In Cooperation with the National Park Service

Preliminary Data Summary for "Synthesizing Vital Signs Data from Klamath and San Francisco Bay Area Networks: Analysis of Linkages and Trends in Climate, Stream Flow, Vegetation, Salmon, and Ocean Conditions"

By Mary Ann Madej, Alicia Torregrosa, Andrea Woodward

U.S. Department of the Interior
U.S. Geological Survey

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Contents

Abstract 6

Introduction 7

Objectives 11

Data Compilation and Standardization 16

Air Temperature 16

Fog 22

Precipitation 23

Stream Flow 24

Stream Temperature 33

Modeled Climate and Hydrology Data 35

Land Use 38

Salmon Populations 41

Future Work: Vital Sign Linkages 43

Precipitation and air temperature 43

Air temperature, stream temperature and stream flow 43

Precipitation and stream flow 44

Regime shifts 44

Background Literature 46

Appendix A: Stream Flow Metrics from USGS gaging records 50

Appendix B. Example of stream flow metrics from IHA analysis in rivers near SFAN 56

List of Figures

Figure 1. Conceptual model of of linkages among long-term data sets available from both NPS and other sources for the SFAN and KLMN area. Note that many linkages are not represented in this conceptual diagram, such as disturbance effects on streams, ocean effects on fog, and habitat changes on the prairie falcon. 9

Figure 2. Simplified representation of the climate-stream-salmon system. The Climate-Atmosphere box has three strongly interacting sub-components, precipitation, air temperature and fog. Likewise the Streams box has three interacting sub-components. In addition to the investigating the linkages between the three sub-components, the project team is analyzing linkages indicated by arrows. 13

Figure 3. Vital sign indicator metrics and linkages for the climate-streams-salmon system. Boxes highlighted in yellow identify the vital sign indicators that were the focus of this year's investigation. 14

Figure 4. Maximum average air temperature in August at Kentfield, California and generalized for Point Reyes National Seashore. 18

Figure 5. Minimum average air temperature in January at Crescent City, California and generalized for Redwood National Park. 19

Figure 6. Average September precipitation through time in REDW. 24

Figure 7. Mean daily discharge at Redwood Creek and San Geronimo Creek, California. 30

Figure 8. Comparison of mean daily discharge at two nearby gaging stations, Redwood Creek and San Geronimo Creek, Marin County, California. 31

Figure 9. 7-day minimum flow at Redwood Creek at Orick, from 1952 to 2009. 32

Figure 10. Maximum weekly average stream temperature (MWAT) for three stations on Redwood Creek. Distances are listed as River kilometers (Rkm) upstream of the mouth. 33

Figure 11. Maximum daily stream temperature vs. maximum daily air temperature in lower Redwood Creek, REDW. ... 34
Figure 12. Maximum daily stream temperature vs. maximum daily air temperature in upper Redwood Creek, REDW. ... 35
Figure 13 Point Reyes National Seashore and selected adjacent watersheds. Watersheds coded with grey symbols do not have stream gage data to assess the accuracy of Basin Characteristic Model output. ... 37
Figure 14. Larry Damm watershed in (A) 1964 (pre-logging); (B) 1973 (post-logging); and (C) 2009 (post-restoration). ... 39
Figure 15. Changes in land cover in the Larry Damm watershed, Redwood National Park (compiled by Sharon Powers and Judy Wartella, Redwood National Park) ... 40
Figure 16. Juvenile salmonid counts at Upper Redwood Creek smolt trap. Data from Michael D. Sparkman, California Department of Fish and Game, Arcata, CA. ... 42

Tables

Table 1. Average Maximum Air Temperature at Park Units and Selected Stations, by Month ... 20
Table 2. Average Minimum Air Temperature at Park Units and Selected Stations, by Month ... 21
Table 3. P-values of PRISM regression of monthly precipitation through time, generalized for REDW and PORE. Values in bold are significant at the 10% level. ... 23
Table 4. List of gaging stations used in hydrologic analyses ... 26
Table 5. Examples of IHA paprameters and their ecosystem influences (from Indicators of Hydrologic Alteration Version 7.1 User's Manual) ... 28
Table 6 Timeline of events at Point Reyes National Seashore with potential to alter conditions in streams harboring coho salmon. ... 41

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Abstract

This report includes a summary of data compilation and standardization as part of the project "Synthesizing Vital Signs Data from Klamath and San Francisco Bay Area Networks: Analysis of Linkages and Trends in Climate, Stream Flow, Vegetation, Salmon, and Ocean Conditions." Average monthly air temperature and precipitation data were compiled for 73 climate stations in or near to Redwood National Park, Golden Gate National Recreation Area (GOGA), Point Reyes National Seashore (PORE), and Muir Wood National Monument (MUWO). These monthly data were then generalized for the areas within park boundaries and were tested for statistically significant trends through time. Daily stream flow data from 56 rivers and streams in or near these park units were compiled and metrics of magnitude, duration, and timing of flows were calculated. Summer stream temperature data from Redwood Creek in Redwood National Park were compiled and compared with maximum and minimum air temperatures. The California Department of Fish and Game and the National Park Service provided preliminary data on salmonid populations and on changes in vegetation detected through remote sensing. Because data checking and statistical analyses are still in progress, no

interpretation of the data sets and linkages are included in this preliminary data summary. but future work will use these data sets in modeling trends through time.

Introduction

The Klamath (KLMN) and San Francisco Bay Area (SFAN) networks of national parks span the Pacific coast of northern California and Oregon. In this region, daily, seasonal, and decadal variation in abiotic drivers (e.g., precipitation, fog, stream flow, and temperatures of air, ocean, and streams) regulate many ecological processes, including the distribution of vegetation and wildlife and frequency of disturbances from fires, floods, landslides, and biotic pests. However, the exact nature of the linkages between abiotic drivers and the direct and indirect effect of these drivers on species of concern and their habitat are not well understood. Specifically, abiotic drivers are commonly analyzed as individual elements (i.e., calculating mean annual precipitation) and the linkages between drivers (such as the influence of changes in stream flow on stream temperature) are poorly defined.

In addition to understanding the basic linkages between abiotic and biotic ecosystem elements, the question of climate change is of increasing concern to land managers in the national parks. They need to understand how climate change has already affected natural resources and whether other changes may be looming. Without this understanding it is increasingly difficult to judge the effects of management efforts (e.g., stream restoration), evaluate the resilience of existing habitats, or plan future management actions. Climate change has been linked to more rain and less snow in the Sierras (Cayan and others 2008), identifying the need for management to address long-term water storage. In contrast, there has been a paucity of information depicting the effects of natural climatic cycles and anthropogenic climate change, aside from sea level rise, in coastal California and Oregon including KLMN and SFAN (Suffling and Scott 2002, Hayhoe and others 2006).

Complicating a manager's ability to respond to climate change effects is the common assumption of stationarity – the idea that natural systems fluctuate within an unchanging envelope of variability (Milly et al., 2008). The stationarity assumption is being compromised by major shifts in background environmental conditions. As a result, the timing, magnitude and intensity of critical abiotic elements in national park units may be changing. In addition, the common assumption that restoration planning can use historical reference conditions as a goal may not be valid if extrinsic drivers in national parks display non-stationarity. Consequently, the understanding of trends, variability, and interactions among abiotic drivers is needed to inform and prioritize restoration sites or activities and to implement scenario planning to foster strategic thinking about future conditions and management alternatives.

Numerous long-term data sets are being collected by SFAN and KLMN as part of the vital signs monitoring program. They represent management concerns and ecologically important constituents of park ecosystems. In discussions with NPS staff, we identified the NPS data sets, other data sets available from other agencies, and created a conceptual model of their linkages (Figure 1) as the basis for designing an integrative data analysis. Further discussion of network priorities and concerns led us to salmon-related data and linkages as a feasible subset for focus.

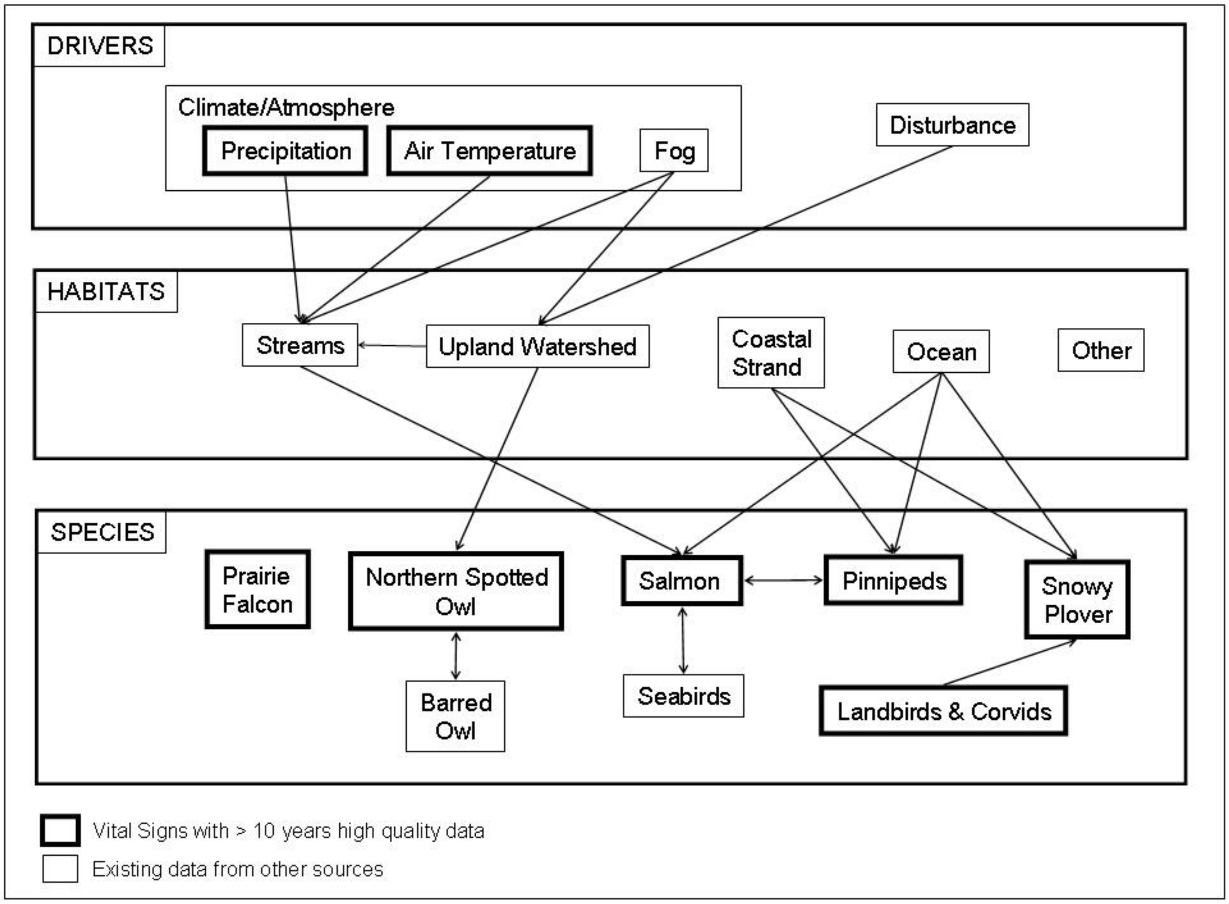

Figure 1. Conceptual model of of linkages among long-term data sets available from both NPS and other sources for the SFAN and KLMN area. Note that many linkages are not represented in this conceptual diagram, such as disturbance effects on streams, ocean effects on fog, and habitat changes on the prairie falcon.

In central and northern California, several salmon populations have been in decline for years. In 1997, coho salmon *(Oncorhynchus kisutch)* were federally listed as threatened in the Southern Oregon/Northern California Evolutionary Significant Unit, including Redwood National Park (REDW), and as endangered in the Central California Coast Evolutionary Significant Unit, including SFAN park units: Golden Gate National Recreation Area (GOGA), Point Reyes National Seashore (PORE), and Muir Wood National Monument (MUWO). Millions of dollars are being spent in coastal parks on watershed and stream restoration projects.

As the NPS plans salmon restoration activities in coastal watersheds, it is critical to understand the abiotic factors and interactions that affect salmonid populations (MacCall and Wainwright 2003, Battin *et al*., 2007).

Our current project will help park managers prioritize restoration activities that have a high probability of success. Linking abiotic data to biological information on riparian habitats and salmon will enhance park management by providing insight into some of the subtle changes influencing the ecosystem. Specifically, managers will be able to understand local salmon population trends within a context of regional salmon population patterns, habitat restoration efforts, anthropogenic modifications (i.e. dams), stream flow, ocean conditions, and climate change including extreme climatic events. The results, for example, could provide some insight regarding whether habitat restoration is enough to counteract the trends imposed by climate change. Similarly, by linking climate change with riparian habitats, we may also be able to tease out current and expected habitat changes due other large scale disturbances such as Sudden Oak Death (SOD), prevalent at both Golden Gate National Recreation Area and Point Reyes National Seashore and recently detected in Redwood National Park.

In addition to influencing management decisions, evaluating short and long-term effects of climate variability on park vital signs and analyzing the effects on biotic indicators will serve as a model for synthetic data analysis. The long-term monitoring programs being established at KLMN and SFAN focus on a variety of vital signs with protocols detailing how measures are collected and how data will be analyzed to detect trends (Sarr *et al.*, 2007, Adams *et al.*, 2006). Although it is a goal, a synthetic approach for analyzing multiple datasets has not been developed. This project will provide a statistical framework for analyzing datasets from multiple vital signs within and across networks.

National Parks are also recognized by adjacent jurisdictions and other agencies as an important resource of monitoring data representing protected ecological systems. Creating institutional linkages that enhance ongoing research and monitoring in parks and elsewhere will not only provide a larger landscape context for site specific actions but also increase the value of a vital signs warehouse. This synthesis can therefore augment other efforts to build linkages with other agencies such as the Bay Area Early Detection Network (BAEDN) which was formed among private and public land management agencies in the San Francisco area to share data and information relating to invasive plant species.

Objectives

Objectives of this project include:

- Identify trends in climate drivers and disturbance regimes that may be having local and regional effects on salmon populations in relevant units of KLMN and SFAN using multivariate statistics and structural equation modeling.
- Exploit the latitudinal gradient of environmental conditions and variety of management contexts among park units to discern relationships and provide a regional view.
- Inform management decisions, including restoration planning, in the face of potential non-stationarity of system drivers by the response of multiple salmon life-history stages to novel ranges of variability.
- Identify gaps in NPS data sets and recommend modifications to the vital signs monitoring program.

- Continue an interactive relationship with NPS staff at all stages of the project: data sets acquisition, data analysis, interpretation of results, development of potential structural equation models, and dissemination of results.
- Provide NPS with tools and a framework for synthetic analysis of multiple sets of monitoring data from NPS while also taking advantage of other sources.

Close consultation with NPS staff determined that the subset of vital sign measures that had the greatest potential for synthesis was the climate-stream-salmon system (Figure 2). A brief description of the important relationships in this system begins with climate, a high priority vital sign for both KLMN and SFAN, which has strong direct linkages to stream condition by determining water input. Variation in precipitation, modulated by land cover, is an indirect geomorphic driver throughout the watershed determining stream flow which in turn affects channel erosion, sedimentation, and water quality. Air temperature variations, as a surrogate for solar radiation, are strongly linked to stream temperatures, which have been shown to be correlated to summer survival of salmonids. Water temperature and flow are also influenced by shade and input of large woody debris from riparian vegetation. Many forms of disturbance (e.g., fire, flooding, diseases, timber harvest) cause abrupt changes in land cover, including riparian and upland vegetation, as well as in physical attributes of stream habitat. An important driver of more gradual change in upland vegetation is fog, which determines the distribution of redwood forests. Fog, in turn, is a function of ocean temperature and atmospheric circulation patterns. Finally, various stage of the salmon life cycle are affected by the characteristics of freshwater and ocean habitats (Laufle *et al*., 1986; Bettelheim, 2000). This complex system cannot be understood using univariate or correlational analysis alone.

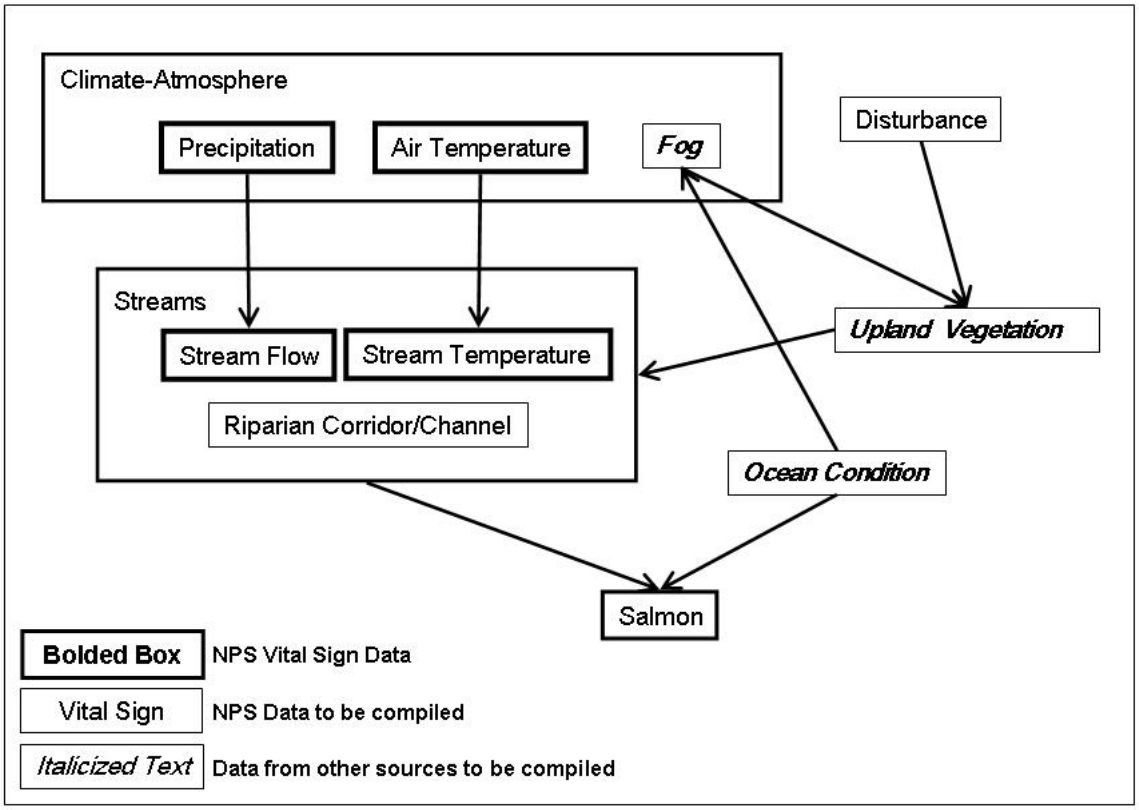

Figure 2. Simplified representation of the climate-stream-salmon system. The Climate-Atmosphere box has three strongly interacting sub-components, precipitation, air temperature and fog. Likewise the Streams box has three interacting sub-components. In addition to the investigating the linkages between the three sub-components, the project team is analyzing linkages indicated by arrows.

Full implementation of vital signs synthesis for the climate-stream-salmon system includes six major categories of activities: compilation and standardization of data –both NPS and other sources; development of time series metrics for each of the nine components of the vital sign synthesis (Figure 3); analysis of linkages between time series metrics of measures within a vital sign (represented by two sets of 3 boxes in Figures 2 and 3), analysis of linkages between vital signs (represented by arrows in Figures 2 and 3); conversion of linkages –in the form of statistical relationships– into structured equation models (SEM); and conceptual model development and refinement. The last category is an ongoing activity that occurs throughout the project and serves two important goals: 1) facilitate decisions about the appropriate metrics to incorporate into the analyses based on the end goal of providing usable results, and 2) ensure strong collaboration and communication through the use of a visual, continuously updated and expanded conceptual model framework.

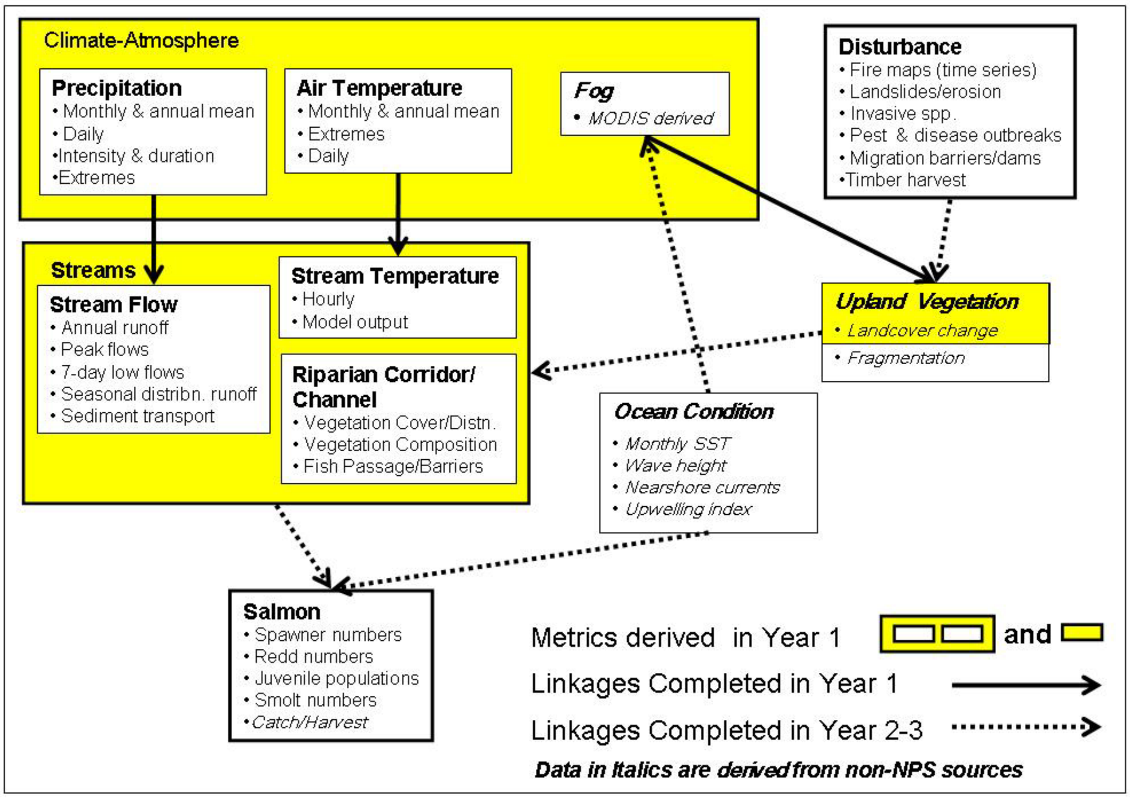

Figure 3. Vital sign indicator metrics and linkages for the climate-streams-salmon system. Boxes highlighted in yellow identify the vital sign indicators that were the focus of this year's investigation.

This report provides a summary of data compilation and trend analysis to date. Data for the climate-stream-salmon system synthesis from NPS are in the form of vital sign measures and other data sets that are not specifically incorporated into the vital sign database (for example, archival timber harvest data). Based on the structure of the datasets, data transformations may be necessary to meet assumptions of statistical analyses or have the same spatial scale for comparable analysis. These transformations can take many forms: spatial and temporal aggregations or disaggregation; normalizing statistical distributions of sample data; log transformations and scale transfers (Bierkens *et al*., 2000).

Because data checking and statistical analyses are still in progress, no interpretation of the data sets and linkages are included in this preliminary data summary. In the coming year, linkage analysis will be applied to various metrics. Analysis of relationships between measures in different indicator boxes such as between precipitation and stream flow or air temperature and stream temperature are identified by arrows in Figure 2.

StreamStats*, a USGS program, was used to calculate stream flow statistics as well as basin characteristics. We used another software program, the Indicators of Hydrologic Alteration (IHA), to compute additional metrics regarding base flow, flow variability, and flood pulses. IHA was developed by The Nature Conservancy. Stream flow metrics compiled include annual runoff, daily mean flow, peak flows, 7-day low flows, timing of channel-scouring flows, and seasonal distribution of runoff. Annual and monthly mean precipitation and annual and monthly mean air temperature were examined for temporal trends. Plots of cumulative departures from the mean identified relatively wet and dry periods, and hot and cold periods. Standard nonparametric analysis (Gilbert 1987) will be used to test significance of trends. Temporal Analyst* (a time series data management program for ArcGIS; www.temporal-analyst.com) was used to process and display precipitation, temperature, and stream flow data within a spatial context on a regional scale.

* Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Data collected by NPS for coho salmon in Redwood Creek (KLMN) and Redwood Creek (SFAN) includes life cycle measures for each year class (juveniles, smolts, and spawners), numbers of nest sites (redds), mortality index, and a measure of observer efficiency. This last measure will be particularly important in autocorrelation analyses between age classes (Shea and Mangel, 2000). To develop methodologies that will be useful for coho salmon time series analysis for NPS staff, additional data from the California Department of Fish and Game and the NMFS Southwest Fisheries Science Center database covering brood years of 1986 – 2019 were used.

Data Compilation and Standardization

Air Temperature

Many climate stations within and around the parks have been recording general climatic data for periods ranging from ten to nearly 100 years. As part of this project, we contracted with the PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Group at Oregon State University, Corvallis, Oregon, to summarize air temperature and precipitation data for the four National Park units involved in this study: Redwood, Golden Gate, Point Reyes, and Muir Woods. The purpose of this collaboration was to determine temporal trends in core climatic parameters at all suitable historical climate stations with the boundaries or near these park units. Thirty-one stations were used in the Redwood analyses, and 42 stations were included in the Bay Area analyses. The full suite of data and temporal trends can be accessed at: *http://gisdev.nacse.org/prism/klamath/*

PRISM values of air temperature and precipitation are the values of grid cells (about 800 m x 800 m) which lie within park boundaries. Station values are measurements made at a specific point, and park values take into account all stations that are within park boundaries. We show examples of output in the following figures. For example, values for average maximum air temperature in August are available for the Kentfield climate station near Point Reyes (Station 044500) from 1903 to present (Figure 4, blue line). The PRISM analysis uses these data as well as data from adjacent stations, to compute an average trend in air temperature for the area of Point Reyes (red line) and a moving five-year average (black line). The regression equation describes the overall trend for PORE, and in this example, the increase in the average maximum temperature in August through time is statistically significant at the 10% level (p-value = < 0.001). Because the Kentfield station is farther inland than much of Point Reyes National Seashore, temperatures are, as expected, higher at the Kentfield station. Average maximum air temperatures in August at Point Reyes show a significant increase through time.

In another example, from Redwood National Park, Figure 5 plots the average minimum air temperatures for January for the Crescent City station (blue line) and Redwood National Park (red line). In this case there is no significant change over the last century. Tables 1 and 2 list the results for similar temporal trend analyses for each month for the park units and selected nearby climate stations. P-values that are significant at the 10% level are in bold.

Additional daily air temperature data were compiled for stations within the park units. At this point, the short periods of record (usually less than 10 years) precludes a rigorous time series analysis. Nevertheless, as the parks continue to collect data, these data sets will become more valuable over the long term and are useful for site-specific studies.

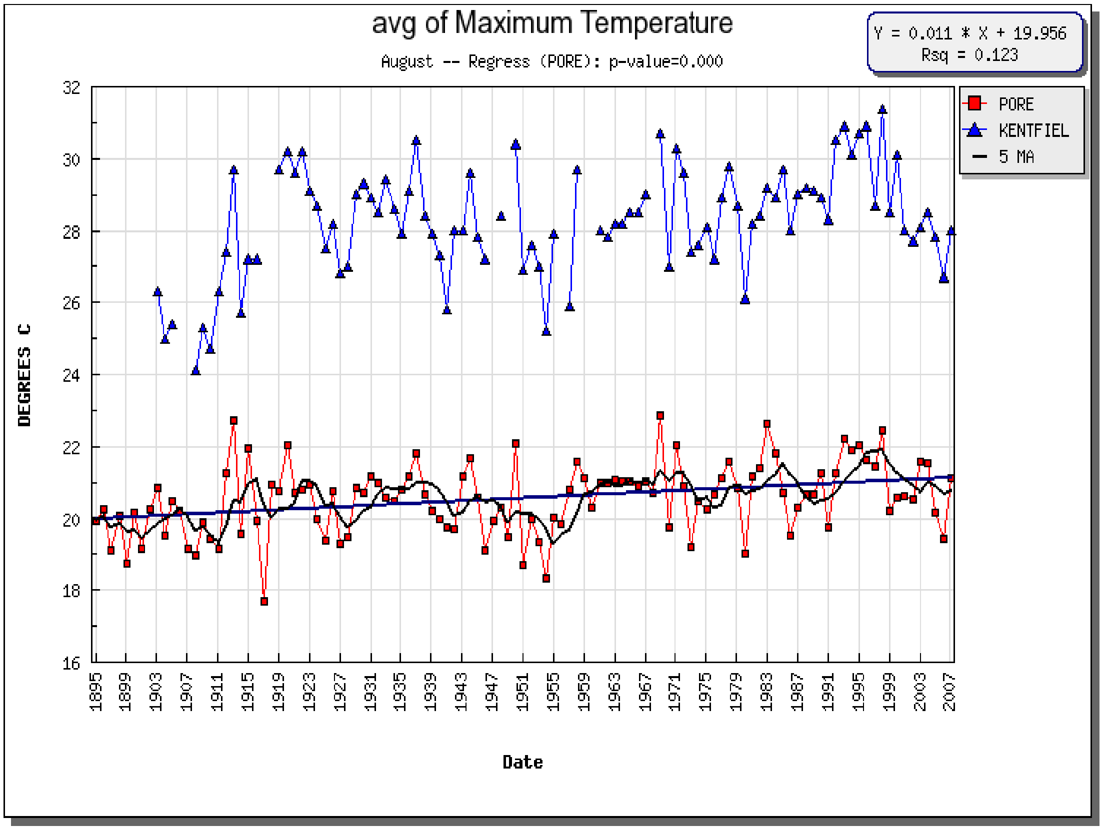

Figure 4. Maximum average air temperature in August at Kentfield, California and generalized for Point Reyes National Seashore.

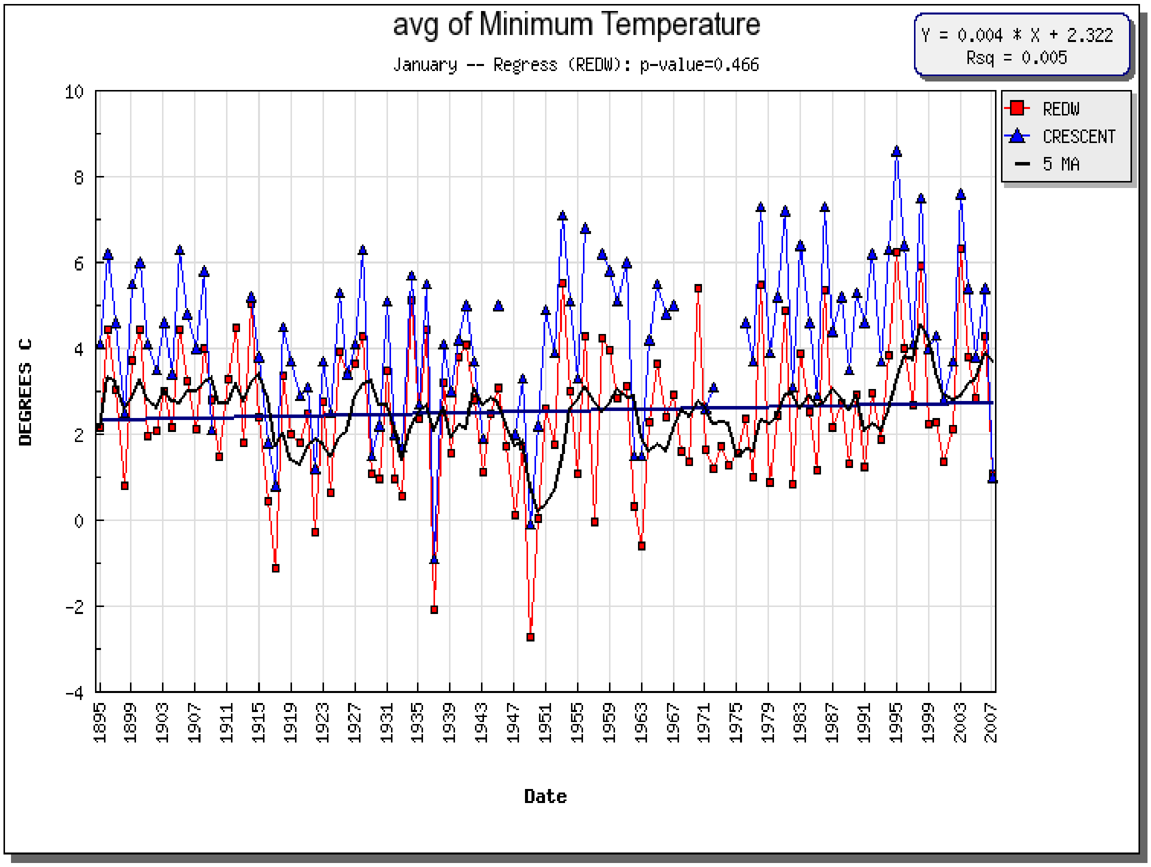

Figure 5. Minimum average air temperature in January at Crescent City, California and generalized for Redwood National Park.

Table 1. Average Maximum Air Temperature at Park Units and Selected Stations, by Month

	P-values at Park Unit or Station										
Period of Record	REDW 1895-2007	GOGA 1895-2007	PORE 1895-2007	Brookings 1914-2001	Crescent City 1895-2007	Eureka 1942-2007	KACV 1961-2007	Klamath 1950-2004	Orick 1937-2006	Orleans 1903-2007	Kentfield 1902-2007
January	**0.095**	**<0.001**	**0.002**	0.152	**0.095**	**0.095**	**0.095**	**0.096**	0.105	**0.095**	**<0.001**
February	0.700	**0.007**	**0.019**	0.626	0.700	0.700	0.700	0.563	0.700	0.700	**0.007**
March	0.692	**0.010**	**0.034**	0.608	0.692	0.692	0.692	0.902	0.692	0.692	**0.010**
April	**0.027**	0.152	0.123	**0.052**	**0.027**	**0.027**	**0.027**	**0.055**	**0.027**	**0.027**	0.152
May	0.960	**0.002**	**0.002**	0.923	0.960	0.960	0.960	0.916	0.960	0.960	**0.002**
June	0.257	0.923	0.626	0.345	0.257	0.257	0.257	0.336	0.296	0.257	0.923
July	0.854	0.538	0.406	0.315	0.854	0.854	0.854	0.495	0.685	0.854	0.538
August	0.214	**<0.001**	**<0.001**	0.278	0.214	0.214	0.214	0.403	0.275	0.214	**<0.001**
September	0.578	**0.005**	**0.006**	0.217	0.578	0.578	0.578	0.193	0.408	0.578	**0.005**
October	0.243	**0.001**	**0.003**	0.633	0.243	0.243	0.243	0.611	0.408	0.243	**0.001**
November	**0.022**	0.443	0.762	**0.039**	**0.022**	**0.022**	**0.022**	**0.022**	**0.022**	**0.022**	0.443
December	0.843	**0.042**	0.187	0.852	0.843	0.843	0.843	0.954	0.843	0.843	**0.042**

***Bold** indicates a p-value of ≤ 0.10

Table 2. Average Minimum Air Temperature at Park Units and Selected Stations, by Month

P-values at Park Unit or Station

Period of Record	1895-2007	1895-2007	1895-2007	1914-2001	1895-2007	1942-2007	1961-2007	1950-2004	1937-2006	1903-2007	1902-2007
	REDW	GOGA	PORE	Brookings	Crescent City	Eureka	KACV	Klamath	Orick	Orleans	Kentfield
January	0.466	0.187	0.172	0.838	0.466	0.466	0.466	0.473	0.488	0.466	0.187
Feburary	0.809	0.122	**0.087**	0.657	0.809	0.809	0.809	0.734	0.809	0.809	0.122
March	0.487	**0.029**	**0.007**	0.667	0.487	0.487	0.487	0.435	0.487	0.487	**0.029**
April	0.647	**0.056**	**0.006**	0.508	0.647	0.647	0.647	0.572	0.647	0.647	**0.056**
May	0.600	**<0.001**	**<0.001**	0.718	0.600	0.600	0.600	0.852	0.600	0.600	**<0.001**
June	0.205	**<0.001**	**<0.001**	0.415	0.205	0.205	0.205	0.324	0.159	0.205	**<0.001**
July	0.270	**<0.001**	**<0.001**	0.824	0.270	0.270	0.270	0.676	0.462	0.270	**<0.001**
August	**0.087**	**<0.001**	**<0.001**	**0.092**	**0.087**	**0.087**	**0.087**	**0.068**	0.126	**0.087**	**<0.001**
September	0.659	**<0.001**	**<0.001**	0.300	0.659	0.659	0.659	0.429	0.705	0.659	**<0.001**
October	0.830	**0.001**	**<0.001**	0.932	0.830	0.830	0.830	0.909	0.827	0.830	**0.001**
November	0.557	**0.031**	**0.022**	0.677	0.557	0.557	0.557	0.551	0.495	0.557	**0.063**
December	0.800	**0.018**	**0.034**	0.441	0.800	0.800	0.800	0.633	0.800	0.800	**0.018**

***Bold** indicates a p-value of ≤ 0.10

Fog

Summers in north coastal California are characterized by frequent summer fog, which influences several ecological properties. Fog reduces moisture stress on plants, and moderates fluctuations in air and stream temperatures. The spatial distribution of modern coast redwoods (*Sequoia sempervirens)* is strongly associated with the presence of summer fog along the Pacific coast of California. In this Mediterranean climate, summer fog, through fog drip from the canopy to the root zone, can provide critical water to redwoods during the dry summer period (Azevedo and Morgan, 1974; Ewing *et al*., 2009; Ingraham and Matthews, 1995; and Oberlander, 1956).

Summer fog frequency is statistically correlated with the ocean temperature patterns of the Pacific Decadal Oscillation (PDO) and the wind-driven upwelling system of the California Current (Johnstone and Dawson, 2010). Fog frequency is highest in north and central California and declines in Oregon and Southern California. Mean fog frequency in the California region, quantified by cloud ceiling height measured at airports, has decreased since 1951, with interannual and multidecadal variation related to phases of the PDO (Johnstone and Dawson, 2010).

Although trends in summer fog patterns are consistent on a regional scale (from Monterey to Arcata, Johnstone and Dawson, 2010), local variations occur which may affect site-specific studies, such as stream temperature monitoring. For example, maximum air temperature for August through October increased at PORE and GOGA, but there was not a significant increase through time at REDW (PRISM Climate Group, 2009, and Table 1).

Precipitation

The PRISM group also developed precipitation statistics for this Vital Signs project. There has not been a significant change in monthly or annual precipitation values at Redwood National Park or Point Reyes National Seashore, except for September (Table 3). September values for REDW are shown in Figure 6. Even though precipitation is highly variable, the decreasing trend is statistically significant. Additional precipitation data are available from park-operated stations, but the period of record (< 10 years) is too short to conduct time series analyses.

Table 3. P-values of PRISM regression of monthly precipitation through time, generalized for REDW and PORE. Values in bold are significant at the 10% level.

	REDW	PORE
Jan	0.601	0.121
Feb	0.142	0.897
Mar	0.810	0.659
Apr	0.632	0.482
May	0.329	0.431
Jun	0.777	0.794
Jul	0.952	0.694
Aug	0.205	0.242
Sep	***0.020***	***0.084***
Oct	0.961	0.861
Nov	0.663	0.579
Dec	0.135	0.175
Annual	0.514	0.772

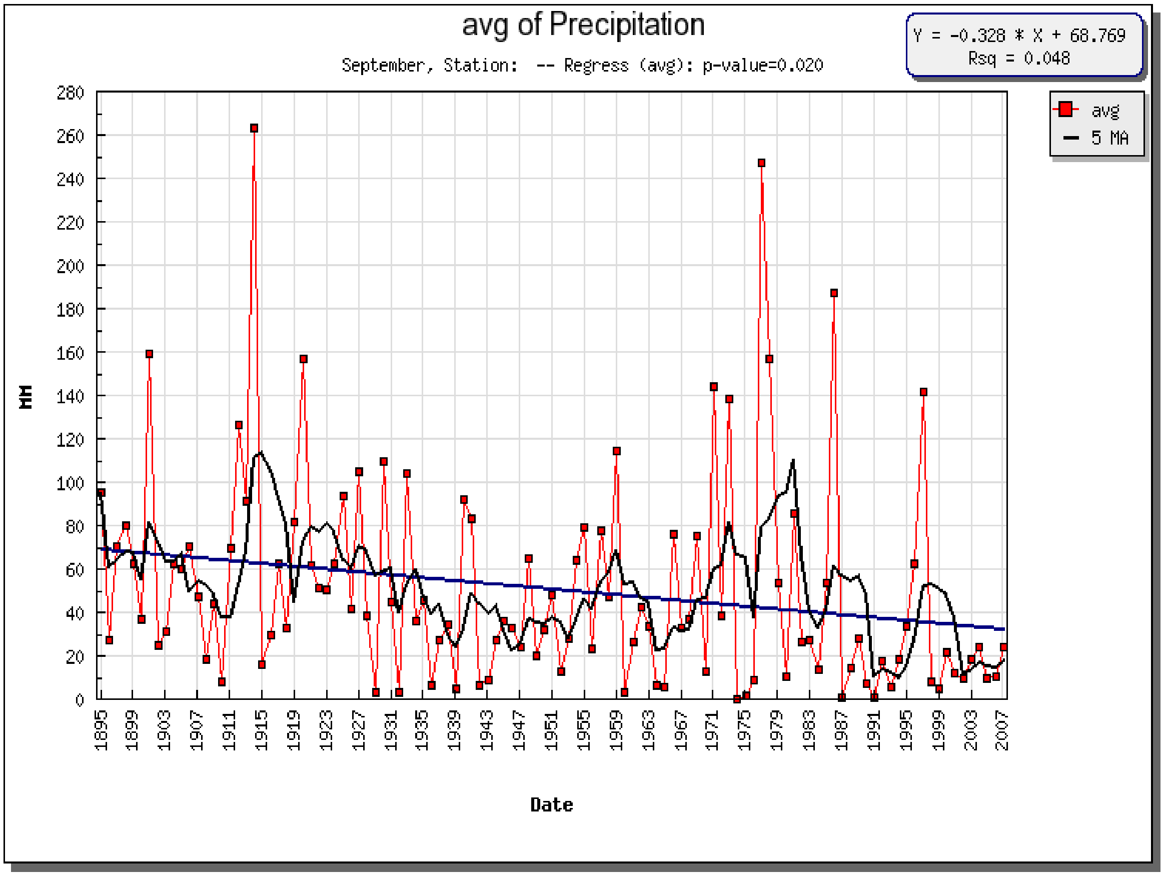

Figure 6. Average September precipitation through time in REDW.

Stream Flow

Daily mean stream discharge values for 56 USGS and NPS gaging stations in or near national park units were compiled and analyzed (Table 4). We computed several metrics which may have biological significance: magnitude of peak flow, timing of peak flow, timing of the 25th, 50th, and 75th percentile of annual runoff, the 7-day, 30-day and 90-day maximum and minimum flows, mean annual flows, and mean monthly flows. We tested if there was a statistically significant trend through time, and p-values of those tests are listed in Appendix A. Gaging stations with dams or diversions cannot be used to examine trends related to climate, but the information may still be of interest to resource managers who need to know trends in water availability. We used the software program “Indicators of Hydrologic Alteration” to compute additional metrics regarding base flow, flow variability, and flood pulses. This software program, developed by The Nature Conservancy (*http://conserveonline.org/workspaces/iha*, accessed 8-5-2010) examines 66 relevant statistics derived from daily hydrologic data (Table 5), representing 33 measures of central tendency and 33 measures of dispersion (Poff *et al.*, 2006). Results from each station cover several pages, and in total encompass more than 200 pages for all the stations we analyzed. Consequently, the full set of results is not included in this report, but will be posted on the USGS web site when this project is completed. An example of results from rivers in the San Francisco Bay area is shown in Appendix B.

Table 4. List of gaging stations used in hydrologic analyses

Station Name	USGS Station Number	Period of Record - WY	County	Contributing Drainage Area (miles^2)	Dams or diversions? (x=yes blank=no)
Alamo Creek at Dublin CA	11174500	10/1/1914-9/30/1920	Alameda	38.7	
Alamo Creek nr Pleasanton CA	11174600	8/30/1979-9/30/1983	Alameda	40.8	
Arroyo Corte Madera del Presidio at Mill Valley CA	11460100	10/1/1965-9/30/1986	Marin	4.69	X
Arroyo Nicasio nr Point Reyes Station CA	11460500	10/1/1953-9/30/1960	Marin	36.6	X
Blue Creek nr Klamath CA	11530300	10/1/1965-9/30/1978	Humboldt	120	
Bull Creek near Weott CA	11476600	10/1/1960-present	Humboldt	28.1	X
Corte Madera Creek at Ross CA	11460000	4/1/1951-9/30/1993	Marin	18.1	X
Eel River bl Scott Dam nr Potter Valley CA	11470500	10/1/1922-9/30/2008	Lake	290	X
Eel River at Van Arsdale Dam nr Potter Valley CA	11471500	12/1/1909-9/30/2008	Mendocino	349	X
Eel River at Hearst CA	11472000	10/1/1910-9/30/1913	Mendocino	466	X
Eel River nr Dos Rios CA	11472150	10/1/1966-12/31/1994	Mendocino	528	X
Eel River ab Dos Rios CA	11472500	4/1/1951-9/30/1965	Mendocino	705	X
Eel River bl Dos Rios CA	11474000	1/25/1912-1/4/1966	Mendocino	1484	X
Eel River at Fort Seward CA	11475000	9/1/1955-present	Humboldt	2107	X
Eel River at Scotia CA	11477000	10/1/1910-present	Humboldt	3113	X
Eel River at Fernbridge CA	11479560	10/2/1989-6/8/2009	Humboldt	3614	X
Elder Creek near Branscomb Ca	11475560	10/1/1967-present	Mendocino	6.5	X
Indian Creek nr Happy Camp CA	11521500	12/15/1956-present	Siskiyou	120	X
Klamath River bl Iron Gate Dam CA	11516530	10/1/1960-present	Siskiyou	4630	X
Klamath River at Walker Br nr Klamath River CA	11517818	7/10/2002-9/15/2003	Siskiyou	5885	X
Klamath River nr Seiad Valley CA	11520500	10/1/1912-present	Siskiyou	6940	X
Klamath River nr Happy Camp CA	11521000	10/1/1911-9/30/1912	Siskiyou	7070	X
Klamath River at Orleans	11523000	10/1/1927-present	Humboldt	8475	X
Klamath River nr Klamath CA	11530500	10/1/1910-present	Del Norte	12100	X
Lacks Creek nr Orick	11482110	10/1/1980-9/30/2002	Humboldt	16.9	
Lagunitas Creek at Samuel P. Taylor State Park CA	11460400	12/21/1982-present	Marin	34.3	X
Lagunitas Creek nr Point Reyes Station CA	11460600	10/1/1974-present	Marin	81.7	X
Little Lost Man Creek a Site No. 2 nr Orick CA	11482468	6/27/1974-9/30/2008	Humboldt	3.46	
Little River nr Trinidad CA	11481200	10/1/1955-present	Humboldt	40.5	
Lobos Creek CA	374715122285601	10/1/2002-9/30/2008	San Francisco		
Mad River ab Ruth Res nr Forest Glen CA	11480390	6/20/1980-present	Trinity	93.8	
Mad River bl Ruth Res nr Forest Glen CA	11480410	10/1/1980-9/30/2008	Trinity	121	X
Mad River nr Forest Glen CA	11480500	10/1/1953-11/9/1994	Trinity	143	X
Mad River nr Kneeland CA	11480750	10/1/1965-9/30/1974	Humboldt	352	X
Mad River nr Blue Lake CA	11480780	12/1/1972-10/5/1976	Humboldt	393	X
Mad River nr Arcata CA	11481000	10/1/1910-present	Humboldt	485	X
Mattole River nr Ettersburg CA	11468900	6/21/2001-present	Humboldt	58.1	
Mattole River nr Petrolia CA	11469000	10/1/1911-present	Humboldt	245	
Middle Fork Smith River at Gasquet CA	11531000	10/1/1911-9/30/1965	Del Norte	131	
Mill Creek near Crescent City CA	11532620	1/16/1974-9/30/1981	Del Norte	28.6	
Morses Creek at Bolinas CA	11460160	6/1/1967-9/30/1969	Marin	0.7	
Napa River nr Napa CA	11458000	10/1/1929-present	Napa	218	X
North Fork Caspar Creek	U. S. Forest Service	11/11/1962-7/31/2004	Humboldt	473	
Novato Creek	11459500	10/1/1946-present	Marin	17.6	X
Panther Creek nr Orick CA	11482125	10/1/1979-9/30/1991	Humboldt	6.07	
Panther Creek nr Denny CA	11527550	2/11/1961-12/22/1964	Humboldt	5.66	
Pine Creek at Bolinas CA	11460170	6/1/1967-9/30/1970	Marin	7.83	
Prairie Creek above Boyes Creek-PAB	NPS	12/8/2003-9/30/2008	Humboldt	8.0	
Prairie Creek below Boyes Creek-PRL	NPS	2/14/1990-9/30/2002	Humboldt	6.4	
Prairie Creek above Brown-PRU	NPS	10/1/1989-9/30/2008	Humboldt	4.1	
Prairie Creek above May Creek-PRW	NPS	2/15/1990-9/30/2008	Humboldt	12.6	
Redwood Creek nr Blue Lake CA	11481500	10/1/1953-present	Humboldt	67.7	
Redwood Creek at Orick CA	11482500	9/1/1911-present	Humboldt	278	

Redwood Creek		11/20/97-9/30/03	Marin	7	
Russian River near Ukiah CA	11461000	10/1/1911-present	Mendocino	100	X
San Geronimo Creek	Balance Hydrologics	10/1/1979-9/30/2009	Marin		
South Fork Caspar Creek	U. S. Forest Service	11/2/1962-7/31/2004	Humboldt	424	
South Fork Eel River at Leggett CA	11475800	10/1/1965-10/1/2009	Mendocino	248	
South Fork Smith River nr Crescent City CA	11532000	10/1/1911-9/30/1979	Del Norte	291	
Smith River nr Crescent City CA	11532500	10/1/1931-present	Del Norte	614	
Smith River nr Fort Dick CA	11532650	10/21/1989-present	Del Norte	672	
Unnamed Trib. to Upper Abbotts Lagoon Point Reyes	380738122560701	2/6/1999-2/22/2001	Marin		?
Van Duzen River nr Dinsmore CA	11477500	10/1/1953-9/30/1974	Humboldt	85.2	
Van Duzen River at Bridgeville CA	11478000	10/1/1911-9/30/1951	Humboldt	202	
Van Duzen River nr Bridgeville CA	11478500	10/1/1950-present	Humboldt	222	
Walker Creek nr Marshall CA	11460750	10/1/1983-present	Marin	31.1	X
Walker Creek nr Tomales CA	11460800	7/1/1959-9/30/1984	Marin	40.1	X

Table 5. Examples of IHA parameters and their ecosystem influences (from Indicators of Hydrologic Alteration Version 7.1 User's Manual)

IHA Parameter Group	Hydrologic Parameters	Ecosystem Influences
1. Magnitude of monthly water conditions	Mean or median value for each calendar month *Subtotal 12 parameters*	• Habitat availability for aquatic organisms • Soil moisture availability for plants • Availability of water for terrestrial animals • Availability of food/cover for fur-bearing mammals • Reliability of water supplies for terrestrial animals • Access by predators to nesting sites • Influences water temperature, oxygen levels, photosynthesis in water column
2. Magnitude and duration of annual extreme water conditions	Annual minima, 1-day mean Annual minima, 3-day means Annual minima, 7-day means Annual minima, 30-day means Annual minima, 90-day means Annual maxima, 1-day mean Annual maxima, 3-day means Annual maxima, 7-day means Annual maxima, 30-day means Annual maxima, 90-day means Number of zero-flow days Base flow index: 7-day minimum flow/mean flow for year *Subtotal 12 parameters*	• Balance of competitive, ruderal, and stress- tolerant organisms • Creation of sites for plant colonization • Structuring of aquatic ecosystems by abiotic vs. biotic factors • Structuring of river channel morphology and physical habitat conditions • Soil moisture stress in plants • Dehydration in animals • Anaerobic stress in plants • Volume of nutrient exchanges between rivers and floodplains • Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments • Distribution of plant communities in lakes, ponds, floodplains • Duration of high flows for waste disposal, aeration of spawning beds in channel sediments

Table 5, continued

3. Timing of annual extreme water conditions	Julian date of each annual 1-day maximum Julian date of each annual 1-day minimum ___ *Subtotal 2 parameters*	• Compatibility with life cycles of organisms • Predictability/avoidability of stress for organisms • Access to special habitats during reproduction or to avoid predation • Spawning cues for migratory fish • Evolution of life history strategies, behavioral mechanisms
4. Frequency and duration of high and low pulses	Number of low pulses within each water year Mean or median duration of low pulses (days) Number of high pulses within each water year Mean or median duration of high pulses (days) ___ *Subtotal 4 parameters*	• Frequency and magnitude of soil moisture stress for plants • Frequency and duration of anaerobic stress for plants • Availability of floodplain habitats for aquatic organisms • Nutrient and organic matter exchanges between river and floodplain • Soil mineral availability • Access for waterbirds to feeding, resting, reproduction sites • Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
5. Rate and frequency of water condition changes	Rise rates: Mean or median of all positive differences between consecutive daily values Fall rates: Mean or median of all negative differences between consecutive daily values Number of hydrologic reversals ___ *Subtotal 3 parameters* ___ **Grand total 33 parameters**	• Drought stress on plants (falling levels) • Entrapment of organisms on islands, floodplains (rising levels) • Desiccation stress on low-mobility streamedge (varial zone) organisms

The stream flow data set for SFAN (Redwood Creek in Marin County) had periods of missing data and the period of record was too short (1997 to 2003) to complete a time-series analysis. We did compare flow records for comparable dates from Redwood Creek to a nearby stream, San Geronimo Creek, that is monitored by Balance Hydrologics, Inc. for the Marin Municipal Water District. General runoff patterns are similar for the two stations (Figure 7), but variability in mean daily discharge between the two stations is high (Figure 8). At this point we will not be able to use San Geronimo data as a surrogate for missing Redwood Creek data. In a similar vein, the gaging data from some of the streams in Redwood National Park had periods of missing data or outliers. We are working with park staff to check data quality, but we will not be able to run some of the hydrologic analyses on park data until data sets are complete. At present we are using data from USGS stations in or near parks for our analyses.

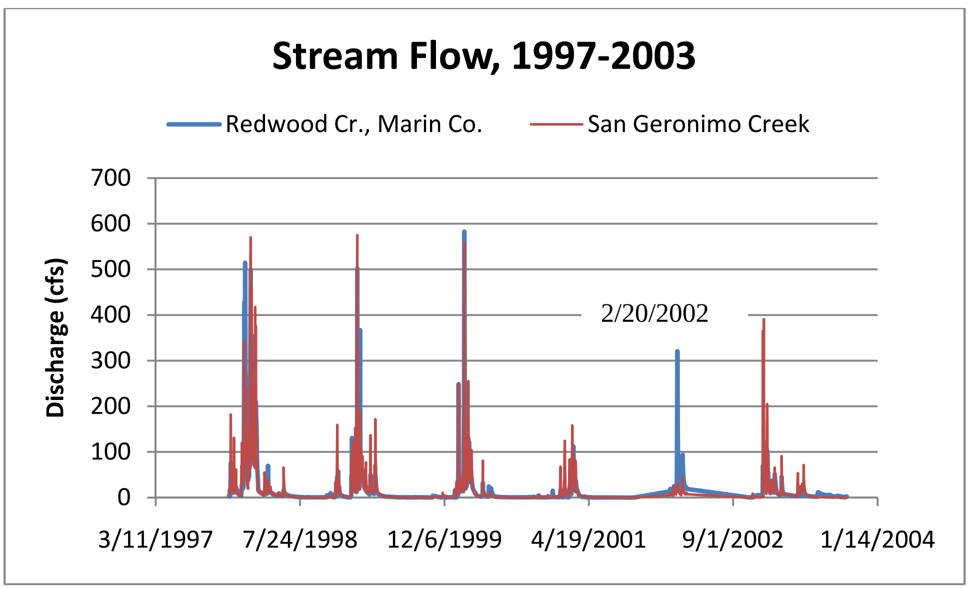

Figure 7. Mean daily discharge at Redwood Creek and San Geronimo Creek, California.

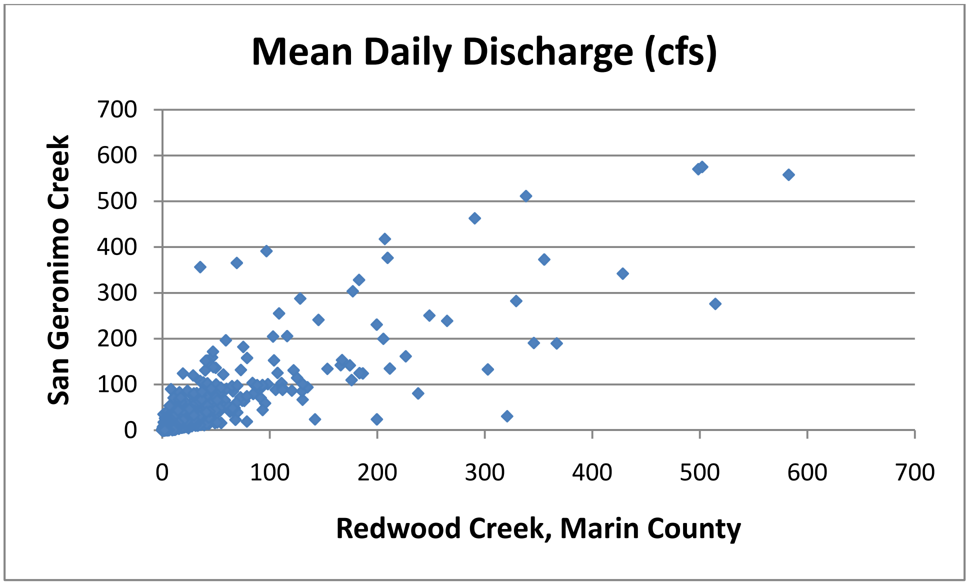

Figure 8. Comparison of mean daily discharge at two nearby gaging stations, Redwood Creek and San Geronimo Creek, Marin County, California.

Several stations show a significant decline in summer low flows. An example is shown in Figure 9. We will be investigating possible reasons for this decline in FY2011.

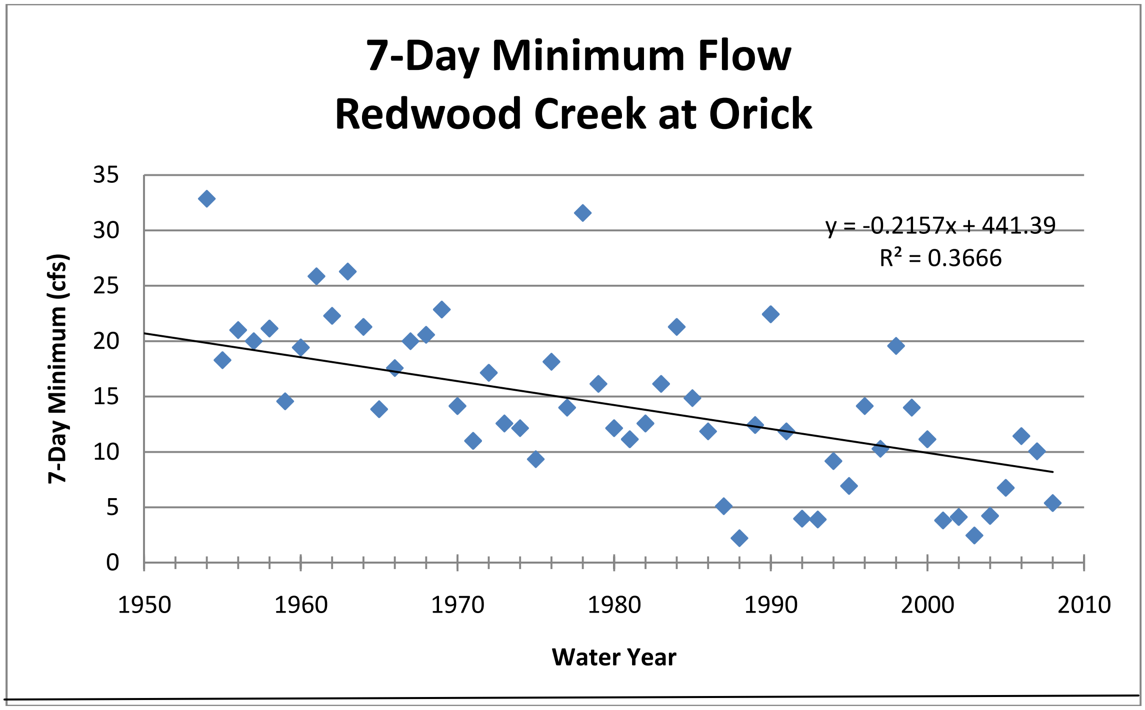

Figure 9. 7-day minimum flow at Redwood Creek at Orick, from 1952 to 2009.

Stream Temperature

Water temperature influences many aspects of a salmon's life cycle, including salmonid egg development, juvenile appetite and growth, and fish migration and distribution. Salmon rearing success during the summer can be limited if water temperature is elevated. Coho salmon *(Oncorhynchus kisutch)* prefer temperatures of <18° C (< 64° F). Redwood National Park and the California Department of Fish and Game (CDFG) have been monitoring summer stream temperatures in Redwood Creek since 1999. Unlike many rivers reported in the literature which get warmer as they flow downstream, Redwood Creek in Redwood National Park reaches its maximum temperature in the middle part of the watershed and becomes cooler farther downstream (Figure 10). Coastal fog and old-growth redwood trees in the riparian zone in the lower basin contribute to the cooling trend there (Madej *et al*., 2006).

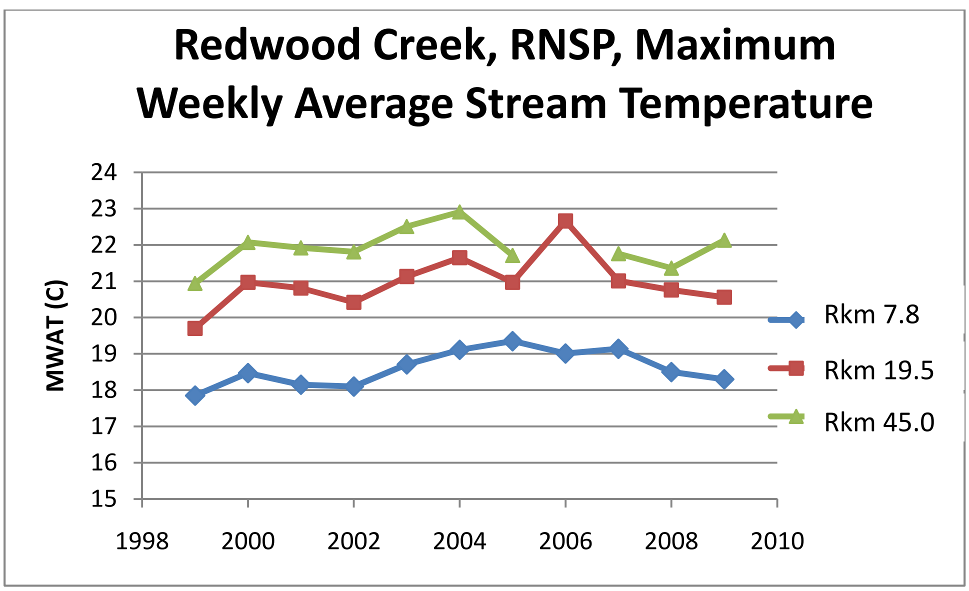

Figure 10. Maximum weekly average stream temperature (MWAT) for three stations on Redwood Creek. Distances are listed as River kilometers (Rkm) upstream of the mouth.

We compared stream temperature data to air temperature data, using air temperature as a surrogate for fog (Figures 11-12). Site-specific fog distribution data are not available, but Redwood National Park and CDFG do operate air temperature sensors in several locations along Redwood Creek. Summer air temperatures are cooler when fog is present. Stream temperatures are also dependent on stream flow, with cooler temperatures associated with higher stream flows. Our next step will be to incorporate daily stream flow values into the temperature analysis, in addition to air temperatures.

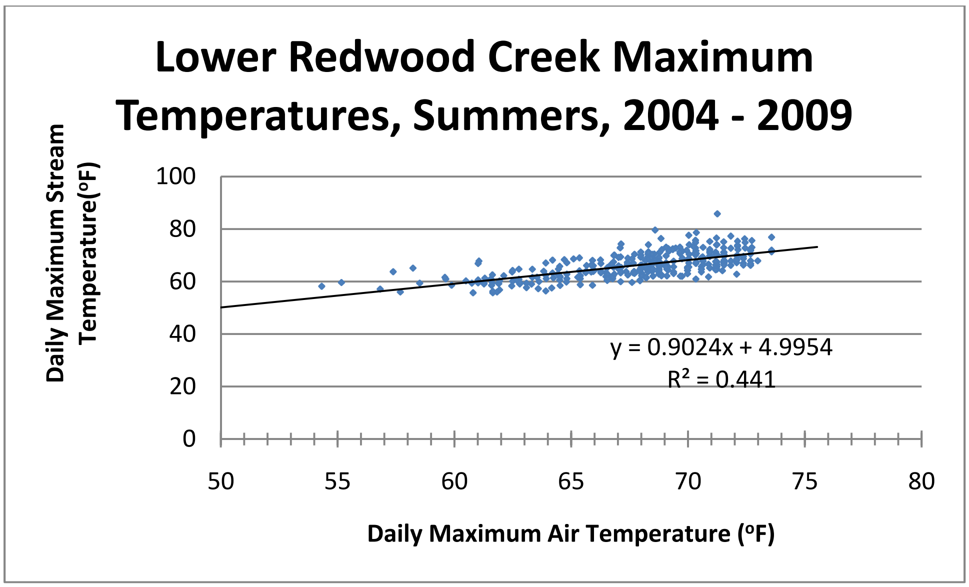

Figure 11. Maximum daily stream temperature vs. maximum daily air temperature in lower Redwood Creek, REDW.

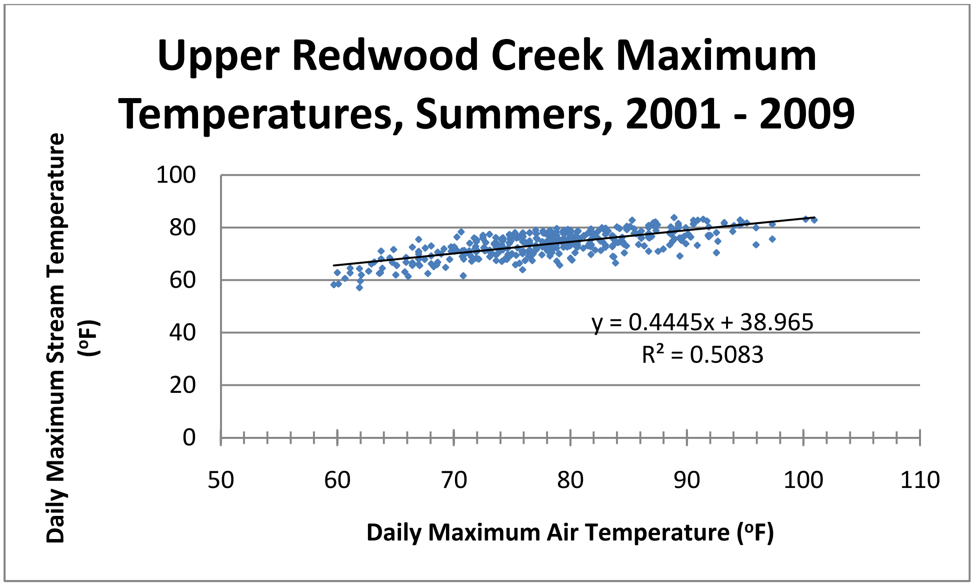

Figure 12. Maximum daily stream temperature vs. maximum daily air temperature in upper Redwood Creek, REDW.

Modeled Climate and Hydrology Data

To accommodate the lack of comprehensive data needed to conduct statistical analyses we examined the potential of using model derived datasets from water balance models. The Basin Characterization Model (BCM) is particularly promising (Flint and Flint, 2007) because the modeled output is showing very high statistical correlation with stream gage data from watersheds across Northern California (personal communication, Lorraine Flint). In addition, the correlation between modeled and observed stream temperatures along the Klamath River has also been high (Flint and Flint, 2008). Water agencies of the northern San Francisco Bay counties supported the development of the model output that is being described here (Figure 13). Model output is currently also available for western states and is being further developed to include future climate scenarios for North America with funding from the USGS Climate

Change Program. Thus the techniques we develop can be readily adapted by other NPS networks.

The BCM computes monthly values for potential evapotranspiration, soil-water storage, in-place ground-water recharge, and runoff (potential stream flow) for every grid cell under study, in this case each 270 m cell. The model uses digital representations of topography, soils, geology, vegetation, PRISM precipitation and air-temperature data, estimates for soil-water storage, saturated hydraulic conductivity of subsoil geological units, and calculations from solar radiation sub-models to take into account topographic shading, cloudiness, and vegetation density for the time-series outputs. From these computations, monthly climatic water deficit time-series show the increasing vulnerability of vegetation

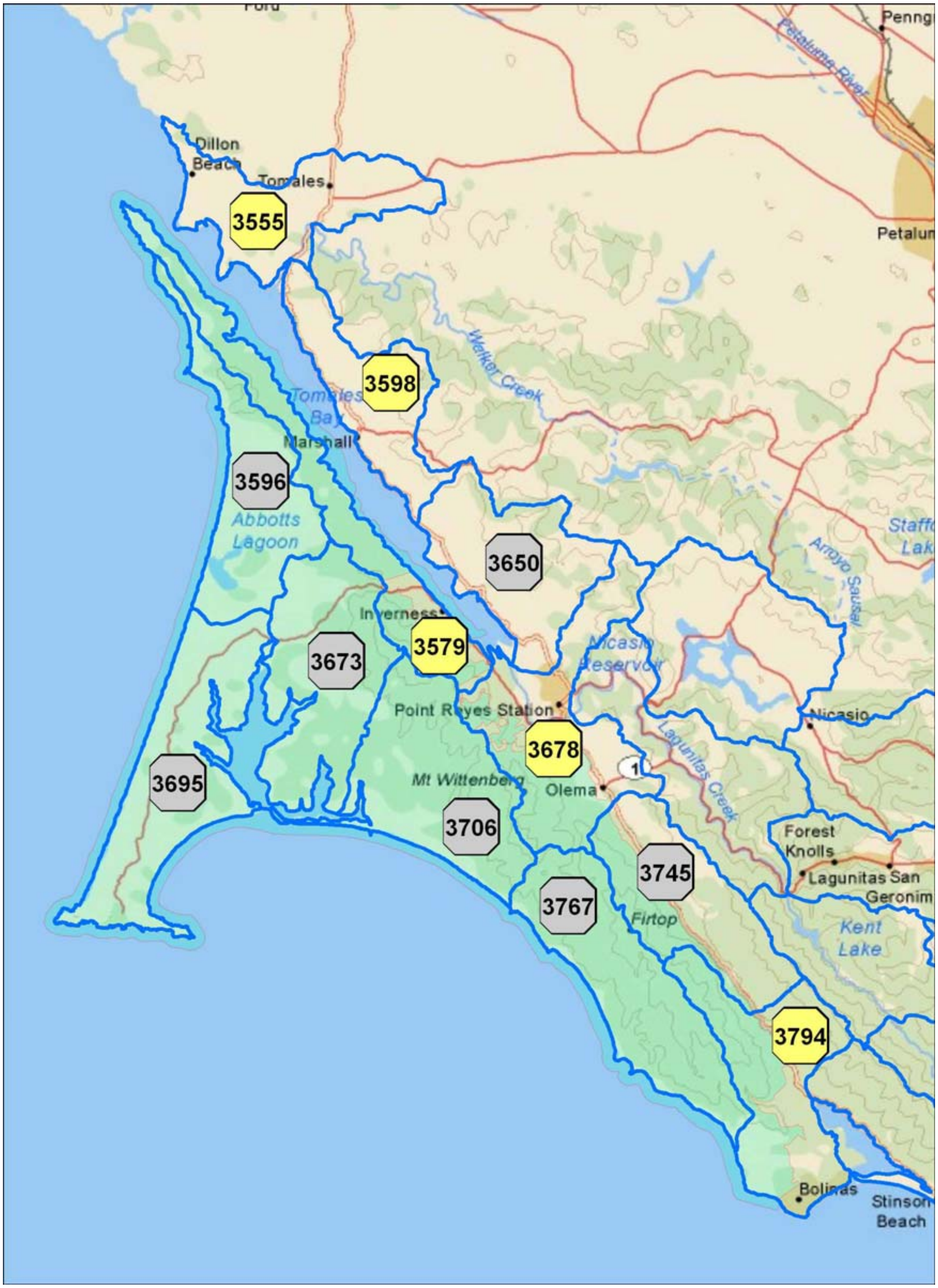

Figure 13 Point Reyes National Seashore and selected adjacent watersheds. Watersheds coded with grey symbols do not have stream gage data to assess the accuracy of Basin Characteristic Model output.

Land Use

Larry Damm is a small watershed within Redwood National Park that was extensively logged by 1973 and has since undergone watershed restoration work (Figure 14). In coordination with Redwood National Park, we conducted a pilot study to evaluate changes in land cover using unsupervised classification of Landsat images for five time periods: 1973 (post logging), 2000 (pre-restoration), 2003 (during restoration work), and 2005 and 2009 (post restoration). The changes in land cover through time are shown in Figure 15. We will pursue the use of remote sensing to detect land use change over broader areas encompassing park lands in the future.

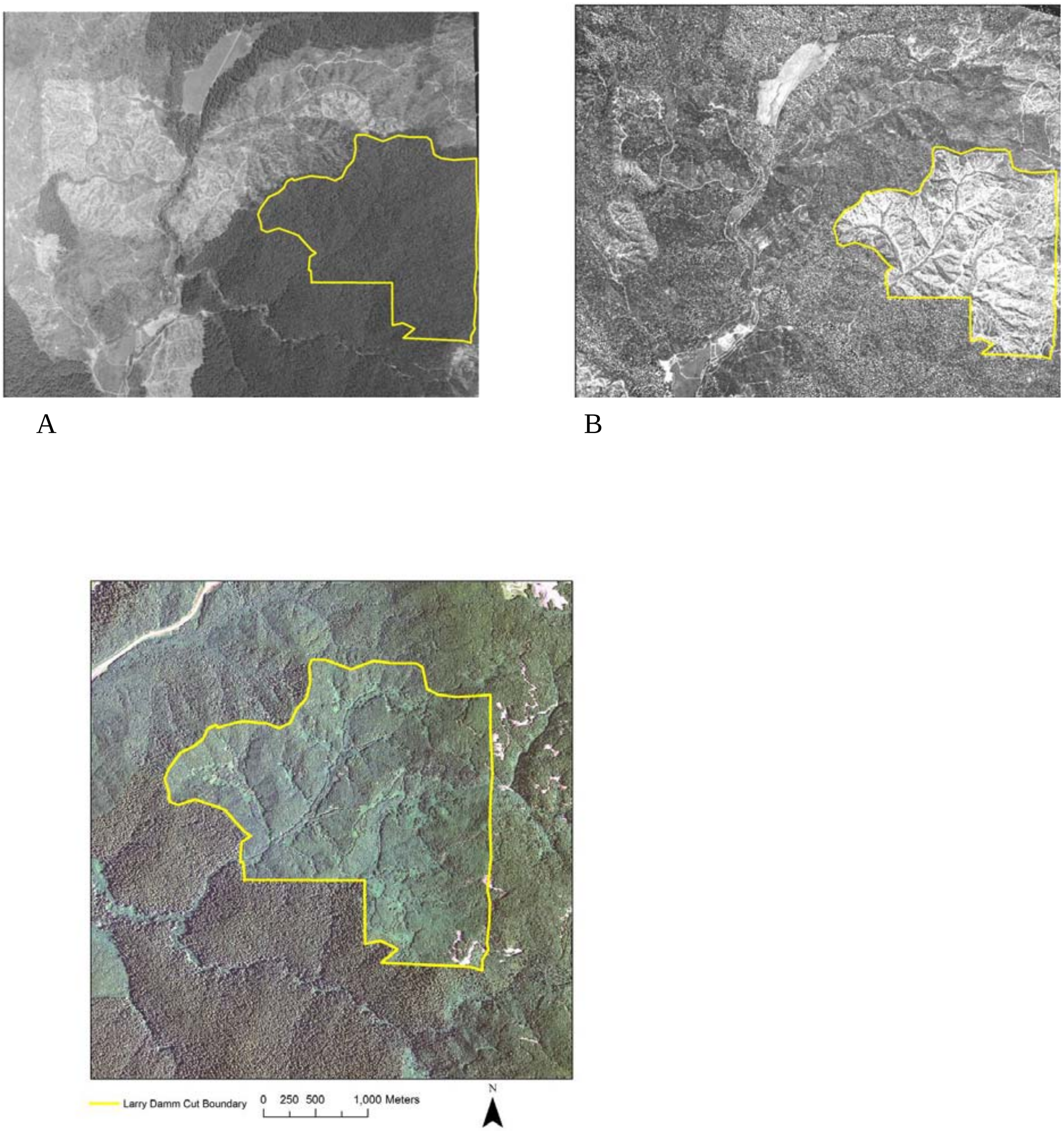

Figure 14. Larry Damm watershed in (A) 1964 (pre-logging); (B) 1973 (post-logging); and (C) 2009 (post-restoration).

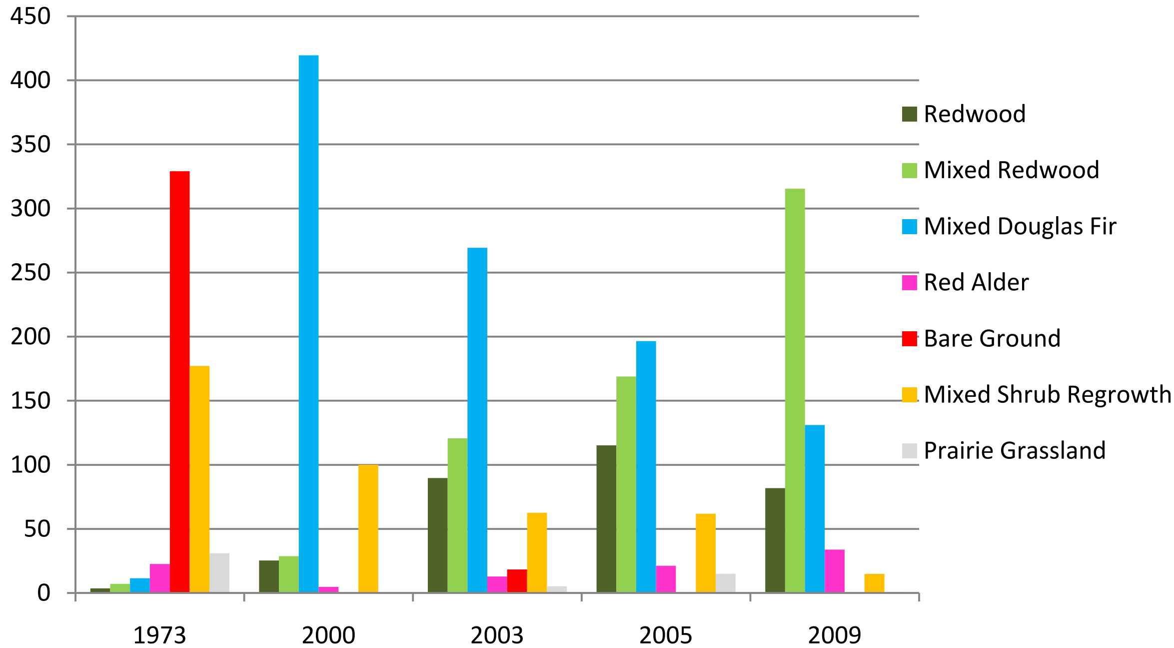

Figure 15. Changes in land cover in the Larry Damm watershed, Redwood National Park (compiled by Sharon Powers and Judy Wartella, Redwood National Park)

At Point Reyes National Seashore the legacy of changing land use has had a potentially large impact on coho salmon a vital sign of significant concern in this project. We have convened several workshops with Park resource specialists to develop spatially explicit maps to link events identified by park staff to the watershed are experiencing legacy effects (Table 6). These effects include altered hydrologic conditions in the streams and cascading effects that impact stream habitat. We will be focusing on the subset of these that can be included in FY11 vital signs synthesis analysis.

Table 6 Timeline of events at Point Reyes National Seashore with potential to alter conditions in streams harboring coho salmon.

Year	Agents of watershed change
1860	Logging; continued into early 1900's
1870	Pine Gulch logged until mid 1960s;
1860	Row cropping continued through 1940s
1905	Bolinas Ridge fire
1906	Earthquake
1927	RCA facility built
1950	Phase out row cropping;
1950	Silage fields, where crops were bagged to cure hay began then stopped in the 1960s, then returned in the 1970s, shrinking to about 2500 acres
1960	Road building for development
	Dams, pond construction 1960-1962. Earlier ponds were for agricultural operations. 30-40 acre ponds were built for recreational use. Borrow pits are located near dams. Over time some dams failed.
	ATT facility built
1968	Non native deer expansion 1968 - 2008
1972	Clean Water Act passed – manure management changed. Instead of dumping in creeks, manure was spread over fields, possibly leading to increase in nonnative species
1978	Reintroduction of tule elk at Tomales Point
1982	flood, debris flow in every drainage
1986	extensive flood and erosion
1995	Vision fire
1998	Reintroduction of tule elk to Limantour
2005	Onset of Sudden Oak Death
2007	Onset of pitch pine canker

Salmon Populations

Juvenile salmonids (smolts) have been trapped in Redwood Creek in and upstream of Redwood National Park by the California Department of Fish and Game for several years. An example of the abundance data from their study is shown in Figure 16. As part of this project, we will test whether trends in fish populations are related to stream flow or stream temperature.

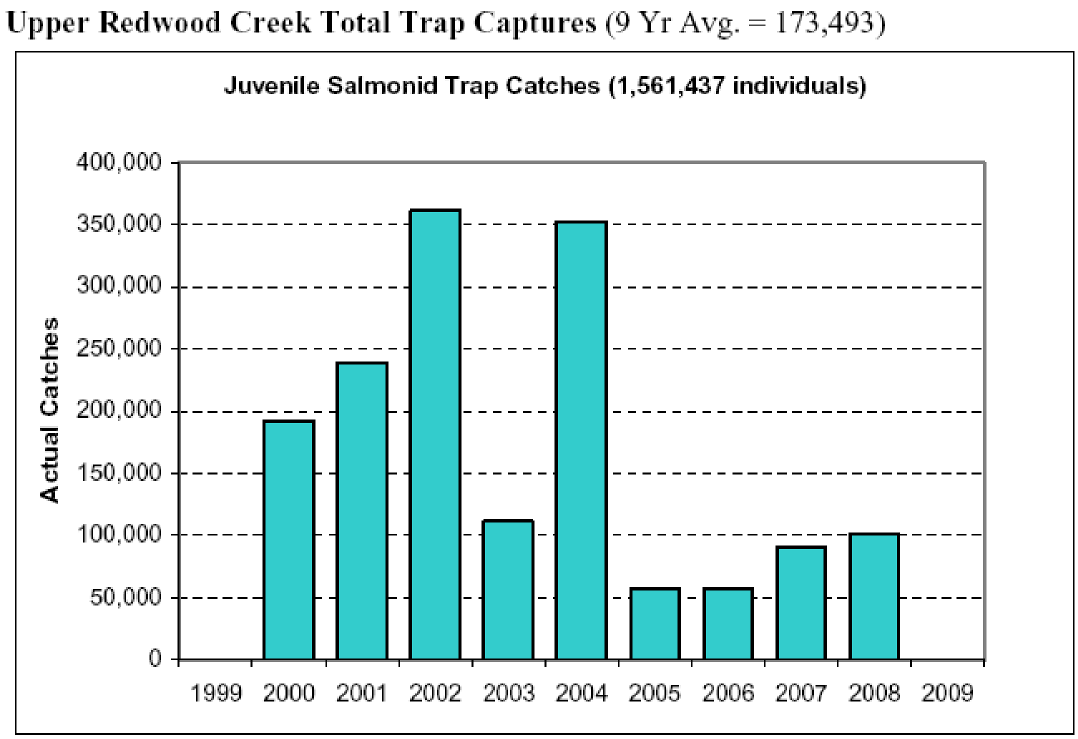

Figure 16. Juvenile salmonid counts at Upper Redwood Creek smolt trap. Data from Michael D. Sparkman, California Department of Fish and Game, Arcata, CA.

In the San Francisco I & M network the vital sign monitoring protocols for salmonid stream fish assemblage are focused on tracking the endangered coho salmon (*Oncorhynchus kisutch*) whose populations in most of central California have experienced a third consecutive season of major declines. Marin County streams, except for Redwood Creek, have had an 85% reduction in returning adult coho spawners. The National Marine Fisheries Service and

California Department of Fish and Game is responding by developing extinction prevention plans that includes minimizing habitat degradation (Michelle O'Herron, August 2010 Network Update). This upcoming year we will be focusing on gathering and integrating salmonid related data into the vital signs synthesis.

Future Work: Vital Sign Linkages

Several relationships among and between resource elements will be investigated. To date, many vital signs have been analyzed as individual elements, but in many cases linkages among the elements have not been investigated. It will be useful for park managers to understand these linkages for several reasons. First, if metrics are correlated (e.g., daily precipitation and mean daily stream flow), data gaps can be filled using those statistical relationships, and the length of record of one element can be extended by using the data record of the second element. In addition, specific hypotheses regarding the linkages can be tested. Examples are listed below.

Precipitation and air temperature

Wentz *et al.* (2007) and Lambert *et al.* (2008) suggest that annual mean precipitation is related to annual mean air temperature. To see if this concept is valid for coastal California National Park units, annual mean precipitation will be regressed directly onto annual mean temperature, based on meteorological stations within or adjacent to parks.

Air temperature, stream temperature and stream flow

Coho salmon are very sensitive to elevated stream temperatures. The relationship between air temperature (as a surrogate for solar radiation, which directly affects water temperature) and stream temperature will be tested to examine maximum and minimum temperatures and duration of elevated temperatures above thresholds of concern. Stream flow also influences stream temperature. Increases in stream temperature can be accelerated by the diversion of stream flow for agriculture or other uses, or may be delayed if summer rains increase stream flow. The relationships among stream temperature, air temperature, and stream flow will be tested more fully through multivariate regression analysis.

Precipitation and stream flow

In the KLMN and SFAN many more data sets are available for precipitation than for stream flow. It would be useful for fish biologists to be able to extend the record of stream flow, especially during time periods critical to salmon spawning, rearing and migration. To assess this possibility, annual and monthly mean stream flow will be regressed directly onto annual and monthly mean precipitation, respectively.

Regime shifts

There is growing evidence that population trends in species such as salmon are affected by climatically induced shifts in potential productivity that result from cyclical trends in oceanic conditions such as the Pacific Decadal Oscillation or ENSO events (Mueter *et al*., 2006). A method for accounting for this variability is to truncate the population time series into segments before and after the regime shift. Regressions will be run with truncated data to investigate if that improves an ability to discern correlations among age class trends.

Multiple regression analyses using combinations of factors influencing stream temperature (air temperature, stream flow, riparian condition, distance from coast, etc.) will be run, and the best fit models will be chosen using Akaike's Information Criterion (AIC) or Bayesian Information Criterion (BIC) (Clark and Gelfand, 2006). These analyses will help inform the nature of the models used in the next step, structural equation modeling.

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Appendix A: Stream Flow Metrics from USGS gaging records

Station Name	USGS Station Number	Period of Record	County	Contributing Drainage Area (miles^2)	Dams or diversions? (x=yes blank=no)	Magnitude of Peak Flow	Date of Peak Flow
Alamo Creek a Dublin CA	11174500	10/1/1914-9/30/1920	Alameda	38.7		0.707	0.125
Alamo Creek nr Pleasanton CA	11174600	8/30/1979-9/30/1983	Alameda	40.8		0.532	0.630
Arroyo Corte Madera del Presidio a Mill Valley CA	11460100	10/1/1965-9/30/1986	Marin	4.69	x	0.075	0.937
Arroyo Nicasio nr Point Reyes Station CA	11460500	10/1/1953-9/30/1960	Marin	36.6	x	0.646	0.107
Corte Madera Creek a Ross CA	11460000	4/1/1951-9/30/1993	Marin	18.1	x	0.608	0.121
Eel River a Fort Seward CA	11475000	9/1/1955-present	Humboldt	2107	x	0.879	0.587
Eel River a Hearst CA	11472000	10/1/1910-9/30/1913	Mendocino	466	x	0.196	0.916
Eel River a Scotia CA	11477000	10/1/1910-present	Humboldt	3113	x	0.039	0.038
Eel River a Van Arsdale Dam nr Potter Valley CA	11471500	12/1/1909-9/30/2008	Mendocino	349	x	0.343	0.531
Eel River ab Dos Rios CA	11472500	4/1/1951-9/30/1965	Mendocino	705	x	0.259	0.328
Eel River bl Dos Rios CA	11474000	1/25/1912-1/4/1966	Mendocino	1484	x	0.584	0.793
Eel River bl Scott Dam nr Potter Valley CA	11470500	10/1/1922-9/30/2008	Lake	290	x	0.216	0.707
Eel River nr Dos Rios CA	11472150	10/1/1966-12/31/1994	Mendocino	528	x	0.087	0.956
Klamath River a Orleans	11523000	10/1/1927-present	Humboldt	8475	x	0.440	0.235
Klamath River bl Iron Gate Dam CA	11516530	10/1/1960-present	Siskiyou	4630	x	0.008	0.064
Klamath River nr Klamath CA	11530500	10/1/1910-present	Del Norte	12100	x	0.444	0.849
Klamath River nr Seiad Valley CA	11520500	10/1/1912-present	Siskiyou	6940	x	0.011	0.583
Lagunitas Creek at Samuel P. Taylor State Park CA	11460400	12/21/1982-present	Marin	34.3	x	0.298	0.062
Lagunitas Creek nr Point Reyes Station CA	11460600	10/1/1974-present	Marin	81.7	x	0.486	0.093
Little River nr Trinidad CA	11481200	10/1/1955-present	Humboldt	40.5		0.991	0.685
Mad River ab Ruth Res nr Forest Glen CA	11480390	6/20/1980-present	Trinity	93.8		0.178	0.690
Mad River bl Ruth Res nr Forest Glen CA	11480410	10/1/1980-9/30/2008	Trinity	121	x	0.100	0.268
Mad River nr Arcata CA	11481000	10/1/1910-present	Humboldt	485	x	0.001	0.538
Mad River nr Blue Lake CA	11480780	12/1/1972-10/5/1976	Humboldt	393	x	0.205	0.206
Mad River nr Forest Glen CA	11480500	10/1/1953-11/9/1994	Trinity	143	x	0.680	0.309
Mad River nr Kneeland CA	11480750	10/1/1965-9/30/1974	Humboldt	352	x	0.049	0.123

Mattole River nr Ettersburg CA	11468900	6/21/2001-present	Humboldt	58.1		0.197	0.248
Mattole River nr Petrolia CA	11469000	10/1/1911-present	Humboldt	245		0.626	0.582
Pine Creek at Bolinas CA	11460170	6/1/1967-9/30/1970	Marin	7.83		0.494	0.632
Redwood Creeek at Orick CA	11482500	9/1/1911-present	Humboldt	278		0.048	0.854
Redwood Creeek nr Blue Lake CA	11481500	10/1/1953-present	Humboldt	67.7		0.861	0.827
Smith River nr Cresent City CA	11532500	10/1/1931-present	Del Norte	614		0.753	0.785
South Fork Smith River nr Crescent City CA	11532000	10/1/1911-9/30/1979	Del Norte	291		<.001	0.099
Van Duzen River at Bridgeville CA	11478000	10/1/1911-9/30/1951	Humboldt	202		0.636	0.488
Van Duzen River nr Bridgeville CA	11478500	10/1/1950-present	Humboldt	222		0.293	0.589
Van Duzen River nr Dinsmore CA	11477500	10/1/1953-9/30/1974	Humboldt	85.2		0.233	
Walker Creek nr Marshall CA	11460750	10/1/1983-present	Marin	31.1	x	0.162	0.369
Walker Creek nr Tomales CA	11460800	7/1/1959-9/30/1984	Marin	40.1	x	0.607	0.458

Station Name*	USGS Station Number	Dams or diversions? (x=yes blank=no)	Annual Mean	June Flow	July Flow	August Flow	September Flow
Alamo Creek a Dublin CA	11174500						
Alamo Creek nr Pleasanton CA	11174600						
Corte Madera Creek a Ross CA	11460000	x				0.03595	
Arroyo Corte Madera del Presidio a Mill Valley CA	11460100	x					
Morses Creek a Bolinas CA	11460160						
Pine Creek a Bolinas CA	11460170						
Lagunitas Creek a Samuel P. Taylor State Park CA	11460400	x	0.08034		<.001	<.001	
Arroyo Nicasio nr Point Reyes Station CA	11460500	x					
Lagunitas Creek nr Point Reyes Station CA	11460600	x		<.001	<.001	<.001	<.001
Walker Creek nr Marshall CA	11460750	x		<.001	<.001	<.001	<.001
Walker Creek nr Tomales CA	11460800	x		0.01358	<.001	<.001	<.001
Mattole River nr Ettersburg CA	11468900						
Mattole River nr Petrolia CA	11469000					0.07435	0.03958
Eel River bl Scott Dam nr Potter Valley CA	11470500	x	0.09514		0.00715	<.001	
Eel River a Van Arsdale Dam nr Potter Valley CA	11471500	x	0.04755	<.001	<.001	<.001	<.001
Eel River a Hearst CA	11472000	x					
Eel River nr Dos Rios CA	11472150	x	0.085		0.095		
Eel River ab Dos Rios CA	11472500	x					
Eel River bl Dos Rios CA	11474000	x					
Eel River a Fort Seward CA	11475000	x					
Eel River a Scotia CA	11477000	x	0.075				
Van Duzen River nr Dinsmore CA	11477500			0.067			
Van Duzen River a Bridgeville CA	11478000						0.023
Van Duzen River nr Bridgeville CA	11478500						
Eel River a Fernbridge CA	11479560	x					
Mad River ab Ruth Res nr Forest Glen CA	11480390						
Mad River bl Ruth Res nr Forest Glen CA	11480410	x			0.015	0.002	<.001
Mad River nr Forest Glen CA	11480500	x	0.090	0.053			0.046
Mad River nr Kneeland CA	11480750	x					

Mad River nr Blue Lake CA	11480780	x				
Mad River nr Arcata CA	11481000	x				
Little River nr Trinidad CA	11481200					
Redwood Creeek nr Blue Lake CA	11481500				0.031	0.015
Lacks Creek nr Orick	11482110					
Panther Creek nr Orick CA	11482125					
Little Lost Man Creek a Site No. 2 nr Orick CA	11482468					
Redwood Creeek a Orick CA	11482500				0.039	0.056
Klamath River bl Iron Gate Dam CA	11516530	x	0.009	0.014		0.002
Klamath River a Walker Br nr Klamath River CA	11517818	x				
Klamath River nr Seiad Valley CA	11520500	x	0.035	<.001	<.001	0.001
Klamath River nr Happy Camp CA	11521000	x				
Indian Creek nr Happy Camp CA	11521500	x				0.067
Klamath River a Orleans	11523000	x			0.014	0.001
Panther Creek nr Denny CA	11527550					
Blue Creek nr Klamath CA	11530300					0.045
Klamath River nr Klamath CA	11530500	x				
Middle Fork Smith River a Gasquet CA	11531000		0.086	0.063		0.083
South Fork Smith River nr Crescent City CA	11532000		0.023	<.001	0.017	
Smith River nr Cresent City CA	11532500					
Smith River nr Fort Dick CA	11532650					
Lobos Creek CA	374715122285601					
Unnamed Trib. to Upper Abbotts Lagoon Point Reyes	380738122560701	?				
Prairie Creek avove Boyes Creek-PAB	NPS					
Prairie Creek below Boyes Creek-PRL	NPS					
Prairie Creek above Borwn-PRU	NPS					
Prairie Creek avove May Creek-PRW	NPS					

*****Only p-values that were significant at the 10% level are shown.

Station Name	Date of 25% Runoff	Date of runoff centroid	Date of 75% Runoff	7-Day Maximum Flow	7-Day Minimum Flow	30-Day Maximum Flow	30-Day Minimum Flow	90-Day Maximum Flow	90-Day Minimum Flow
Alamo Creek a Dublin CA	0.993	0.569	0.917	0.131	0.372	0.162	0.403	0.232	0.370
Alamo Creek nr Pleasanton CA	0.893	0.541	0.285	0.256	0.277	0.301	0.276	0.263	0.264
Arroyo Corte Madera del Presidio a Mill Valley CA	0.187	0.010	0.001	0.496	0.007	0.244	0.006	0.186	0.007
Arroyo Nicasio nr Point Reyes Station CA	0.652	0.897	0.846	0.002	0.024	0.001	0.029	0.004	0.026
Corte Madera Creek a Ross CA	0.198	0.701	0.676	0.050	0.477	0.036	0.451	0.081	0.661
Eel River a Fort Seward CA	0.121	0.129	0.359	0.001	0.012	0.001	0.020	0.001	0.016
Eel River a Hearst CA	0.246	0.711	0.085	0.003	0.003	0.003	0.002	0.002	0.002
Eel River a Scotia CA	0.448	0.421	0.748	0.001	0.000	0.008	0.004	0.000	0.000
Eel River a Van Arsdale Dam nr Potter Valley CA	0.094	0.782	0.402	0.000	0.000	0.000	0.000	0.000	0.000
Eel River ab Dos Rios CA	0.150	0.271	0.692	0.000	0.000	0.000	0.000	0.000	0.000
Eel River bl Dos Rios CA	0.866	0.510	0.691	0.000	0.000	0.000	0.000	0.000	0.000
Eel River bl Scott Dam nr Potter Valley CA	0.068	0.640	0.267	0.043	0.243	0.016	0.161	0.015	0.194
Eel River nr Dos Rios CA	0.736	0.365	0.087	0.064	0.015	0.033	0.018	0.020	0.015
Klamath River a Orleans	0.016	0.024	0.062	0.616	0.666	0.425	0.821	0.182	0.980
Klamath River bl Iron Gate Dam CA	0.982	0.079	0.023	0.011	0.002	0.005	0.004	0.006	0.003
Klamath River nr Klamath CA	0.174	0.942	0.501	0.042	0.002	0.033	0.007	0.039	0.013
Klamath River nr Seiad Valley CA	0.616	0.043	0.123	0.037	0.015	0.018	0.019	0.014	0.011
Lagunitas Creek at Samuel P. Taylor State Park CA	0.108	0.023	0.348	0.009	0.151	0.007	0.118	0.008	0.050
Lagunitas Creek nr Point Reyes Station CA	0.373	0.191	0.024	0.174	0.004	0.244	0.008	0.227	0.009
Little River nr Trinidad CA	0.204	0.013	0.058	0.010	0.005	0.417	0.054	0.007	0.007
Mad River ab Ruth Res nr Forest Glen CA	0.461	0.875	0.833	0.368	0.890	0.309	0.889	0.310	0.490
Mad River bl Ruth Res nr Forest Glen CA	0.546	0.480	0.763	0.205	0.780	0.173	0.780	0.174	0.591
Mad River nr Arcata CA	0.176	0.054	0.011	0.084	0.003	0.041	0.001	0.029	0.001
Mad River nr Blue Lake CA	0.427	0.947	0.917	0.997	0.411	0.374	0.405	0.377	0.341
Mad River nr Forest Glen CA	0.399	0.276	0.500	0.028	0.372	0.036	0.350	0.042	0.341
Mad River nr Kneeland CA	0.341	0.978	0.322	0.038	0.001	0.034	0.003	0.026	0.015
Mattole River nr Ettersburg CA	0.588	0.977	0.623	0.270	0.102	0.189	0.137	0.132	0.065

Mattole River nr Petrolia CA	0.018	0.088	0.140	0.218	0.046	0.160	0.033	0.149	0.028
Redwood Creeek at Orick CA	0.850	0.578	0.014	0.488	0.004	0.271	0.003	0.278	0.002
Redwood Creeek nr Blue Lake CA	0.135	0.256	0.454	0.581	0.955	0.475	0.989	0.578	0.972
Smith River nr Cresent City CA	0.028	0.524	0.363	0.941	0.674	0.975	0.751	0.861	0.815
Van Duzen River at Bridgeville CA	0.312	0.061	0.213	0.000	0.023	0.000	0.013	0.000	0.007
Van Duzen River nr Bridgeville CA	0.030	0.129	0.766	0.479	0.678	0.480	0.565	0.530	0.356
Van Duzen River nr Dinsmore CA	0.837	0.621	0.853	0.449	0.419	0.225	0.415	0.183	0.320
Walker Creek nr Marshall CA	0.200	0.156	0.698	0.415	0.101	0.322	0.304	0.288	0.146
Walker Creek nr Tomales CA	0.390	0.546	0.616	0.085	0.779	0.050	0.630	0.039	0.366

Appendix B.   Example of stream flow metrics from IHA analysis in rivers near SFAN

Station ID --->	Alamo Creek		Arroyo Corte Madera	Arroyo Nicasio	Corte Madera Cr.	Lagunitas Creek		Napa River	Novato Creek	Russian River
Parameter	Dublin	Pleasanton				Pt. Reyes	SPT State Park			
Period of Analysis	1915-1920	1979-1983	1966-1986	1954-1960	1951-1993	1975-2009	1983-2009	1930-2009	1947-2009	1912-2009
Period of Analysis (years)	6	5	21	7	43	35	27	53	63	59
Mean annual flow	7.64	24.43	7.36	40.59	26.64	93.76	53.18	202.7	12.56	174.5
Annual coefficient of variation	6.12	4.27	3.77	4.56	4.03	3.78	2.94	3.98	4.5	3.12
Flow predictability	0.76	0.46	0.37	0.66	0.43	0.4	0.55	0.45	0.4	0.48
Constancy/predictability	0.67	0.37	0.36	0.43	0.45	0.4	0.56	0.46	0.55	0.44
% of floods in 60d period	0.89	0.53	0.52	0.69	0.52	0.54	0.51	0.54	0.57	0.47
Flood-free season	235	154	162	241	146	180	162	145	74	135
Base flow index	0	0.2354	0.02824	0.0001748	0.004535	0.0872	0.1799	0.003818	0.004479	0.0007622
High pulse count	3	6.2	4.571	4.571	5.419	4.543	4.704	4.434	3.857	6.864
Extreme low duration	155.8	4.333	8.882	35.43	12.22	20.84	22.58	39.55	40.34	19.36
Extreme low timing	87.57	275.5	260.2	214.7	259.1	204.5	259.8	237.1	223.7	245
Extreme low frequency	2.167	1.2	4.333	3.143	3.628	1.771	1.704	1.377	2.873	2.288