

Experience

1969 -	Discovered the problem of acid rain in North America
1970 -	Participant in the C.S.S. Hudson Cruise – the first vessel to circumnavigate the Americas
1970 – 72	Visiting Scientist at Woods Hole Oceanographic Institute
1972 – 74	Research Scientist at the Freshwater Institute in Winnipeg, studying impacts on airborne pollution on fishes
1974 – 77	Research Scientist at the Pacific Biological Station, Nanaimo
1977-	Head of Groundfish section - Discovered that fish were substantially older than previously thought
1980 – 93	Director, Pacific Biological Station
1993 – 99	Senior Scientist, Pacific Biological Station - Discovered that climate and Pacific Salmon abundance are linked
1998	Appointed to Order of Canada

Recent Publications

Published approximately 150 articles including book chapters.

Beamish, R.J., and G.A. McFarlane. 1998. Applying ecosystem management to fisheries in the Strait of Georgia. Accepted, Lowell Wakefield Symposium Series.

Beamish, R.J., D. McCaughran, J.R. King, R.M. Sweeting, and G.A. McFarlane. 1998. Estimating the relative abundance of juvenile coho salmon in the Strait of Georgia using surface trawls. Submitted, North Amer. J. Fish Mgmt.

Beamish, R.J., and C. Mahnken. 1998. Natural regulation of the abundance of coho and other species of Pacific salmon according to the critical size and critical period hypothesis. (NPAFC Doc. NO. 319). X p. Dept. of Fisheries and Oceans, Sciences Branch - Pacific Region, Pacific Biological Station, Nanaimo, B.C. Canada, V9R 5K6. National Marine Fisheries Service, 7305 Beach Drive East, Port Orchard, WA, USA, 98366.

King, J.R., V.V. Ivanov, V. Kurashov, R.J. Beamish, and G.A. McFarlane. 1998. General circulation of the atmosphere over the North Pacific and its relationship to the Aleutian Low. Revised and published in Russia, in the Russian language.

Beamish, R.J., K.D. Leask, O.A. Ivanov, A.A. Balanov, A.M. Orlov, and B. Sinclair. 1998. The ecology, distribution, and abundance of midwater fishes of the Subarctic Pacific gyres. Accepted Prog.

Oceanography. 71 p. Dept. of Fisheries and Oceans, Sciences Branch - Pacific Region, Pacific Biological Station, Nanaimo, B.C. Canada. V9R 5K6.

Beamish, R.J., and C. Mahnken. 1998. Taking the next step in fisheries management. Accepted Lowell Wakefield Symposium Series. Dept. of Fisheries and Oceans, Sciences Branch - Pacific Region, Pacific Biological Station, Nanaimo, B.C. Canada. V9R 5K6. National Marine Fisheries Service, 7305 Beach Drive East Port Orchard, Washington 98366.

Beamish, R.J., J.H. Youson, and L.A. Chapman. 1998. Status of the Morrison Creek Brook Lamprey *Lametra richardsoni var. marifuga* in Canada. In Review. Can. Field Nat.

Beamish, R.J., G.A. MacFarlane, and J.R. King. 1999. Fisheries Climatology: Understanding the Interannual and Decadal scale processes that regulate British Columbia fish populations naturally. (Book chapter, in review).

Docker, M.F., J.H. Youson, R.J. Beamish, and R.H. Devlin. 1998. Phylogeny of the Lamprey Genus *Lampetra* inferred from mitochondrial Cytochrome b and ND3 gene sequences. Can. J. Fish. Aquat. Sci. (submitted).

Noakes, D., R.J. Beamish, and M. Kent. 1998. On the decline of Pacific salmon and speculative links to salmon farming in British Columbia. Aquaculture (submitted).

Doubleday, W.G., B. Atkinson, R.J. Beamish, M. Chadwick, M. Henderson, R.O. Boyle, L. Savard, and M.M. Sinclair. 1999. Overview statement for forum on fisheries in relation to fisheries management. (To be published in C.S.F.A.S).

Ferra, L.C., R.J. Beamish, and J.H. Youson. 1998. The nature of the fin-ray annulus in chinook salmon (*Oncorhynchus tshawytscha*). I. Macroscopic structure. Can. J. of Zoology. (Accepted for publication).

Beamish, R.J., D. Noakes, G.A. McFarlane, L. Klyashtorin, V.V. Ivonov, and V. Kurashov 1998. The regime concept and natural trends in the production of Pacific salmon. Accepted Can. J. Fish. Aquatic. Sci.

Beamish, R.J., G.A. McFarlane, and R.E. Thomson. 1998. Recent declines in the recreational catch of coho salmon in the Strait of Georgia are related to climate. Can. J. Fish. Aquat. Sci. (Accepted for publication).

Beamish, R.J., D.J. Noakes, G.A. McFarlane, W. Pinnix, R. Sweeting, and J. King. 1998. Trends in Coho Marine Survival in relation to the Regime Concept. Fish. Oceanogr. (in review).

Beamish, R.J., and G.A. McFarlane. 1999. Reevaluation of the interpretation of annuli from otoliths of a long-lived fish, *Anoplopoma fimbria.* 2nd International Symposium on Fish Otolith Research and Application (accepted).

McFarlane, G.A., and R.J. Beamish. 1998. The relationship between longevity of sablefish, *Anoplopoma fimbria*, and ocean productivity regimes, and implications for management. N. Am. J. Fish. Mgmt. (submitted).

Zhang, Z., and R.J. Beamish. 1998. Use of Otolith Microstructure to Study Life History of Juvenile Chinook Salmon in the Strait of Georgia in 1995 and 1996. 2nd International Symposium on Fish Otolith Research and Application (accepted).

King, J.R., G.A. McFarlane, and R.J. Beamish. 1998. Decadal scale patterns in the relative year class success of sablefish (*Anoplopoma fimbria*). Fish. Oceanogr (submitted).

Beamish, R.J., J.H. Youson, and L.A. Chapman. 1998. Status of the Morrison Creek Brook Lamprey *Lampetra richardsoni var. marifuga* In Canada. Can. Field. Nat. (in review).

Beamish, R.J. 1999. Shifting Regimes in Fisheries Science and Salmon Management. Wild Steelhead and Salmon, The International Journal of Salmon Conservation 5(2):12-16.

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EDUCATION

Ph.D. in Oceanography	*University of Rhode Island, Graduate School of Oceanography*. Narragansett, RI, USA, 1993.
Master of Marine Affairs	*University of Rhode Island, Department of Marine Affairs*. Kingston, RI, USA, 1992.
Master of Science in Oceanography	*University of Rhode Island, Graduate School of Oceanography*. Narragansett, RI, USA, 1990.
Licenciate in Biological Sciences	*University of Buenos Aires, School of Exact and Natural Sciences*. Buenos Aires, Argentina, 1983.

PROFESSIONAL EXPERIENCE

- Northwest Power Planning Council, Division of Fish and Wildlife, Portland, OR, USA
  Fisheries Research Coordinator – 09/1994-Present

- National Oceanic and Atmospheric Administration (NOAA), Office of the Deputy Assistant Secretary for International Affairs and National Marine Fisheries Service, Office of Protected Resources, Washington, DC and Silver Spring, MD, USA
  International Affairs Specialist – 02-09/1994
  National Sea Grant College/Dean John A. Knauss Marine Policy Fellow – 02/1993-02/1994

- University of Rhode Island, Kingston and Narragansett, RI, USA
  Graduate Research Assistant (Several terms) – 09/1987-12/1992
  Graduate Teaching Assistant (Several terms) – 09/1987-12/1992

- National Institute for Fisheries Research and Development (INIDEP), Mar del Plata, Argentina
  University of Buenos Aires Fellow – 07/1986-06/1987

- Fisheries Monitoring Program at Salto Grande Reservoir, Uruguay River (Mixed Technical Commission Argentina and Uruguay)
  Consultant – 08/1985-06/1986

PUBLICATIONS (Peer reviewed)

Bisbal, G.A. and W.E. McConnaha. 1998. Consideration of ocean conditions in the management of salmon. **Canadian Journal of Fisheries and Aquatic Sciences, 55 (9)**: 2178-2186.

Bisbal, G.A. and J.D. Ruff. 1996. Quality of 1995 Spring total dissolved gas data: Columbia and Snake Rivers. **Journal of the American Water Resources Association, 32 (6)**: 1177-1186.

Bisbal, G.A. 1995. The Southeast South American Shelf Large Marine Ecosystem: Evolution and components. **Marine Policy, 19 (1)**: 21-38.

Bisbal, G.A. and D.A. Bengtson. 1995. Description of the starving condition in summer flounder, *Paralichthys dentatus*, early life history stages. **U.S. Fishery Bulletin, 93 (2)**: 217-230.

Bisbal, G.A. and D.A. Bengtson. 1995. Effects of delayed feeding on survival and growth of summer flounder, *Paralichthys dentatus*, larvae. **Marine Ecology Progress Series, 121(1-3)**: 301-306.

Bisbal, G.A. 1993. Fisheries management on the Patagonian shelf: A decade after the 1982 Falklands/Malvinas conflict. **Marine Policy, 17 (3)**: 213-229.

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Guerrero, C.A. and G.A. Bisbal. 1992. Fecundity of *Percichthys colhuapiensis* (Perciformes, Percichthyidae) from Ezequiel Ramos Mexia Reservoir, Neuquén and Río Negro Provinces, Argentina. **Physis (Buenos Aires, Argentina), Secc. B, 47 (119):** 33-37. (In Spanish)

Bisbal, G.A. and J.L. Specker. 1991. Cortisol stimulates hypoosmoregulatory ability in Atlantic salmon, *Salmo salar* L. **Journal of Fish Biology, 39:** 421-432.

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Bisbal, G.A. and S.E. Gómez. 1986. Comparative morphology of the pectoral spine of some Siluroid fishes from Buenos Aires (Argentina). **Physis (Buenos Aires, Argentina), Secc. B, 44 (107):** 81-93. (In Spanish)

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Education

B.A.	Botany, Duke University (1972).
M.S.	College of Marine Studies, University of Delaware (1975).

Positions Held

Monitoring Coordinator for the Oregon Plan for Salmon and Watersheds, Oregon Department of Fish and Wildlife, 1997 to present.

Faculty (courtesy), Fisheries and Wildlife Department and College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, Sept. 1996- present.

Project Manager, Pacific Rim Salmon Study, Center for Analysis of Environmental Change, Oregon State University, Corvallis, OR, 1993-1997.

Fisheries Research Project Leader, Oregon Department of Fish and Wildlife, 1977-present.

Professional Recognition

Fishery Worker of the Year Award, Oregon Chapter of the American Fisheries Society, 1996.

Member national advisory panel to the Responsible Care Program, an environmental initiative of the Chemical Manufacturers' Association, 1990-95.

Member Eastside Forests Scientific Society Panel formed at request of members of Congress, 1992-94.

President, Oregon Chapter American Fisheries Society, 1990-91.

Vice-Chairman, Oregon Estuarine Research Council, 1979.

E. Sam Fitz Award (for professional development in the field of marine studies), College of Marine Studies, University of Delaware, 1976.

Professional Societies

American Association for the Advancement of Science
American Fisheries Society
Ecological Society of America
Society for Conservation Biology

Selected Publications

Independent Scientific Group (R.N. Williams; P.A. Bisson; D.L. Bottom; and 10 others). 1999. Return to the river: Scientific issues in the restoration of salmonid fishes in the Columbia River. Fisheries 24(3): 10-19.

Bottom, D. L., J. A. Lichatowich, and C. A. Frissell. 1998. Variability of Pacific Northwest marine ecosystems and relation to salmon production. Pages 181-252 *In* G.R. McMurray and R. J. Bailey, editors. Change in Pacific Northwest Coastal Ecosystems. Proceedings of the Pacific Northwest Coastal Ecosystems Regional Study Workshop, August 13-14, 1996, Troutdale, Oregon. NOAA Coastal Ocean Program Decision Analysis Series No. 11. NOAA Coastal Ocean Office, Silver Spring, MD. 342 pp.

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Williams, R., L.D. Calvin, C. C. Coutant, M. W. Erho, J. A. Lichatowich, W. J. Liss, W. E. McConnaha, P. R. Mundy, J. A. Stanford, R. P. Whitney, D. L. Bottom, and C. A. Frissell. 1996. Return to the river: Restoration of salmonid fishes in the Columbia River ecosystem. Northwest Power Planning Council, Portland.

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

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Henjum, M. G., J. R. Karr, D. L. Bottom, D. A. Perry, J. C. Bednarz, S. G. Wright, S. A. Beckwitt, and E. Beckwitt. 1994. Interim protection for late-successional forests, fisheries, and watersheds: National forests east of the Cascade Crest, Oregon and Washington. The Wildlife Society, Bethesda.

Bottom, D.L., K.K. Jones, J.D. Rodgers, and R.F. Brown. 1993. Research and management in the Northern California Current Ecosystem. Pages 259-271 *In* K. Sherman, L. Alexander, and B. Gold, editors. Stress, mitigation, and sustainability of large marine ecosystems. AAAS, Washington, D.C.

Bottom, D.L., and K.K. Jones. 1990. Species composition, distribution, and invertebrate prey of fish assemblages in the Columbia River Estuary. Progress in Oceanography 25:243-270.

Jones, K.K., C.A. Simenstad, D.L. Higley, and D.L. Bottom. 1990. Community structure, distribution, and standing stock of benthos, epibenthos, and plankton in the Columbia River estuary. Progress in Oceanography 25: 211-241.

Bottom, D.L., K.K. Jones, J.D. Rodgers, and R.F. Brown. 1989. Management of living marine resources: a research plan for the Washington and Oregon continental margin. National Coastal Resources Research and Development Institute, Publication No. NCRI-T-89-004, Newport, OR.

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EDUCATION:

- B.A. Environmental Biology, University of California, Santa, Barbara, CA, 1972
- M.S. Fisheries Biology, University of Washington, Seattle, WA, 1974
- Ph.D. Fisheries Biology, University of Washington, Seattle, WA, 1978

POSITIONS:

- Program Manager, Estuary & Ocean Ecology, National Marine Fisheries Service, 1997-Present
- Program Manager, Environmental Physiology, National Marine Fisheries Service, 1993-1997
- Supervisory Research Fishery Biologist, National Marine Fisheries Service, 1991-1993
- Member of the Editorial Board, Aquatic Toxicology, 1985-1991
- Affiliate Assistant Professor, Laboratory Medicine, University of Washington, 1982-1986
- Research Associate, Laboratory Medicine, University of Washington, 1980-1982
- Research Fishery Biologist, National Marine Fisheries Service, 1980-1991
- Senior Postdoctoral Fellow, Laboratory Medicine, University of Washington, 1978-1980

PROFESSIONAL SOCIETIES

- American Institute of Fishery Research Biologists
- American Fisheries Society

FIVE RELATED PUBLICATIONS:

Varanasi, U., E. Casillas, M.R. Arkoosh, T. Hom, D.A. Misitano, D.W. Brown, S-L Chan, T.K. Collier, B.B. McCain, and J.E.Stein. 1993. Contaminant exposure and associated biological effects in juvenile chinook salmon (*Oncohynchus tshawytscha*) from urban and nonurban estuaries of Puget Sound. U.S. Dept. of Comm., NOAA Tech. Memo. NMFS-NWFSC-8, 112p.

Casillas, E., B.B. McCain, M.Arkoosh, and J.E. Stein. 1997. Estuarine pollution and juvenile salmon health: Potential impact of survival. *In* R.L. Emmett and M. H. Schiewe (eds.) Estuarine and Ocean Survival of Northeastern Pacific Salmon: Proceedings of the workshop. U.S Dept Comm., NOAA Tech. Memo. NMFS-NWFSC-29, pp. 169-179.

Arkoosh, M.A., E. Casillas, P. Huffman, E. Clemons, J. Evered, J.E. Stein, and U. Varanasi. 1998. Increased susceptibility of juvenile chinook salmon (*Oncorhynchus tshawytscha*) from a contaminated estuary to *Vibrio anguillarum*. Trans Amer. Fish. Soc. 127:260-374.

Arkoosh, M., E. Casillas, E. Clemons, A. Kagley, R.E. Olson, P. Reno, and J.E. Stein. 1998. Effect of pollution on fish disease: potential population impacts. J. Aquat. Anim. Health 10:182-190.

Peterson, W.T., M. Schiewe, E. Casillas, R. Emmett, and K. Jacobson. 1998. Hydography and zooplankton off the central Oregon coast during the 1997-1998 El Niño event. NPAFC Technical Report: Workshop on Climate Change and Salmon Production, Vancouver, Canada. pp. 32-34.

FIVE OTHER PUBLICATIONS:

Casillas, E., M.S. Myers, L.D. Rhodes, and B.B. McCain. 1985. Serum chemistry of diseased English sole (*Parophrys vetulus*) from polluted areas of Puget Sound, Washington. J. Fish Diseases. 8:437-449.

Casillas, E., D.A. Misitano, L.L. Johnson, L.D. Rhodes, T.K. Collier, J.E. Stein, B.B. McCain, and U. Varanasi. 1991. Inducibility of spawning and reproductive success of female English sole (*Parophrys vetulus*) from urban and nonurban areas of Puget Sound, Washington. Mar. Environ. Res. 31:99-122.

Casillas, E., D. Weber, C. Haley, and S.Sol. 1992. Comparison of growth and mortality in juvenile sand dollars (*Dendraster excentricus*) as indicators of contaminated sediments. Environ. Toxicol. Chem. 11:559-569.

Krishnakumar, P.K., E. Casillas, and U. Varanasi. 1994. Effects of environmental contaminants on the health of *Mytilus edulis* from Puget Sound, Washington, USA. I. Cytochemical measures of lysosomal responses in the digestive cells using automatic image analysis. Mar. Ecol. Prog. Ser. 106:249-261.

Casillas, E., M. R. Arkoosh, E. Clemons, T. Hom, D. Misitano, T. K. Collier, J. E. Stein, and U. Varanasi. 1995. Chemical contaminant exposure and physiological effects in outmigrant Chinook salmon from selected urban estuaries of Puget Sound, Washington. *In* M. Keefe (ed.) Salmon Ecosystem Restoration: Myth and Reality. Proceedings of the 1994 Northeast Pacific Chinook and Coho Salmon Workshop, American Fisheries Society, Oregon Chapter, Corvallis, OR. pp. 86-102.

GRADUATE STUDENTS AND POSTDOCTORAL ASSOCIATES:

Dr. P.K. Krishnakumar, India, Postdoctoral Fellow Advisor (1992-93)
Dr. Laura Inouye, NRC Postdoctoral Fellow Advisor (1995-97)
Dr. Kym Jacobson, NRC Postdoctoral Fellow, Co-Advisor (1996-97)
Dr. Jim Moore, NRC Postdoctoral Fellow, Co-Advisor (1996-98)
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Casimir Rice, Master of Science Program Committee Member (1996-98)

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Educational Training

B.A., Mathematics, University of California, Santa Barbara, 1964
M.S., Biomathematics, University of Washington, 1966
Ph.D., Biomathematics, University of Washington, 1970

Employment

School of Fisheries, University of Washington
    Professor, 1986-present
    Director, Fisheries Research Institute, 1986-1993

School of Marine Affairs, University of Washington
    Adjunct Professor, 1986-present

School of Oceanography, University of Washington
    Adjunct Professor, 1989-present

National Marine Fisheries Service, Northwest and Alaska Fisheries Center
    Fisheries Biologist (Research), 1979-1985

Fisheries Research Division, Ministry of Agriculture and Fisheries, New Zealand
    Scientist, 1976-1979

Inter-American Tropical Tuna Commission, La Jolla, CA
    Scientist, 1971-1976

Scripps Institution of Oceanography, UCSD, La Jolla, CA
    Lecturer, 1973-1976

Department of Statistics, Colorado State University, Fort Collins, CO
    Assistant Professor, 1969-1971

Grasslands Biome, US IBP, Colorado State University, Fort Collins, CO
    Mathematical Modeler, Biometrician, 1969-1971

Selected Professional Activities

- National Marine Fisheries Service Ecosystem Principles Advisory Panel, 1997-present
- National Academy of Sciences, National Research Council
  - Chair, Committee on the Bering Sea Ecosystem, 1993-1996
  - Chair, Committee on Porpoise Mortality from Tuna Fishery, 1990-1993
- Ecological Society of America
  - Ad Hoc Working Group on Ecosystem Management, 1993-1996
- Pacific Fishery Management Council
  - Scientific and Statistical Committee, 1987-1990, 1999
  - Groundfish Management Ream, 1980-1985

Selected Recent Publications

Francis, R.C., and S.R. Hare. 1994. Decadal scale regime shifts in large marine ecosystems of the northeast Pacific: A case for historical science. *Fish. Oceanog.* 3(4):279-291.

Hare, S.R., and R.C. Francis. 1995. Climate change and salmon production in the northeast Pacific Ocean. In R.J. Beamish (ed.) Climate change and northern fish populations. *Can. Spec. Publ. Fish. Aquat. Sci.* 121.

Christensen, N.L. et. al. 1996. The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. *Ecol. Appl.* 6(3):665-691.

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POSITIONS	Auke Bay Laboratory, Alaska Fisheries Science Center, NOAA, NMFS, U.S. Department of Commerce

(Permanent)
- Program Manager, Ocean Carrying Capacity Program, 1996-present
- Task Leader, Stock Identification Research, U.S./Canada Treaty Program 1982 - 1995.
- Project Leader, Olsen Bay Field Station, Prince William Sound, 1972-1981
- Auke Bay Laboratory, U.S. Department of Interior, U S. Fish and Wildlife Service, Bureau of Commercial Fisheries.
- Project Leader, Olsen Bay Field Station, 1966-1971
- Fishery Research Biologist, 1960 - 1965

(Temporary)
- Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, U.S. Department of the Interior
  - Fishery Aid, Prince William Sound, Alaska March-August 1958, July August 1959
- U.S. Forest Service, U.S. Department of Agriculture
  - Smokejumper, McCall, Idaho 1954-57 and 1960

PROFESSIONAL MEMBERSHIPS

- American Institute of Fishery Research Biologists - 1968 - present
  - President- 1991-92
  - District Director - 1982-83
  - Fellow - elected in 1985
- American Fisheries Society - 1958 - present
- Certified Fisheries Scientist – 1981
- American Association for the Advancement of Science – 1979-present
- Xi Sigma Pi
- Sigma Xi

SELECTED COMMITTEES

- North Pacific Anadromous Fish Commission - Chairman, 1999 Symposium
- Pacific Salmon Commission - Member, Northern Boundary Technical Committee - 1984 - present

- Pacific Salmon Commission - Member, Committee on Research and Statistics
- Pacific Salmon Commission - Member, Coho Technical
- Committee - 1984-91
- North Pacific Fishery Management Council - Member, Plan Development Team, Troll Fishery - 1980-84
- Laboratory Safety Committee - Chairman 1966-67
- Regional Safety Committee - Member 1965-67
- Regional Safety Officer - 1969-70
- Co-Chairman of Northeast Pacific Pink and Chum Salmon Workshop -1976 -Juneau, Alaska

SELECTED ADVISORY SERVICES

- Scientific Advisor and Lecturer - Juneau Icefield, Research Program, National Science Foundation, University of Idaho - 1978-present.
- Salmonid Genetic Resources Committee, California Gene Resource Conservation Program, 1982-85.
- Affiliate Associate Professor- University Alaska, 1983-88, 1997-present.

SELECTED AWARDS

Special Act Award: Bureau of Commercial Fisheries, May 3,1963, for: assuming command of the RV HERON and manning the wheel for 30 hrs during a severe storm in the Gulf of Alaska when the vessel's Master was incapacitated in an accident.

Special Service Award: Bureau of Commercial Fisheries, May 1966, for production of Field Station Safety Guide.

Species name: A new species of aquatic oligochaete was discovered in Olsen Creek, Prince William sound, Alaska, and named, *Vejdovskyella hellei* (for the collector) by Dr. R.O. Brinkhurst on page 349 of his book: "Oligochaeta of the World", 1971.

American Men and Women of Science: Inducted 1987, R.R. Bowker Company.

Who's Who in Science and Engineering: Third Edition, Marquis Who's Who.

Who's Who in the West: 24-25th editions, Marquis Who's Who.

Hall of Fame Alumni--University of Idaho, inducted May 1999

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Lecturer in Biology, Portland State University. Design and teach a senior-graduate student level course entitled, *Biology and Ecology of Pacific Salmonids.*

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Master of Science, Fisheries 1977. University of Washington, College of Fisheries.

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Regional Committees

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Chair, Artificial Production Review Panel
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Important Papers

Independent Scientific Group *(including Willis E. McConnaha)* 1999. Scientific issues in the restoration of salmonid fishes in the Columbia River. Fisheries 24(3): 10-19.

Bisbal, G. A. and *Willis E. McConnaha* 1998. Consideration of ocean conditions in the management of salmon. Canadian Journal of Fisheries and Aquatic Sciences 55(9): 2178-2186.

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McConnaha, Willis E. 1993. Biological modeling in the Columbia Basin: An organized approach to dealing with uncertainty. *In* Katherine Hon, [ed.] Water Management in the 90's. American Society of Civil Engineers, New York.

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Professional Experience:

1989- Oregon State University
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- Responsible for weather and climate data archives for the state of Oregon

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Santa Barbara Softworks
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- Air quality analysis and field studies

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Redmond, K. T., and G.H. Taylor. 1997. Climate of the Coastal Temperate Rain Forest. *In:* The Rain Forests of Home, Island Press, Washington D.C.

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