PACIFIC SALMON

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OVERVIEW

Abundances for a number of West Coast salmon population groups declined over the last ten years. For Chinook salmon, the Lower Columbia and Willamette Spring-run data series exhibited the steepest declines, while the Central Valley Fall-run, Spring-run, and Winter-run Chinook salmon as well as the Southern Oregon/Northern California, California Coast, and Klamath fall-run Chinook salmon stocks exhibited more moderate declines. On the positive side, Snake River and Upper Columbia River Chinook salmon abundance increased. All Chinook salmon Evolutionarily Significant Units (ESUs) were near their longer-term (25-30 year) average abundance. For coho salmon, all recent abundance series were near their 25-30 year averages. The California Coast and Southern Oregon/Northern California Coasts trends in abundance declined steeply, while the trends abundance of Lower Columbia River coho salmon increased. Oregon Coast coho salmon demonstrated no significant recent trend over 2003 to 2012.

Recent ocean conditions and the forage complex indicate a likelihood of improved early marine survival of Chinook salmon and coho salmon in 2012 and 2013, suggesting improved adult returns in the next few years. In contrast, freshwater flows and temperatures suggest reduced smolt production in the near future across California. Anthropogenic climate change trends are likely to increase risks facing West Coast salmonid stocks in future decades of the 21st century.

Salmon and steelhead populations and habitat have been influenced by dynamic interactions between natural landscape features (e.g., resource abundance, climate, topography) and human activities such as fur trading, mining, logging, agriculture, dams, hatcheries, and fisheries. Historical development of these activities was largely driven by economic interests and encouraged by robust market demand and prices, improvements in extractive and processing technologies and transportation, and expansionist government policies. Most of these activities (other than fur trading) continue to the present day in some form. Public policies have changed over time, from an ethos of laissez faire resource extraction to one that also considers effects of extraction on wild salmon populations and the habitat and ecological processes that affect salmon. Such policy shifts reflect recognition that salmon and salmon habitat are components of human values and well-being.

EXECUTIVE SUMMARY

Both short- and long-term trends for salmon indicators of West Coast salmon abundance and aspects of their ecosystems are reported in this summary. An indicator is considered to have changed over the short-term if the trend over the last 10 years (2003-2012) of the series showed a significant increasing or decreasing slope. An indicator is considered to be above or below long-term norms if the mean of the last 10 years of the time series differs from the mean of the full time series by more than 1.0 s.d. of the full time series. A major motivation for presenting long- and short-term trends is to distinguish stocks/populations that were once very large and suffered historical declines as much as 100 years ago but have stabilized at lower abundances from populations with ongoing declines; we do not address issues of historical declines prior to the mid-1980s. This issue most affected populations with very long time series of abundance (e.g., certain Columbia River Chinook salmon populations). Such long time series are not available for most Californian populations. We avoided reliance on data prior to 1985 because of concerns over data quality. Therefore, references to "long-term" abundance, condition, etc. refer to periods of record from 1985. It should be noted that many if not most of these populations are now at levels far below historical values – so caution should be used when interpreting the "long-term" status in this report.

Generally, all California Chinook salmon stocks from 2004-2013 were within 1 s.d. of their longer-term average. However, during the last ten years there was a significant decline in abundance of most California populations examined, with Central Valley Winter-run Chinook salmon at extremely low abundances from 2007-2011. This relates to a reduction from series highs during the early 2000s and a return to the very low values typical of the 1980s and 1990s. For the Columbia/Snake Basin Chinook salmon stocks, recent abundances were also close to average, except for a positive deviation for the Snake River Fall-run. There is a notable contrast in recent trends between steep declines in the lower Columbia River and Willamette River stocks and increases in the upper Columbia and Snake River stocks. As for the California stocks, the observed steep declines follow peak abundances in the early 2000s.

With a few noteworthy exceptions, both the recent trends and recent average levels of condition indices for Chinook salmon have been near long-term average values. In general, there are significant downward trends in condition for Lower Columbia River and Willamette River series, with the exception of improving trends for Willamette River percent natural spawners and age diversity. Klamath River Fall-run Chinook salmon also exhibited an upward trend for percent natural spawners. Notably, Lower Columbia River percent natural reflects a long-term decline in this indicator (Figure S4). Similarly, the Central Valley Fall-run Chinook salmon falls on the border of the "low and decreasing" quadrant for percent natural spawners.

While recent abundance of all coho salmon stocks are near their long-term average, there is a sharp contrast in recent trends. The Central California Coast and Southern Oregon/Northern California Coast stocks both had steep declines following strong peaks in 2004, while the Lower Columbia River stock had a fluctuating increase in recent years. The two northern stocks (Oregon and Lower Columbia) are both well above their historic low abundances in the 1990s.

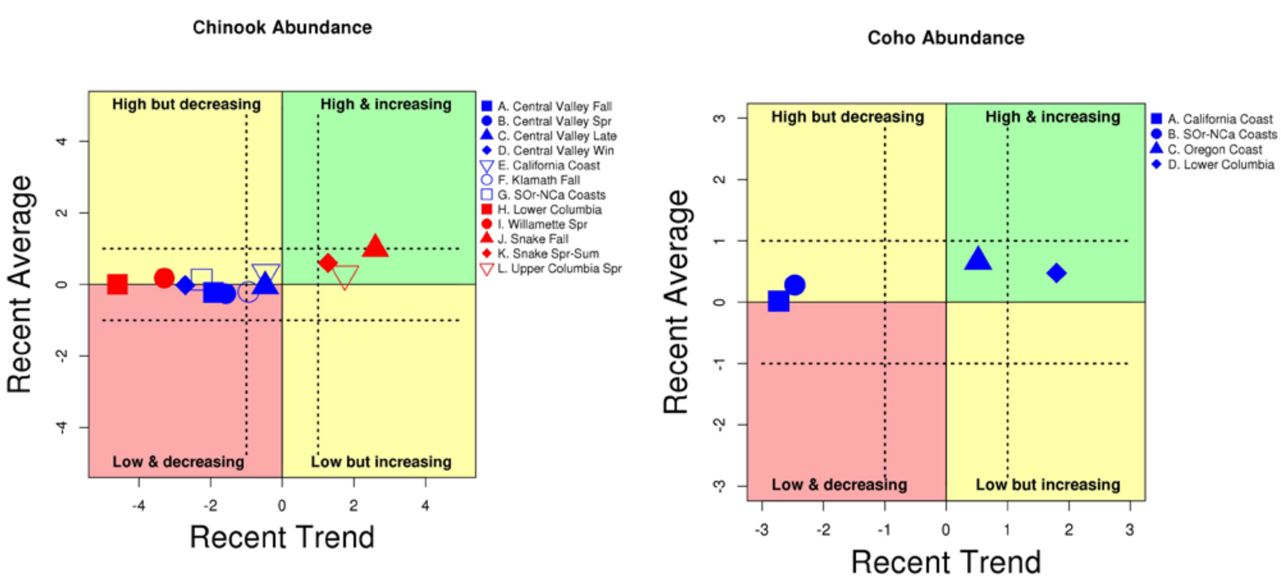
There is no condition data available for the two southernmost coho salmon ESUs, and data for the two northern ESUs are limited to percent natural spawners (both stocks) and population growth rate (for the Oregon Coast stock). None of the data series exhibit significant recent trends, and both series for the Oregon Coast stock are near 25-30 year averages. Recent percent natural spawners for the Lower Columbia River stock is higher than the longer-term average. The Oregon Coast stock exhibits an encouraging long-term upward trend in percent natural spawners.

In this report we consider those environmental factors demonstrated to affect salmon abundance and condition. We evaluate the state of the environment, its potential influence on salmon abundance and condition, and the potential for effects from future climate change. Recent ocean conditions and the forage complex indicate a likelihood of improved early marine survival of Chinook and coho salmon in 2012 and 2013, suggesting improved adult returns in the next few years. In contrast, freshwater flows and temperatures suggest reduced smolts per spanwer in the near future for the

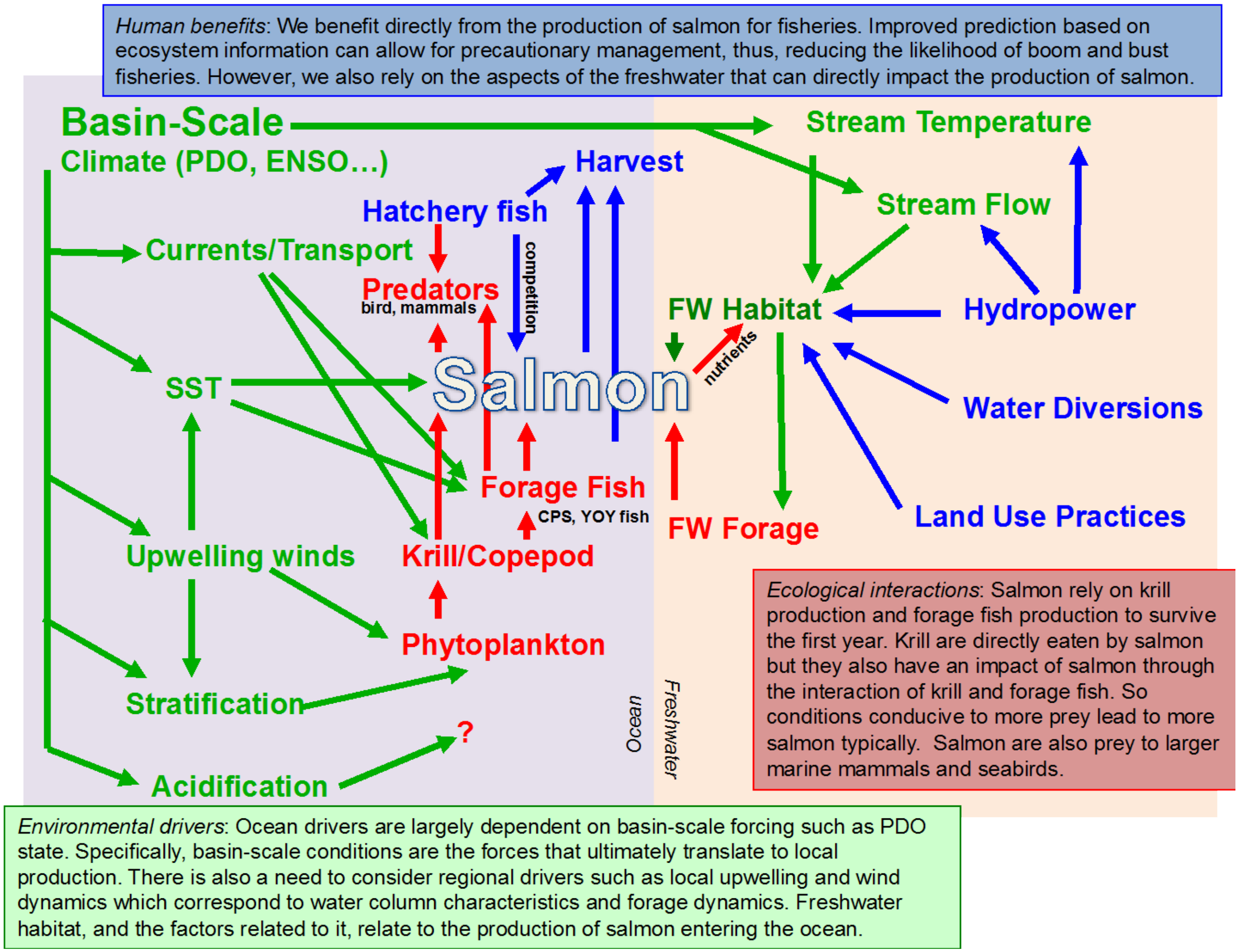
Snake River Basin and across California. Anthropogenic climate change trends are likely to increase risks facing West Coast salmon stocks over the future decades of the 21st century and beyond.

Salmonid populations and habitat have been influenced by dynamic interactions between natural landscape features (e.g., resource abundance, climate, topography) and human activities such as fur trading, mining, logging, agriculture, dams, hatcheries and fisheries. Historical development of these activities was largely driven by economic interests and encouraged by robust market demand and prices, improvements in extractive and processing technologies and transportation, and expansionist government policies. Most of these activities (other than fur trading) continue to the present day in some form. Public policies have changed over time, from an ethos of *laissez faire* resource extraction to one that also considers effects of extraction on wild salmon populations and the habitat and ecological processes that affect salmon. Such policy shifts reflect recognition that salmon and salmon habitats are components of human values and wellbeing.

Most of the quantitative information regarding anthropogenic influences on salmon pertained to outputs from commercial activities (e.g., timber production, agricultural values, salmon harvest). Additional work is needed to consider other indicators that are inclusive of other aspects of human wellbeing. An important next step toward operationalizing the CCIEA is to identify goal(s) that managers wish to achieve by considering salmon in a California Current integrated Ecosystem Assessment (CCIEA) framework, as those goals will affect model specification and the types of indicators appropriate for inclusion in the model.



Salmon abundance. Quadplot summarizes information from multiple time series of coho and Chinook salmon abundances. Prior to plotting, time series were normalized to place them on the same scale. The short-term trend (x-axis) indicates whether the indicator increased or decreased over the last 10-years. The y-axis indicates whether the mean of the last 10 years is greater or less than the mean of the full time series. Dotted lines show ± 1.0 s.d.



The conceptual diagram demonstrates the various environmental and anthropogenic influences that interact to affect salmon through their life cycle. We have included information in this report on each factor when available. We discuss its history, status, and/or trend in the context of salmon and management of the ecosystem. This model should aide in the understanding of the complex web that must be considered when managing the trade-offs associated with human wellbeing and salmon viability

DETAILED REPORT

Pacific salmon (*Oncorhynchus* spp.) are iconic members of North Pacific rim ecosystems, historically ranging from Baja California to Korea (Groot and Margolis 1991). Historically, salmon supported extensive native estuarine and freshwater fisheries along the U.S. West Coast, followed more recently by large commercial marine and recreational marine and freshwater harvest. Salmon and steelhead connect marine and freshwater ecosystems through extensive migrations up to 1500 km.

The purpose of this chapter of the CCIEA is to examine trends in available indicators relevant to salmon along the California Current. It is important to recognize that we refer to population "status" quite differently than that reported by Pacific Fisheries Management Council (PFMC) and in current Endangered Species Act status reports, therefore, any difference between our status statements and those should not be considered a conflict. We use different models and benchmarks than those traditionally used by fishery managers. Our purpose is to set the framework for evaluating the salmon community from an ecosystem perspective. This approach starts with a simple selection of indicators and evaluation of the trends. Here, to a limited degree, we use these biological indicators in combination with indicators of environmental and anthropogenic pressures to evaluate potential risk to the salmon community. Indicators for various pressures can be found in other chapters of the full CCIEA (e.g., Anthropogenic Drivers and Pressures, Oceanographic and Climatic Drivers and Pressures).

Due to a variety of factors, salmon populations in the California Current Large Marine Ecosystem (CCLME) have experienced substantial declines in abundance (Nehlsen et al. 1991), to the extent that a number of stocks have been listed under the U.S. Endangered Species Act. This has resulted in extensive reviews of salmon population status and recovery efforts (Good et al. 2005, Ford 2011, Williams et al. 2011). Rather than attempting to summarize the extensive data and literature that has been accumulated regarding West Coast salmon status, we focus on a few key stocks and indicators that represent variation relevant to the overall condition of the CCLME.

We focus on the two most abundant salmon species in the CCLME Chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*), which have historically supported large fisheries and continue to support economically and culturally important fisheries when and where they remain open (Pacific Fisheries Management Council 2012). Within these species, we selected stocks that span a range of geographic and life-history variation characteristic of the broader community. Pacific salmon species have complex population structures, leading to a variety of ways of defining 'stock' (e.g., Cushing 1981, Dizon et al. 1992). We have chosen to use the Evolutionarily Significant Unit (ESU) defined by NOAA for use in Pacific salmon conservation management (Waples 1991). ESUs are defined on the basis of reproductive isolation and their contribution to the evolutionary legacy of the species as a whole, and are often composed of a number of geographically contiguous populations. They do not correspond exactly to the stock delineations that are used for harvest management; in most cases several stocks/populations make up an ESU. It is worth noting, future Phases of the CCIEA will also include more representation of steelhead(*O. mykiss*).

Both short- and long-term trends are reported in this summary. An indicator is considered to have changed over the short-term if the trend over the last 10 years (2003-2012) of the series showed a significant increasing or decreasing slope. An indicator is considered to be above or below long-term norms if the mean of the last 10 years of the time series differs from the mean of the full time series by more than 1.0 s.d. of the full time series. A major motivation for presenting long- and short-term trends is to distinguish stocks/populations that were once very large and suffered historical declines as much as 100 + years ago but have stabilized at lower abundances from populations with ongoing declines. This issue most affected populations with very long time series of abundance (e.g., certain Columbia River Chinook salmon populations). Such long time series are not available for most Californian populations. We avoided reliance on data prior to 1985 because of concerns over data quality. Therefore, references to "long-term" abundance, condition, etc. refer to periods of record from 1985. It should be noted that many if not most of these populations are now at levels far below historical values – so caution should be used when interpreting the "long-term" status in this report.

We expanded this report from CCIEA Phase II to include environmental pressures and anthropogenic activities that affect salmon abundance and condition either directly or indirectly. The state of current and potential future environments are discussed in the context of the salmon and salmon habitat. We also discuss the patterns and trends of resource-related activities occurring post-1848, including fur trading, mining, logging, farming, dams, hatcheries and fishing that provides a context for the historical declines over the past 100-150 years to most if not all salmonid populations throughout the California current. We relate these activities to major demographic, economic, social, technological and policy changes that occurred with Euro-American settlement in the region. This historical perspective considers legacy as well as ongoing effects of those activities on wild salmon and salmon habitat, and shows how more recent environmental protections have moderated the single-minded resource exploitation characteristic of earlier decades. It also provides (with the benefit of hindsight) the opportunity to illustrate, with concrete examples, the dynamic relationship between human dimensions and salmon, and may suggest ways in which such relationships can be modeled in an ecosystem context. The quantitative indicators provided here regarding trends in human activities are a first step in that direction, though much more work needs to be done.

SALMON ABUNDANCE AND CONDITION INDICATOR SELECTION PROCESS

SUMMARY OF INDICATORS

An extensive search and evaluation of indicators of salmon abundance and condition was conducted. The specifics of that search are outlined in greater detail below. In summary, Table S1 shows the relevant ESUs for Chinook salmon and coho salmon and indicators types (abundance or condition) used in this report.

Table S1. Salmon ESUs/stocks and available data. 'X' indicates that a data series is available, a blank indicates insufficient data are available**.**

		Condition Index		
Stock/ESU Name	**Abundance**	**Age Diversity**	**Percent Natural**	**Population Growth Rate**
Chinook Salmon				
A. Central Valley Fall-run	X		X	X
B. Central Valley Spring-run	X			
C. Central Valley Late Fall-run	X			
D. Central Valley Winter Run	X			
E. California Coast	X			
F. Klamath River Fall-run	X	X	X	X
G. Southern Oregon/ Northern California Coasts	X	X	X	
H. Lower Columbia River	X	X	X	X
I. Willamette River Spring-run	X	X	X	X
J. Snake River Fall-run	X	X	X	X
K. Snake River Spring-Summer-run	X	X	X	X
L. Upper Columbia Spring-run	X	X	X	X
Coho Salmon				
A. Central California Coast	X			
B. Southern Oregon/ Northern California Coasts	X			
C. Oregon Coast	X		X	X
D. Lower Columbia River	X			

INDICATOR EVALUATION

Rather than develop an unique suite of indicators for this report, we have relied on the extensive previous work in evaluating the status of salmon populations and ESUs on the Pacific coast (Allendorf et al. 1997, Wainwright and Kope 1999, McElhany et al. 2000, Lindley et al. 2007). In particular, we selected indicators that were not inconsistent with these previous efforts and also the Viable Salmon Population (VSP) characteristics (McElhany et al. 2000) that are the foundation of current conservation and recovery planning efforts for Pacific salmonids; in addition, they are the bases for on-going evaluation of status updates of Pacific salmonid populations. McElhany et al. (2000) described four characteristics of populations that should be considered when assessing viability: abundance, productivity, diversity, and spatial structure. Since a high priority of the IEA effort it to develop frameworks that can expand to include new data and address multiple issues (e.g., protected species, fisheries, and ecosystem health), we felt it most appropriate to use indicators that are used in status reviews and ESA recovery planning documents (Table S1, S2). From this list of potential indicators, we selected those with the most widespread data availability (to allow for comparisons across species and regions) and with most relevance to the state of the marine ecosystem. The following sections describe the indicators we considered as measures of stock abundance and condition.

Table S2. Key indicators for salmon, identified during the ESA listing and recovery planning processes. Indicators categories chosen for this analysis are in ***bold italic*** font.

Indicator	Selection/Deselection Reasoning
Abundance	
Spawning escapement	Widely measured; key measure of reproductive population
Ocean abundance (recruitment)	Requires stock-specific harvest rate estimates; not widely available
Juvenile abundance	Not widely available, but key indicator of reproduction for some ESUs
Population Condition	
Population growth rate (lambda)	Widely available, standard measure of population trend
Natural return ratio (NRR)	A measure of sustainability of the natural component of mixed hatchery-natural stocks; requires both age-structure and natural proportion data, and knowledge of the relative fitness of hatchery fish.
Intrinsic rate of increase	Widely available, but depends on a specific formulation of density dependence.
Proportion of natural spawners	Widely available
Genetic diversity	Indicator of stock genetic integrity and effectiveness of natural production
Age structure diversity	Available for most Chinook salmon stocks; a quantifiable measure of phenotypic diversity; indicator of harvest-related risk
Population spatial structure	Available for few stocks.

POTENTIAL INDICATORS FOR ASSESSING ABUNDANCE (POPULATION SIZE)

Monitoring population size provides information of use both for protected species conservation and for harvest management. We considered three primary indicators of abundance, and chose to focus on one (spawning escapement) as the most widely available and relevant (Table S2).

1. Spawning escapement–Estimates of spawning escapement are extremely important to salmon management as an indication of the actual reproductive population size. The number of reproducing adults is important in defining population viability, as a measure of both demographic and genetic risks. It is equally important to harvest management, which typically aims at meeting escapement goals such that the population remains viable (for ESA-listed populations) or near the biomass that produces maximum recruitment (for stocks covered by a fisheries management plan). Spawning escapement is the most widely available measure of abundance for West Coast salmon, although these data are often limited to the most commercially important stocks and often stock/population estimates only make up a portion of an ESU.

2. Recruitment–An estimate of the number of adults in the ocean that would be expected to return to spawn in freshwater if not harvested. This is typically estimated as the number of adults that return to spawn divided by the total fishery escapement rate (one minus the total harvest rate). Recruitment is the primary indicator of importance for harvest management, as it determines how much harvest can be tolerated while still meeting escapement goals. It is also the best indicator of overall system capacity for the stock. However, because estimation depends on stock-specific harvest rates, recruitment estimates are not always available.

3. Juvenile abundance–The abundance of juveniles in freshwater or early marine environments is a good measure of reproductive success for a stock. This is monitored for many West Coast salmon stocks, but data series are typically short, and often are made for only a small proportion of an ESU, so are difficult to interpret and compare on a regional basis.

POTENTIAL INDICATORS FOR ASSESSING POPULATION CONDITION

There are a number of potential metrics for assessing the condition of a managed salmon population (Table S2). These fall into the broad categories of population growth/productivity, diversity, and spatial structure (McElhany et al. 2000). We considered the seven commonly used metrics, and based on data availability and relevance, chose three of those metrics (population growth rate, hatchery contribution, and age-structure diversity) to reflect a range of assumptions about the effects of various stressors on the populations.

1. Population growth rate–Calculated as the proportional change in abundance between successive generations, population growth rate is an indication of the population's resilience. In addition, growth rate can act as a warning of

critical abundance trends that can be used for determining future directions in management. Also, the viability of a population is dependent in part on maintaining life-history diversity in the population. Because of limited information on hatchery fish and natural return ratio (see below) this value includes hatchery-origin fish.

2. Natural return ratio (NRR)–NRR is the ratio N/T, where N is naturally produced (i.e., natural-origin) spawning escapement and T is total (hatchery-origin plus natural-origin) spawning escapement in the previous generation. It is a measure of the sustainability of the natural component of mixed hatchery-natural stocks and is an important conservation-oriented measure of stock productivity. However, the calculation requires both age-structure and natural proportion data, and depends on assumptions regarding the relative fitness of hatchery-origin fish in natural environments. This makes it problematic as an ecosystem status indicator.

3. Intrinsic rate of increase–The intrinsic rate of increase is estimated from the statistical fitting of stock-recruit models and is a measure of the rate of population increase when abundance is very low. It is an important parameter in harvest management theory, used in the estimation of optimum yield from a fishery. However, computations require long-term data on both harvest rate and age-structure data, and an assumed theoretical form for the stock-recruit function; therefore it is not easy to use as a status indicator.

4. Hatchery contribution–Defined as the proportion of hatchery-origin fish in naturally-spawning populations. Hatchery fish are relatively homogeneous genetically in comparison to naturally produced populations, typically are not well-adapted to survival in natural habitats, and their presence may reduce the fitness of natural populations (Bisson et al. 2002, Lindley et al. 2007). Thus, this is an important measure of the health of natural populations. Data are available for most West Coast salmon ESUs.

5. Genetic diversity–Genetic diversity is an important conservation consideration for several reasons, particularly in providing adaptive capacity that makes populations resilient to changes in their environment (Waples et al. 2010). Genetic monitoring of salmon populations has become common, and is being used for genetic stock identification as part of harvest management (Beacham et al. 2008). However, there are as yet no time series of genetic data that would allow detection of trends in diversity nor is there an understanding of historical population-specific patterns of genetic diversity to provide context when evaluating contemporary patterns, so this is not a useful status indicator at this time.

6. Age structure diversity–A diverse age structure is important to improve population resilience. Larger, older Chinook salmon produce more and larger eggs (Healey and Heard 1984). Therefore, they produce a brood that may contribute proportionally more to the later spawning population than broods from younger, smaller fish. However, the diversity of ages including younger fish is important to accommodate variability in the environment. If mortality on any given cohort is great, there is benefit to having younger spawners. An individual that produces offspring that return at different adult ages (i.e., overlapping generations) may increase the likelihood of contributing to future generations when environmental conditions are less than favorable one year to the next. This bet hedging is a critical aspect of Chinook salmon that allow it to naturally mitigate year-to-year environmental variability (Heath et al. 1999). Adult age structure is not an issue for coho salmon, which in our region spawn predominantly at age three (with the exception of a small

proportion of younger male 'jacks'). While coho salmon in our region spawn predominantly at a single age, Chinook salmon typically spawn over an age range of 3 or 4 years, and exhibit differences in spawning age both among years and among populations. Data are available for most Chinook salmon populations of commercial importance or of ESA interest ESUs (e.g., Sacramento River Winter-run), although data are typically stock/population specific and might not be representative of an ESU.

7. Spatial structure–The spatial structure of a stock, both among- and within- subpopulations, is important to the long-term stability and adaptation of the stock/population/ESU. A number of methods have been proposed for indexing the structure of both spawning and juvenile salmon (McElhany et al. 2000, Wainwright et al. 2008, Peacock and Holt 2012). Unfortunately, there are not widespread data nor a consistent method used for evaluating spatial structure of West Coast salmon ESUs.

SELECTING APPROPRIATE STOCKS/POPULATIONS FOR EVALUATION OF ABUNDANCE AND CONDITION

Stock selection was based on economic and ecosystem importance, geographic and life-history diversity, and data availability. This resulted in selections consistent with current ESU delineations. Because of regional differences in the availability of data, we considered stocks and data series separately within two regions: California (including southern Oregon south of Cape Blanco) and Oregon-Washington coasts (Cape Blanco to the mouth of the Strait of Juan de Fuca). For each ESU, a variety of data series are available; each series has been used in management documents, status reports, and/or the scientific literature. Any data series that was less than 15 years long was removed; within each ESU, all data series were truncated to match the shortest series. Available data series meeting these criteria for given ESUs are listed in Tables S3-S6. It should be noted that in many cases we used data that were not used for recent ESA status updates. Many of the available time series are at the stock or population scale and may not be representative of the whole ESU (the listing unit for ESA efforts) and therefore may not be appropriate for evaluating the status of an ESU. For our purposes we determined that development of the indicators and ecosystem models using stock/population scale measures was appropriate at this initial stage of development of IEA and we should be able to accommodate ESU representative data as rigorous monitoring programs are established.

For California ESUs (Tables S3 & S4), the data series were compiled from a variety of sources and are presented in Williams et al. (2011), PFMC (2012), and Spence and Williams (2011). Because of the diversity of data types available, indicators for each stock were selected based on their availability, time series lengths, and scientific support. Data series that were used are highlighted in the tables.

For Oregon and Washington ESUs, data were obtained from the NWFSC's "Salmon Population Summary" database (https://www.webapps.nwfsc.noaa.gov/apex/f?p=238:home:0), with additional data for Oregon Coast coho salmon (Oregon Department of Fish and Wildlife, http://oregonstate.edu/dept/ODFW/spawn/data.htm), and from PFMC (2012) for the Upper Columbia Summer/Fall-run Chinook Salmon.

When data were only available for a portion of an ESU (e.g., single stream or tributary, but not necessarily representative of the whole ESU) and no ESU-wide estimates were available, we used these data as a proxy for the ESU unless it was not recent enough or was incomplete (Table S3). If data restrictions or reporting required multiple series be used for a given indicator within a single ESU, we computed an ESU-wide average (e.g., Table S3, Central Valley Spring-run). To do this, series were standardized and then averaged across populations within ESUs. These standard scores represent the index for abundance or conditions for that ESU. Data series that represented similar values (e.g., escapements) were weighted by absolute spawning abundance.

APPROPRIATE INDICATORS

We evaluated abundance using the metric of escapement of natural-origin spawners. Selection rationale for assessing only escapement and no other abundance metrics is listed in Table S2. The populations/ESUs that had sufficiently met the criteria for inclusion in the analyses are listed in Tables S3 and S5. When ESU-wide estimates were available and sufficient they were used. If data were only available at the sub-ESU level, escapement values from the component subpopulations were used. As well, we only used data beginning in 1985 so that, when possible, the longer time series could be compared equivalently among populations. Data series for multiple subpopulations were standardized by subtracting the series mean and dividing by the series standard deviation. If a consolidated index for the stock was needed we computed an annual weighted average of the standardized series, with weights proportional to the average abundance for each subpopulation.

To evaluate condition we restricted our analyses to examination of population growth rate, proportion of natural-origin spawners, and age-structure diversity. Selection rationale for assessing only these metrics of condition and no other condition metrics is listed in Table S2. The populations/ESUs that had sufficiently met the criteria for estimation of condition are listed in Tables S4 and S6.

Population growth rate for each subpopulation was estimated as the ratio of the 4-year running mean of spawning escapement in one year to the 4-year running mean for the previous year (Good et al. 2005). Proportion of natural-origin spawners was calculated for those populations where spawning abundance estimates are broken down into hatchery-origin and natural-origin components; the proportion was computed for a single population as the fraction N_N/N_T, where N_N is the number of naturally-origin spawners, and N_T is the total number of spawners. Population fractions were then averaged across the populations within the ESU, weighted by total spawner abundance. Age-structure diversity for Chinook salmon was computed as Shannon's diversity index of spawner age for each population within each year. The indices were then averaged across populations, weighted by total spawner abundance.

Table S3. California ESUs/Stocks and data available for abundance estimates. Each of these series met the criteria for inclusion in the analyses and was used.

Population	Data Available: Escapement	Period
Chinook Salmon		
Central Valley Fall Run	Escapement to system	1983-2012
Central Valley Late Fall Run	Escapement to system	1971-2011
Central Valley Winter Run	Escapement to system, carcass survey	2001-2011
Central Valley Spring Run	Escapement Antelope Creek	~1982-2012
	Escapement Battle Creek	1989-2012
	Escapement Big Chico Creek	1970-2012
	Escapement Butte Creek	1970-2012
	Escapement Clear Creek	1992-2012
	Escapement Cottonwood Creek	1973-2012
	Escapement Deer Creek	1970-2012
	Escapement Feather River Hatcher	1970-2012
	Escapement Mill Creek	1970-2012
Klamath R. Fall Run	Escapement to system (Klamath+Trinity)	1978-Present

Population	Data Available: Escapement	Period
SOr-NCa Chinook Fall	Huntley Park (Rogue River)	1973-2013
Cal Coastal Chinook	Tomki Creek (Live/Dead Counts)	1979-Present
	Cannon Creek (live/Dead Counts)	1981-Present
	Sprowl Creek (Live/Dead Counts)	1974-Present
Coho salmon		
SOr-NCa Coho	Huntley Park (Rogue River)	1973-2013
California Coastal Coho	Lagunitas Creek coho salmon reddcounts	1995-2012

Table S4. Data series that met the criteria for inclusion in the condition analyses of California ESUs. Each of these series met the criteria for inclusion in the analyses and was used.

Population	Data Series on Condition	Period
Chinook Salmon		
CV Fall Sacramento R. Fall Run	Hatchery contribution	1983 -2012
	Population Growth Rate	1983-2012
Klamath R. Fall Run	Klam Age diversity (S-W)	1981-2012
	Hatchery contribution	1978 -2011
	Population Growth Rate	1981-2013
SOr-NCa Chinook Fall	Rogue Age Diversity	1980-2013
	Hatchery Contribution	1972-2011

Table S5. Oregon-Washington ESUs/stocks and data available for abundance estimates. Each of these series met the criteria for inclusion in the analyses and was used.

Stock/ESU	Data Available: Escapement	Period
Chinook Salmon		
Lower Columbia River ESU	Clatskanie River Fall	1974-2006
	Coweeman River Fall	1977-2010
	Elochoman River Fall	1975-2010
	Grays River Fall	1964-2010
	Kalama River Fall	1964-2010
	Kalama River Spring	1980-2008
	Lewis River	1964-2010
	Lewis River Fall	1973-2009
	Lower Cowlitz River Fall	1977-2010
	Mill Creek Fall	1980-2010
	North Fork Lewis River Spring	1980-2008
	Sandy River Fall (Bright)	1981-2009
	Sandy River Spring	1981-2008
	Toutle River Fall	1964-2009
	Upper Cowlitz River Spring	1980-2009

Stock/ESU	Data Available: Escapement	Period
	Upper Gorge Tributaries Fall	1964-2008
	Washougal River Fall	1977-2010
	White Salmon River Fall	1976-2009
Snake River Fall-run ESU	Snake River Lower Mainstem Fall	1975-2012
Snake River Spring/Summer-run ESU	Bear Valley Creek	1960-2012
	Big Creek	1957-2012
	Camas Creek	1963-2012
	Catherine Creek Spring	1955-2011
	Chamberlain Creek	1985-2012
	East Fork Salmon River	1960-2012
	East Fork South Fork Salmon River	1958-2012
	Grande Ronde River Upper Mainstem	1955-2011
	Imnaha River Mainstem	1949-2011
	Lemhi River	1957-2012
	Loon Creek	1957-2012
	Lostine River Spring	1959-2011
	Marsh Creek	1957-2012

Stock/ESU	Data Available: Escapement	Period
	Minam River	1954-2012
	Pahsimeroi River	1986-2012
	Salmon River Lower Mainstem	1957-2012
	Salmon River Upper Mainstem	1962-2012
	Secesh River	1957-2011
	South Fork Salmon River Mainstem	1958-2012
	Sulphur Creek	1957-2012
	Tucannon River	1979-2011
	Valley Creek	1957-2012
	Wenaha River	1964-2012
	Yankee Fork	1961-2011
Upper Columbia River Spring-run ESU	Entiat River	1960-2011
	Methow River	1960-2011
	Wenatchee River	1960-2011
Willamette River ESU	Clackamas River Spring	1974-2011
	McKenzie River Spring	1970-2012

Stock/ESU	Data Available: Escapement	Period
Coho Salmon		
Lower Columbia River ESU	Clackamas River	1970-2010
	Sandy River	1970-2010
Oregon Coast ESU	Alsea River	1990-2012
	Beaver Creek	1990-2012
	Coos River	1990-2012
	Coquille River	1990-2012
	Floras/New River	1990-2012
	Lower Umpqua River	1990-2012
	Middle Umpqua River	1990-2012
	Necanicum River	1990-2012
	Nehalem River	1990-2012
	Nestucca River	1990-2012
	North Umpqua River	1990-2012
	Salmon River	1990-2012
	Siletz River	1990-2012
	Siltcoos Lake	1990-2012

Stock/ESU	Data Available: Escapement	Period
	Siuslaw River	1990-2012
	Sixes River	1990-2012
	South Umpqua River	1990-2012
	Tahkenitch Lake	1990-2012
	Tenmile Lake	1990-2012
	Tillamook Bay	1990-2012
	Yaquina River	1990-2012

Table S6. Oregon-Washington ESUs/stocks and data available for condition estimates. These data series met the criteria for inclusion in the condition analyses Data types available are: HC – hatchery contribution to natural spawning; PGR – population growth rate; Age – spawning age structure. Period is the period of availability for the longest series for that population.

Stock/ESU	Population	Data Types	Period
Chinook Salmon			
Lower Columbia River ESU	Clatskanie River Fall	HC, PGR, Age	1974-2006
	Coweeman River Fall	HC, PGR	1980-2010
	Elochoman River Fall	HC, PGR	1975-2010
	Grays River Fall	HC, PGR	1964-2010
	Kalama River Fall	HC, PGR	1964-2010
	Kalama River Spring	PGR	1980-2008
	Lewis River	HC, PGR	1978-2010
	Lewis River Fall	PGR	1977-2009
	Lower Cowlitz River Fall	HC, PGR	1973-2009
	Mill Creek Fall	HC, PGR	1980-2010
	North Fork Lewis River Spring	PGR	1980-2008
	Sandy River Fall (Bright)	HC, PGR, Age	1981-2006
	Sandy River Spring	HC, PGR, Age	1981-2008
	Toutle River Fall	PGR	1964-2009

Stock/ESU	Population	Data Types	Period
	Upper Cowlitz River Spring	PGR	1980-2009
	Upper Gorge Tributaries Fall	HC, PGR	1964-2008
	Washougal River Fall	HC, PGR	1977-2010
	White Salmon River Fall	HC, PGR, Age	1976-2009
Snake River Fall-run ESU	Snake River Lower Main. Fall	HC, PGR, Age	1975-2012
Snake River Spring/Summer-run ESU	Bear Valley Creek	HC, PGR, Age	1960-2012
	Big Creek	HC, PGR, Age	1957-2012
	Camas Creek	HC, PGR, Age	1963-2012
	Catherine Creek Spring	HC, PGR, Age	1955-2011
	Chamberlain Creek	HC, PGR, Age	1985-2012
	East Fork Salmon River	HC, PGR, Age	1960-2012
	E. Fork S. Fork Salmon River	HC, PGR, Age	1958-2012
	Grande Ronde River - Upper Main	HC, PGR, Age	1955-2011
	Imnaha River Mainstem	HC, PGR, Age	1949-2011
	Lemhi River	HC, PGR, Age	1957-2012
	Loon Creek	HC, PGR, Age	1957-2012
	Lostine River Spring	HC, PGR, Age	1959-2011

Stock/ESU	Population	Data Types	Period
	Marsh Creek	HC, PGR, Age	1957-2012
	Minam River	HC, PGR, Age	1954-2012
	Pahsimeroi River	HC, PGR, Age	1986-2012
	Salmon River Lower Mainstem	HC, PGR, Age	1957-2012
	Salmon River Upper Mainstem	HC, PGR, Age	1962-2012
	Secesh River	HC, PGR, Age	1957-2011
	South Fork Salmon River Mainstem	HC, PGR, Age	1958-2012
	Sulphur Creek`	HC, PGR, Age	1957-2012
	Tucannon River	HC, PGR, Age	1979-2011
	Valley Creek	HC, PGR, Age	1957-2012
	Wenaha River	HC, PGR, Age	1964-2012
	Yankee Fork	HC, PGR, Age	1961-2011
Upper Columbia River Spring-run ESU	Entiat River	HC, PGR, Age	1960-2011
	Methow River	HC, PGR, Age	1960-2011
	Wenatchee River	HC, PGR, Age	1960-2011
Willamette River ESU	Clackamas River Spring	HC, PGR, Age	1974-2011

Stock/ESU	Population	Data Types	Period
	McKenzie River Spring	HC, PGR, Age	1970-2012
Coho Salmon			
Oregon Coast ESU	Alsea River	HC, PGR	1990-2012
	Beaver Creek	HC, PGR	1990-2012
	Coos River	HC, PGR	1990-2012
	Coquille River	HC, PGR	1990-2012
	Floras/New River	HC, PGR	1990-2012
	Lower Umpqua River	HC, PGR	1990-2012
	Middle Umpqua River	HC, PGR	1990-2012
	Necanicum River	HC, PGR	1990-2012
	Nehalem River	HC, PGR	1990-2012
	Nestucca River`	HC, PGR	1990-2012
	North Umpqua River	HC, PGR	1990-2012
	Salmon River	HC, PGR	1990-2012
	Siletz River	HC, PGR	1990-2012

Stock/ESU	Population	Data Types	Period
	Siltcoos Lake	HC, PGR	1990-2012
	Siuslaw River	HC, PGR	1990-2012
	Sixes River	HC, PGR	1990-2012
	South Umpqua River	HC, PGR	1990-2012
	Tahkenitch Lake	HC, PGR	1990-2012
	Tenmile Lake	HC, PGR	1990-2012
	Tillamook Bay	HC, PGR	1990-2012
	Yaquina River	HC, PGR	1990-2012

STATUS AND TRENDS OF SALMON ABUNDANCE AND CONDITION

MAJOR FINDINGS OF SALMON ABUNDANCE AND CONDITION

A number of salmon population groups [ESUs] have demonstrated declines over the last ten years. For Chinook salmon, the Lower Columbia and Willamette Spring-run data series exhibited the steepest declines, while the Central Valley Fall-run, Spring-run, and Sacramento River winter-run and the Southern Oregon/Northern California series exhibited more moderate declines. On the positive side, Snake River fall-run, Snake River spring/summer-run, and Upper Columbia River spring-run Chinook demonstrated increases. All Chinook salmon ESUs were near their longer-term (25-30 year) average abundance.

For coho salmon, all recent abundance averages were near their longer-term averages, but the California Coast and Southern Oregon/Northern California Coasts series demonstrated recent steep declines, while the Lower Columbia River showed an increase. Oregon Coast coho salmon demonstrated no significant recent trend.

SUMMARY AND STATUS OF TRENDS OF SALMON ABUNDANCE AND CONDITION

Both short- and long-term trends are reported in this summary. An indicator is considered to have changed over the short-term if the trend over the last 10 years (2003-2012) the series showed a significant increasing or decreasing slope. An indicator is considered to be above or below long-term norms if the mean of the last 10 years of the time series differs from the mean of the full time series by more than 1.0 s.d. of the full time series. “Long-term” trends reflect data since 1985, not historical abundance. A major motivation of presenting long- and short-term trends is to distinguish between stocks/populations that were once very large and suffered historical declines but have stabilized at lower abundances from populations with ongoing declines. This was a particular issue for populations with very long time series of abundance (e.g., certain Columbia River Chinook salmon populations). Information on historical abundances indicate that for many if not most of these populations current values are now far below historical values – so caution should be used when interpreting “long-term,” and not associate it with historically robust populations. We did not include data prior to 1985 in our analysis because data quality and consistency is much lower in the early years, and such long time series are not available for most California populations.

CHINOOK SALMON: ABUNDANCE

Generally all California Chinook salmon stocks were within 1 s.d. of their long term average (since 1985). However, during the last ten years there has been a significant decline in abundance of most California populations examined, with Central Valley Winter Run Chinook salmon at extremely low abundances from 2007-2011 (Figure S1). Largely, though, this relates to a reduction from series highs during 2000s and a return to previous values (Figure S2). For the northern Chinook salmon stocks, recent abundances were also close to average, except for a positive deviation for the Snake River Fall-run (Figure S1). There is a notable contrast in recent trends between steep declines in the lower Columbia River and Willamette River stocks and increases in the upper Columbia and Snake River stocks (Figure S1). As for the California stocks, the observed steep declines follow higher abundances in the early 2000s. This suggests that 10 years may be too short a time frame for evaluating status of these stocks.

CHINOOK SALMON: CONDITION

With a few noteworthy exceptions, both the recent trends and recent average levels of condition indices for Chinook salmon have been near long-term average values (Figure S3). In general, there are significant downward trends in condition for Lower Columbia River and Willamette River series, with the exception of improving trends for Willamette River percent natural spawners and age diversity. Klamath River Fall-run also exhibits an upward trend for percent natural spawners. Notably, Lower Columbia River percent natural spawners falls into the “low and decreasing” quadrant, reflecting a long-term decline in this indicator (Figure S4). Similarly, the Central Valley Fall-run falls on the border of the “low and decreasing” quadrant for percent natural spawners.

COHO SALMON: ABUNDANCE

While recent abundance of all coho salmon stocks are near their long-term average (since 1985), there is a sharp contrast in recent trends (Figure S5). The Central California Coast and Southern Oregon/Northern California Coast stocks both exhibit steep declines following increased abundance in 2004, while the Lower Columbia River stock exhibited a fluctuating increase in recent years (Figure S6). The two northern stocks are both well above their historical low abundances in the 1990s.

COHO SALMON: CONDITION

There is no condition data available for the two southernmost coho salmon ESUs, and data for the two northern ESUs are limited to percent natural spawners (both stocks) and population growth rate (for the Oregon Coast stock). None of the data series exhibit significant recent trends, and both series for the Oregon Coast stock are near long-term 25-30 averages (Figure S7). Recent percent natural spawners for the Lower Columbia River stock is higher than the 25-30 year average. The Oregon Coast stock exhibits an encouraging long-term upward trend in percent natural spawners (Figure S8).

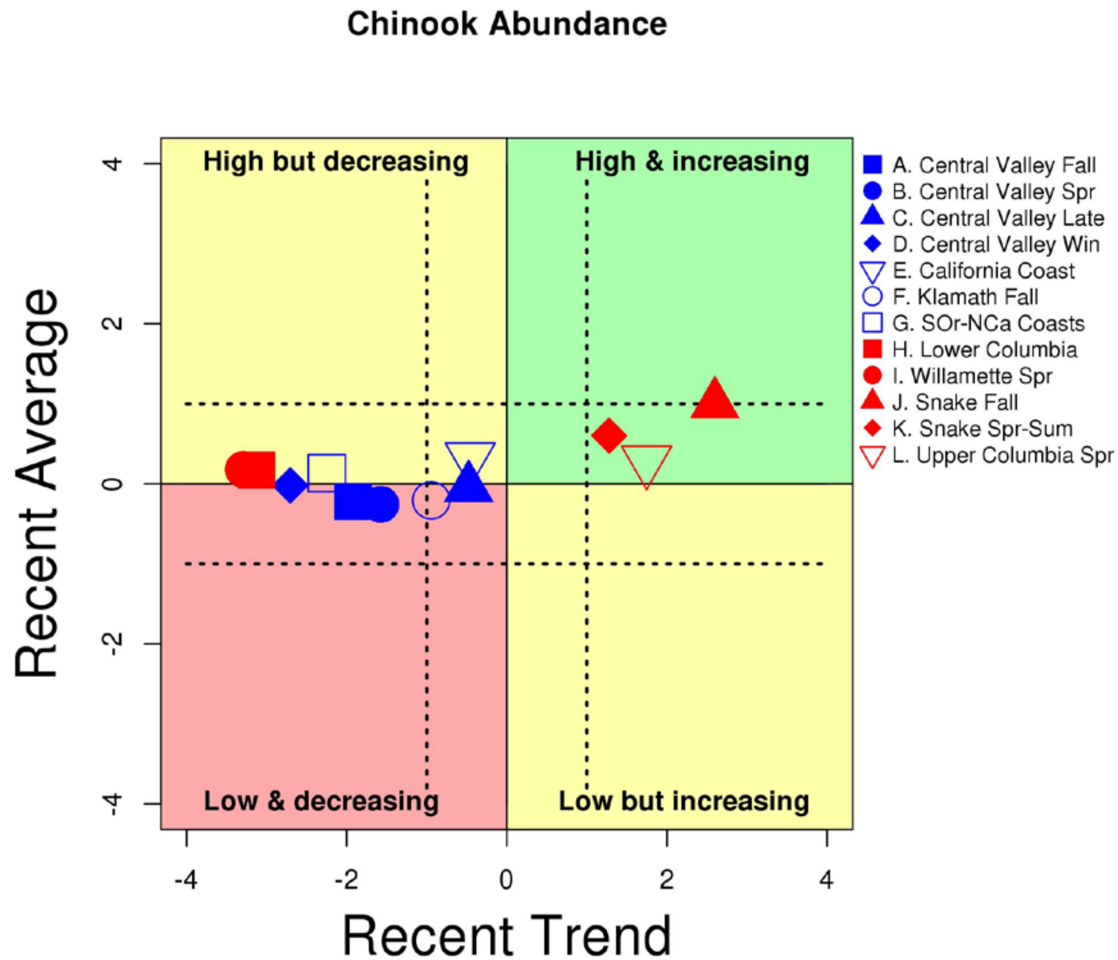
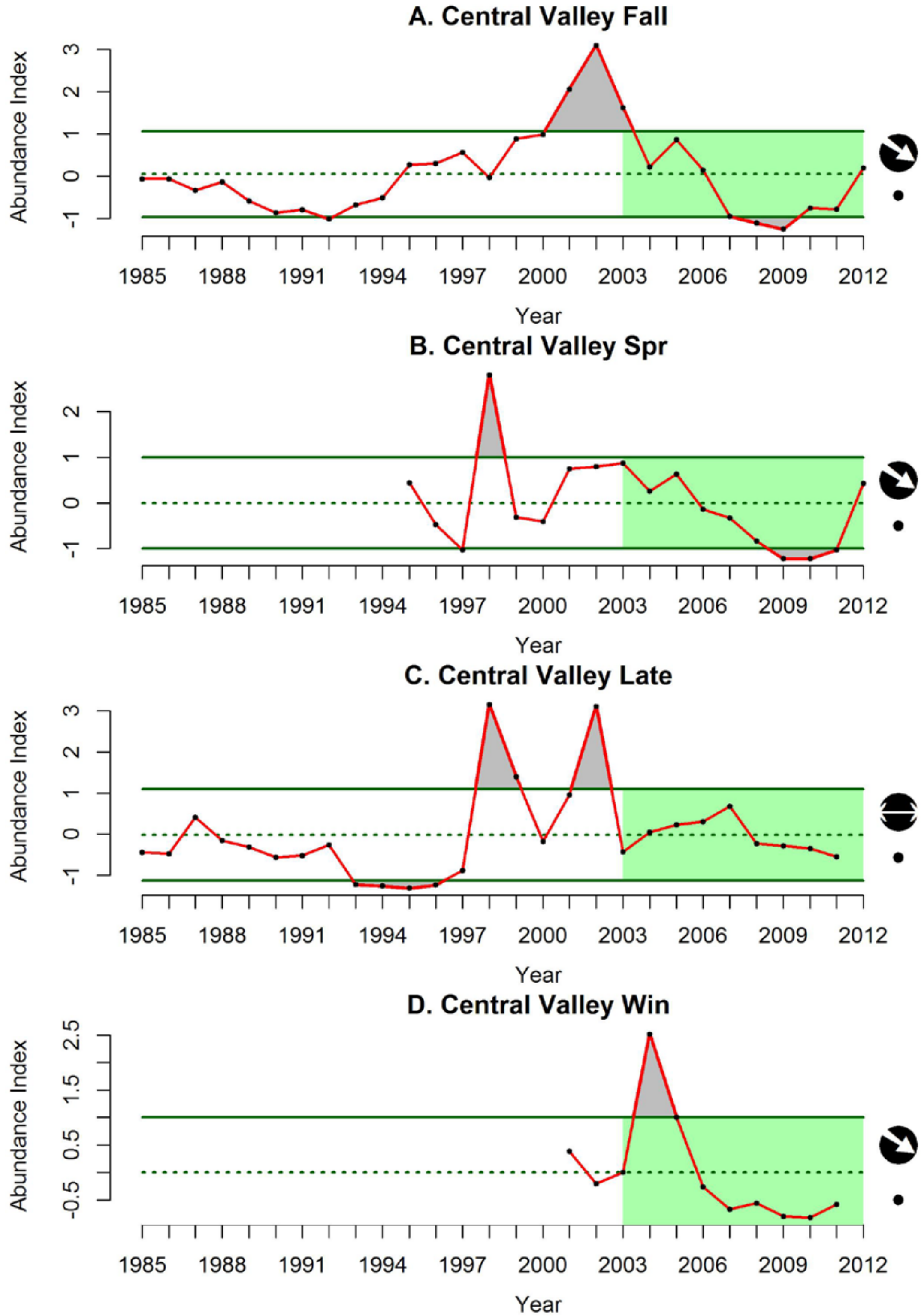
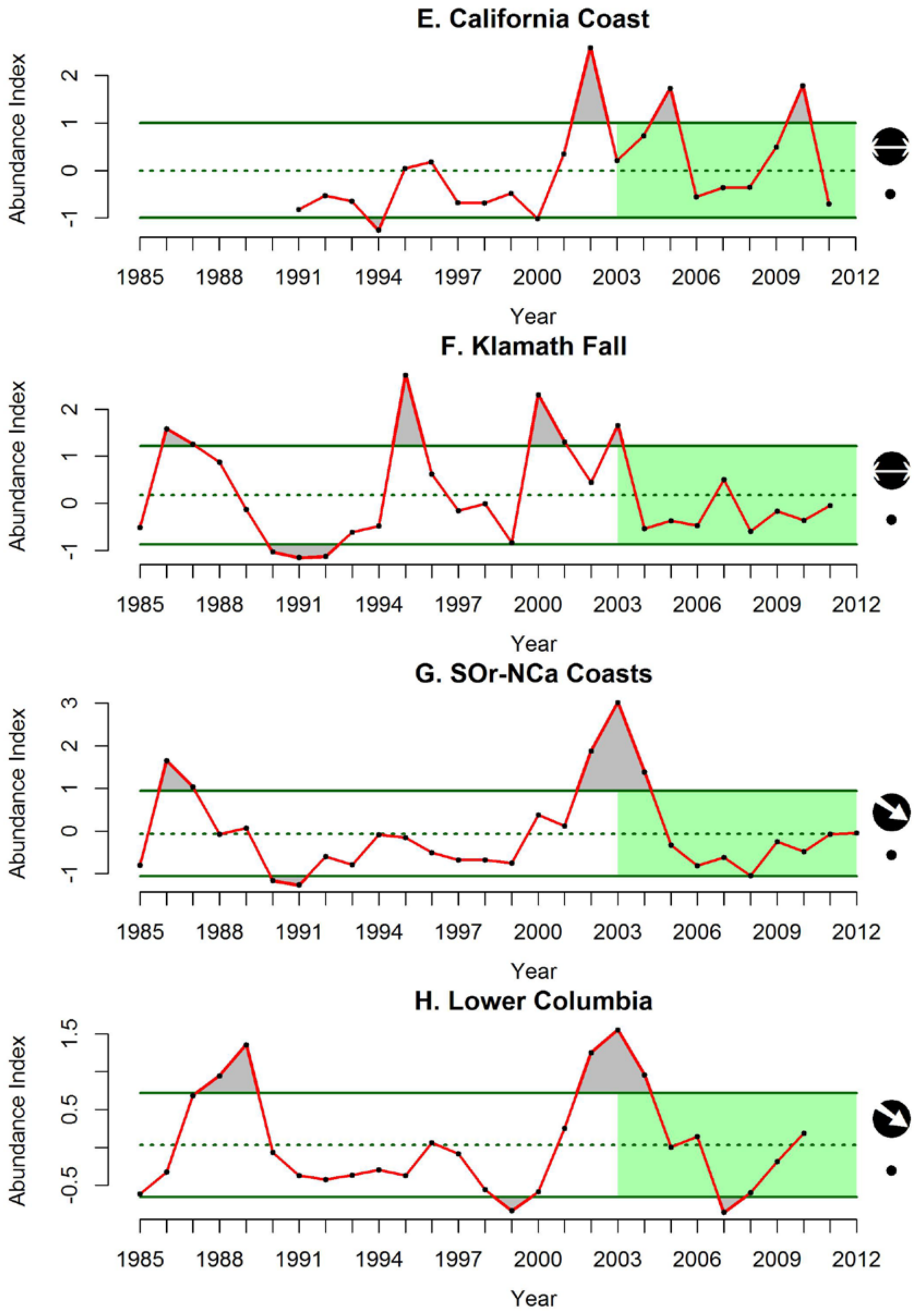


Figure S1. *Chinook salmon abundance.* Quadplot summarizes information from multiple time series figures. Prior to plotting time series were normalized to place them on the same scale. The short-term trend (x-axis) indicates whether the indicator increased or decreased over the last 10-years. The y-axis indicates whether the mean of the last 10 years is greater or less than the mean of the full time series. Dotted lines show ± 1.0 s.d. Populations listed correspond to data series in Tables S3 & S4.



A. Central Valley Fall
B. Central Valley Spr
C. Central Valley Late
D. Central Valley Win
Abundance Index
Year
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012



E. California Coast
Abundance Index
Year
1985 1988 1991 1994 1997 2000 2003 2006 2009 2012
F. Klamath Fall
Abundance Index
Year
G. SOr-NCa Coasts
Abundance Index
Year
H. Lower Columbia
Abundance Index
Year

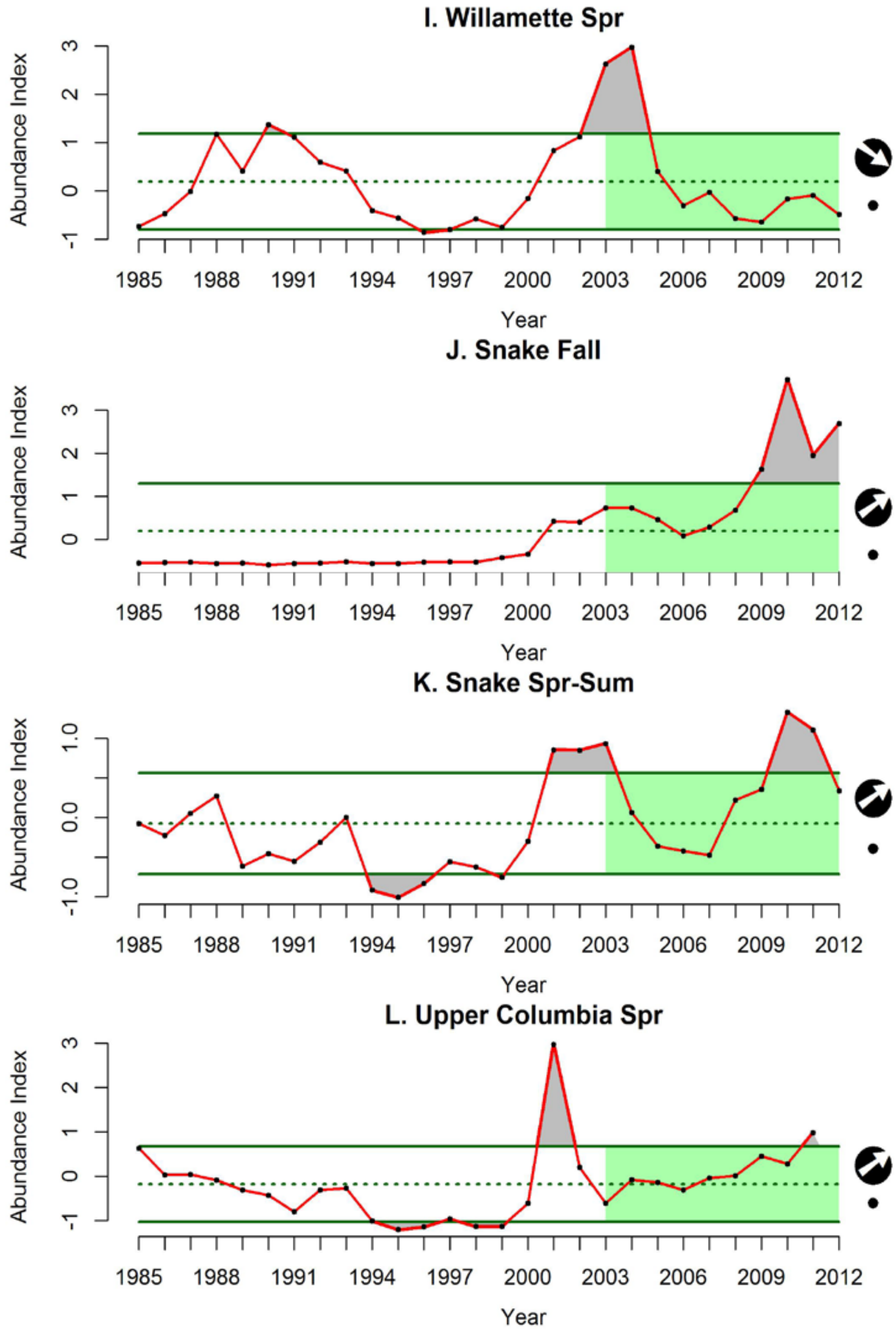


Figure S2. *Chinook salmon abundance*. The abundance index is calculated as anomalies (observed-mean/standard deviation). Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 10-years, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend was significant over the last 10-years. The lower symbol indicates whether the mean during the last 10 years was greater or less than or within one s.d. of the long-term mean. Population abbreviations correspond to populations listed in Tables S3 & S4. Abundances are shown as anomalies.

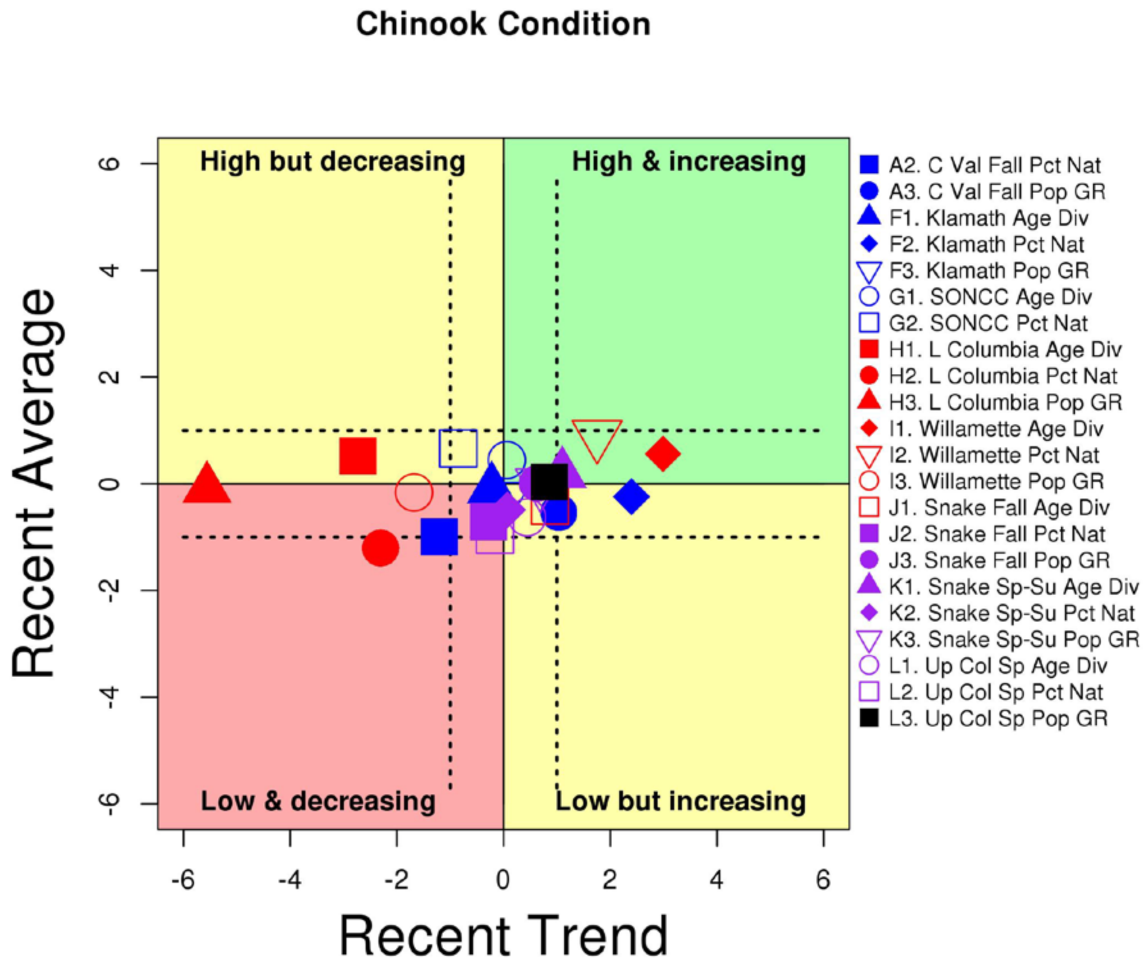
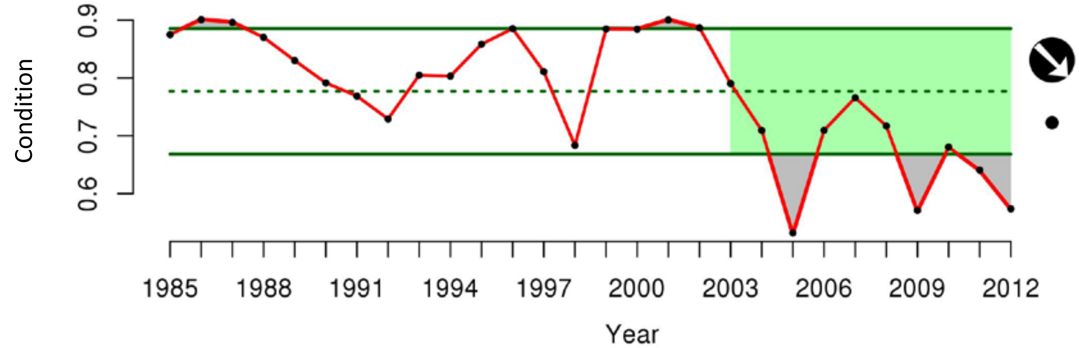
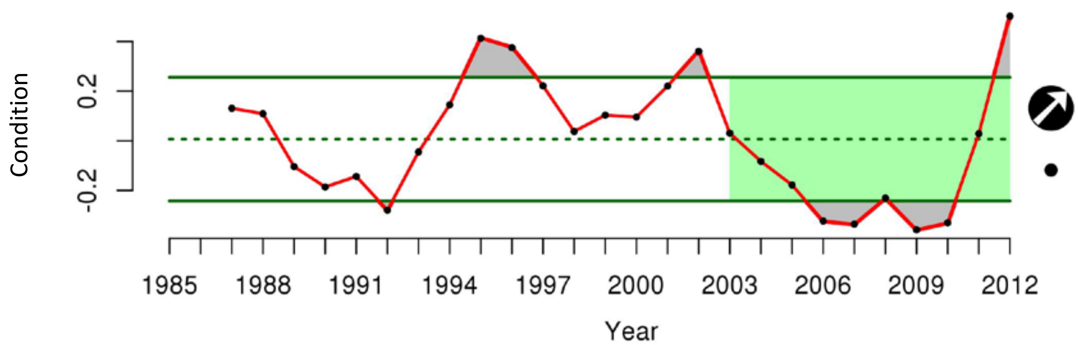


Figure S3. *Chinook salmon condition.* Quadplot summarizes information from multiple time series figures. Prior to plotting time series were normalized to place them on the same scale. The short-term trend (x-axis) indicates whether the indicator increased or decreased over the last 10-years. The y-axis indicates whether the mean of the last 10 years is greater or less than the mean of the full time series. Dotted lines show ± 1.0 s.d. When possible we evaluated percent natural spawners (Pct Nat), age-structure diversity (Age Div), and population growth rate (Pop GR).

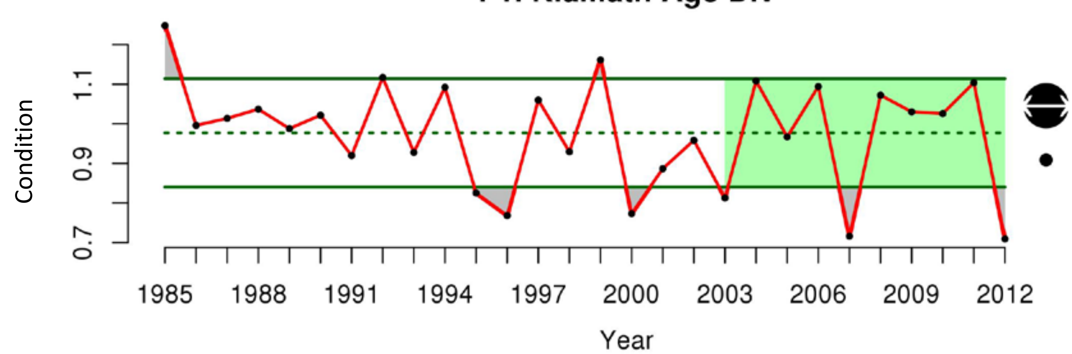
A2. C Val Fall Pct Nat



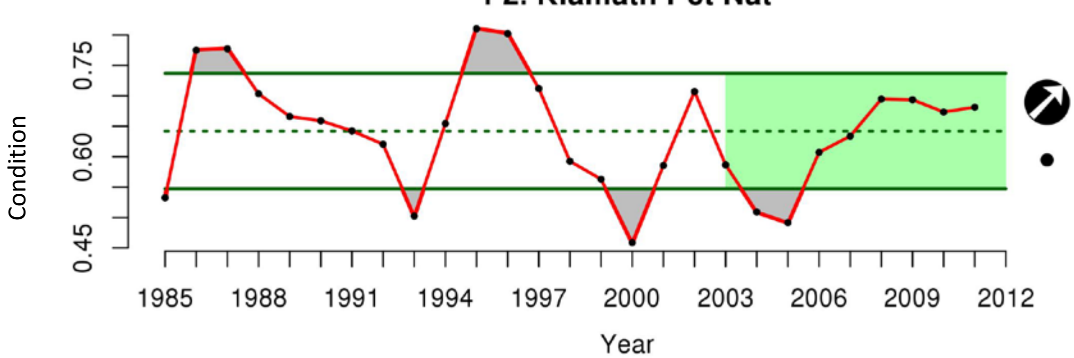
A3. C Val Fall Pop GR

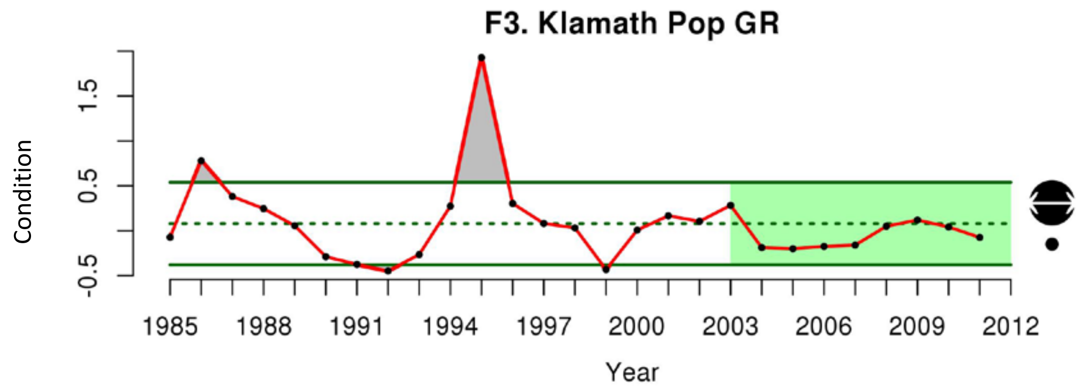


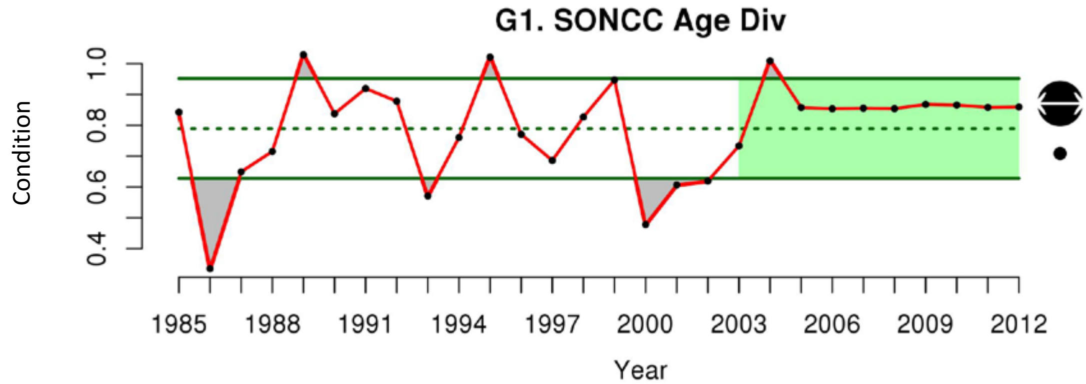
F1. Klamath Age Div

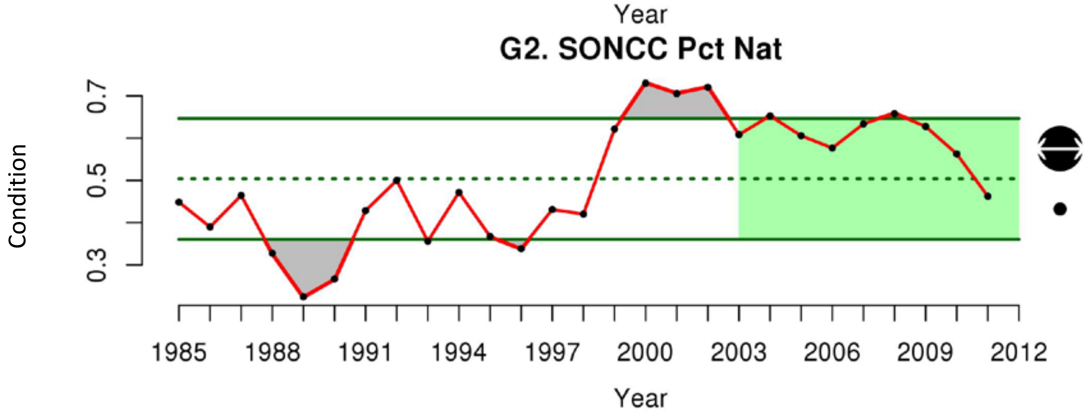


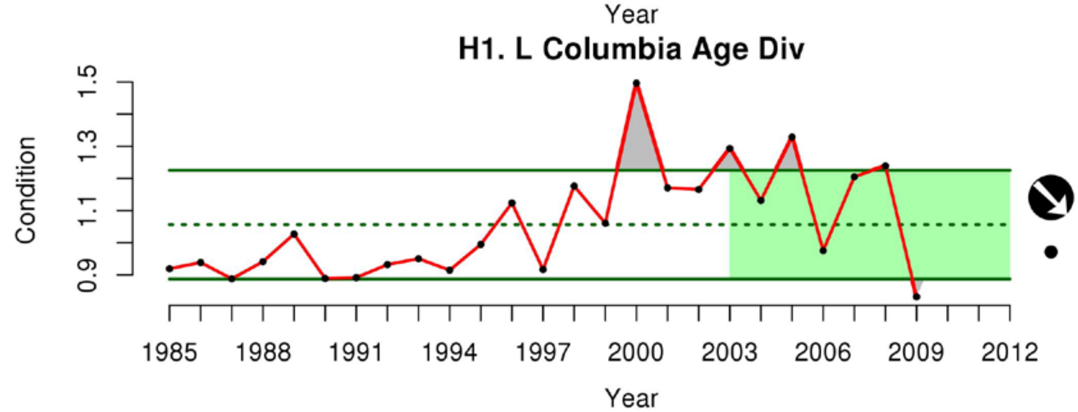
F2. Klamath Pct Nat

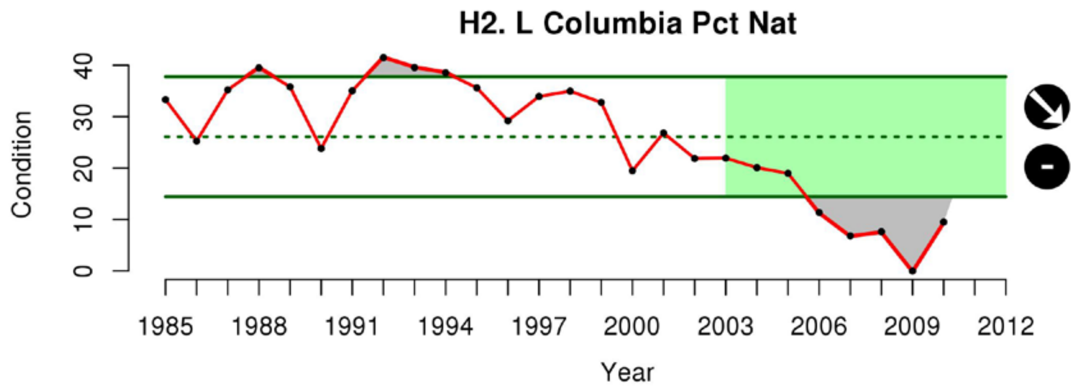


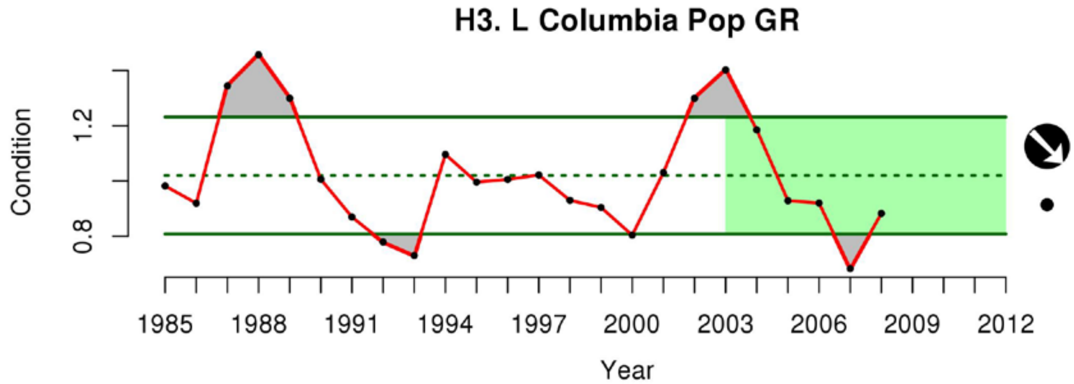

F3. Klamath Pop GR
Condition
-0.5
0.5
1.5
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year

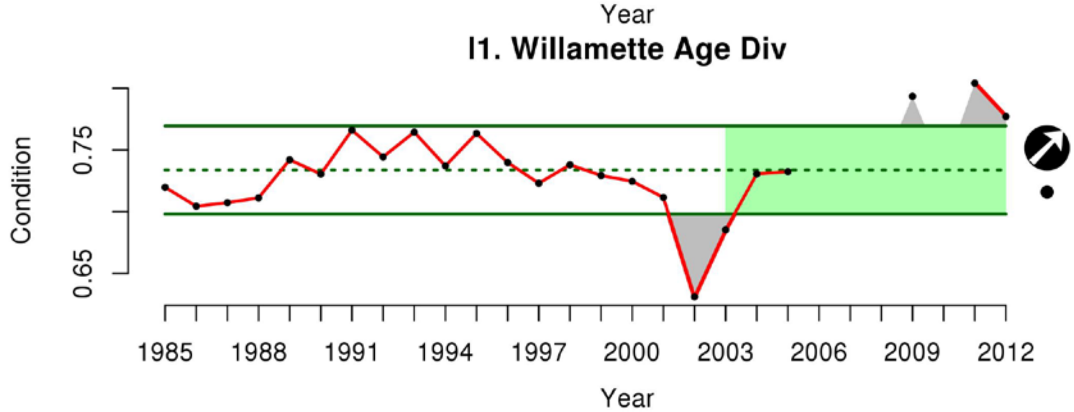

G1. SONCC Age Div
Condition
0.4
0.6
0.8
1.0
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year

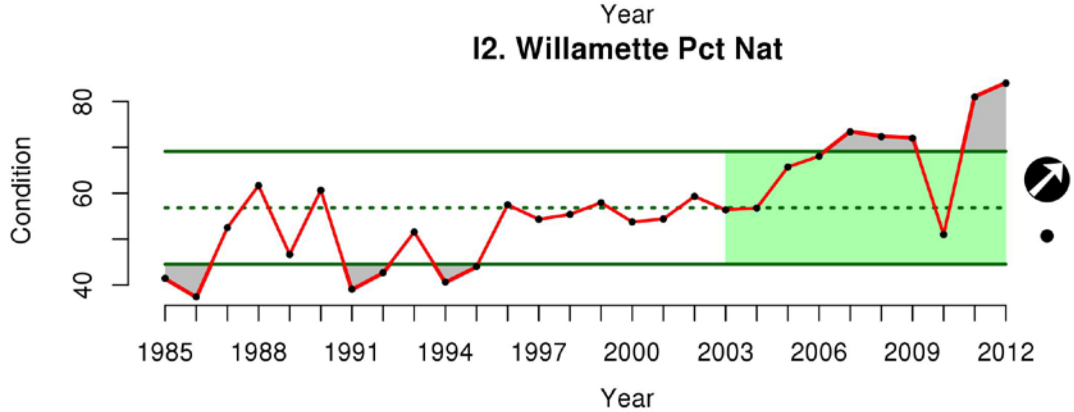

G2. SONCC Pct Nat
Condition
0.3
0.5
0.7
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year


H1. L Columbia Age Div
Condition
0.9
1.1
1.3
1.5
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year

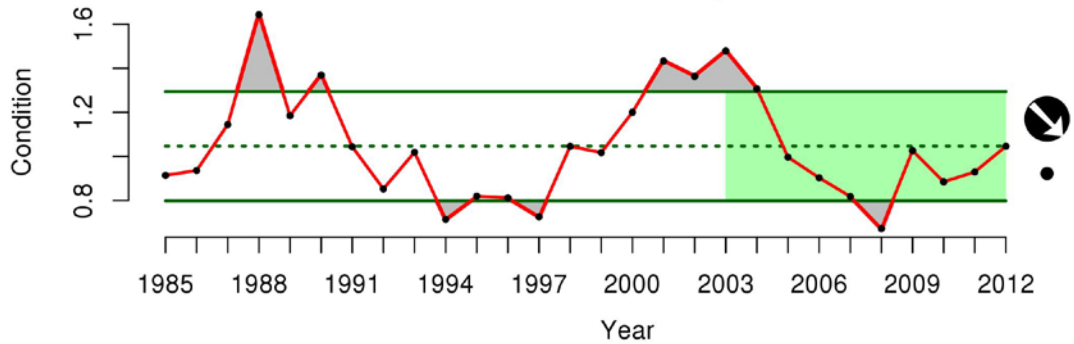

H2. L Columbia Pct Nat
Condition
0
10
20
30
40
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year


H3. L Columbia Pop GR
Condition
0.8
1.2
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year

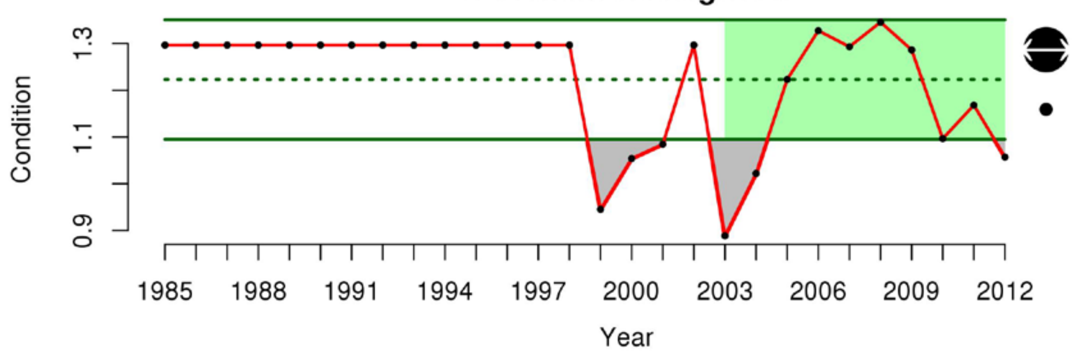

I1. Willamette Age Div
Condition
0.65
0.75
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year


I2. Willamette Pct Nat
Condition
40
60
80
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
Year

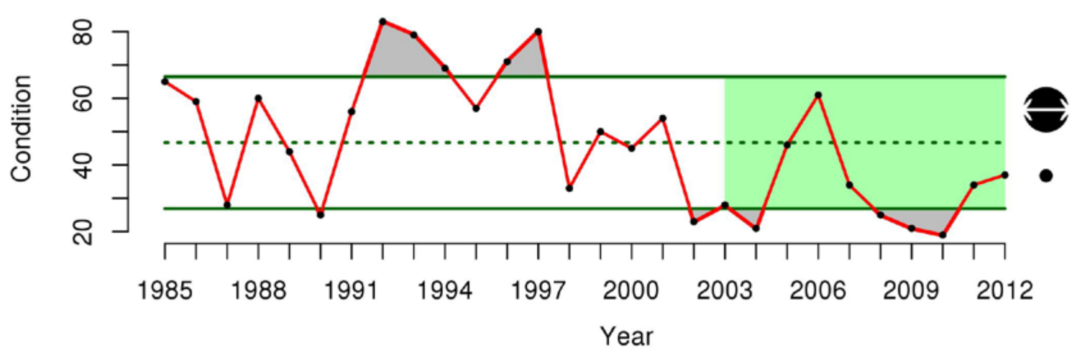
I3. Willamette Pop GR



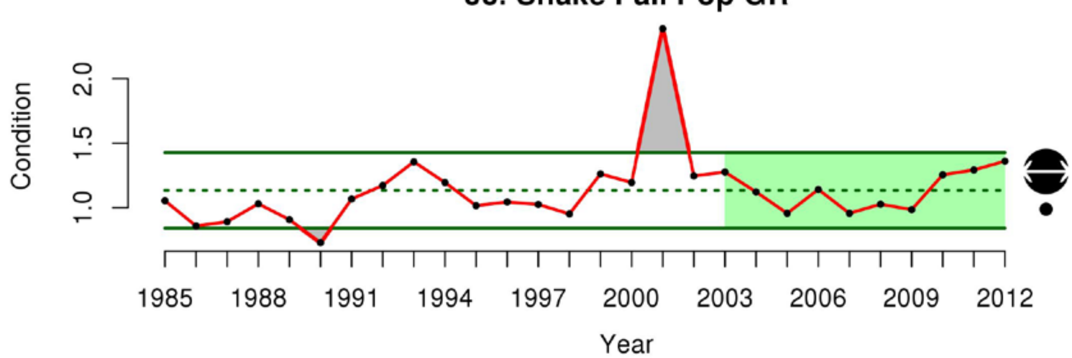
J1. Snake Fall Age Div



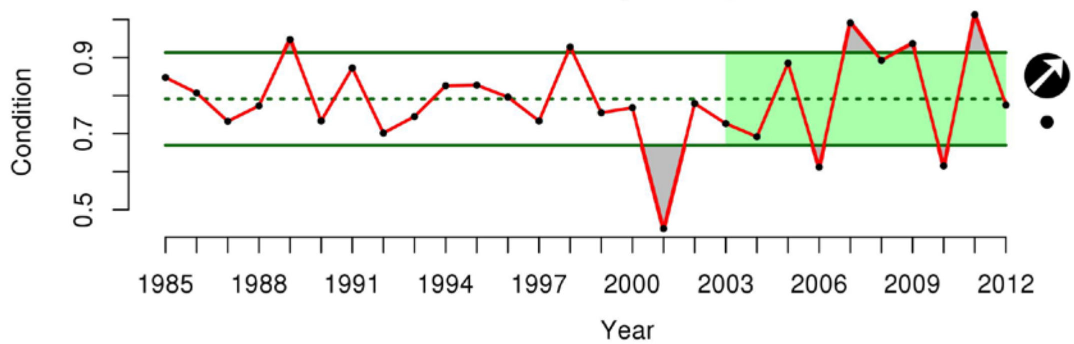
J2. Snake Fall Pct Nat



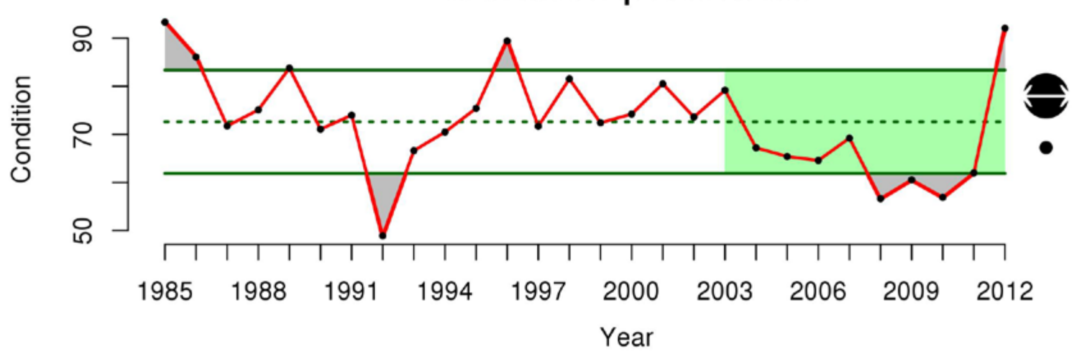
J3. Snake Fall Pop GR



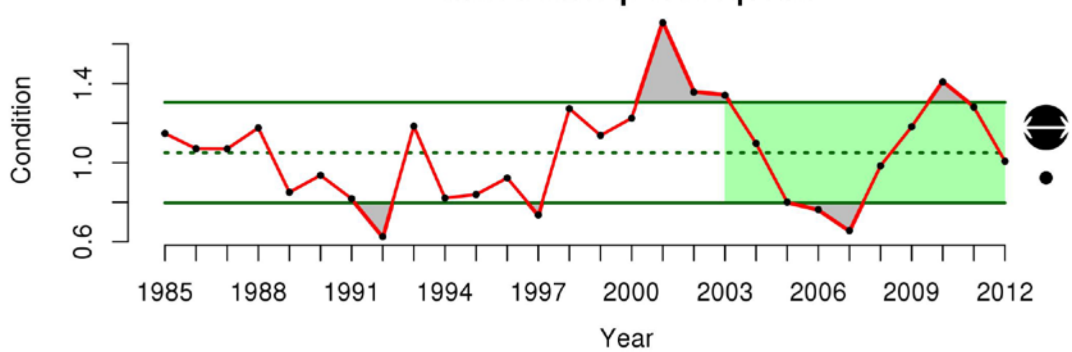
K1. Snake Sp-Su Age Div



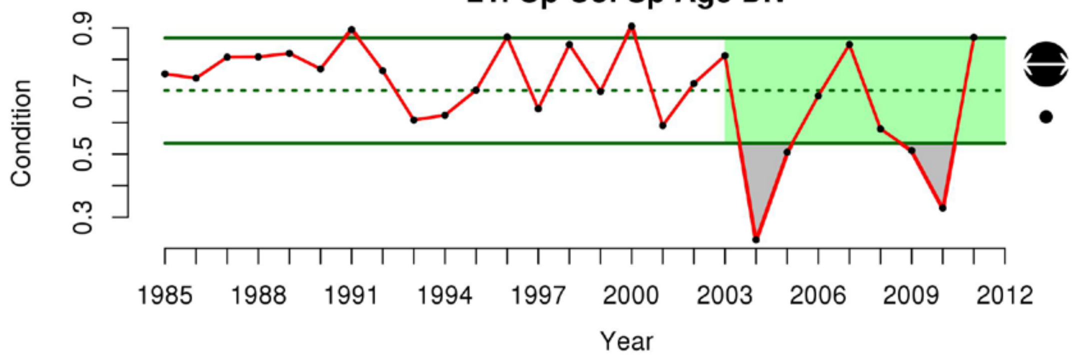
K2. Snake Sp-Su Pct Nat



K3. Snake Sp-Su Pop GR



L1. Up Col Sp Age Div



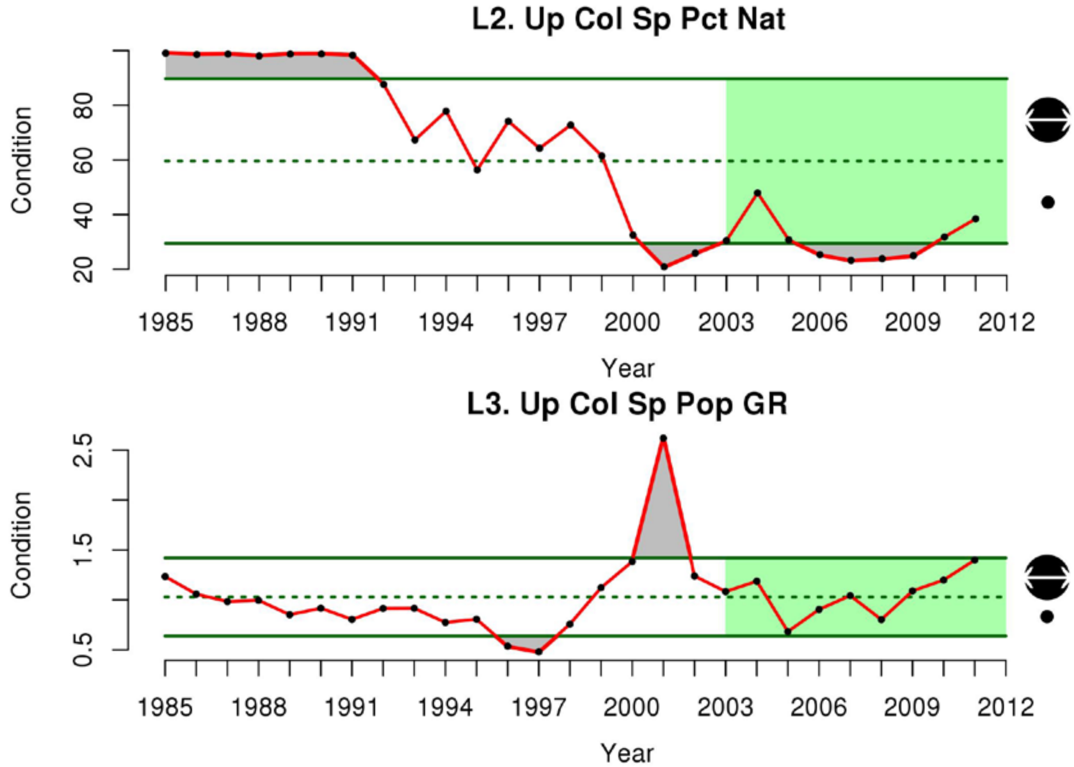


Figure S4. *Chinook salmon condition*. The series titles are titled by different populations (letters) and data series type (numbers). Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 10-years, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend was significant over the last 10-years . The lower symbol indicates whether the mean during the last 10 years was greater or less than or within one s.d. of the long-term mean. When possible we evaluated age-structure diversity (Age Div, 1), percent natural spawners (Pct Nat, 2), and population growth rate (Pop GR, 3).

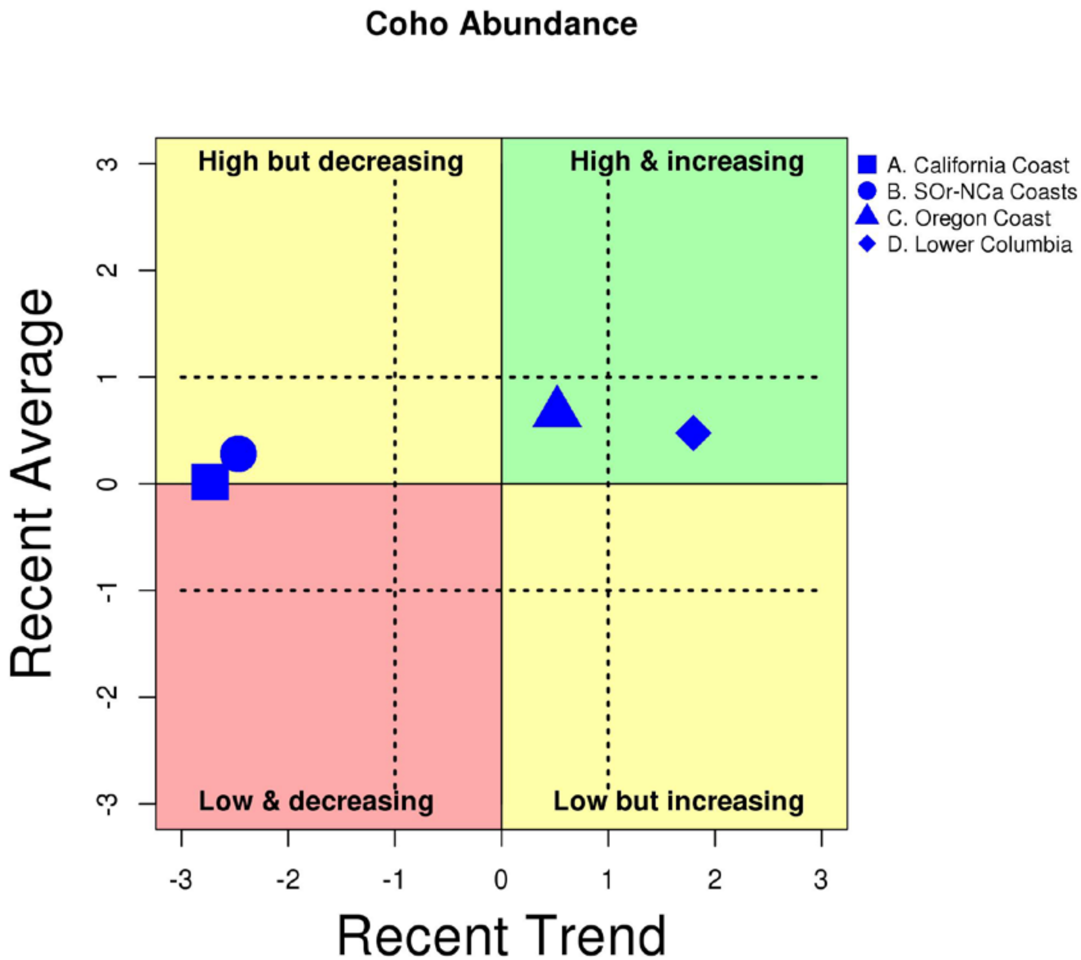


Figure S5. *Coho salmon abundance.* Quadplot summarizes information from multiple time series figures. Prior to plotting time series were normalized to place them on the same scale. The short-term trend (x-axis) indicates whether the indicator increased or decreased over the last 10-years. The y-axis indicates whether the mean of the last 10 years is greater or less than the mean of the full time series. Dotted lines show ± 1.0 s.d.

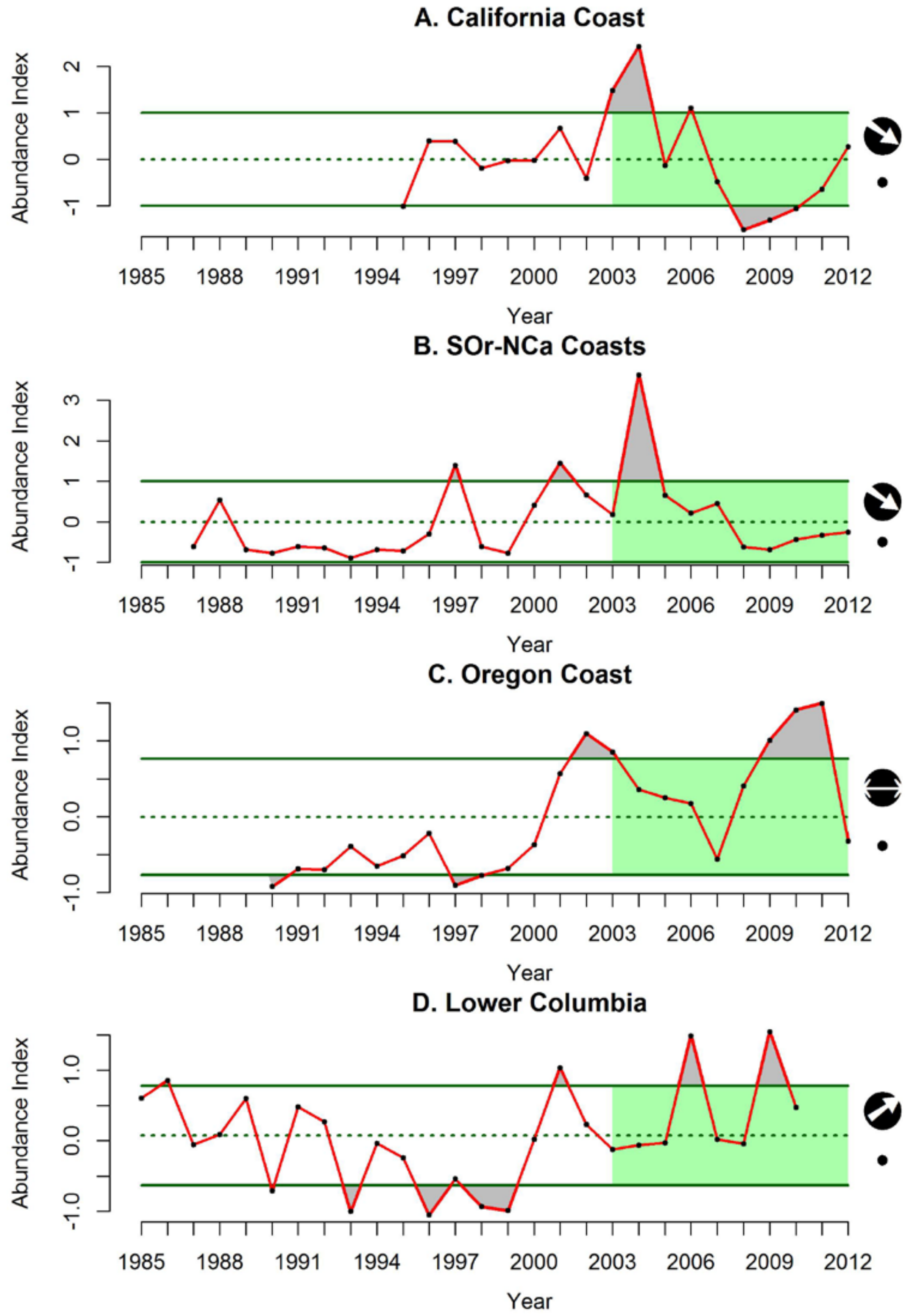


Figure S6. *Coho salmon abundance*. The abundance index is calculated as anomalies (observed-mean/standard deviation). Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 10-years, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend was significant over the last 10-years . The lower symbol indicates whether the mean during the last 10 years was greater or less than or within one s.d. of the long-term mean. Abundances are shown as anomalies.

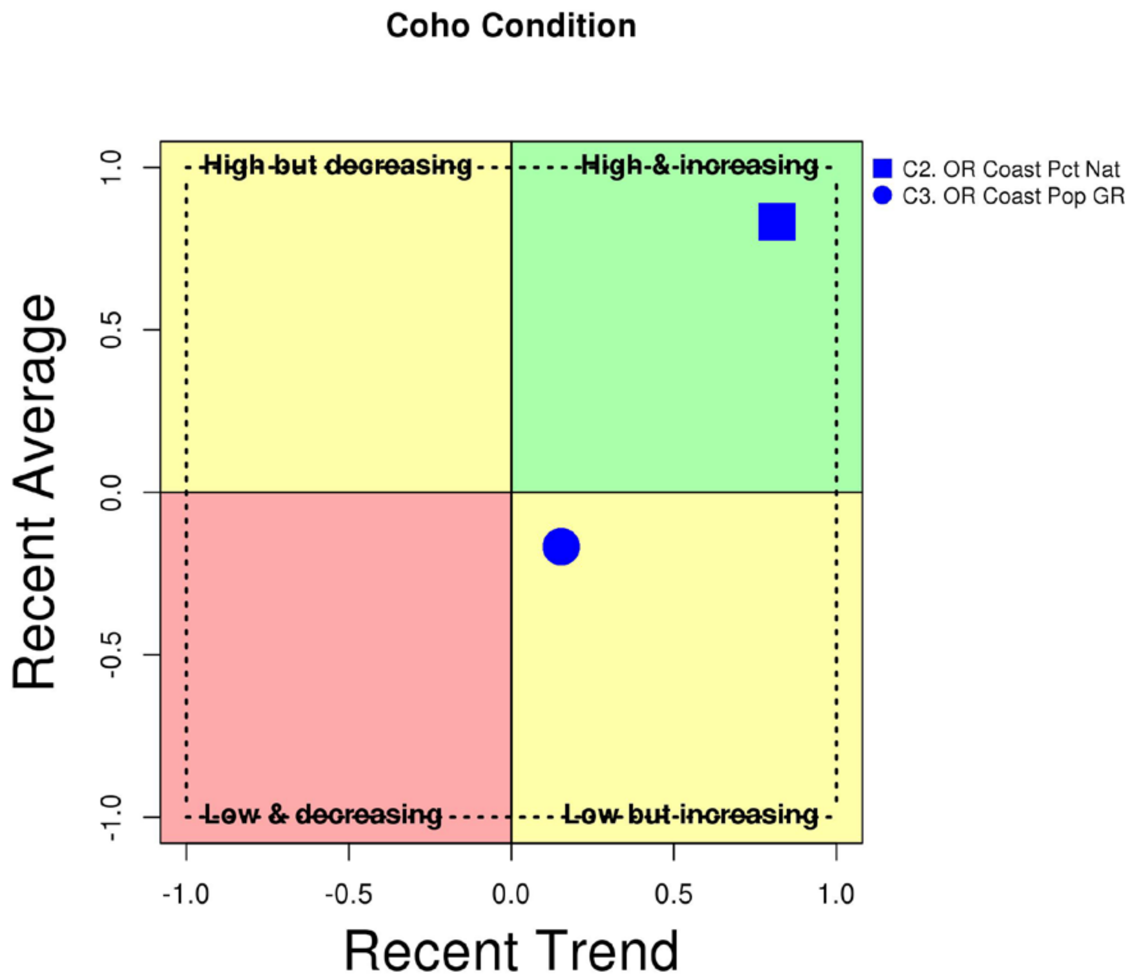


Figure S7. *Coho salmon condition.* Quadplot summarizes information from multiple time series figures. Prior to plotting time series were normalized to place them on the same scale. The short-term trend (x-axis) indicates whether the indicator increased or decreased over the last 10-years. The y-axis indicates whether the mean of the last 10 years is greater or less than the mean of the full time series. Dotted lines show ± 1.0 s.d. When possible we evaluated percent natural spawners (Pct Nat), age-structure diversity (Age Div), and population growth rate (Pop GR).

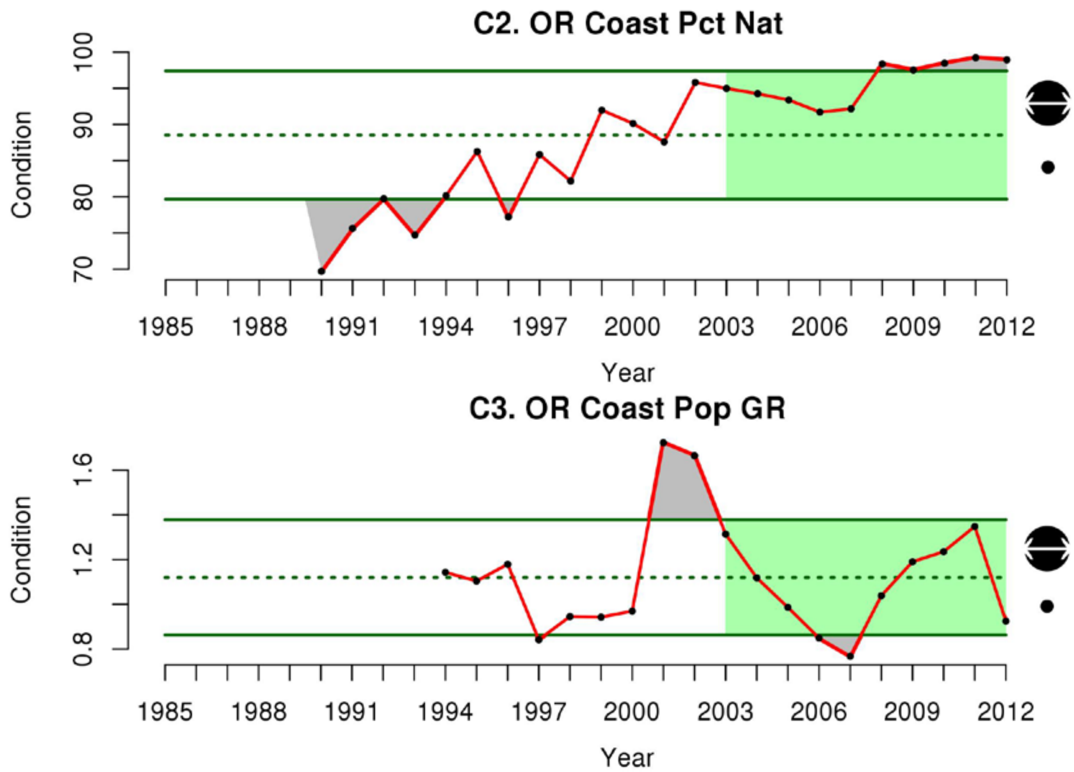


Figure S8. *Coho salmon condition*. Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 10-years, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend was significant over the last 10-years . The lower symbol indicates whether the mean during the last 10 years was greater or less than or within one s.d. of the long-term mean. When possible we evaluated percent natural spawners (Pct Nat) age-structure diversity (Age Div), and population growth rate (Pop GR).

EVNIRONMENTAL PRESSURES RELEVANT TO SALMON

Here, we briefly review recent ocean and freshwater conditions, and longer-term risks related to global climate change. Where appropriate, we reference figures from the ‘Oceanographic and Climatic Drivers and Pressures’ (Hazen et al. 2014) and ‘Coastal Pelagic and Forage Fishes’ (Wells et al. 2014) chapters of this web report , indicated by the prefixes ‘OC’ or ‘C’, respectively. In summary, recent ocean conditions indicate a likelihood of improved early marine survival of Chinook salmon and coho salmon in 2012 and 2013, suggesting improved adult returns in the next two years. Freshwater flows and temperatures in the Pacific Northwest suggest improved smolts per spawner from 2008 to 2012, but poor conditions in 2013. However, conditions have been poor from southern Oregon through California for much of the last decade. Longer-term climate change trends are likely to increase risks for most West Coast salmon stocks.

RECENT OCEAN CONDITIONS

Based on historical relationships between ocean conditions and observed Chinook salmon and coho salmon survival rates, basin-scale, regional, and local seascapes were likely conducive to improved early survival of Chinook salmon and coho salmon in 2012 and 2013.

BASIN-SCALE PROCESSES

The basin-scale forcing acting on salmon while in marine waters, in part, determines the later adult abundance (Mantua and Hare 2002, Wells et al. 2006, Wells et al. 2007, Wells et al. 2008, Black et al. 2011, Schroeder et al. 2013). In 2012 and spring 2013 the basin conditions were likely conducive to improved early salmon survival and growth. The multivariate El Niño Southern Oscillation (ENSO) index (MEI) (Wolter and Timlin 1998) transitioned from El Niño to La Niña conditions in summer of 2010 through January 2012 (see Figure OC27 in Hazen et al. 2014, Ocean and Climate Drivers section in this report). In the summer of 2012, the MEI increased but the values were too low and short-lived to be classified as an El Niño event; the values returned to neutral conditions in the spring of 2013. The Pacific Decadal Oscillation index (PDO) (Mantua and Hare 2002) became negative (cool in the CCS) coinciding with the start of the La Niña in the summer of 2010 (Figure OC7). The PDO continued in a negative phase through the summer of 2012, with a minimum in August. After October 2012, the PDO increased to slightly negative values in the winter and spring of 2013. The North Pacific Gyre Oscillation index (NPGO) (Di Lorenzo et al. 2008) was positive from the summer of 2007 to the spring 2013 with a peak value in July 2012 (Figure OC28).

LOCAL AND REGIONAL PROCESSES

Local and regional-scale coastal processes (including coastal winds, upwelling, and temperature) are the proximate influences on salmon food webs (including ecosystem structure) in the ocean (Wells et al. 2007, Black et al. 2011, Wells et al. 2012).

Spring and summer coastal upwelling drives the seasonal supply of nutrients to the CCE, and thus is an important influence on food supply for juvenile salmon. Coastal upwelling conditions were also conducive to improved salmon production in 2012 and 2013. In March 2012 upwelling winds north of 39°N were anomalously low while winds south of 39°N remained near the climatological mean. Upwelling north of 39°N did not resume again until May and for summer and fall remained at close to climatological values. In contrast, south of 39°N average upwelling prevailed from winter 2011 to April 2012, after which it intensified. Strong upwelling continued off central California until fall 2012. North of 36°N, high upwelling persisted through winter 2012 and into January-February 2013 (Figure OC19).

Phenology (seasonal timing) of winds and upwelling, particularly the timing of the spring transition, is also important in determining the productivity of the CCE (Chavez and Messie 2009, Checkley and Barth 2009) and salmon survival (Koslow et al. 2002, Logerwell et al. 2003). The cumulative upwelling index (CUI) gives an indication of how upwelling influences ecosystem structure and productivity over the course of the year (Bograd et al. 2009). At 45°N, the upwelling season began later than average from 2007 to 2012, with 2012 being the latest spring transition since 2007 (Figure OC21). The upwelling season began early in southern and central California (33°-39°N) during 2012 (Figure OC21). Strong upwelling continued into the summer off southern California (33°N) with CUI estimates at the end of July being the highest since 1999. At 36°N, the 2012 CUI values at the end of the year were the second highest on record, falling just below the high in 1999. Through mid-2013, CUI values are greater than previously observed records throughout the CCS. While there were significant regional differences in upwelling in 2012, strong upwelling occurred more widely in the CCS in winter and spring of 2013.

SALMON FORAGE IN THE OCEAN

An examination of zooplankton communities in the northern region of the CCIEA shows that secondary production was conducive to improved salmon production from 2010-2012. Examination of the copepod community can help to determine source waters and provide insights into the productivity of the system (Peterson and Keister 2003). Copepods that arrive from the north are cold–water species that originate from the coastal Gulf of Alaska and include three cold–water species: *Calanus marshallae*, *Pseudocalanus mimus*, and *Acartia longiremis*. Copepods that reside in offshore and southern waters (warm-water species) include *Paracalanus parvus*, *Ctenocalanus vanus*, *Calanus pacificus*, and *Clausocalanus* spp. among others. Copepods are transported to the Oregon coast, either from the north/northwest (northern species) or from the west/south (southern species). The Northern Copepod Index (Peterson and Keister 2003) was positive from autumn 2010 through summer 2012 (see data at http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip), indicating an abundance of boreal zooplankton species. In central California, springtime krill (*Euphausia pacifica* and *Thysanoessa spinifera*) abundance was increased during 2008-2013 compared to 1990-2007, indicating good prey for salmon as they initiate their marine migration. At the time of emigration to sea has been identified as a critical period for determining later adult abundance (Wells et al. 2012, Woodson et al. 2013).

The ichthyoplankton and juvenile fish communities along the Newport Hydrographic Line off the coast of Oregon in May 2012 were similar to the average assemblages found in the same area and month during the previous five years both in terms of mean concentrations and relative concentrations of the dominant taxa (Wells et al. 2013), indicating that forage conditions were not poor. However, larval myctophids were found in the highest concentration in July 2012 of the five-year time series, while larval northern anchovy were found in higher concentrations (>3x) in July 2012 than in the same month in 2007-2010. In addition, concentrations of the dominant taxa of juvenile fish were higher in July 2012 than in the same month in the previous five years, largely due to the abnormally high concentration of juvenile rockfish found in July 2012 (>10x that of any other year in 2007-2011). No juvenile age-0 Pacific hake or northern anchovy were collected from the midwater trawl samples in May or July 2012, although age- 1 and adult specimens of both species were found. Similarly, the biomass of ichthyoplankton in 2013 from winter collections along the Newport Hydrographic Line were above average (1998-2013), which should have favored average-to-good feeding conditions for juvenile salmon during the 2013 out migration. Consistent with these results, in the region between Tatoosh Island, WA and Cape Perpetua, OR the forage community was typical and not indicative of a poor forage environment for salmon (Figure C7).

In central California, the forage assemblage in both 2012 and 2013 showed higher productivity for the species and assemblages that tend to do better with regionally cool, high southward transport conditions, including juvenile rockfish, market squid and krill (predominantly *Euphausia pacifica* and *Thysanoessa spinifera*) (Figure C5). On the shelf these species provide the bulk of prey resources to salmon (Wells et al. 2012, Thayer et al. 2014). In 2012, juvenile rockfish catches were above average, as they have been in most years since 2008, and in 2013 the highest catches of juvenile rockfish in the time series of the survey were recorded, with huge numbers of juvenile rockfish of all species (as well as young-of-year groundfish of other species, such as Pacific hake, flatfishes and lingcod, *Ophiodon elongates*) encountered throughout both the core and expanded survey areas. Market squid and krill were at very high levels in 2012 and 2013 as well. Although more northern anchovy were encountered in 2013 than in the previous five years, catches of both that species and of Pacific sardine remained well below long-term averages. As with the 2012 results, 2013 continued to indicate a pelagic micronekton community structure dominated by cool-water, high transport, high productivity forage species (like juvenile groundfish), krill and market squid (see Ralston et al. 2013).

RECENT FRESHWATER CONDITIONS

Although this IEA is focused on the marine environment, salmon forge a strong connection between marine and freshwater ecosystems, and both marine and freshwater phases of the life history are important determinants of population status and trends (Bradford 1995); for this reason, we include a review of recent freshwater conditions. The key factors discussed here are river flows and water temperatures; we leave discussions of habitat structure (e.g, woody debris, pools, gravel, side channels) to later reports. In the Pacific Northwest, indices related to freshwater conditions have been similar or slightly more favorable for many salmon stocks in the past 10 years compared with the average since 1976 and especially frorm 2009 to 2012. In California, however, recent freshwater conditions have been below average due to, among other factors, drought and resource conflicts. A number of the human activities that relate directly or indirectly to flow and temperature are discussed in the section “Human dimensions relevant to salmon abundance and condition.” In the framework of CCIEA, these human activites should be considered in the context of the environmental variability and considered in any management scenario evaluation.

Interior Columbia basin salmon generally migrate upstream as adults from spring to fall, depending on the population. Those that migrate in the summer or early fall (summer and fall Chinook salmon and sockeye salmon) can confront stressful temperatures particularly in the mainstem Columbia and Snake rivers (Crozier et al. 2008a, Crozier et al. 2011). High temperatures expose the fish to direct thermal stress, but also increase morbidity and mortality from some diseases and raise energetic costs due to the exponential rise in metabolic rate with warmer temperature (McCullough 1999). Spring Chinook salmon migrate earlier in the year and thus rarely experience high temperatures during the migration, but like summer Chinook salmon they risk prespawn mortality due to stressfully warm temperatures in the tributaries while they wait to spawn in late summer or fall. Thus high summer temperatures can increase adult mortality in these populations. Juvenile growth and survival can also be affected by summer temperature, but negative effects of warmer years are seen most in the warmer streams of spring/summer Chinook populations (Crozier and Zabel 2006, Crozier et al. 2008b). Thus summer temperatures affect all the life stages that inhabit freshwater in this season, and although most populations remain below stressful temperatures in most years, unusually high temperatures are generally negative for these cold-water fish.

Stream flow also affects multiple life stages in a complex manner. The level of flow can affect available habitat area, the distribution and availability of prey, refuges from predators, water temperature, and other factors (e.g., Arthaud et al. 2010, Poff and Zimmerman 2010). Accordingly, Snake River spring/summer Chinook salmon populations are vulnerable to low flows in the fall (Crozier and Zabel 2006, Crozier et al. 2008b). In lower elevation spawning areas (e.g., fall Chinook salmon and coho salmon), winter precipitation generally falls as rain. Heavy rains can scour nests, or bury them in sediment, thus reducing egg viability, so high flows present risks over winter. In spring, high flows are generally favorable for migrating smolts because they facilitate transit to the ocean. Increased flow increases migration speed, which decreases exposure to factors such as predation and temperature stress in reservoirs (e.g., Ferguson et al. 1998), and it affects ocean entry timing and early ocean survival (Scheuerell et al. 2009).

To describe recent freshwater conditions affecting these life stages, we summarize trends first in a composite index, the Pacific Northwest Index, then at selected locations in the Columbia River Basin where temperature and flow have been measured over multiple decades. The Pacific Northwest Index is based on 1) air temperature at Olga in the San Juan Islands, averaged annually from daily data; 2) total precipitation at Cedar Lake in the Cascade Mountains; and 3) snowpack depth at Paradise on Mount Rainier on March 15 of each year (Ebbesmeyer and Strickland 1995). Lower values of this index correspond to cooler and wetter conditions in freshwater, especially west of the Cascade Mountains. Since 1976, the five-year running mean of this index has been positive since the 1976 regime shift, and like the PDO, shifted negative in recent years (since 2006), indicating better freshwater conditions for Pacific Northwest salmon in recent years.

Long-term water temperature records are relatively scarce, and are most accessible from the mainstem dams in the Columbia and Snake Rivers. Mean August temperature has been similar or slightly cooler in the last 10 years compared with the long-term mean (since 1976) at both Bonneville Dam on the Columbia River and Ice Harbor Dam on the Snake River, but by much less than one standard deviation (0.18˚C cooler, much less than 0.5-0.7˚C s.d. in the long-term time series). However, recent summer air temperatures have been increasing, so tributary temperatures might be warmer than reflected in the mainstem.

Fall flows (average of September and October) in the Salmon River, the largest free flowing tributary to the Snake River, have averaged lower in the last 10 years than since 1976 (1976-2012: 1129 cubic feet per second (cfs) fall spring, 2003-2012: 1090 cfs), but have been climbing since 2001. Similarly, spring freshet flows have been rising recently (since 2001), but unlike fall flows, spring flows are slightly higher than their long term mean (1976-2012: 5335 cfs spring, 2003-2012: 5415 cfs spring). The good smolt migration conditions (relatively higher flows and lower temperatures) have likely contributed to improved ocean survival from 2009-2012.

However, July 2013 witnessed high mortality of adult Columbia Basin salmon on their spawning migration, attributed to an early rise in temperature (Crozier et al. 2014). Adult Snake River sockeye salmon died at high rates throughout the spawning migration compared with recent years (only 13% reached the spawning grounds in the Upper Salmon River Basin from Bonneville Dam).

Much of California experienced drier than average conditions in 2008-2010, and 2012- April 2014, and most of the state is currently under extreme or exceptional drought conditions (in May 2014; see http://droughtmonitor.unl.edu). In summer 2013, there were multiple conflicts over in-stream and out-of-stream flows that impacted California Chinook salmon stocks. For example, water temperature standards in June 2013 were relaxed for Sacramento River salmon by moving the boundary for water temperature targets upstream because of the limited supply of cold water in reservoir storage. There was conflict between the Westlands water district and fish advocates in the Klamath basin over diverting stored water in Trinity reservoir into the Trinity River and Klamath River to reduce the risk of a significant fish kill, thereby reducing exports in the Central Valley Project. As well, there was adjudication of water rights by the state of Oregon that awarded the Klamath Tribes senior water rights in the upper Klamath Basin, and the tribe's subsequent decision to exercise those rights to keep water in the river at the expense of junior rights holding irrigators. Generally speaking, the drought of 2013-2014 will likely have widespread negative impacts on the spawning and juvenile freshwater rearing success for California's natural (and possibly hatchery) spawning salmonids.

CLIMATE CHANGE

A number of studies have examined the potential effects of climate change on Pacific salmon populations (see reviews Battin et al. 2007, Independent Scientific Advisory Board 2007, Crozier et al. 2008b, Schindler et al. 2008), and concern for these effects has led to the inclusion of climate change as a risk factor in recent Endangered Species Act status reviews for salmon (e.g., Ford 2011). The overall effect of climate change on any anadromous stock must consider all habitats and life stages simultaneously and cumulatively (Crozier et al. 2008b, Wainwright and Weitkamp 2013). For example, because Pacific salmon are cold water fishes, increases in temperature—whether in freshwater, estuarine, or marine environments—are likely to be detrimental near the warmest edges of their range.

In a recent review of climate effects across the life cycle of Oregon Coast coho salmon, Wainwright and Weitkamp (2013) found that, despite substantial uncertainties in future climate scenarios and biological response, the preponderance of negative effects across the life cycle indicates a significant risk to long-term sustainability of those populations; while the details would differ by region and species, we expect that these conclusions would apply to most West Coast salmonid populations. A warming climate points to changes in freshwater, estuarine, and marine habitats that are likely to put salmon populations at greater risk. In freshwater, significant reductions in cold-water flows in summer may affect juvenile and adult migration, spawning, egg incubation, and rearing. In estuaries, rising sea levels will lead to inundation of low-lying lands and increases in salinity that will cause substantial transformations in estuary habitats. In the ocean, rising water temperatures, acidification, and changes in coastal water circulation will have both direct and indirect (via foodweb processes) effects on salmon. In all of these habitats, some effects (such as the physiological response to temperature) are predictable while others (such as interspecies competitions and changes in community structure) are uncertain both in the direction (positive or negative) and magnitude of the effect on salmon. Despite these uncertainties, the overall effect of climate change will very likely be to increase risks facing salmon populations, particularly those near the southern/warmer limits of their species' range.

Freshwater

Future climate change scenarios mostly point to degraded freshwater habitat for West Coast salmonids. These scenarios include a general pattern of increased winter precipitation in the wettest locations (northern California to BC) and reduced winter precipitation in the driest locations (southern California) (see Dalton et al. 2013, Garfin et al. 2013). However, all regions are expected to warm substantially (2 to 6 °C by 2100), and the atmospheric warming will lead directly to warmer stream temperatures (Arismendi et al. 2012, Isaak et al. 2012) and will support trends to a higher fraction of precipitation falling as rain rather than snow (Elsner et al. 2010, Mantua et al. 2010, Cloern et al. 2011). For affected watersheds, this combination causes reduced springtime snowpack and reduced snow-fed stream flow in late spring and early summer, and increased rain-fed runoff and stream flow in winter. The combination of reduced spring freshet and higher river temperatures will likely reduce smolt survival for life history types that include freshwater rearing in summer. Adult migrants might benefit energetically from weaker flows, but thermal costs to migration and longer pre-spawn periods will likely outweigh this benefit. Peak flows in winter are likely to increase, as a larger fraction of affected basins will generate runoff than in a colder climate. Some adult coho populations use fall rains to trigger their spawning migration. The impact on spawning migration timing is still uncertain. Increasing fall flows, predicted for some locations under some scenarios, might benefit juveniles (see analysis in Crozier and Zabel 2014 chapter of this web report). In summer and fall, base flows are expected to decline in many watersheds as a consequence of increased water deficits driven by warming temperatures that increase the atmosphere's demand for water. The shift to a more amplified hydrograph, both seasonally and episodically, will likely increase redd-scour in fall and winter, and reduce freshwater rearing habitat in summer and fall, which combined would reduce spawner to smolt productivity rates.

Stream temperatures are expected to warm for most locations year round, although the local sensitivity to surface warming will vary widely depending on specific watershed characteristics (deep and shallow groundwater interactions with surface flows, proximity to the coast and frequency of summer fog, channel characteristics like depth and width, vegetative cover, and water infrastructure and management). Growth rates in the coldest streams and coldest seasons will likely improve (Beer and Anderson 2013, Crozier and Zabel 2014), but growth rates, thermal stress (Crozier and Zabel 2014), and temperature and flow mediated fish kills and migration barriers in already warm streams will likely increase in frequency and distribution (McCullough 1999, Mantua et al. 2010, Cloern et al. 2011). Anoxic conditions may result from strong deep groundwater upwelling combined with weak river flows (Roegner et al. 2011). These conditions threaten juvenile outmigrants.

Estuaries

Within West Coast estuaries, changes in temperature, flow, and sea level are the primary physical factors responsive to a changing climate. Global sea level is projected to rise by 0.3 to 1.2 m by 2100, relative to 1986-2005 (Intergovernmental Panel on Climate Change 2013). Rising sea levels will favor increased seawater intrusion into estuaries, increased inundation of intertidal habitats and low-lying areas, and transformations in habitat types along the interfaces between terrestrial, freshwater and marine habitats. For key estuaries like California's Bay-Delta region and the Columbia River estuary, substantial changes in temperature, salinity, and water levels are expected by 2100 (Cloern et al. 2011).

Temperature changes can potentially affect all salmon life stages that inhabit or migrate through estuaries. First, shallow water habitats (such as tide flats and marshes) will likely warm more than other areas, which may result in seasonal shifts in habitat use, and potential reductions in total habitat available to salmon. Juveniles will leave habitats when they get too hot, potentially exposing themselves to higher predation rates in deeper water. Second, before temperatures exceed thermal limits, we can expect other thermal responses to occur. In particular, all species and life stages will respond bioenergetically. For example, yearling size fish will encounter elevated temperatures during their migration through the estuary that can affect their metabolic rates while sub yearling Chinook salmon can encounter elevated but not stressful temperatures in wetlands. At more modest temperature increases, growth rates of salmon may actually increase, assuming food resources do not diminish. It is unclear how migration and rearing timing will adapt to changes in the estuarine temperature regime. Finally, temperature-mediated shifts in species distributions will also lead to changes in community composition (Roessig et al. 2004), with unpredictable effects on salmon.

The second major type of physical change that will impact the Columbia River estuary is sea level rise. As the level of the sea rises, a number of changes can be expected. Tidal wetlands may become submerged or have longer periods of inundation than they do currently, and nearby terrestrial habitats will be flooded (Kirwan et al. 2010). In other cases, shallow water habitats such as wetlands may erode as sea levels rise. Diking and other barriers may prevent wetlands from expanding and keeping up with erosion impacts. The net effect of these processes on estuarine habitats depends on the rate of sea level rise, the rate of vegetation growth and sedimentation, and the land contours in and adjacent to the estuary (Roessig et al. 2004, Kirwan et al. 2010), but in general the global rate of sea level rise is currently faster than the colonization rate for new wetlands (Roessig et al. 2004). Also, rising sea levels will push the saline portion of the estuary upstream into freshwater areas and change the location of freshwater-saltwater ecotones (Flitcroft et al. 2013). Such changes will affect how these estuarine habitats function for salmon. For example, the head of tide in tributaries will move upstream with accompanying changes in physical structure of the estuary (due to changes in the tidal prism) and biological characteristics of these river mouth systems.

A third type of change that can affect salmon in the estuary (and the coastal plume) is flow-related changes as a result of changes in precipitation patterns, snow melt, and water management practices. As previously discussed, climate scenarios for the Pacific coast suggest that there will be a reduction in precipitation that occurs as snowfall and an increase in rainfall, which would increase winter flow levels and diminish summer flows. Coupled with increased temperatures, such a scenario could critically limit salmon migration periods. In the estuary, there is a relationship between flow, tides, and salinity at any point. Changes in salinity (e.g., either the upstream extent of measurable salinity or the regime at any particular place) will depend on freshwater flow, tides, and basic sea level rise (polar and glacial melting). Changes in salinity or water levels in the estuary will alter the biological community structure as well as accessibility of these locations to salmon. Flow changes are also important in terms of downstream fish migration rates through the estuary. Reduced flows during the time salmon are outmigating, for example, could slow the downstream migration of salmon and affect their timing of ocean entry. Changes in flow (e.g., resulting from changes in precipitation patterns) could also affect the nearshore ocean via changes in river plume characteristics (Burla et al. 2010).

The Ocean

Salmon will be affected by climate-driven changes in the ocean's physical, chemical, and biological components and processes (Doney et al. 2012, Howard et al. 2013). The major physical changes in the ocean, especially the California Current System, that are of concern for West Coast salmonids are higher ocean temperatures, intensified or weakened upwelling, delayed spring transition, intensified stratification, and increased ocean acidity (Crozier et al. 2008; Wainwright and Weitkamp 2013).

The direct and indirect effects of ocean temperature changes on salmonids have received the most attention. Water temperature has a strong effect on fish physiology, development, distribution, and behavior (e.g., Marine and Cech 2004, Richter and Kolmes 2005). As ocean temperatures warm a number of things will occur that will ultimately reduce survival rates of some anadromous populations. Effects of ocean warming are suggested for a number of different salmon and steelhead stocks including Snake River steelhead and Chinook salmon (Petrosky and Schaller 2010), Fraser River sockeye salmon (Hinch et al. 1995), Central Valley Chinook salmon (MacFarlane 2010), and steelhead in general (Welch et al. 2000, Atcheson et al. 2012) In particular, metabolic rates will likely increase such that growth will be impacted (Hinch et al. 1995, Atcheson et al. 2012). This will also affect adult size at age and age at maturity, which in turn may have consequences for fecundity, migration ability, and ability to dig spawning redds.

One of the mechanisms by which warming water temperatures will affect salmon and steelhead is by changing bioenergetics of the fish. Diet information on yearling Chinook salmon from 19 years of ocean research indicates that during warmer ocean years, juvenile salmon consume 20-29% more food than in the colder ocean years and are in significantly lower body condition (E. Daly personal communication). Research also suggests that the biomass of fish prey is reduced during warmer ocean conditions at the same time that the salmon are consuming more food (Daly et al. 2013). This food stress, along with direct effects of temperature on physiology, can shift competitive responses and increase predation risk for salmonids (Reeves et al. 1987, Marine and Cech 2004). Increasing ocean temperatures will also change food web relationships involving salmon, especially as ranges shift for predators, competitors, and prey (e.g., Murawski 1993, Hays et al. 2005, Cheung et al. 2009).

Overall, the combination of these temperature effects will result in changes in the range of the species. Temperature is a main factor determining the northern and southern limits of fishes in the California Current (Horn and Allen 1978). Climate-driven range shifts in marine fishes have been observed (Hsieh et al. 2009) and predicted for the future (Cheung et al. 2009). Warming of the upper ocean in the CCS will likely lead to poleward and shoreward shifts in the distribution of sub-tropical species (e.g., Hazen et al. 2013), which could increase competition with and predation on maturing salmon. Range shifts for Pacific salmon have been observed in past periods of climate change (Ishida et al. 2009) and are occurring now (Irvine and Fukuwaka 2011). For the future, Abdul-Aziz et al. (2011) illustrate this point for Pacific

Northwest salmon by showing how climate scenarios can result in a dramatic contraction (30-50% by the 2080s) of the summer thermal range suitable for chum salmon, pink salmon, coho salmon, sockeye salmon, and steelhead in the marine environment. They predict an especially large contraction (86-88%) of Chinook salmon summer range under two commonly-used IPCC (2007) greenhouse gas scenarios. Previous analyses focusing on sockeye salmon (Welch et al. 1998) came to similar conclusions. A consequence of northward shifts of suitable salmon marine habitats is that populations near the southern limit of their species' range will be more susceptible to climate change than those near the species' center of distribution. For example, populations of sockeye salmon in the Columbia River Basin and coho salmon and Chinook salmon in central California may be more vulnerable than populations further north. Maintaining these salmon populations under future climate conditions may require greater improvements in freshwater habitat and the river migration corridor than will be needed for more northerly populations.

Beyond water temperature, other climatological changes in the California Current are also likely to affect West Coast salmonids. The timing and intensity of upwelling has an important but complex relationship to salmon production. Changes in the intensity of upwelling winds could have profound impacts on upper ocean properties (temperature, salinity, nutrients, and primary productivity) in the CCS (Checkley and Barth 2009). There have been observed increases in upwelling intensity (Bakun 1990) and shifts in timing of spring transition and the total length of the upwelling season (Bograd et al. 2009), but analyses using climate models find little agreement on future changes in upwelling, largely because current models do not have sufficiently fine scale to resolve coastal wind and circulation processes (Diffenbaugh 2005). Upwelling of nutrient-rich water is also limited by the degree of water-column thermal stratification (Kosro et al. 2006), which is expected to increase as surface waters warm (Di Lorenzo et al. 2005). Upper ocean warming, absent substantial changes in upper ocean salinity, would increase stratification in ways that tend to reduce the upwelling of cold, nutrient rich water from greater depth, which absent other changes would lead to reduce concentrations of macronutrients and primary productivity, and a shift in the phytoplankton community structure away from large diatoms to smaller phytoplankton species (e.g., dinoflagellates). However, increased stratification in the open waters of the North Pacific might also reduce ventilation rates in upwelling source waters in ways that substantially increase nutrient concentrations of upwelled waters (Rykaczewski and Dunne 2010).

A final major issue for coastal waters is acidification as a consequence of increasing atmospheric CO_2; increasing acidity is already being observed in the California Current System (Hauri et al. 2009). Ocean acidification in the CCS will be affected by changes in global ocean acidity as well as processes that include coastal upwelling and changes in upwelling source-water chemistry (Rykaczewski and Dunne 2010). Acidification will likely have little direct effect on salmon and steelehad, with the exception of some possible biochemical stress (Fabry et al. 2008). However, it may have a dramatic impact on invertebrates that are important in salmon food webs (Fabry et al. 2008); the consequences for salmonids depend on potentially complex shifts in prey availability and abilities of salmon to shift diets.

Note, that biological effects of climate change, whether in freshwater, estuarine or ocean environments, are extremely difficult to predict. The rapid expansion of Humboldt squid—a voracious predator-- along the West Coast of North America in recent years and their population explosion in 2009 (Field et al. 2013), remind us that although physical processes are more straightforward to predict, the response of biological systems to physical changes are much more difficult to predict.

INTEGRATED ENVIRONMENTAL EFFECTS

So far, we have discussed a number of individual climate factors that affect salmon and steelhead in certain habitats or specific parts of their life cycle. In order to fully assess the consequences of climate change, we need to consider the interactions of all the individual effects as they multiply across life stages within generations and across generations within populations (Wainwright and Weitkamp 2013). While many of the effects described above are difficult to project with much certainty, most are more likely than not to have negative effects on salmonid growth and survival. Thus, the overall consequences of climate change for West Coast salmonids are likely to be negative, and will require management strategies that increase resiliency of these ESUs over the foreseeable future.

HUMAN DIMENSIONS RELEVANT TO SALMON ABUNDANCE AND CONDITION

Native Americans have lived in the Pacific region for thousands of years, and salmon have played a central role in their diet, culture and economy. By approximately three thousand years ago, Native Americans of the Northwest coast began to organize their lives around the fluctuating, seasonal runs of salmon, a primary source of protein (White 1980, Schalk 1986). Salmon runs helped determine the location of villages, as well as the timing of visits with relatives living in other watersheds (Suttles 1987). Early Northwesterners could access, enhance, and exploit such a diversity and concentration of resources – including forest game and berries, abundant salmon runs and many other species of fish, shellfish and marine mammals – that they were among the only people in the world who developed relatively settled, dense, stratified, and wealthy societies without relying on intensive agriculture (White 1980, Lichatowich 1999). Instead, they developed sophisticated salmon harvesting, drying, and storage technologies (Stewart 1977), and they enhanced the region's natural resources by actively managing the land with periodic burns that encouraged berries, bracken, and grazers, and by planting and tending camas meadows, estuarine gardens, and shellfish beds (White 1980, Boyd 1999). Most notably, Native Americans developed complex and cooperative resource ownership and access systems that enabled them to sustain and cope with the dynamism of their local resources (Suttles 1987, Singleton 1998). For example, the problem of how to allocate salmon was addressed through territorial fishing grounds, potlatchs, and intermarriage among families in different river basins, which helped ensure access to such a variable and unpredictable resource (Suttles and Sturtevant 1990).

Since Euro-American settlement, Native Americans suffered enormous losses of land, people, culture, language, and spirit through disease, colonization, forced assimilation, criminalization, and discrimination (Breslow 2011). In particular, and as detailed below, industrial resource exploitation and non-Native settlement decimated the salmon runs that have been keystones in the social integrity of coastal tribes. Nevertheless, contemporary Native Americans in the

Northwest region continue to rely directly and extensively on their local environment for sources of food, ceremonial materials, spiritual power, and cultural identity (Onat and Hollenbeck 1981, Sepez 2001, Donatuto 2008). Salmon and salmon fishing remain central to their way of life and essential for overcoming historical trauma, and revitalizing cultural traditions, including indigenous food systems and resource management practices (Swinomish Tribal Mental Health Project 1991, Donatuto 2008, Brave Heart et al. 2011, Northwest Indian College 2012). The role of salmon in food practices and as iconic species and markers of regional identity is also experienced by other sociocultural groups (in addition to Native Americans) who live in the Northwest (Nabhan et al. 2010).

Sporadic encounters with foreign explorers, missionaries and entrepreneurs became more common by the 1770s (National Research Council 1995). The 1848 California Gold Rush was the start of large-scale Euro-American settlement in the Pacific region that continued at a rapid pace even after the peak of the mining boom. Factors that encouraged such exploitation included the abundance of natural resources, development of steamship and railroad lines (which facilitated westward migration and eastward market expansion), advances in extractive and processing technologies, and government policies encouraged rapid development (e.g., land grants to railroads).

The 1848 Gold Rush occurred at a time when Mexico was about to surrender California to the U.S. and the only form of U.S. authority was federal troopers. Western settlers devised their own ways of staking claims to resources. Water was an essential resource – a critical input into activities such as mining, logging, farming, hydropower production, and fishing. When California became a state in 1850, the Legislature adopted the common-law riparian doctrine already in use in the eastern states. This doctrine granted riparian landowners the right to use water flowing through their land, so long as they did not impair the rights of other riparians and regardless of whether they actually used the water. Beginning with the Gold Rush, prospectors and non-riparian farmers began claiming water by simply appropriating it (i.e., by building diversions). By the end of the nineteenth century, prior appropriation became the basis of water rights throughout the western states: claims to water must be based on a reasonable and beneficial use, rights can apply to riparian or non-riparian lands, priority of rights is determined on the basis of "first in time, first in right," and water rights can be lost due to non-use (Gillilan and Brown 1997, Hundley 2001). As noted by Gillilan and Brown (1997), "The allocation of water to those who took it first provided incentives for settlers to take and put to use all the water that they could possibly use as quickly as possible, rather than leaving it for instream uses or for potential out-of-stream uses by future settlers."

By 1900, practically the only rivers in the West that were undeveloped were those that were too remote or too large to be developed without public investment (Gillilan and Brown 1997). Such investment was initiated in the 1930s, with the construction of large federal dams serving multiple purposes (irrigation, flood control, navigation, municipal/industrial water supply, recreation). From the Gold Rush to the 1960s, little effort was made to mitigate effects of resource extraction on wild salmon populations. By the 1970s, growing environmental awareness led to a spate of federal legislation – e.g., 1970 National Environmental Policy Act, 1972 Clean Water Act, 1973 Endangered Species Act, 1980 Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund Act) – that gave legal standing to the needs of fish and wildlife, including salmon. Prior-appropriation water rights have been limited by the

Courts (through mechanisms such as public trust doctrine, an expansive interpretation of navigable waters in the commerce clause of the U.S. Constitution, and federal reserved rights doctrine) and by legislation (e.g., appropriations of instream flow for environmental use, minimum flow standards) (Butler 1990). According to Hundley (2001), “Reserved rights are often among the most senior in a watershed, because many federal land reservations were made quite early, in the late 1800s or early 1900s. Federal reserved water rights are based on the purposes for which they were reserved rather than actual use and cannot be lost through nonuse. And, perhaps most important from the perspective of federal land management agencies, reserved rights are based on federal, rather than state, law, and are presumably not subject to diminishment by the states.” A notable example of the exercise of federal reserved water rights occurred in 2013, when Oregon recognized a U.S. claim to surface water in the Klamath River basin on behalf the Klamath Tribes as the most senior water right in the Basin (Oregon Water Resources Department 2013).

This section describes post-1848 resource-related activities – fur trading, mining, logging, farming, dams, hatcheries, and fishing – and relates these activities to major demographic, economic, social, technological, and policy changes that occurred with Euro-American settlement in the region. This historical perspective considers legacy as well as ongoing effects of those activities on wild salmon and salmon habitat, and shows how more recent environmental protections have moderated the single-minded resource exploitation characteristic of earlier decades. It also provides (with the benefit of hindsight) the opportunity to illustrate, with concrete examples, the dynamic relationship between human dimensions and salmon, and may suggest ways in which such relationships can be modeled in an ecosystem context. The quantitative indicators provided here regarding trends in human activities are a first step in that direction; though much more work needs to be done. Importantly, river flows and water temperatures that are discussed in “Recent freshwater conditions” and escapement, as discussed in “Summary and status of trends of salmon abundance and condition,“ are reliant on many of the anthropogenic activities that we present. *Therefore, in the context of the ecosystem-based management, these human activities should be considered as part of any management scenario and the current and future environmental condition should be used to help determine appropriate trade-offs and choices.*

Figure S9 depicts current land use patterns in the Pacific region, including forests, farmland and population centers. These patterns reflect the legacy effects of early settlement and development, as well as changes in resource abundance, economic conditions, technology, and law and public policy that have occurred since the Gold Rush.

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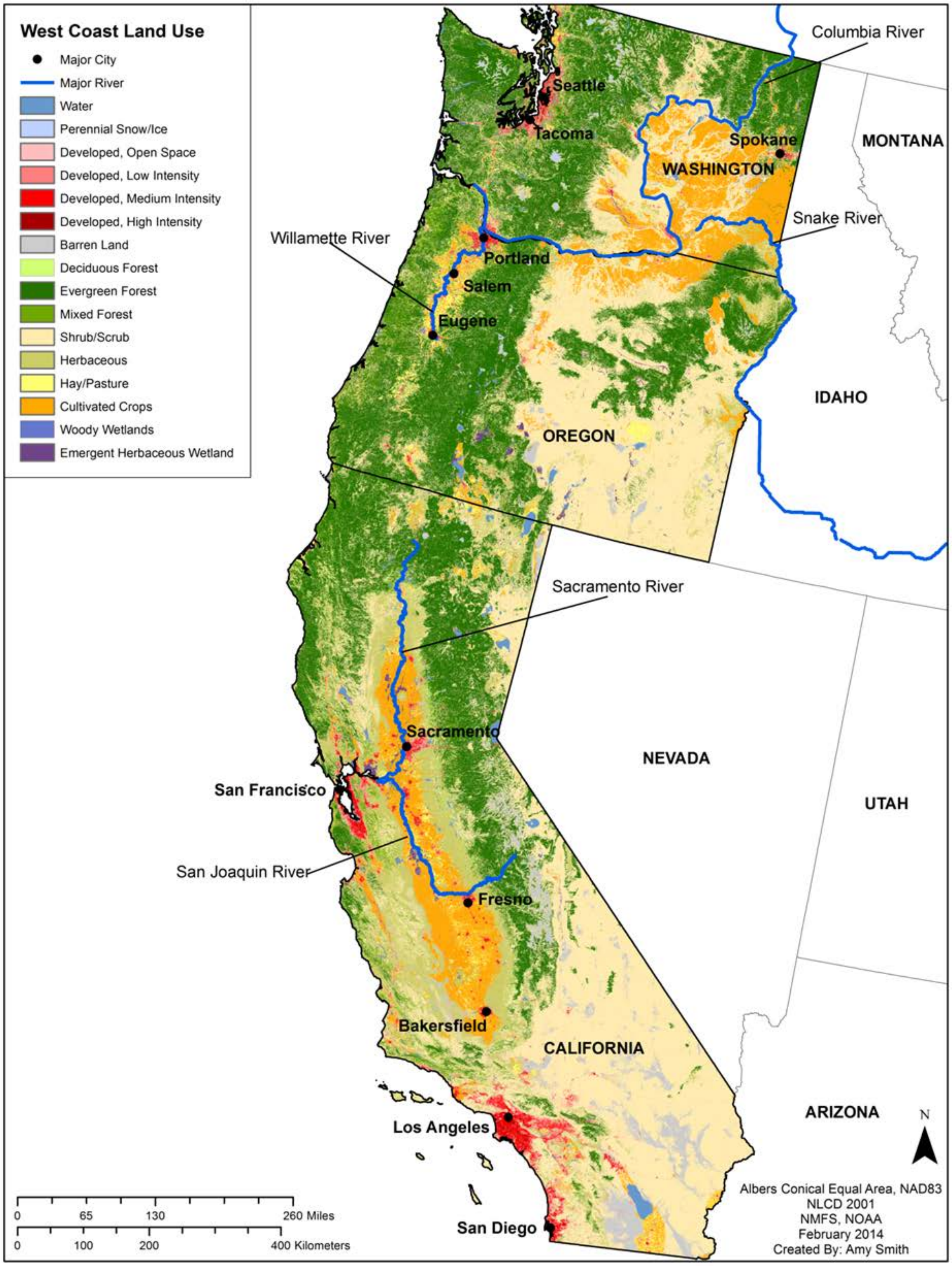

Figure S9. Land use in California, Oregon and Washington

STATUS, PATTERNS, AND TRENDS OF ACTIVITIES RELEVANT TO SALMON

FUR TRAPPING

Fur trapping and trading were lucrative enterprises from the 1780s to the 1830s, but subsequently dwindled due to declines in beaver populations and the market for pelts. The decimation of beaver populations had adverse effects on salmon, as beaver ponds provided nutrients and important rearing habitat for salmon and also stabilized habitat by dampening the effects of currents and flows (Lichatowich 1999, Taylor 1999).

MINING

In 1848, gold was discovered on the American River in California. The mining boom – which also included other metals (e.g., silver), minerals (e.g., sand, gravel) and coal – spread, albeit on a lesser scale, to other parts of California as well as Oregon and Washington Territories (Wissmar et al. 1994, Schwantes 1996). Methods of placer mining depended on water availability and included ground sluicing, dredging, diversion of streams to diggings that lacked water, and hydraulic mining that washed entire hillsides into streams (Pomeroy 1965). By 1870 almost 7000 miles of ditches had been constructed in California to move water from rivers to mines (Gillilan and Brown 1997). In 1884 the Ninth Circuit Court in San Francisco shut down the hydraulic mining industry in California, citing its destructive effects on property and the navigability of the Sacramento and Feather Rivers (Hundley 2001). Mining impeded salmon spawning, migration and survival by changing the course of rivers, stream flows, temperatures and suspended sediment, altering bottom substrate composition, damaging riparian habitats, and creating high sediment loads that clogged salmon gills and smothered salmon eggs and aquatic insects (Nelson et al. 1991, Wissmar et al. 1994, Lichatowich 1999).

The extralegal property rights system established by the miners, allowing free and open access to minerals on public lands, was codified in the 1872 Mining Act. The 1920 Mineral Leasing Act (administered by the Bureau of Land Management) provided a system for private companies to lease and develop mining interests on federal lands. Today, BLM shares authority for minerals management with four other Department of the Interior (DOI) agencies: Minerals Management Service, Office of Surface Mining and Reclamation, Bureau of Mines and U.S. Geological Survey. Major environmental laws governing mining include the Clean Water Act, the Superfund Act, and the Endangered Species Act (Klyza 1997). Acid pollution from some abandoned mines persists to the current time. For example, Iron Mountain Mine in the Klamath Mountains of northern California was designated a Superfund site in 1983. At that time, acid drainage from the mine included a ton of copper and zinc each day – about one-quarter of the total discharge of copper and zinc into surface waters by all municipal and industrial point sources in the U.S. Since 1963, spills from Spring Creek Reservoir (where the acid drainage is contained) during large storms have caused at least 20 major fish kills on the Sacramento River (U.S. Department of Justice 2000, U.S. Environmental Protection Agency 2013).

LOGGING

The Hudson Bay Company established the Pacific region's first sawmill at Fort Vancouver, Washington in 1827 (Schwantes 1996). Beginning with the 1848 Gold Rush, timber production increased rapidly to meet the demand for mining infrastructure, housing and fuel for the rapidly growing population (McKelvey and Johnston 1992). Numerous small sawmills were built in California's Sierra Nevadas to serve nearby mining towns. In 1848, there were about 22 sawmills in western Oregon and Washington. In Oregon alone, the number of mills increased from 100 in 1851 (Lichatowich 1999) to 173 in 1870 to nearly 500 by 1900 (Taylor 1999). Mills dumped tons of sawdust into streams and bays – consuming oxygen and smothering plants as well as salmon eggs and alevin (Taylor 1999).

Mills were often located near water to facilitate the transport of logs. Logs were floated down mountains in water-filled flumes or "skidded" by oxen to a river transport site, then washed downriver when flows were sufficiently high. To overcome the problem of seasonal flows, logs and water were held in splash dams and periodically released into the river for the trip downstream, with dynamite used to break up subsequent logjams (Taylor 1999, Lichatowich 1999). These practices resulted in rapid changes in flow, destruction of stream bottoms and banks, loss of spawning gravel and refugia, and direct destruction of salmon (particularly Chinook, which spawn and rear in the main stem where log drives occurred). The loss of old-growth riparian forests elevated stream temperatures, increased stream bank erosion, and reduced the supply of nutrients needed for biological productivity (Gregory and Bisson 1997, Lichatowich 1999, Taylor 1999).

The invention of steam donkeys (steam-powered engines used to yard logs) and narrow-gauge logging railroads in the 1880s allowed logging to expand into previously inaccessible mountain areas once riparian forests were cut (Lichatowich 1999). High-lead logging, developed in 1905-10 and used to elevate logs above ground-level obstructions, facilitated the cutting of forests for the next forty years. By 1909 the so-called "Kraft process" was being used to convert wood pulp into paper, and the market for plywood developed in the 1920s (Schwantes 1996). Washington was the largest lumber producer in the U.S. during 1905-1938, except for one year when it was surpassed by Oregon (Schwantes 1996). After World War II, logging railroads were replaced by logging roads traveled by heavy-duty equipment such as trucks and bulldozers. Railroad and road construction contributed to landslides that blocked streams and caused siltation that smothered salmon eggs. Old skid trails and abandoned and poorly maintained logging roads continue to create landslides and sediment problems, particularly in areas of steep terrain, heavy rainfall and sedimentary soils. Habitat problems associated with logging should be considered in the context in which they occur (National Research Council 1995).

Today, the vast majority of public forest lands are owned by the federal government and managed by the U.S. Department of Agriculture (USDA) Forest Service (with the remainder under DOI's Bureau of Land Management and Park

Service). Passage of the 1976 National Forest Management Act and the 1976 Federal Land Policy and Management Act changed the federal government's historical pro-timber orientation by requiring the Forest Service and the BLM to consider wildlife protection as part of forest management, implement forest practice regulations, and develop a new planning process that included public participation as required by the 1970 National Environmental Policy Act (Gregory 1997, Hoberg 1997). In 1990 the Forest Service developed a conservation strategy for the Northern Spotted Owl, which was listed as "threatened" under the ESA that same year. In 1994 the agency implemented its Northwest Forest Plan, which expanded the scope of its owl strategy to include "ecologically significant late-successional ecosystems, species, and processes, including but not confined to Northern Spotted Owls" (Thomas et al. 2006). Protection of old-growth forests necessitated large reductions in Northwest timber harvests. Timber harvest reductions also occurred in the Pacific Southwest Region to protect the California spotted owl. Since the early twentieth century, the U.S. Congress has allocated 25% of federal timber sale revenues to counties to compensate them for the loss of tax base associated with federal land ownership. Thus reductions in federal timber harvest have direct economic effects not only on the logging industry but on counties with acreage in federal forests (Hoberg 1997). Since the early 1970s, non-federal (state and private) forest lands have been managed on the basis of forest practices rules developed and enforced by the states. A number of state and federal programs provide technical and financial assistance for voluntary efforts by private forest landowners, conservation districts and non-profit watershed groups to improve forest management. According to Gregory and Bisson (1997), "In general, society has called for high standards of environmental protection on public and private forest lands, but management activities in public forests are restricted to a greater extent than in private forests."

Timber production is considerably higher in Oregon and Washington than California. The early 1990s (when protection of old growth forests became an important concern) marked the beginning of a decline in timber harvest in all three states (Figure S10). The percentage of timber harvest derived from public lands fell from an average of 41% in 1978-1989 to 11% in 1995-2013 in California, from 55% in 1962-1989 to 20% in 1995-2010 in Oregon, and from 33% in 1965-1989 to 21% in 1995-2012 in Washington. Timber production continues to be concentrated in the densely forested areas of northern California and coastal Oregon and Washington (Figure S11).

Interestingly, it was the ESA listing of the Spotted Owl, rather than the listing of salmonid populations themselves, that has so far enabled the most reliable and widespread protection of salmon habitat in the Pacific Northwest (Lombard 2006). The ESA listing of the spotted owl eventually led to the federal Northwest Forest Plan, state Habitat Conservation Plans, and, in Washington State, the multi-stakeholder Timber, Fish and Wildlife Agreement and Forest and Fish Law. These provisions require loggers to leave 100-300 foot-wide buffers of stream side forest in order to protect salmon and other wildlife habitat. As Lombard notes, "No representatives of any other major land use in the state [of Washington] have accepted anything remotely similar" (Lombard 2006). Furthermore, Lombard argues, the spotted owl listing led to state forestry regulations that are "arguably the strictest in the country" and that so far it is the owl, not the salmon, that has had "the greatest effect of any listed species on ecosystem protection in the Pacific Northwest," including the protection of salmon habitat (Lombard 2006).

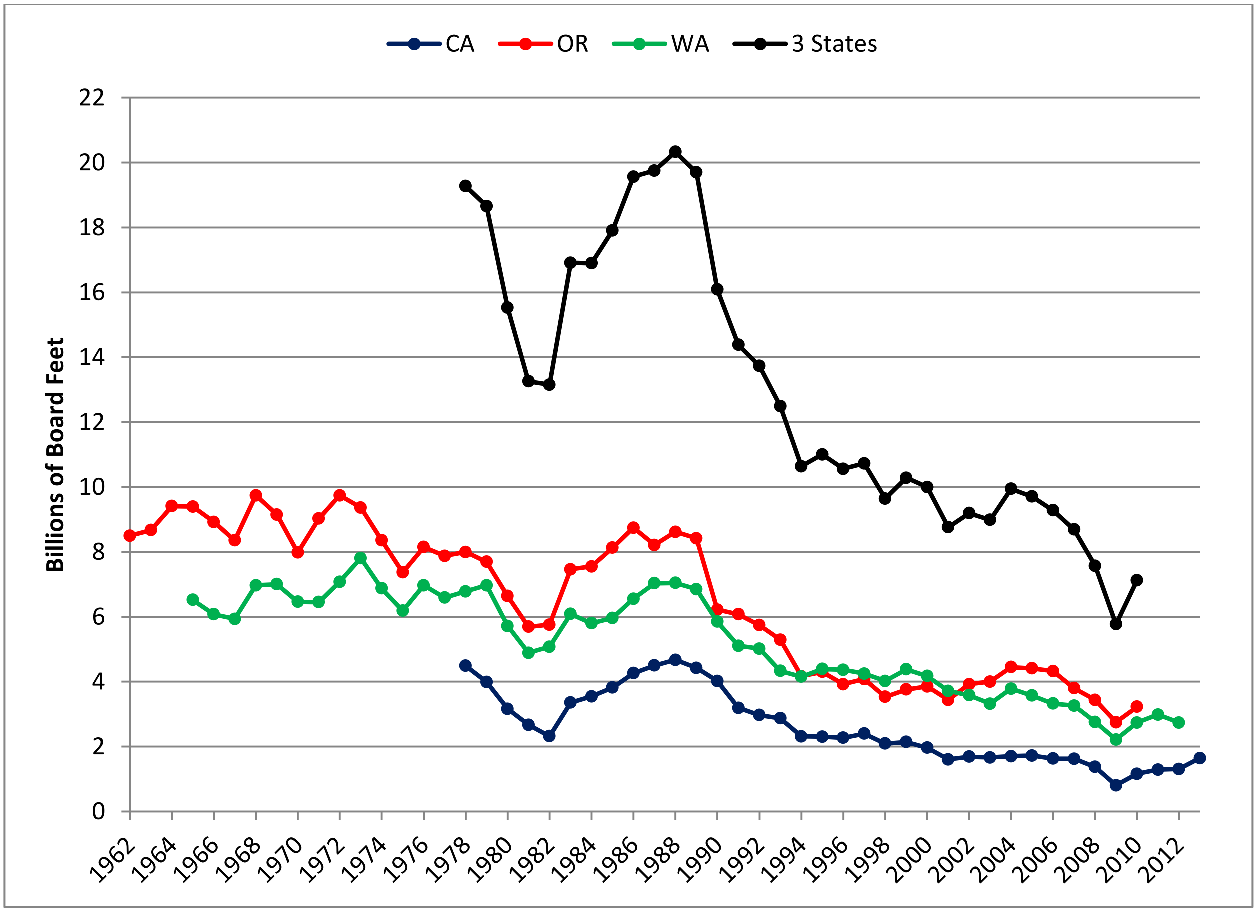

Figure S10. Timber production (billions of board feet) by state and three-state total, 1962-2013 as available (sources: California Board of Equalization, Oregon Department of Forestry, Washington State Department of Natural Resources).

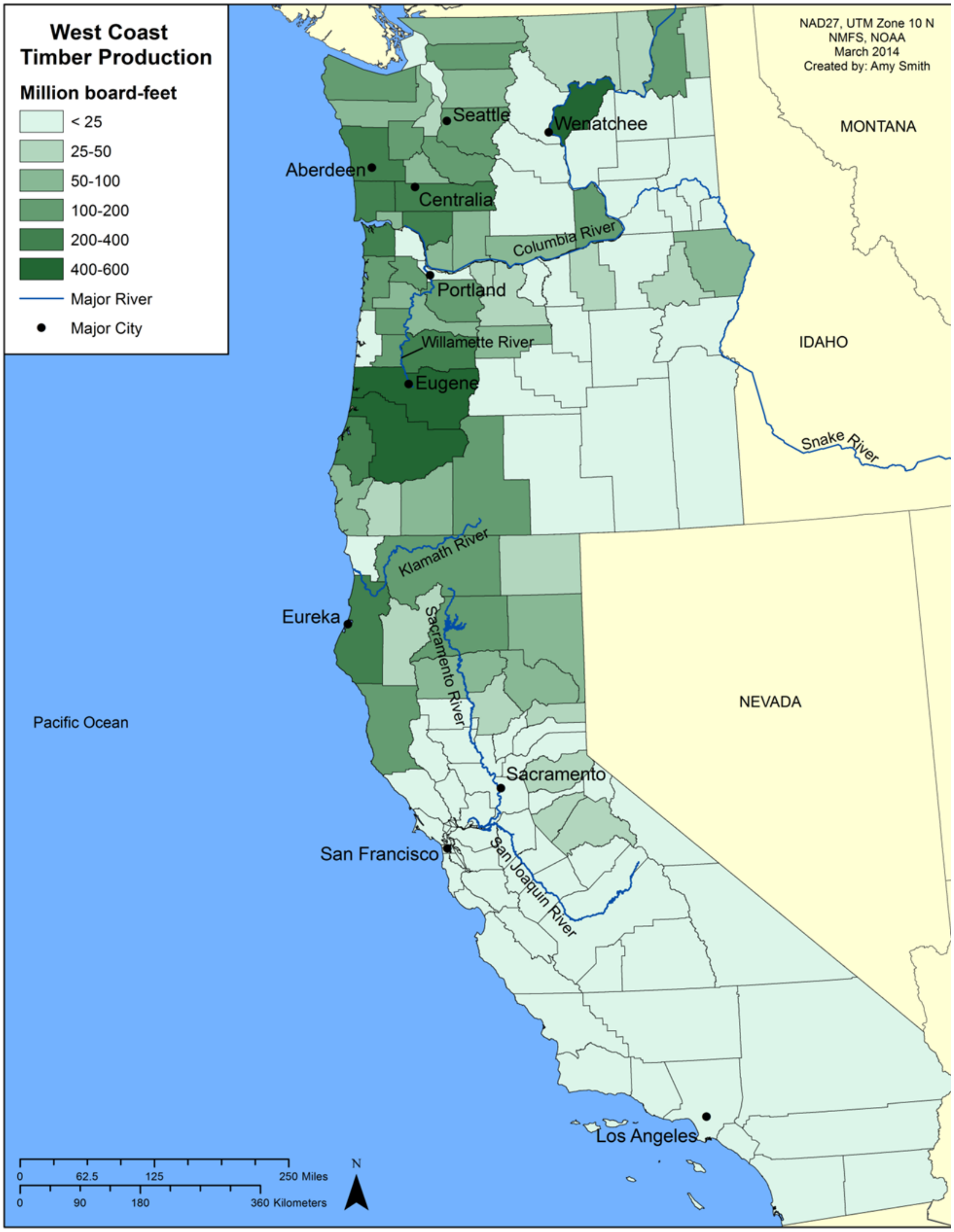

Figure S11. Counties categorized by volume of timber production

AGRICULTURE

Livestock grazing began in California in 1769 when Franciscan missionaries brought cattle and horses from Mexico to their first mission at San Diego. After winning independence from Spain in 1821, Mexico began secularizing the mission landholdings and, by the mid-1830s, had issued land grants for over 400 ranchos, largely for cattle raising (Burcham 1956). In the Pacific Northwest, Native American tribes such as the Nez Percés began grazing horses in the 1700s (Pomeroy 1965, Galbraith and Anderson 1991). White settlers began large-scale cattle raising in the 1860s from stock raised at Hudson Bay Company posts and mission stations, or from animals driven over the Oregon Trail or from California and Texas (Schwantes 1996). While grazing was well-established before the 1848 Gold Rush, demand for meat in mining towns greatly expanded the scale of livestock production. Even after the mining boom, demand for meat remained strong as railroads and the introduction of stock cars and refrigerated cars in the late 1800s opened up new markets as far away as Chicago. By the 1880s, deterioration of the range and mass starvation of cattle during severe California droughts and harsh Northwest winters led cattlemen to abandon open-range grazing in favor of summer grazing on public and private lands and containment and hay provision in the winter. As cattle herds were reduced to numbers that could be contained during the winter, less-costly sheep herds increased and by 1900 exceeded cattle in most western states. The range of cattle and sheep shrank as grazing areas were converted to cropland, settlers fenced off land and streams, and railroads received large land grants (Galbraith and Anderson 1991, Schwantes 1996). Nevertheless, livestock and livestock products remain important components of today's farm economy. Cattle are attracted to riparian areas, where they trample and eat streamside vegetation, erode and destabilize stream banks, reduce water retention by compacting the soil, increase siltation, elevate water temperatures, disturb salmon nesting areas, and deposit waste into streams (Platts 1991, Gillilan and Brown 1997).

Agriculture expanded to include not only livestock and livestock products but also grains and other commodities. The first wheat and apple harvests in the Northwest occurred in the 1820s at Fort Vancouver, Washington – the first permanent white settlement in the region (Schwantes 1996). In the 1830s emigrants from the Midwest began traveling the Oregon Trail to farm in the fertile Willamette Valley. In the mid-1800s, farming expanded east of the Cascades to the warmer, dryer Columbia Plateau; by the 1880s, wheat fields extended throughout eastern Washington and Oregon. Completion of the Northern Pacific Railway in 1883 resulted in another population boom, and refrigerator cars expanded markets for agricultural products. The first irrigation project began in 1859 in the Walla Walla River Valley, followed by similar projects in Oregon. Irrigation expanded cultivation of apples and other commercial crops, and large-scale commercial orchards became common in the valleys of Oregon and Washington by 1905-1915 (Schwantes 1996, Pomeroy 1965).

In California, large expanses of flat fertile land, combined with rainy winters and hot dry summers, were ideally suited to wheat. The wheat boom peaked in the 1880s and 1890s, facilitated by innovations such as the combined grain harvester. During 1890-1914 the farm economy – aided by irrigation – rapidly shifted from large-scale livestock and grain operations to smaller-scale, intensive crops (cotton, fruits, nuts, vegetables). Previously marginal or under-utilized lands were brought into cultivation. Dairy and poultry operations expanded rapidly, and after 1940, non-dairy livestock resurged in the form of large-scale, commercial feed-lot operations. Labor shortages, the large-scale nature of farm operations, high yields, flat landscape, and the absence of rain during harvest season were conducive to highly mechanized farms – e.g., steam and later gasoline tractors, giant combines, high capacity seeders, mechanical harvesters (cotton, sugar beets, tomatoes). Production was also enhanced by a sizeable agricultural research establishment and innovations that reduced perishability and enhanced the quality of fruits and vegetables (Olmstead and Rhode 2003).

The 1935 Rural Electrification Act provided federal loans for installation of electrical distribution systems in rural areas. Rural electrification proceeded rapidly in the Pacific region, spurred by to the large amounts of power needed to pump water for irrigation and for activities such as dairy and poultry farming. By 1939, 75% of farms in California, 50% in Oregon and 57% in Washington were electrified, compared to 22% in the U.S. as a whole (Beall 1940). Irrigation made possible the conversion of vast areas into farmland, but also had adverse effects on salmon habitat. Farmers diverted water from streams using gravity systems with head gates or low dams that often spanned entire streams. Many small dams remain undocumented and unscreened. Unscreened diversions impede salmon passage, reduce river flows (particularly during summer months), and cause high mortality of juvenile and adult fish. Return flows elevate stream temperatures and also transport silt, nutrients, and chemicals that are adverse to salmon (Taylor 1999).

Pumps were used to access groundwater as well as divert surface water. Invention of the deep-well turbine pump in 1930 allowed water to be pumped at greater depths (Faunt et al. 2009a). During 1901-1950, California accounted for about 70% of the nation's agricultural pumps; acreage irrigated by groundwater increased more than thirty-fold, while acreage irrigated by surface water only tripled (Olmstead and Rhode 2003). Today, groundwater accounts on average for more than one-third of the water used by California's cities and farms; much more is pumped in dry years (California Natural Resources Agency et al. 2014). The current drought in California (which began in 2012) is the most recent of many such multi-year droughts since 1900: 1918-1920, 1923-1926, 1928-1935, 1947-1950, 1959-1962, 1976-1977, 1987-1992, 2000-2002, and 2007-2009 (California Department of Water Resources 2012). Oregon and Washington manage their groundwater, while California authorizes local agencies to do so. Many groundwater basins are not managed sustainably, although the current drought is highlighting the need for a stronger state role in groundwater management (Faunt et al. 2009a, California Natural Resources Agency et al. 2014). Nearly all surface water bodies interact with groundwater. Poor groundwater management has resulted in reductions in stream flow, shrinkage of riparian areas, land subsidence, adverse effects on water quality, and more costly and energy intensive pumping due to lowering of groundwater levels (Gillilan and Brown 1997, California Natural Resources Agency et al. 2014).

The 1934 Taylor Grazing Act established the Grazing Service (later BLM) to regulate grazing on public lands (National Research Council 1995). State and local agencies are responsible for permitting, inspection and enforcement of environmental regulations on private farms and ranches; these regulations are generally based on regulatory guidance provided by the U.S. Environmental Protection Agency (EPA). The USDA Natural Resources Conservation Service provides educational outreach and technical and financial assistance to encourage farmers to adopt environmentally sustainable practices (Stubbs 2011). As indicated by Gregory and Bisson (1997), “Land use regulations for agricultural and range lands tend to be less protective of streams than forest policies.”

California first led the U.S. in cash farm receipts in 1929 and has maintained that lead since 1949 (Hundley 2001). Today California produces over 350 agricultural commodities, including over one-third of the nation’s vegetables and nearly two-thirds of the nation’s fruits and nuts (California Department of Food and Agriculture 2013). Cash farm receipts in California have increased significantly since 1980. Washington values have increased modestly since 1970, and Oregon values (as available) are about 50% of Washington’s (Figure S12). Based on 2012 data, the highest valued commodities in California are dairy, grapes, almonds, greenhouse/nursery, and cattle/calves. The top counties in terms of value are Fresno, Tulare, Kern, and Merced (San Joaquin Valley) and Monterey (central coast). Oregon’s highest valued commodities are greenhouse/nursery, cattle/calves, dairy, wheat, and hay. Top counties are Marion, Washington and Clackamas (northwest Oregon) and Morrow and Umatilla (northeast Oregon). Washington’s highest valued commodities are apples, dairy, wheat, cattle/calves, and potatoes. Top counties are Yakima, Benton, Grant, Franklin and Walla Walla (all south central Washington) (U.S. Department of Agriculture 2014).

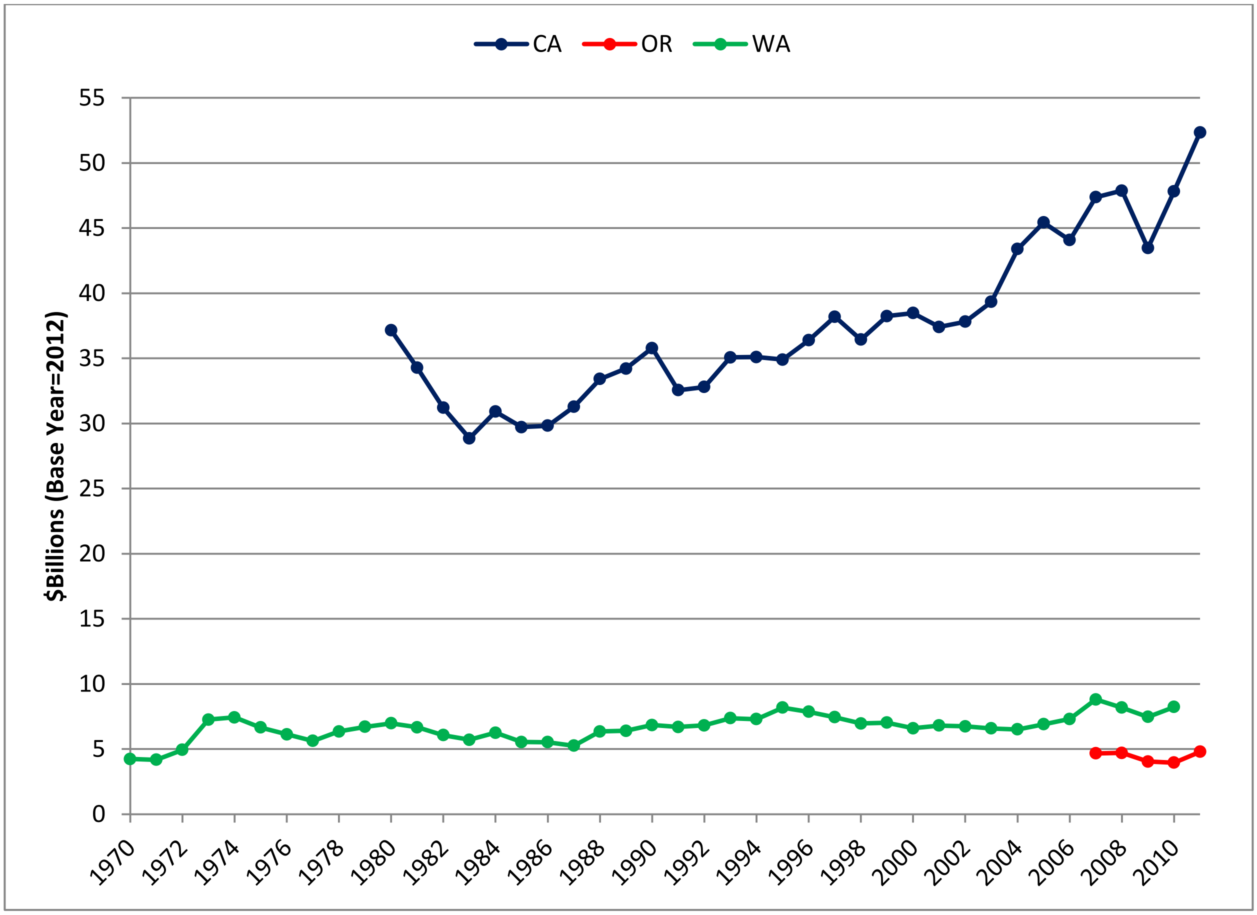

Figure S12. Cash farm receipts in California, Oregon and Washington, 1970-2011 as available (base year=2012).

DAMS

The 1902 Reclamation Act authorized construction of large federal irrigation projects in the arid western states, with construction costs to be recovered without interest from irrigators who benefit from the project. The 1939 Reclamation Project Act transformed the program by authorizing construction of water projects for multiple uses, with costs to be shared among all such uses. These Acts – as well as other laws and budget appropriations – led to construction of some of the largest water storage, withdrawal, conveyance and diversion systems in the world. These water projects stimulated population growth and greatly expanded economic opportunities in the Pacific region, but also fundamentally and adversely affected salmon populations and their habitat. According to the National Research Council (1995), "Of the various human-caused changes in the region, particularly the Columbia River basin, perhaps none has had greater impact than dams."

Dams block or impede access of salmon to historical upstream habitat. Passage facilities (when available) provide some access but also delay upstream migration, increase prespawning mortality and reduce spawning success.

Downstream migrants must pass through reservoirs, survive dams, spillways, bypass facilities and turbines, and overcome hazards such as increased predation. Disruption of the natural flow regime (in terms of timing as well as volume of flows) elevates water temperatures, affects the flow of nutrients and energy, and alters habitat of vegetation, fish and other biota. Flow changes also affect downstream channel morphology and hinder flushing of sediments, recruitment of sediments and spawning gravel, and transport of large woody debris. Dams and associated structures are highly disruptive to a river's ecological processes (Ligon et al. 1995, National Research Council 1995).

Beginning in the 1930s, a number of large federal dams were constructed in the Columbia River Basin. These included Bonneville (1937), Grand Coulee (1942), McNary (1954), Chief Joseph (1955), The Dalles (1960), and John Day (1971) on the Columbia River, and Ice Harbor (1962), Lower Monumental (1969), Little Goose (1970) and Lower Granite (1972) on the Snake River. These dams are operated by the U.S. Army Corps of Engineers except for Grand Coulee, which is operated by the U.S. Bureau of Reclamation. Construction of Bonneville and Grand Coulee helped lift the Northwest economy out of the Depression and brought electricity to rural areas (Lichatowich 1999). By the late 1970s, 14 mainstem Columbia River dams and 13 main stem Snake River dams were operating in the Columbia Basin. Today the Northwest depends on hydropower for 80% of its electricity (Foundation for Water and Energy Education 2014). Salmon passage can be particularly challenging at high dams. Upstream migration can be facilitated by trap-and-haul operations or fishways, but the sheer size of the reservoirs can hinder the ability of outmigrating smolts to find their way to sea (National Research Council 1995).

Grand Coulee (the largest dam by mass in the U.S.) is part of the Columbia Basin Project (CBP) in central Washington – the largest reclamation project in the U.S. The Project includes over 300 miles of main canals, 2000 miles of lateral irrigation canals, and 3500 miles of drains and wasteways. CBP purposes include flood control, navigation, irrigation, and municipal and industrial uses. Fish and wildlife purposes were recognized in 1980, based on a Court interpretation of the 1958 Fish and Wildlife Coordination Act (U.S. Bureau of Reclamation 2013b). Even before 1930, hundreds of smaller dams were built in the Pacific region, including 32 major dams on Columbia River tributaries (Lichatowich 1999). By 1975, about 48% of the spawning and rearing habitat accessible to Chinook in the Columbia River Basin was lost to dam construction. Habitat loss has been greater for spring and summer Chinook than for fall Chinook (Mundy 1997).

About one-sixth of the irrigated land in the U.S. is in California's Central Valley and about one-fifth of the nation's groundwater demand comes from Central Valley aquifers (Faunt et al. 2009b). High water demand and frequent droughts make "water wars" a fact of life in California (Speir et al. In review, Speir and Stradley In review). The major water projects in California are the Central Valley Project and the State Water Project. The nexus of these two projects is the Sacramento/San Joaquin Delta. The Delta is also a central corridor on the migration route of Central Valley salmonids.

Central Valley Project: The federal Central Valley Project (CVP) was authorized in 1935 to increase economic opportunities in the fertile lands of the flood-prone Sacramento Valley and the arid San Joaquin Valley by regulating flows and more equally distributing water between the two valleys (Hundley 2001). The CVP, operated by the U.S. Bureau of Reclamation, extends 400 miles from the Cascade Mountains near Redding to the Tehachapi Mountains near Bakersfield. The CVP manages about nine million acre feet (11.1 billion cubic meters) of water and includes 20 dams and reservoirs, 11 power plants, and 500 miles of major canals that manage water for irrigation, municipal and industrial use, flood control, hydropower and recreation to Central Valley communities. Today about 78% of CVP water goes to irrigation, 9% to municipal and industrial use, and 13% for release into rivers for the benefit of fish and wildlife (U.S. Bureau of Reclamation 2013a).

The CVP includes water impounded on the Sacramento, Trinity, American, Stanislaus, and San Joaquin rivers. Sacramento River water is impounded at Shasta Dam (the second largest U.S. dam in mass, after Grand Coulee) and Keswick Dam. Trinity River water is impounded at Trinity Dam, released downstream to Lewiston Dam, and then diverted through the Trinity Mountains via the Clear Creek Tunnel to the Sacramento River. Water in Sacramento River reservoirs is released (1) to the Tehama-Colusa and Corning canals to serve irrigators on the west side of the Sacramento Valley, and (2) down the Sacramento River to the Sacramento/San Joaquin Delta. Water from the central Delta is transported via the Contra Costa Canal to Contra Costa County, while water from the south Delta is intercepted at the Delta Cross Channel and pumped through the Delta Mendota Canal. The Delta Mendota Canal transports water south to the Mendota Pool near the town of Mendota on the San Joaquin River, with some water diverted to the San Luis Reservoir and other CVP reservoirs along the way; this water is allocated to San Joaquin Valley irrigators. Water from the American River (a Sacramento River tributary) is impounded at Folsom Dam for use by local communities and to augment water supplies in the rest of the CVP. San Joaquin River water is impounded at Friant Dam and diverted to irrigators in the south San Joaquin Valley via the Madera and Friant-Kern Canals. Water from the Stanislaus River (a tributary of the San Joaquin River) is impounded at New Melones Dam for eventual release to the San Joaquin (Hundley 2001, U.S. Bureau of Reclamation 2013a).

State Water Project: The State Water Project (SWP) – authorized by the 1960 California Water Resources Development Bond Act – is operated by the California Department of Water Resources. Today, the SWP includes 33 storage facilities, 21 lakes and reservoirs, and 700 miles of canals, pipelines and tunnels. The SWP stores and re-regulates about 5.8M acre-feet (7.2 billion cubic meters) of water originating from the Feather River (a tributary of the Sacramento River). This water is impounded in large reservoirs, then released into the Sacramento River and transported downstream to the Sacramento/San Joaquin Delta. From the Delta, the water is pumped to (1) the North Bay Aqueduct for delivery to Napa and Solano counties, (2) the South Bay Aqueduct for delivery to Alameda and Santa Clara counties, and (3) the 444-mile California Aqueduct for off stream storage at the San Luis Reservoir. South of the San Luis Reservoir, the Coastal Branch of the California Aqueduct diverts water to San Luis Obispo and Santa Barbara counties. The California Aqueduct then carries water 2000 feet over the Tehachapi Mountains, where water is supplied by the West Branch to Ventura and Los Angeles counties, by the East Branch to Los Angeles and areas south, and by the East Branch Extension to Riverside and San Bernardino counties. Due to its prodigious pumping requirements, the SWP is the largest single user of power in the state. About 70% of SWP water is used for municipal and industrial use in Southern California and the San Francisco Bay area, and the other 30% for irrigation (California Department of Water Resources 2008a, 2010).

Sacramento/San Joaquin Delta: The Sacramento/San Joaquin Delta is where fresh water from the Sacramento and San Joaquin rivers mingles with saltwater from the Pacific Ocean, creating the West Coast's largest estuary. It is the hub of California's water system – the Central Valley Project and the State Water Project. Historical development of the Delta was spurred by the 1850 Swamp Land Act, which provided California and 12 other wetland-abundant states with grants to reclaim wetlands through construction of levees and drains. In California, about two million acres of wetlands were reclaimed – including 500,000 acres of tidal marsh in the flood-prone Delta. Due to widespread reclamation, California has experienced the largest percentage loss of wetlands of any state (91%) (Dahl 1990). In 1861, California enacted the Reclamation and Swampland Act authorizing the creation of swampland districts (later reclamation districts) responsible for financing and providing flood control within their boundaries (Hundley 2001). Today flood control is the shared responsibility of California's Central Valley Flood Protection Board, the California Department of Water Resources, local levee maintaining agencies, and the Army Corps of Engineers (ACOE). The ACOE sets standards for levee safety, and both the Corps and the State provide rehabilitation assistance to qualifying local agencies. Comprehensive flood management is needed to address problems associated with aging levee infrastructure, susceptibility of levees to earthquakes and floods, increasing costs of levee maintenance, and growing population in flood-prone areas (California Central Valley Flood Protection Board 2013).

Today 55 islands and tracts in the Delta are protected by 1100 miles of levees. The levees protect not only farms but also hundreds of thousands of people who live and work in the Delta and $47 billion in infrastructure (e.g., highways, railroads, energy transmission lines, water and petroleum pipelines) serving the San Francisco Bay area. The levees were constructed from fertile peat soils native to the area. Land subsidence due to peat oxidation has gradually lowered the elevations of Delta islands – in some cases more than 20 feet below sea level – and increase the risk of levee failure (California Department of Water Resources 2008b). The natural intrusion of brackish water into the Delta is exacerbated by levee subsidence and reductions in freshwater inflow due to water exports. Some of this intrusion has been offset by modifications to CVP and SWP dam operations that increase freshwater inflow in dry summer months for the benefit of migrating salmon and resident Delta smelt. The powerful south Delta pumps that supply water for the CVP and SWP cause Delta water to flow from north to south instead of east to west, disrupting fish migration and causing salinity buildup in the east Delta, where salts can no longer be flushed to the ocean by natural river flows. The ecology of the Sacramento/San Joaquin Delta has been profoundly affected by the CVP and SWP and the human activities that depend on these Projects (Ingebritsen and Ikehara 1999).

Figure S13 depicts the location of CVP and SWP irrigation districts and populous cities in southern California, San Francisco Bay and the Central Valley. The map reflects the importance of the CVP and SWP to irrigated agriculture and municipal water users throughout the state.

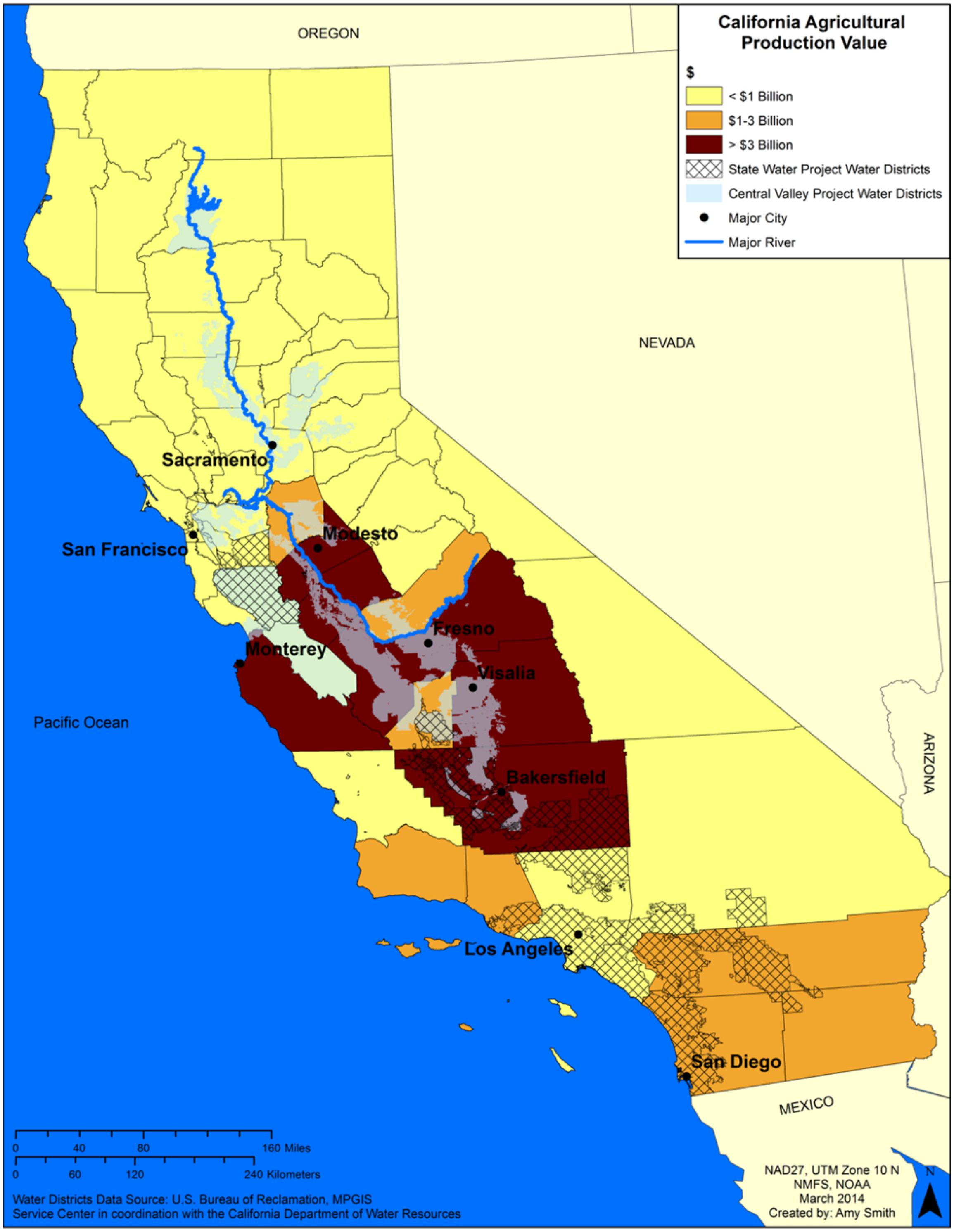

Figure S13. California counties categorized by the value of agricultural production, overlaid with location of Central Valley Project and State Water Project water districts.

In addition to government projects such as the CBP, CVP and SVP, the 1906 General Dam Act authorized the construction of hydropower facilities by private utility companies, subject to Congressional approval (Gillilan and Brown 1997). In addition, thousands of smaller diversions throughout the Pacific region provide water for irrigation, livestock and other uses. These latter dams have not been fully inventoried and the extent to which they impede passage and impair spawning and rearing habitat is not well documented (National Research Council 1995).

Effects of federal dams on salmonids are addressed via ESA Section 7 consultations. Non-federal hydropower dams are regulated by the Federal Energy Regulatory Commission (FERC) as authorized by the 1935 Federal Power Act (FPA). The FPA has received renewed interest since the 1990s, when many of the FERC licenses originally issued 40-50 years ago are getting ready to expire – providing an opportunity for NOAA to prescribe salmonid passage as a condition for relicensing (Gillilan and Brown 1997). Federal legislation intended to address more regional salmon needs include the 1980 Pacific Northwest Power Planning and Conservation Act, the 1984 Trinity River Basin Fish and Wildlife Management Act, the 1992 Central Valley Project Improvement Act, and the 2009 San Joaquin River Restoration Act (Gillilan and Brown 1997). Regional programs that include salmonid recovery as a goal have also been established, including the Puget Sound Shared Strategy, the California Bay-Delta Program (later superseded by the Delta Stewardship Council), and the Trinity River Restoration Program.

Structural and operational methods of mitigating effects of dams on anadromous salmonids include (for example) fish ladders for upstream migration, trucking and barging of downstream migrants, screens and spillways to reduce turbine mortality, reservoir drawdown to reduce travel time through reservoirs, control of predators (e.g., pikeminnow), and flow augmentation to facilitate migration and reduce water temperatures. Some of these measures (e.g., trucking and barging) have detractors as well as supporters (National Research Council 1995). Another mitigation method is dam removal. Examples of recent dam removals are Condit Dam on the White Salmon River in Washington, Elwha and Glines Canyon dams on the Elwha River in Washington, Savage Rapids Dam on the Rogue River in Oregon, and San Clemente Dam on the Carmel River in California. Consideration is being given to removal of four private hydroelectric dams on the Klamath River (USDOI undated). Hatcheries have also been used as mitigation for dams.

HATCHERIES

The first salmon hatchery in the Pacific region was established in 1872 on the McCloud River (a Sacramento River tributary) by the U.S. Fish Commission to incubate eggs to supplement declining Atlantic salmon stocks. In 1877, the Commission established a second hatchery on the Clackamas River near Portland, with partial funding from Columbia River cannery operators who were concerned about the decline of prized spring-run Chinook. Later that year, when a flood wiped out the eggs at the Clackamas hatchery, eggs were transferred from the McCloud hatchery to Clackamas (Gregory and Bisson 1997). Although the canners were critical of transplanting practices and the fish culturists' unwillingness to distinguish salmon by runs, they had no scientific basis for their objections. Federal and state hatcheries proliferated during the late nineteenth century. Hatchery releases became a means of increasing salmon abundance, and hatchery monitoring was too sporadic to demonstrate otherwise. Pacific salmon eggs were transferred to distant hatcheries in Australia, New Zealand, South America, Europe, Iowa and the Great Salt Lake (Taylor 1999). Fish culturists of the time did not understand that salmon had natal streams. The role of genetics in distinguishing races and runs and the importance of reproductive isolation for salmon survival was not known until the 1930s (Lichatowich 1999,Taylor 1999).

The 1938 Mitchell Act provided funding (derived from user fees collected from commercial fishermen) to recover salmon runs affected by water diversions, dams, pollution and logging on the Columbia River (Taylor 1999). From the 1930s through the early 1950s, support for hatcheries declined due to poor returns and disease problems (National Research Council 1995). However, a 1946 amendment to the Mitchell Act (originally intended to rebuild salmon runs upstream of Bonneville Dam) stimulated a resurgence of hatcheries in the Columbia Basin. The newly amended Act allowed hatcheries to be constructed downstream of Bonneville to mitigate for effects on salmonids upstream – including extirpation of runs above Grand Coulee Dam, which had no fish passage. These downstream hatcheries encouraged dam construction by providing a means of mitigating their effects. In the 1960s, the introduction of pasteurized and formulated feeds reduced the incidence of disease and further raised expectations that hatcheries provide would effective mitigation for dams. More than 80 hatcheries have been built in the Columbia Basin – including 39 Mitchell Act hatcheries (National Research Council 1995). Use of hatcheries, fishways, screens and spillways as dam mitigation measures has been common practice in California as well as the Northwest. Figure S14 depicts major hatcheries and dams in the Pacific region.

The location of hatcheries below dams has dramatically shifted the distribution of salmon production from upper to lower river areas. The selective preference of fishery managers for certain species (primarily coho salmon and fall-run Chinook salmon) altered relative species abundance. Between 1850 and 1977-1981, coho doubled as a proportion of total abundance while sockeye salmon and chum salmon virtually disappeared in the Columbia Basin (National Research Council 1995). Collection, mating, rearing and release practices may cause hatchery fish to experience loss of genetic variation, inbreeding depression, and poor adaptation to wild conditions. Hatchery releases can affect the effective population size of wild fish and lead to outbreeding depression through hybridization with less fit hatchery fish (Naish et al. 2008). Hatcheries can also induce genetic changes in wild populations even with no interbreeding of hatchery and wild fish, due to selective fisheries that target hatchery fish (Reisenbichler 1997). Efforts such as the Pacific Northwest Hatchery Reform Project, established by Congress in 2000, are underway to review and reform hatchery practices (Hatchery Scientific Review Group 2009).

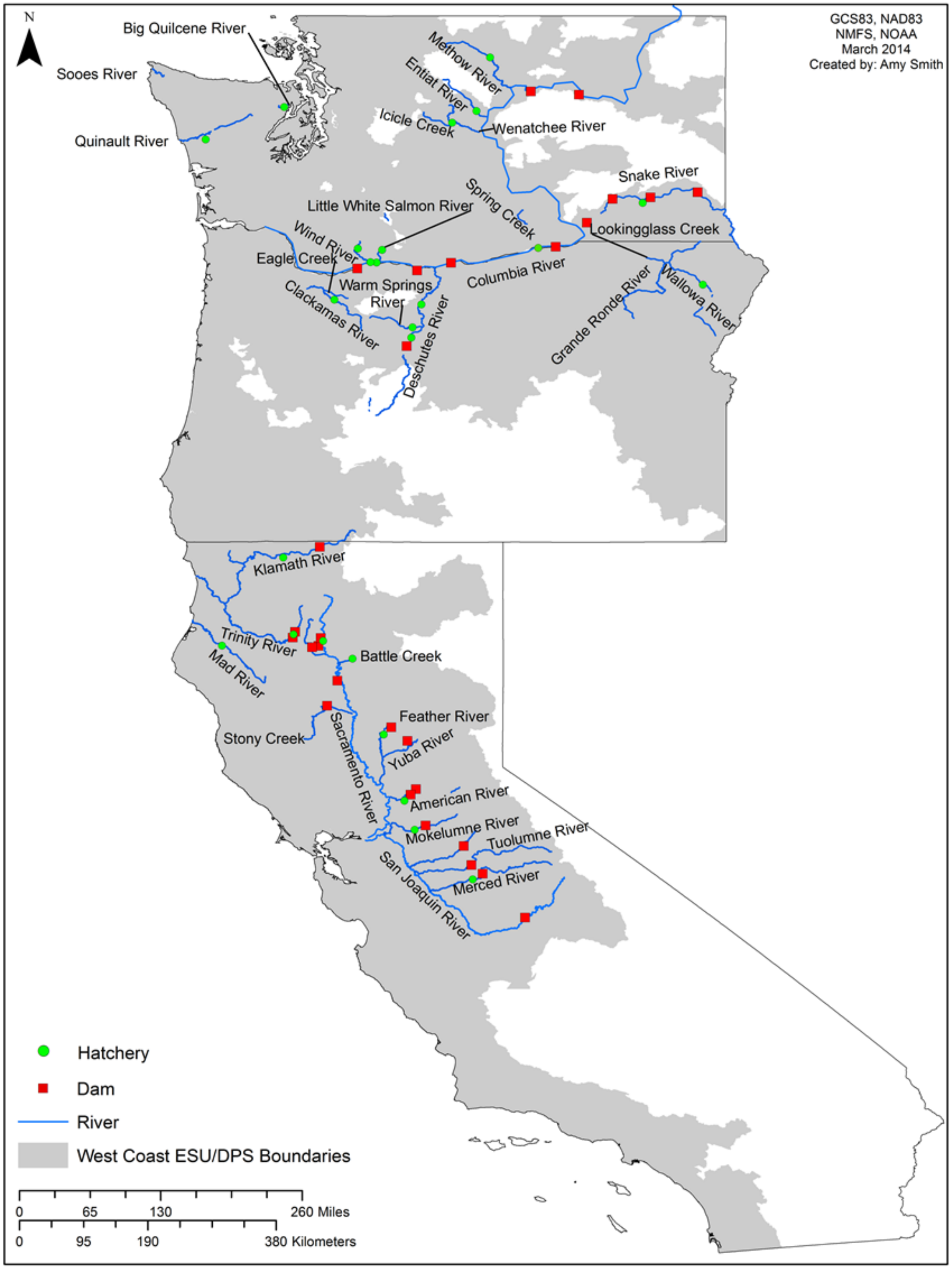

Figure S14. Distribution of major hatcheries and dams

FISHERIES

For thousands of years, salmon has been an integral part of the cultural, subsistence and ceremonial life of Native American tribes who inhabited coastal and riparian areas of the Pacific region (Taylor 1999). Traditional fishing methods included gillnets, dip nets, traps, fishing spears, and communal fishing dams (weirs); preservation methods included drying and smoking (Taylor 1999, Biedenweg et al. 2014). The first return of salmon to the river was celebrated by a First Salmon Ceremony (Lichatowich 1999). Such rituals served to reflect, reinforce, and transmit to younger generations a world view of salmon as integral to and inseparable from the river ecosystem. Historical salmon harvests by tribes in California's Central Valley are thought to have exceeded 8.5 million pounds annually. Tribes on California's north coast annually consumed up to 2000 pounds of salmon per family (Boydstun et al. 2001). Among the Northwest coastal tribes, annual per-capita consumption was more than 365 pounds (Taylor 1999). Salmon was also valued as an item of trade with non-coastal tribes. During the 1700s, it is estimated that aboriginal harvests of salmon were at least as large as contemporary peak tribal harvests (Breslow 2011). Mining, logging and agriculture interfered with the ability of Native Americans to engage in traditional subsistence and cultural practices. Native Americans found themselves at great disadvantage in the competition with Euro-Americans for resources, including salmon (McEvoy 1986), and were driven off their lands to reservations (Taylor 1999). For Euro-Americans, salmon was a commodity to be harvested rapidly and exhaustively (not moderated by long-term communal interests), processed using high-volume preservation methods (canning), and sent via high-volume transport (railroads and steamships) to distant markets (Taylor 1999).

The commercial salmon fishery developed in California several years after the 1848 Gold Rush. The fishery was initially constrained by the volatile labor market (with fishers distracted by the lure of gold) and a shortage of salt for curing. In 1864, William Hume established the first salmon cannery in the Pacific region on the Sacramento River (National Research Council 1995). Completion of the First Transcontinental Railroad in 1869 provided access to markets for cheap, nutritious canned salmon on the East coast, Britain and elsewhere. Although Hume moved his cannery to the Columbia River in 1866 to take advantage of the larger runs, 20 other canneries were established on the Sacramento/San Joaquin River system by 1880. Production peaked at 200,000 cases (from a harvest of 12 million pounds) in 1882, then declined as intensive fishing and habitat destruction from mining, logging and agriculture took their toll on the runs. Declines of spring Chinook meant greater reliance on other Chinook salmon runs and coho salmon. The last cannery closed in 1919, and California proceeded to close its river fisheries – the Mad River in 1919, the Eel River in 1922, the Smith and Klamath/Trinity rivers (including tribal fisheries) in 1933, and the Sacramento and San Joaquin rivers in 1957 (Boydstun et al. 2001).

The cannery relocated by Hume from California to the Columbia River in 1866 was the first in the Northwest. By 1883, more than 50 canneries were located on the Columbia River and its tributaries, and many others on the coastal rivers of Oregon and Puget Sound. Astoria, where fattened salmon enter the Columbia River, became a center of canning operations. Harvest of spring-run and summer-run Chinook salmon peaked in 1883. When spring-run Chinook salmon became scarcer, canneries began processing what they considered to be inferior fall-run Chinook salmon, then turned to sockeye salmon and steelhead and later coho salmon and chum salmon (Lichatowich 1999). Total cannery pack of all species on the Columbia River peaked in 1895 at 635,000 cases, then declined as the runs were diminished by habitat deterioration and overfishing (Lichatowich 1999); the last Columbia River cannery closed in 1975 (National Research Council 1995). Cannery operations on Puget Sound dated from 1877 and peaked in 1913 at 2.5 million cases (Schwantes 1996). Production in Alaska and British Columbia eventually eclipsed that of Oregon and Washington.

Advances in processing technology – e.g., mechanized fish gutting and cutting, the sanitary can (which replaced glass jars), and the double seamer (which eliminated hand soldering) – were adopted shortly after 1900 and stimulated the demand for fish to feed the cannery lines (Lichatowich 1999). The number of gillnetters on the Sacramento River increased from 60 boats in the 1850s to 1500 boats in 1884 (McEvoy 1996). The fleet expanded its range to the lower Sacramento/San Joaquin River, San Francisco Bay, and rivers north of San Francisco (Boydstun et al. 2001). In the Northwest, gillnetters attached additional webbing and weights to their nets to better entangle salmon at more river depths. In the late 1870s, poundnets and fishwheels – stationary structures that blocked river passage in areas where the current ran too slow or too fast for gillnets – were introduced into the fishery. In the 1890s, teams of horses were used along tidewater to haul beach seines packed with salmon. On the Columbia River, the number of gillnets increased from 900 in 1880 to 2,200 in 1894, traps increased from 20 in 1881 to 378 in 1895, and fishwheels increased from one in 1882 to 57 in 1895 (Taylor 1999). At times, huge piles of salmon were left to rot when harvests from large runs exceeded processing capacity (Taylor 1999).

The ocean commercial troll fishery began in Monterey Bay in the 1880s with boats powered by sails. In about 1908, several powered gillnetters from the Sacramento River entered the Monterey troll fishery. As gasoline engines replaced sails, the fleet grew to 200 boats and expanded northward to Fort Bragg, Eureka and Crescent City by 1916. During the 1920s and 1930s, the arduous work of retrieving lines, weights and fish was done by hand. Power gurdies, invented in the 1940s, were quick adopted by professional trollers. The troll fleet grew from about 570 boats in 1935 to 1,100 by 1947. By the 1970s, the fleet comprised almost 5,000 vessels, many of them part-time summer fishers who had other jobs during the year (Boydstun et al. 2001). In the Northwest, gasoline engines began replacing sails on Columbia River gillnet boats by the late 1890s and also gave rise to a mobile troll fleet at the river mouth. The Columbia River troll fleet grew from a handful of boats in 1900 to 500 boats in 1915 to 1500 boats by 1919 (Lichatowich 1999).

For many years tribal fishing rights throughout the Pacific region had been eroded by Euro-American fishing interests, backed by the power of the state. By the late 1950s, Native Americans in the Northwest were taking less than 5% of the harvest but continued to be resented and blamed for the declining runs. In 1969 Judge Robert Belloni affirmed the right of treaty Native Americans in Oregon to “a fair and equitable share of all fish.” In 1974, Judge George Boldt ruled that treaty Native American tribes in Washington were entitled to 50% of the available harvest in their "usual and accustomed areas" (Taylor 1999). In 1993, the DOI Office of the Solicitor issued an opinion requiring that 50% of the allowable harvest of Klamath-Trinity salmon be reserved for the Yurok and Hoopa Valley tribes (U.S. Department of the Interior 1993). In 1977, four Columbia River tribes with treaty fishing rights formed the Columbia River Inter-Tribal Fish

Commission to coordinate management. Today, Columbia River fisheries are managed by Oregon, and Washington state agencies and Columbia River treaty tribes under the Columbia River Compact. Puget Sound fisheries are jointly managed by Western Washington treaty tribes and the state of Washington. The Yurok Tribe and Hoopa Valley Tribe in northern California manage their own fisheries. Native American tribes are actively represented on the Pacific Fishery Management Council and Council advisory committees.

Northwest treaty tribes continue to actively pursue their right to harvest fish. In Washington State, the current major legal debate centers on whether treaty tribes have the right to the existence of salmon at all, and therefore the right to maintain healthy salmon habitat – which stretches from open ocean to mountain streams. Court rulings are so far in the tribes' favor. Note that with the potential to require landscape-wide habitat protection across all jurisdictions, the treaty fishing right is possibly the most powerful legal tool available to protect salmon habitat in this region—even more powerful than the Endangered Species Act, which is effectively limited to federal jurisdictions (Lombard 2006, Blumm and Steadman 2009). Note also that with the Boldt and Belloni decisions, the treaty right to take fish would protect the non-tribal half of salmon harvest from habitat destruction, as well (Breslow 2014b).

Commercial salmon fishing is now conducted in the ocean by trollers equipped with fish-finding sonar, radio communications and global positioning systems, and Native American gillnetters in Puget Sound and the Klamath/Trinity River. Combined tribal and non-tribal commercial salmon landings have declined since the mid-1980s, although ex-vessel value has generally increased since 2000 (Figure S15). The divergence between the landing and revenue trends is largely due to price increases over the past decade.

Since 1981, landings have generally been highest in the Native American sector of the salmon fishery and lowest in the commercial troll sector (Figure S16). Revenues have followed a similar pattern since the mid-2000s but show a less consistent pattern in previous years (Figure S17).

Since 1981, salmon landings have been consistently and considerably higher in Puget Sound than in other regions (Figure S18). Revenues show a similar but less marked pattern (Figure 11), as the species composition of Puget Sound harvest tends toward lower-priced species.

Figure S20 shows a general decline in ex-vessel salmon prices from 1981 to the early 2000s, followed by a general increase. The increase is particularly marked for troll-caught Chinook. The "missing" prices for pink salmon reflect the fact that the pink salmon fishery is open every other year.

Figure S21 depicts major salmon ports, selected on the basis of average 1981-2012 ex-vessel salmon revenue (base year=2012). The fishery extends from central California to Washington, with troll gear predominating in coastal ports in California and Oregon, net gear predominating in Columbia River and Puget Sound ports, and both gears used in coastal Washington ports. The mix of troll and net gears in Ilwaco and Neah Bay reflects the fact that both non-tribal commercial trollers and tribal gillnetters land in these ports. The importance of salmon relative to total fishing activity varies by port (Norman et al. 2007, Speir et al. 2014).

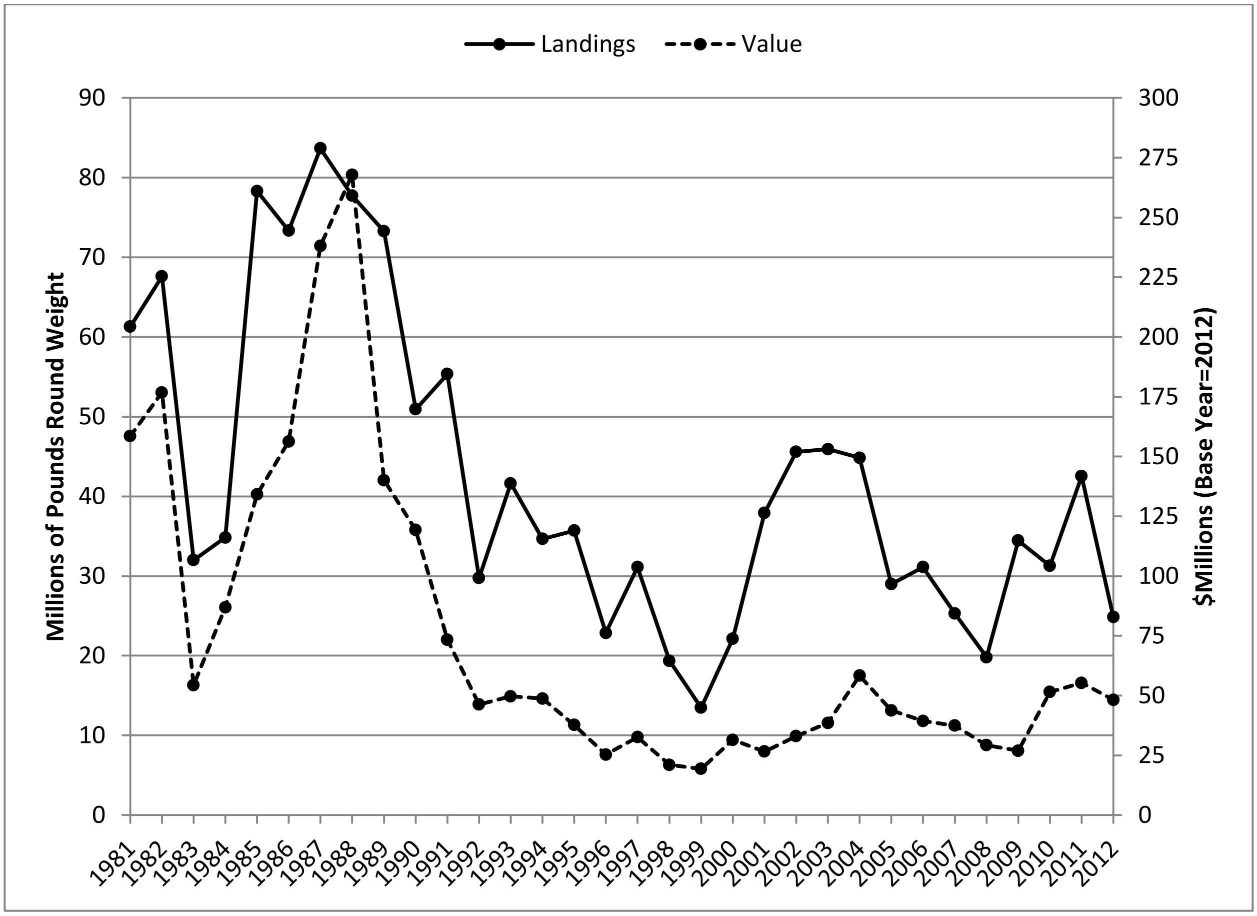

Figure S15. Landings and ex-vessel value (base year=2012) of tribal and non-tribal commercial salmon fisheries in California, Oregon and Washington, 1981-2012 (source: PacFIN).

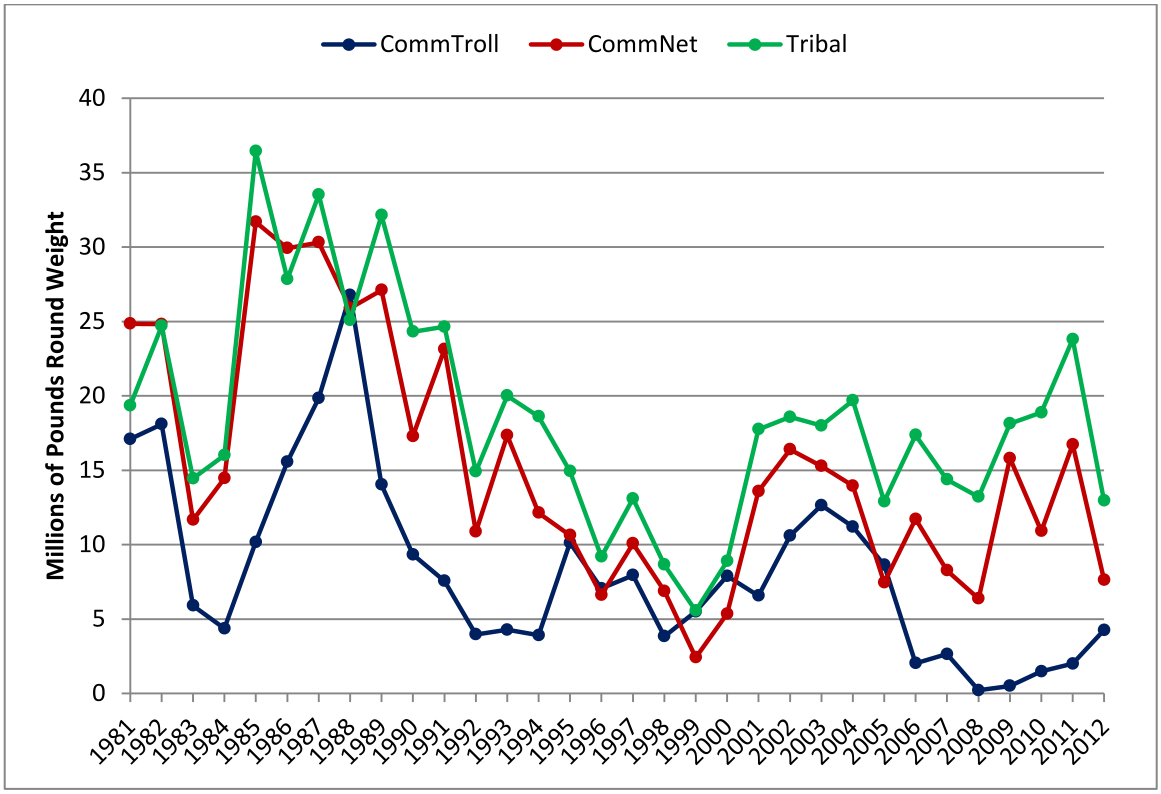

Figure S16. Coastwide tribal and non-tribal commercial salmon landings, by fishery sector, 1981-2012, combined for the three states (source: PacFIN).

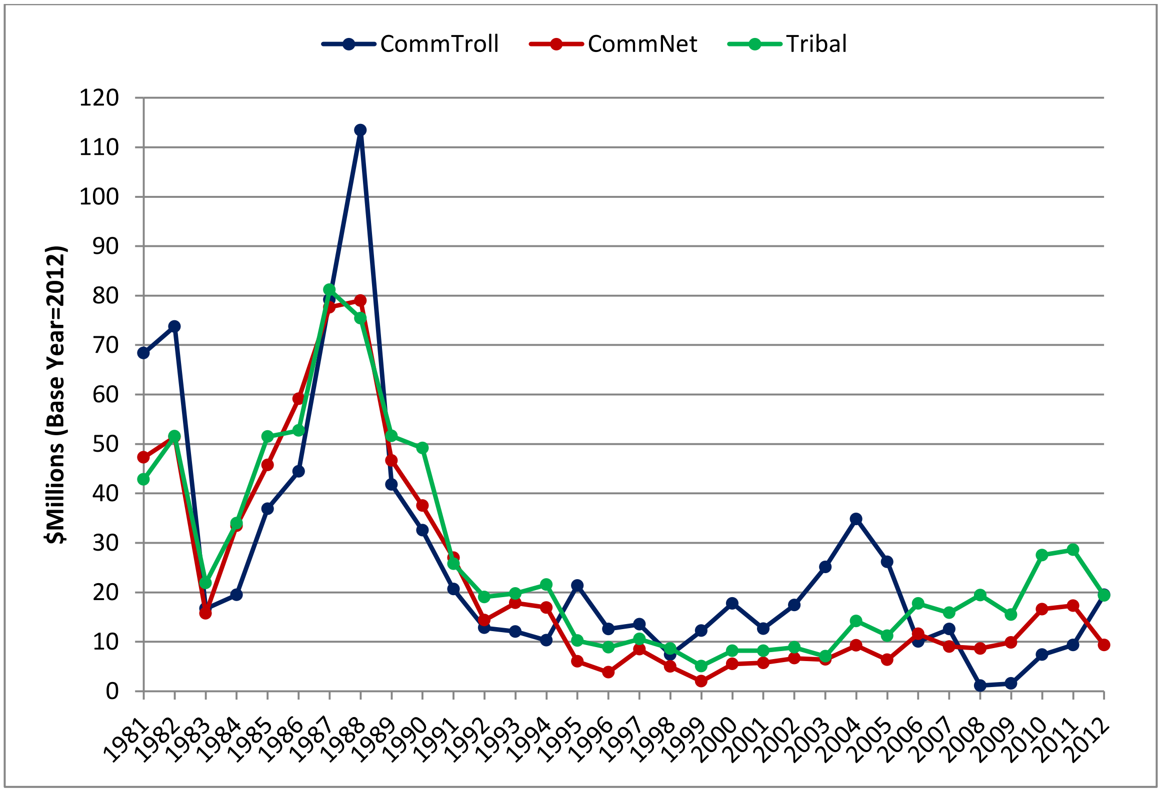

Figure S17. Ex-vessel value of coastwide tribal and non-tribal commercial salmon landings (base year=2012), by fishery sector, 1981-2012, combined for the three states (source: PacFIN).

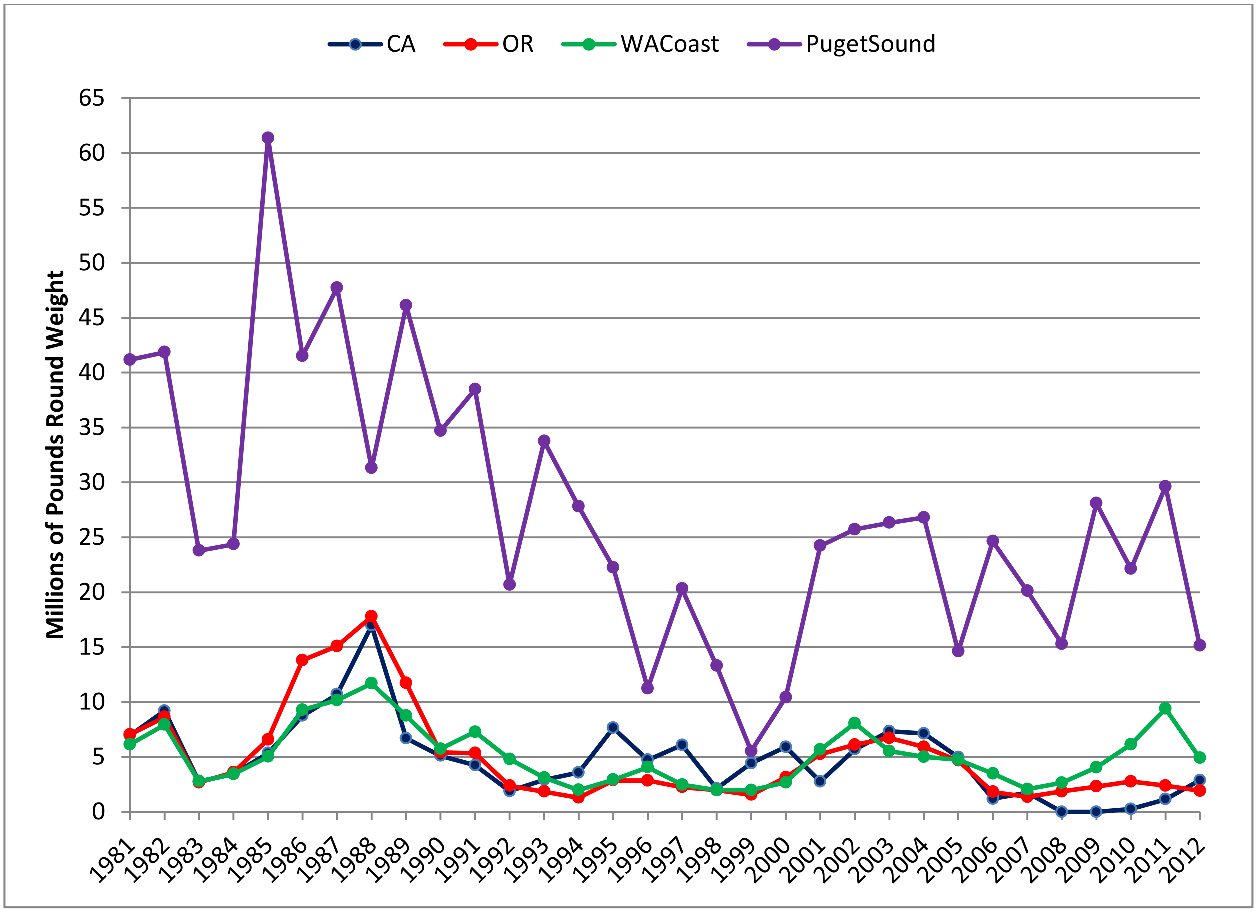

Figure S18. Tribal and non-tribal commercial salmon landings, by region, 1981-2012 (source: PacFIN).

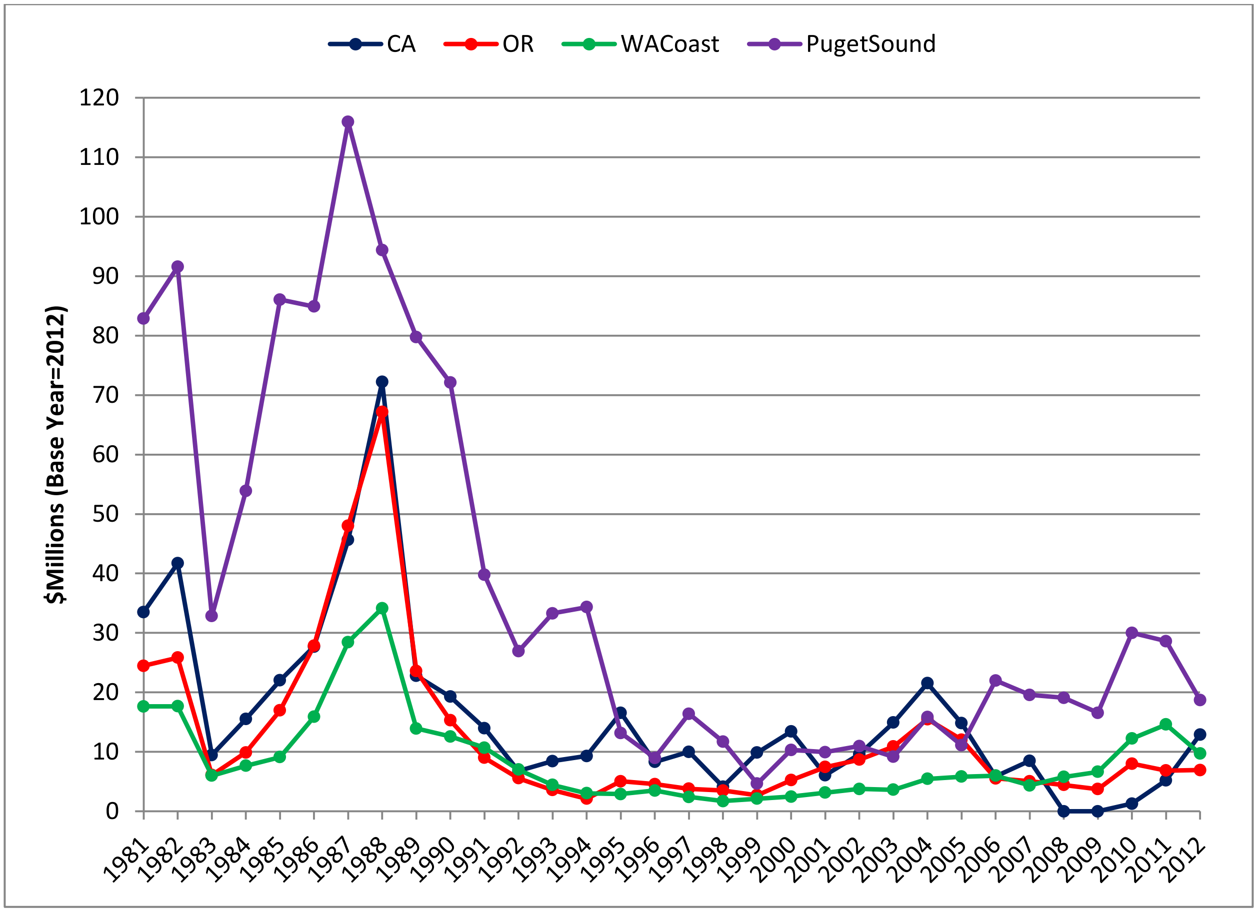

Figure S19. Ex-vessel value of tribal and non-tribal commercial salmon landings (base year=2012), by region, 1981-2012 (source: PacFIN).

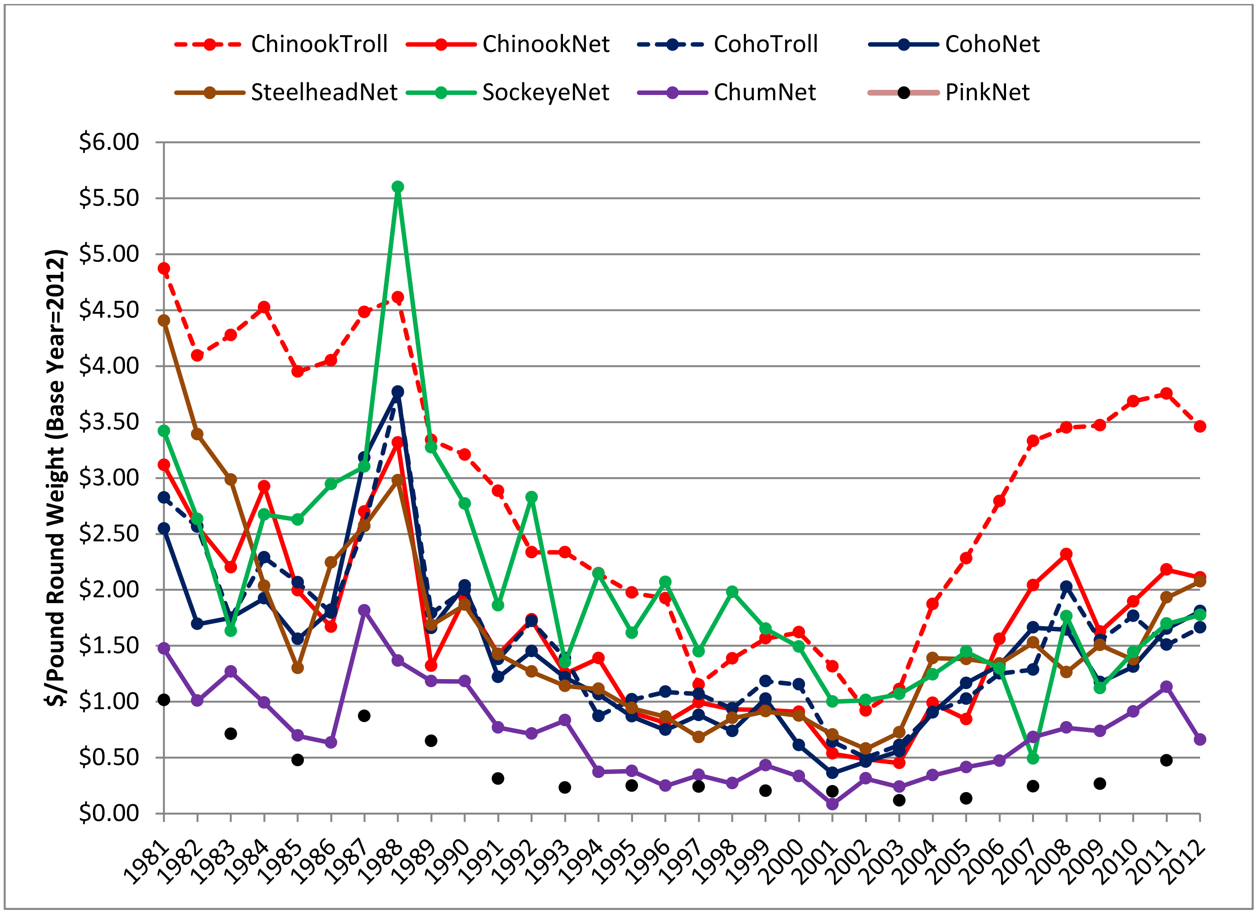

Figure S20. Ex-vessel prices of major commercial salmon stocks (base year=2012), 1981-2012, combined for the three states (source: PacFIN).

Figure S21. Major commercial salmon ports, based on average 1981-2012 ex-vessel revenue (base year=2012) (source: PacFIN).

RECREATION, TOURISM, EDUCATION, VOLUNTEERISM, MANAGEMENT, RESEARCH

Recreation, tourism, education, volunteerism, management and research are rich areas of wellbeing related to salmon and will be discussed in more detail in future iterations of the CCIEA. Salmon are an important part of the cultural heritage of the Northwest (Lichatowich 1999). Fishing, agriculture, hatcheries, and dams provide recreational as well as commercial opportunities. Recreational salmon fisheries occur both in river and in the ocean. Agricultural and fishing communities and organizations sponsor events such as salmon, garlic, artichoke and apple festivals. Farmers markets and wine tasting are venues for recreation and tourism as well as consumer purchases. Hatcheries provide tours and exhibits that educate the public regarding the salmon life cycle. People visit rivers as well as hatcheries to watch salmon spawn. Dam operators provide reservoir recreation and dam tours; dam operations also indirectly affect the timing and location of river recreation due to effects on the river's flow regime. People join organizations such as fishing clubs and 4-H, and volunteer for river cleanups and other habitat restoration activities. A large research establishment – including federal and state agencies, educational institutions (including land grant and sea grant universities), and private entities – conducts research relevant to the understanding, management and improvement of agriculture, fisheries and forestry. The complex challenge of salmon recovery has required new forms of social organization and cooperation, and has also engendered passionate debates among diverse communities in the region who are grappling with how to ensure that salmon, fishing, and other resource-based livelihoods can survive in an increasingly globalized economy and urbanizing landscape (Breslow 2014a).

HUMAN POPULATION TRENDS

Figure S22 describes population growth in the Pacific states during 1850-2010. Estimates for the earlier decades only partially reflect the Native American population, as Native Americans were not fully enumerated in the U.S. Census until 1890. Diseases brought by Euro-Americans had already caused an 80-90% decrease in the Native American population by the late 1850s (National Research Council 1995). Additional Native American mortality resulted from conflicts with the U.S. Army and white settlers, and loss of traditional modes of subsistence (Harden 1996).

Population trends (reflecting births, deaths and net migration) since 1850 represent the cumulative effect of many factors – e.g., climate and weather, natural resource abundance, economic opportunities, amenities and disamenities of various types (e.g., schools, traffic), aesthetic qualities – and are suggestive of the pressures exerted on a state's water resources. Many major metropolitan areas in the Pacific region (e.g., Willamette Valley, Puget Sound, Columbia Plateau, San Francisco Bay, Central Valley - Figure S24) are located on historical wetlands and/or near major rivers, tributary junctions and estuaries. According to Gregory and Bisson (1997), "Though forest practices and, to a much lesser degree, agricultural practices have drawn intense scrutiny resulting in more protective land-use regulations, urbanization and industrial development tend to cause the most extensive alternation of aquatic ecosystems." Population growth has been disproportionately high in California, as indicated by the growth and density trends in Figures S22 and S23. In drought-prone California, population growth exacerbates longstanding and heated conflicts over water. Due to the large water storage and conveyance systems that link the entire state, salmon is affected by population pressures even in areas well outside the range of its habitat.

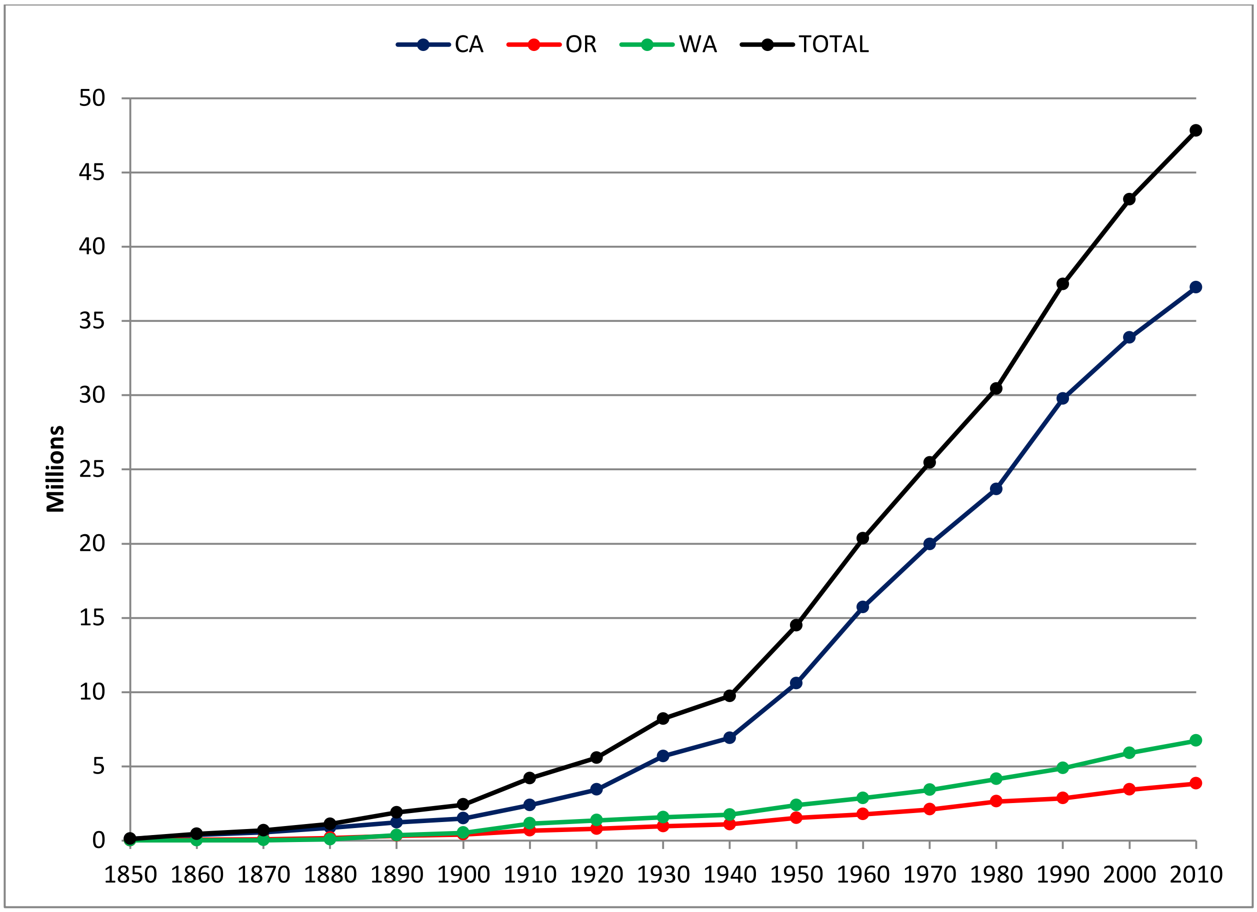

Figure S22. U.S. population by state and total all states, 1850-2010 (source: U.S. Census).

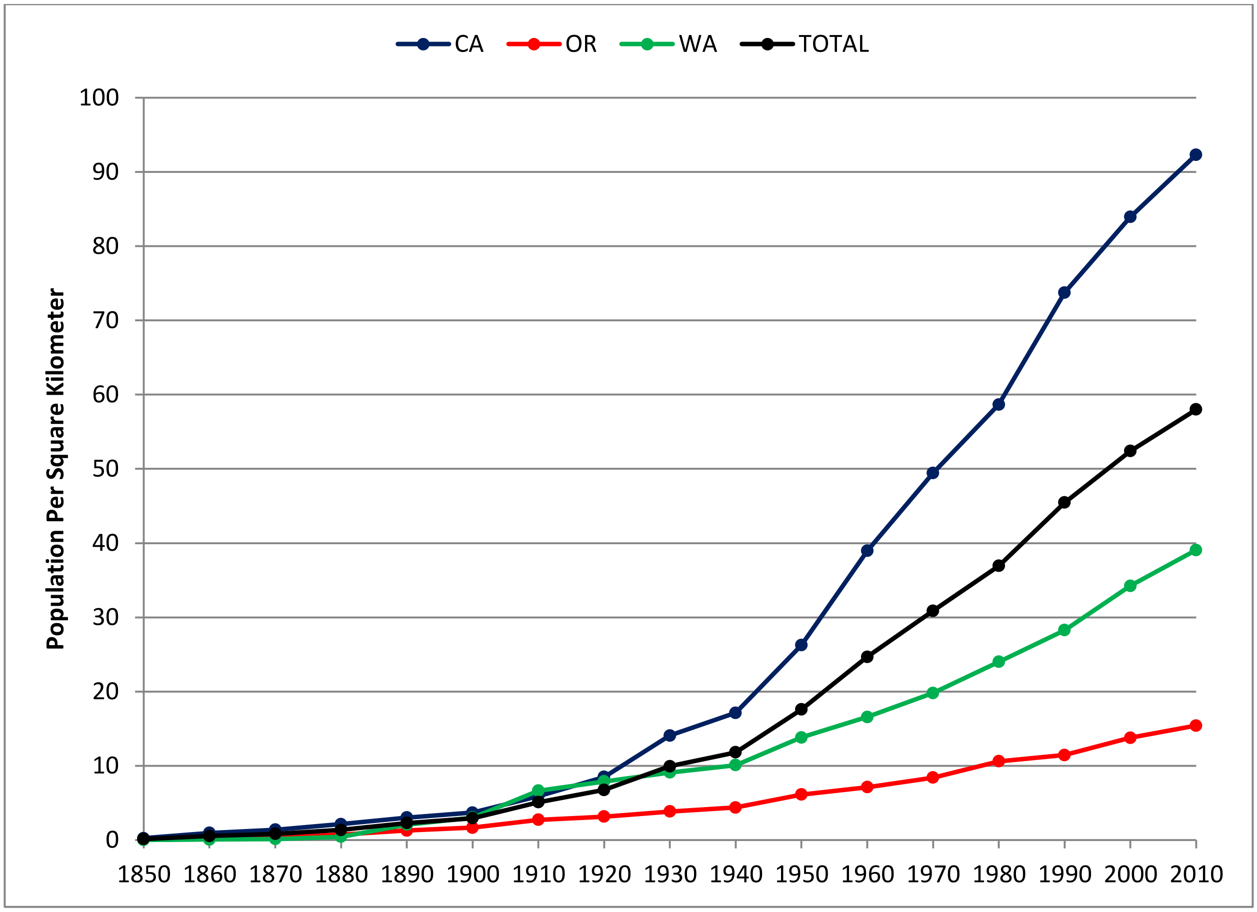

Figure S23. Population density (population per square kilometer) by state and total all states, 1850-2010 (source: U.S. Census).

Figure S24. Counties categorized by Rural-Urban Continuum Code (1= county in metro areas of 1 million population or more, 2= county in metro areas of 250,000 to 1 million population, 3= counties in metro areas of fewer than 250,000 population, >3=county in non-metro areas) (source: USDA Economic Research Service).

SUMMARY AND NEXT STEPS FOR INTEGRATING THE HUMAN DIMENSION

Salmonid populations and habitat have been influenced by dynamic interactions between natural landscape features (e.g., resource abundance, climate, topography) and human activities such as fur trading, mining, logging, agriculture, dams, hatcheries and fisheries. Historical development of these activities was largely driven by economic interests and encouraged by robust market demand and prices, improvements in extractive and processing technologies and transportation, and expansionist government policies. Most of these activities (other than fur trading) continue to the present day in some form. Public policies have changed over time, from an ethos of laissez faire resource extraction to one that also considers effects of extraction on wild salmon populations and the habitat and ecological processes that affect salmon and steelhead. Such policy shifts reflect a recognition of salmon and salmon habitat as components of human values and well-being.

Most of the quantitative information provided in this section pertained to outputs from commercial activities (e.g., timber production, agricultural values, salmon harvest). Additional work is needed to consider other indicators that are inclusive of other aspects of human well-being. An important next step toward operationalizing the CCIEA is to identify goal(s) that managers wish to achieve by considering salmon in a CCIEA framework, as those goals will affect model specification and the types of indicators appropriate for inclusion in the model.

CCIEA PHASE IV: NEXT STEPS

At this point of the CCIEA, salmon indicators have been developed for quantifying the status of a number of Chinook salmon and coho salmon populations across the California Current. We have, in this current iteration of the CCIEA, explored the potential effects of current and future environment on Chinook salmon and coho salmon populations. We also examined the temporal, spatial and demographic aspects of resource uses that interact with salmon populations. In the next iteration of the CCIEA, Phase IV, we will examine how various management strategies across the environmental and resource needs landscape may potentially affect salmon populations. Specifically, we are developing salmon life-cycle models across the California Current that can be used to simulate the potential responses by the salmon populations and to human well-being under a suite of potential management scenarios including but not limited to hatchery practices, river flow management, and fishery regulations. As well, in future reports we will include status and trends of steelhead salmon.

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