Identifying Ecological Indicators of Climate Change and Land Use Impacts to a Coastal Watershed

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Executive Summary

Climate change and land use impacts are growing concerns for communities, policy-makers, scientists and land managers around the world. Coastal communities are increasingly faced with the effects of climate change and land use impacts as sea levels rise and weather patterns change while development and population growth increases pressure on those coastal ecosystems.

The Coos Watershed Association (Coos WA) and the South Slough National Estuarine Research Reserve (SSNERR) are located in the Coos Watershed on the southern coast of Oregon. Coos WA and SSNERR formed the Partnership for Coastal Watersheds (The Partnership) to address the growing pressures of climate and land use changes. A grant from the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) and the Norton Family Foundation ădzLJLJƨNJű ă űKŜ tŀNJű ƴŜNJ objectives, which are:

1) To monitor the long-term impacts of climate and land use changes to the Coos Watershed through the development of an ecological indicators program.
2) To evaluate the effectiveness of management and restoration efforts through an adaptive management process informed by an ecological indicators program.

Within the larger Coos Watershed, the Partnership identified the South Slough Coastal Frontal Watershed as the pilot study area for the initial development of indicators program because the area has not yet been assessed by the Coos WA and it is the location of the SSNERR, which maintains long-term environmental data about the watershed. The Partnership aims to use the pilot study area to demonstrate the Coastal Watersheds Ecosystem Management Process, an integrated ecosystem decision-support process. The process brings together scientists, resource managers, and community members to respond to local problems associated with climate change and changing land use patterns. This partnership will build on current local and regional ecosystem management efforts to demonstrate a decision-support process focused on adaptively managing the effects of land use and climate change in the South Slough and Coastal Frontal watersheds (Coos WA and SSNERR 2009).

The Partnership identified the Pressure-State-Response (PSR) framework as the structure within which to develop their indicators program. The PSR framework, developed by the Organisation for Economic Co-operation and Development, is widely used because its premise is easily understood by stakeholders including, scientists, managers, citizens and policymakers. This framework is based on the idea that human activities can change the state of an ecosystem and its individual components. When those changes are undesirable to society, this can prompt action to mitigate the effects of those human activities through policies and actual changes to the environment, such as restoration efforts.

To assist with the initial stages of the indicator development process, the Partnership collaborated with the Field Naturalist Program at the University of Vermont. The goals of this project were:

1) To apply the PSR ƑNJŀ ƳŜ ǿ ƨNJ ɩ ű ƨ űKŜ tŀNJű ƴŜNJ ă K ƛ LJ Ω ă LJ ƛ ƪ ƨ ű ă ű
2) To identify applicable ecological indicators already in use through a review of literature and existing indicator programs.

3) To use stream temperature as an example indicator by taking it through the PSR framework.

The goal of this report is to provide a resource for managers, citizens and policymakers to use as a reference for understanding the development process for ű K Ŝ t Ͱ NJ ű ʎ Ŝ NJ ă Ś ƚ ŝ Ŭ Ω ă ecological indicators pilot program. This reports steps through the process of using the Pressure State Response framework. It then uses stream temperature as an example potential indicator by taking it through the PSR framework for the Coos Watershed Indicators Program.

Finally, overall recommendations are focused on data collection, Quality Assurance-Quality Control (QAQC) protocols, and on communicating indicators to the public. It is recommended that The Partnership develop QAQC protocols for data collection. The recommendations for stream temperature data collection are to reduce the number of stream stations to 4 key locations, while ensuring that the data from those stations are consistent in quality. To help ensure quality data collection, it would be helpful to place two temperature units at each location, which would allow the manager to check the accuracy of the units while also assuring data collection should a unit fail or become lost.

Lastly, indicator programs that plan to report on the status and trends of an ecosystem, such as the Coos Watershed, should be linked to public values and should involve the public in the development of those indicators. Therefore, it is recommended that The Partnership hold multiple Coffee Klatches throughout the indicator development process to assess stakeholder values, refine indicator selection and to create a common language for communicating indicator information.

As pressures from climate and land use changes increase in coastal communities, the importance of understanding how these changes are impacting human and natural communities also grows. The Partnership must have the support and trust of the Coos Watershed community in their efforts to track Ͱ ʏ Ř Ͱ Ř Ͱ LJ ű ƛ Ø Ŝ ƒ è Ƴ Ͱ ʏ Ͱ Ǝ Ŝ ű K Ŝ / ƻ ƻ ă ² Ͱ ű Ŝ NJ ă Ʀ Ŝ Ř Ω ă based effort Ŏ K Ͱ ʏ Ǝ ƛ ű ƻ ō dz ƛ ƒ Ř ű K Ŝ / ƻ ƻ ă ² Ͱ ű Ŝ NJ ă K Ŝ Ř Ω ă NJ Ŝ ă ƛ ƒ ƛ Ŝ ʏ Ŏ Ŝ Ͱ ʏ Ř Ͱ Ř Ͱ LJ change pose now and in the future.

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Abbreviations

Abbreviation	Definition
7dAM	7 day average maximum; moving average
CICEET	The Cooperative Institute for Coastal and Estuarine Environmental Technology
Coos WA	Coos Watershed Association
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
EPA	Environmental Protection Agency
EPIC	Environmental Protection Indicators for California
HUC	Hydrologic Unit Code
NERRS	National Estuarine Research Reserve System
ODF	Oregon Department of Forestry
ODFW	Oregon Department of Fish and Wildlife
OECD	Organisation for Economic Co-operation and Development
OIMB	Oregon Institute of Marine Biology
OWEB	Oregon Watershed Enhancement Board
PNW	Pacific Northwest
PSR	Pressure-State-Response framework
SSNERR	South Slough National Estuarine Research Reserve
SWMP	System Wide Monitoring Program
TAG	Technical Advisory Group

Image Credits

Cover: Author, June 28, 2009.

Page 5: Author, July 2009

Page 7: Daniel Draper, Coos Watershed Association

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Introduction

Located on the southern coast of Oregon, the Coos Watershed is a coastal watershed where communities face increasing pressures from climate and land use changes. The Coos Watershed Association and the South Slough National Estuarine Research Reserve are partnered to develop an ecological indicators program to track the condition of the Coos Watershed and to evaluate the effectiveness of their management actions.

Indicators are common in our everyday lives. They are meant to inform us quickly and easily about the condition of something of value to the society. For example, we follow unemployment rates among other economic measures to get an understanding of the state of the economy. Likewise with human health, blood pressure is measured and tracked to provide a quick assessment of the state of our health. An indicator is a measure of some characteristic, which is used to represent a host of other characteristics as a whole τ these other Ŏ K ŀ NJ ŀ Ŏ ű Ŝ NJ ƛ ă ű ƛ Ŏ ă K ŀ Ǿ Ŝ ƴ Ω ű ƴ Ŝ Ŏ Ŝ ă ă ŀ NJ ƛ ƚ è ā Ŝ Ŝ ƴ measured and may never be measured.

ά Indicators are meant to inform us quickly and easily about something of interest. They communicate how the condition of a specific measure is changing over time and any ŀ LJLJ ŀ NJ Ŝ ƴ ű ű NJ Ŝ ƴ Ř ă X ű K Ŝ è ŀ NJ Ŝ ƴ Ŝ Ŝ Ř Ŝ Ř ō Ŝ Ŏ ŀ dz ă Ŝ ƛ ű ƛ ă not possible to measure everything έ (National Research Council, 2000).

The information we receive from monitoring unemployment rates or our blood pressure might cause government officials to propose new legislation, while a result of high blood pressure might cause an individual to change their eating or exercise habits. We continue to follow unemployment rates or our blood pressure to evaluate whether our responses are changing those previous undesirable conditions.

Similarly, ecological indicators are used to give us a picture of an ecosystem Ω ă Ŏ ƨ ƴ Ř and to ű ƛ ƨ ƴ Σ help guide our management decisions and actions. Ecological indicators are used to establish the condition of an ecosystem by using a few, specific measures that indicate the larger picture τ ű K Ŝ Ŝ Ŏ ƨ ă è ă ű Ŝ Y Ω ă Ŏ relative to what is accepted according to ă Ŏ ƛ Ŝ ƴ ű ƛ ă ű Ω ă ˥ ƴ ƨ ǿ ƚ Ŝ Ř ∃ Ŝ ŀ ƴ Ř

The use of indicators in environmental management is growing, especially in response to climate change and land use impacts to communities and their surrounding environments. Increasingly, scientists, public officials and citizens want to know how to identify signals of climate change and how to address the associated impacts to the environment and human communities. Land managers also want to understand more about how to manage for ecosystem resilience in the face of climate and land use changes.

Indicators of climate and land use impacts are especially important in coastal watersheds, where communities are concerned about rising sea levels, the impacts of a warming climate couple with the increased pressures from land use changes on the ecosystems that comprise and sustain coastal economies.

Audience

This document is intended specifically for the Coos Watershed Association (Coos WA) and the South Slough National Estuarine Research Reserve (SSNERR) for their use in the development of ecological indicators of the impacts of climate and land use changes to the Coos Watershed. It is also for use by natural resource professionals and citizens beyond the

Coos Watershed, looking for a resource about the development of ecological indicators of climate and land use changes in a coastal watershed using the Pressure-State-Response framework.

Purpose

The purpose of this project was to assist the Partnership with the initial stages of the indicator development process. The objectives for the project were:

1) To apply the PSR framework to the tłNJűƴŜNJăĶƛLJΩă LJƛ ƒ ƻ ű
2) To identify applicable ecological indicators already in use through a review of literature and existing indicator programs.
3) To use stream temperature as an example indicator by taking it through the PSR framework.

The purpose of this document is to provide the Partnership with a reference that provides background, resources, and recommendations for the indicator development process.

Structure

This document is constructed in four main parts:

Chapter 1 briefly profiles the study area, reviews ecological indicators, and examines land use and climate changes locally.

Chapter 2 reviews ecological indicators and their use in environmental monitoring.

Chapter 3 introduces the PSR framework for developing ecological indicators and applies it to the pilot study area, identifying potential indicators.

Chapter 4 uses stream water temperature as an example indicator taken through the Pressure-State-Response framework.

Chapter 5 offers overall recommendations for the tłNJűƴŜNJăĶƛLJΩă pilot Indicators program. Appendices follow the recommendations, providing additional resources.

Content and Definitions

This document is a synthesis of a fraction of an extremely large body of scientific and social literature about the development and use of ecological indicators to measure, monitor, predict and address human-induced environmental change.

The terms environmental and ecological indicators are often used synonymously (Niemi 2004). Environmental indicators are those measures that represent all the parts of a chain linking human activities to environmental impacts, and ăƻŎƛŜ response to those impacts (Smeets & Wetering 1999). Thus, environmental indicators are conceptually very broad, encompassing any physical characteristic within an environment.

Ecological indicators are a more specific subset of environmental indicators that apply to ecological processes, are most often biological and respond to chemical, physical and other biological processes (US EPA 2002b). Ecological indicators are derived from the measurement of ecosystem processes in the field and are often combined intƻ ădzƳƳłNJè Øł ƒdzŜăΣ ădz Index of Biotic Integrity (IBI) used by the EPA. The most important function of ecological indicators is to measure the response of an ecosystem to anthropogenic disturbance (Niemi 2004, US EPA 2002b).

Indicator programs should be developed within a framework to provide conceptual structure for how to address the environmental questions. The lack of a framework can result in an ineffective program τ one in which the objectives are not clear or the indicators do not provide the desired information.

Oregon State University Archives

Document Overview:

Chapter1 briefly profiles the study area and examines land use and climate changes regionally and locally.

Chapter 2 reviews ecological indicators and their use in environmental monitoring.

Chapter 3 introduces the PSR framework for developing ecological indicators, applies it to the study area, identifying potential indicators

Chapter 4 uses stream water temperature as an example indicator taken through the PSR framework.

Chapter5 offers overall recommendations for the development of the t ŀ NJ ű ƴ Ŝ NJ ă K ǻ LJ Ω ă program.

Chapter 1: The Coos Watershed & Climate Change

The Coos Watershed

The Coos Watershed is a coastal watershed drained by the Coos River, which enters the Pacific Ocean along the southern coast of Oregon. Tucked into the biologically rich temperate rainforest, the watershed comprises 390,000 acres, of which roughly 85% is privately owned (Coos Watershed Association). Estuaries, upland forests, riverine ecosystems and increasing urban development broadly characterize the landscape of the Coos Watershed.

Through the Oregon Watershed Enhancement Board (OWEB) and external grant funding, the Coos Watershed Association (Coos WA), a 501(c)(3) non-profit, works collaboratively with local landowners and other environmental organizations to test and implement science-based management practices that support the ecological and economic integrity of the Coos Watershed (Coos Watershed Association).

South Slough National Estuarine Research Reserve is a 4,800-acre natural area located in the Coos estuary on the south coast of Oregon. Designated in 1974 as the first reserve of the National Estuarine Research Reserve System (NERRS), established by Congress as part of the Coastal Zone Management Act (CZMA). NERRS is a network of estuarine habitats protected and managed for research, education and coastal stewardship. The NERRS also has the System-Wide Monitoring Program (SWMP). Initiated in 1995 to provide standardized data on national estuarine environmental trends, SWMP also allows each reserve to use the data collected to address specific coastal management issues of regional or local concern.

Climate Change

The difference between weather and climate can be confusing. They are defined differently, but are directly related, differing in time scale. Weather describes short term atmospheric conditions, while climate is the long term pattern of weather in an area, which is simply the nature of the weather over a relatively long period of time (NOAA, February 2005).

*How is climate change defined?*The Intergovernmental Panel on Climate Change defines climate change as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. The United Nations Framework Convention on Climate Change (UNFCCC) makes a distinction between natural climate variability and a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, and which is in addition to natural climate variability observed over comparable time periods (IPCC 2007).

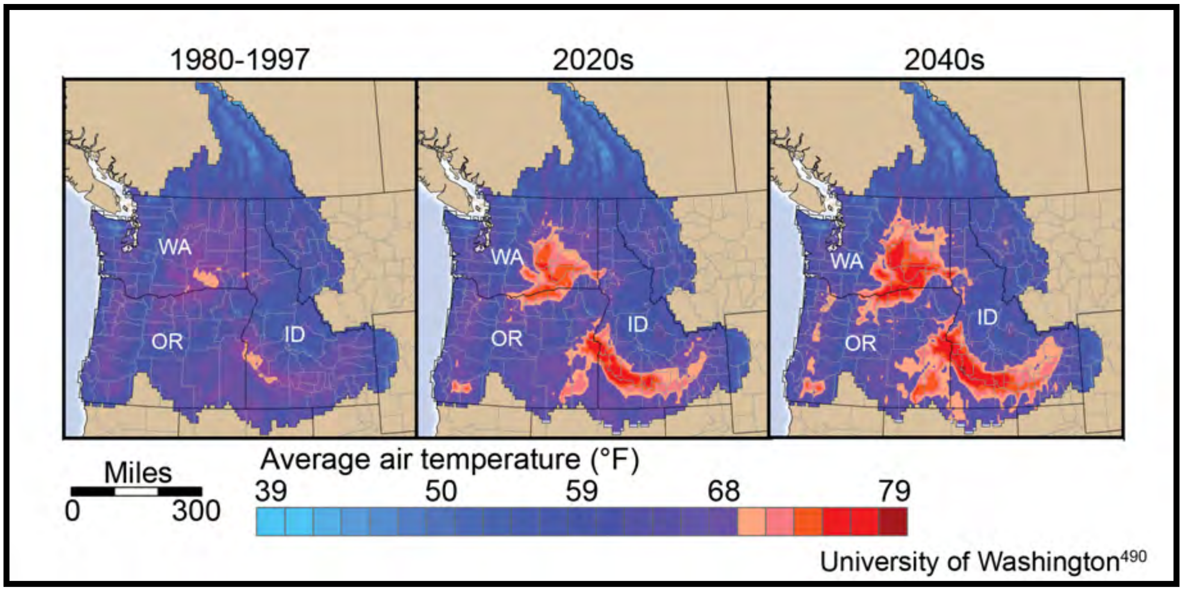

Figure 1: Historical and projected average air temperature change for the PNW. *U.S. Global Change Program*

Climate Change Models

Most climate change models are global climate models (GCMs), and regional climate models (RCMs) are extrapolated from larger global climate models and modified to account for complex topographical features and land cover heterogeneity (IPCC 2007). While RCMs continue to improve their statistical accuracy at finer spatial scales, they are limited because they do not account for feedback loops between global and regional climate models. RCMs are also limited because the temporal scale at which GCMs are established does not match the finer scale data needed for regional models (IPCC 2007).

Thus climate changes at the local scale, such as the Coos Watershed, cannot be easily extrapolated from the larger global and regional climate models because of local differences in topography, land use, vegetation, weather patterns and overall general climate variations. It may be more useful for local environmental managers to identify specific, sensitive indicators of climate change through which impacts can be observed, allowing local management actions to be focused on ecological climate preparedness and resilience, which does not exclude humans in that system.

Expected Regional and Local Climate Changes

For this project, local air temperature, precipitation, and wind data from the North Bend Regional Airport NOAA weather station were analyzed and compared to regional trends (see Appendices E-G). Another source of regional data and local climate modeling is the Climate Leadership Initiative (CLI), which is a research collaborative between the Resource Innovation Group and the University of hNJŜ∃ƻƴΩă Lƴăűƛűdzűŝ Environment. CLI provides technical assistance to an array of organizations to help develop solutions to the complex problems global climate change presents for communities.

According to the Regional Climate Impacts Report published by the U.S. Global Change Research Program (USGCRP), the northwest is already experiencing the effects of climate change. Average annual air temperature has increased by 2 degrees in the past century, with some locations experiencing a 4-degree increase.

The U.S. Global Change Program predicts several factors will affect communities on the Pacific coast. Among the impacts identified are sea-level rise; increased spring run-off and increased summer drought; higher water temperatures; ocean acidification and changing ocean currents. Each is projected to impact the NortƘ øŜăűΩă øŜƚűƘŜNJ coastal ecosystems and fisheries (U.S. Global Change 2009).

In a consensus report on the potential impacts of climate change in the Pacific Northwest, 67 scientists agreed on the likely impacts to the major ecosystem processes: temperature, precipitation, sea level, snowpack, marine ecosystems and terrestrial ecosystems.

Temperature

The U.S. Global Change Research Program reports annual average temperature has increased 1-4 ̅F over most of the PNW region in the last century. It is predicted that in the next 10-50 years, temperatures will increase 2.7° F (1.5° C) by 2030 and 5.4° F (3° C) by the 2050s (U.S. Global Change Research Program, 2009). Scientists believe these changes may result in increase elevation of the upper tree line and change vegetation zones, which are trends that would happen over a long period of time. Changes that might occur in a shorter period of time is an increase in the growing season; increased fire season duration; earlier breeding by animals and plants; and longer, more intense allergy seasons because some allergenic plants, which typically flourish in warmer temperatures with increased levels of CO_2 (Ziska, et al., 2003).

Precipitation

There are conflicting reports about precipitation, as climate scientists continue to examine climate change models, and precipitation can be rather difficult weather pattern to analyze and predict, especially at the regional and local scales. Scientists in Oregon report that there is not yet a consistent precipitation signal in the Western states, however from 1916 to 1997 scientists have concluded that there was a moderate increase in precipitation (Water Resources Breakout Group, 2004). Since the beginning of the 20th Century however, the USGCRP reports that precipitation has increased across the PNW region by an average of 10 percent.

The IPCC climate models suggest the PNW will see increases in winter precipitation and winter storm severity, while summer precipitation will decrease. Increasing air temperatures will likely translate to earlier snowmelt, which when coupled with drier summers could have a number of impacts. Potential impacts agreed upon by scientists in the PNW are:

- Increased water demand due to population growth and development with decreased streamflow, which could result in water shortages and a decrease in the ability to meet instream flow targets.
- Greater stress on fish populations such as salmon because of decreased streamflows and increased air temperatures, creating decreased fish habitat; salinity and pollutant concentration could also become greater threats to fish and shellfish populations, as stream flow decreases and sea level rises.

Sea Level

Land on the southern Oregon coast between Florence and Coos Bay has been rising faster than worldwide increases in sea level by roughly 1 mm per year (Abbott, 2004), however land to the north is being submerged by rising sea level at 1.5-2 mm per year. Although the southern Oregon Coast is rising, the Charleston, NOAA station has recorded an increase in sea level.

Sea levels will continue to rise as global temperatures increase, however the impact of sea level rise on the Oregon will vary due to tectonic processes occurring in the Pacific Northwest. It is expected that the Coos Bay area will rise faster than the increased sea level, but the increase in shoreline movement and maximum wave heights from storm surges will still have an impact on near shore and estuarine ecosystems, and in the long term tectonic uplift will not counteract sea level rise (Allan, 2009).

Snowpack

Mote (2003) describes the foremost impact from climate change in the PNW will be reduction in regional snowpack. Between 1950 and 2000, the April 1 snowpack has declined and timing of peak snowpack has changed, so that March streamflows have increased while June streamflows have decreased. Climate scientists report that snowpack at low- to mid-elevations are the most sensitive to warming temperatures (*The Scientific Consensus Statement on the Likely Impacts of Climate Change on the Pacific Northwest*, 2004). Projections suggest the April 1 snowpack will continue to decline with an earlier peak in streamflow.

Marine Ecosystems

In response to changing ocean-atmospheric processes, ocean circulation is predicted to keep changing, although specifically how it will change is unclear. Scientists suggest an increase in the magnitude and duration of seasonal upwelling, as well as an increase in storm severity and surges. The changes in upwelling may increase the severity and duration of hypoxic events off the coast of Oregon like those that occurred in 2002 and 2004 (*The Scientific Consensus Statement on the Likely Impacts of Climate Change on the Pacific Northwest*, 2004).

Terrestrial Ecosystems

It is unclear exactly how terrestrial ecosystems will respond to changing climate patterns, however scientists agree that warming temperatures and decreasing summer precipitation will cause drought stress in forests and increase vulnerability to fire, disease, insects and invasive species (*The Scientific*

Consensus Statement on the Likely Impacts of Climate Change on the Pacific Northwest 2004). Predictions suggest that species composition in the landscape will shift and the growing season will lengthen.

Land Use and Climate Change

The Pacific Northwest has experienced several decades of population and economic growth at nearly twice the national rate, with the population almost doubling since 1970. Many people are attracted to the region by the temperate climate and outdoor recreation opportunities. Of course, the same environmental qualities that attract newcomers are also stressed by increased development and use (U.S. Global Change Research Program). According to the U.S. Census, the Coos Bay area is the largest urban center directly on the Oregon coast with 30,000 people. The population is projected to increase to 90,000 by 2018.

Urbanization, rural residential development and increased recreational development can alter stream channels and landscape drainage patterns; contribute to nutrient, pesticide and sediment loads in waterways; and, increase bacterial loads and the introduction of invasive, non-native plants and animals (Coos WA, SSNERR 2009).

Scientists suggest climate change will only exacerbate land use impacts to the local environment. Uncertainty exists about how marine and terrestrial ecosystems will change. Scientists suggest changes in land use and other human activities will be convolved with changes in the natural environment, which will have a greater impact on ecosystems (*The Scientific Consensus Statement on the Likely Impacts of Climate Change on the Pacific Northwest* 2004).

Adaptive Capacity & Climate Change Resilience

The rising pressures faced by coastal communities from climate change and land use impacts have caused scientists and land managers to place a greater focus on adaptive capacity and resilience of both natural and anthropogenic systems (Gibbs, 2009). The scale of global climate change is so large that managers are not able to take actions or create policies at the local scale, which can have a direct and measurable impact on climate change. Instead, managers are focusing on mitigation of the impacts being felt by communities, and management strategies that will increase human and natura ƭ Ǒ ƛ ƳƳdzƴ ƪ ű ƪ Ŝ ă
adaptive capacity and resilience to climate change pressures.

Resilience is commonly thought of the ability of something to withstand or resist perturbation and still function in the capacity intended (Gibbs, 2009). It is seen as the ability of something to return to a state of equilibrium after a disturbance. This view is largely developed from an engineering viewpoint, which focuses on the design of structures and their resilience to outside forces. Structures can reach a point beyond which their ability to function is destroyed.

When applied to ecosystems, resilience is the ability to maintain core functions, such as nutrient cycling; and to maintain flexibility in response to rapidly changing conditions, so that the structure and physical appearance of the system may change, but that the essential functions and services are maintained.

There are many types of ecological indicators. These may offer one way to track an
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pressures from climate and land use changes.

Chapter 2: Defining Ecological Indicators

Although ecological indicators have not been considered as powerful as the most influential economic indicators because of the complexity of environmental systems, they are gaining importance. Indicators, such as global mean temperature, sea surface temperature and atmospheric carbon dioxide concentrations have gained considerable clout in the last decade as climate changes have become more apparent (National Resource Council 2000). The rate of increase of mean surface temperature in the last 50 years has been +0.13 C per decade, which is nearly double the rate of the last one hundred years. Sea surface temperature has a similar story. The rate of increase in sea surface temperature has been greatest in the last 30-40 years, increasing roughly 0.133 C per decade globally (Solomon, et al., 2007).

These are examples of ecological indicators developed at the global scale, however developing indicators at the local and regional scale of comparable influence ecologically can be challenging for scientists and land managers due to data and resource constraints. Their development however will direct attention to environmental conditions in our communities and can help to shape policy at the local level. Ecological indicators can also help us to measure and evaluate the performance of those public and land management policies (Natural Resource Council 2000).

Types of Indicators

Effective indicators inform us about whether things we value are being maintained (or sustained), and warn us of an impending breach in a value or a group of values. ŏTypically, the values we wish to maintain are highly complex (e.g., the economy, biodiversity) and we cannot afford to measure all the possible components in the system of concern. Indicators are specific components of these complex ecosystems that, when measured, can tell us a great deal about the present or future condition of the larger ăèăűŜƳΩŧ (Dent, Salwasser, & Achterman, 2005)

Due to the variety and complexity of environmental issues and data, and the pressing need for effective management decisions, many types of indicators have been developed for an array of purposes. These different types can reflect physical, chemical and biological aspects of an ecosystem and have been used to characterize status, track or predict change, identify stressors or stressed systems, assess risk, and influence management actions (Kurtz, Jackson, & Fisher, 2001).

Indicator literature emphasizes that an effective ecological indicators program should incorporate different types of indicators (Kelly and Harwell 1990, Hughes et al. 1992, Water Quality Guidelines Task Group 1996). Table 1 identifies many types of indicators based on what they measure in the ecosystem. The term ά ƛ ʏ Ř ƛ Ŏ ŀ ű ƻ NJ ἑ ƛ ă ƻ Ŧ ű Ŝ ʂ NJ Ŝ Ř Ŝ Ŧ use, however ecological indicators are intended to describe and evaluate the state and function of an ecosystem (Hughes et al. 1992, Landres 1992, Watzin et al. 2005), as well as the Ŝ Ŏ ƻ ă è ă ű Ŝ Ƴ Ω ă NJ Ŝ ă interactions ű ƻ Ƴ (Watzin et al. 2005).

Table 1: **Adapted from Watzin 2005, Kelly and Harwell 1990, Council of Great Lakes Research Managers 1991, Landres 1992, Karr 1992, Rapport 1992, OECD 1993, Nip and Uno de Haes 1995, Niemi 2004, Water Quality Guidelines Task Group 1996, Harwell, et al. 1999.**

Indicator Type	Description
Pressure	Measures the direct and indirect impacts from human activities.
State/Condition	Measures current environmental condition.
Response	Measures societal or management response to the state of the environment.
Structural/Environmental	Measures biotic and abiotic components of an ecosystem.
Process/Function	Measures the rate or extent of changes in ecosystems processes.
Disturbance	Measures disturbance regimes that maintain ecosystem structure.
Compliance/Management	Evaluates effectiveness of management actions toward achieving goals and objectives.
Diagnostic/Sensitive	Provides information as to cause of ecosystem changes.
Early Warning	An indicator that quickly signals ecosystem changes before significant degradation occurs.
Long Term	Detects ecosystem changes over a long time.
Index	Combines multiple environmental characteristics into a single measure of ecological condition.
Ecological	Measurable characteristics of the structure, composition, and function of ecological systems.

Chapter 3: Steps for Establishing an Indicators Program for the Coos Watershed

Step 1: Scale and Objectives for Coos Watershed

The first step in an indicators program is to establish the scale and objectives for which ecological indicators will be developed. The Partnership focused their efforts on a pilot study area: the South Slough and Coastal Frontal Watershed, with a larger goal being to establish a program for the entire Coos Watershed. Coos WA works across the entire watershed, while SSNERR is focused on the South Slough and Coastal Frontal watershed. The organizations partnered to create an indicators program to track the condition of the pilot study area and to evaluate the impacts of climate and land use changes.

To establish an ecological indicators program the most important first step is to define the objectives, then identify public values and concerns, as well as understand current, relevant regulations, and then frame the objectives within the context of that information (U.S. EPA 2008).

The Partnership identified two main objectives for the development of ecological indicators under their CICEET proposal:

1. Monitor the long-term impacts of climate and land use changes to a coastal watershed τ the Coos Watershed.

2. Evaluate the effectiveness of management and restoration efforts through use of indicators.

Step 2: Set the Framework: Pressure-State-Response

A conceptual framework is used to outline a preferred approach to an idea or problem. There are a number of frameworks available for developing indicators, and a common challenge to establishing an indicators program is choosing the best framework by which to conceptualize potential indicators. Choosing a ŦNJŀΥŜǿƨNJƪ űKŀű ŘƨŜăƴΩű ƛƴű scale and objectives can often lead to indicators that are not clearly linked to űKŜ LJNJƨ∃NJŀΥΩ purpose, as well as public values or management actions, resulting in a lack of importance to the public and potentially ineffective management policies and programs (Watzin, et al., 2005).

The Partnership chose the Pressure-State-Response Framework because of its simplicity and because of its wide use by other organizations, such as the EPA and the National Park Service. The Pressure-State-Response framework is used by organizations around the world, including entities such as the U.S. EPA. The PSR framework is so widely accepted because of its ease of interpretation by the public. It clearly shows the relationship between human activities that act on the condition of an ecosystem, and the management responses and policies that are meant to reduce the impact of those pressures. Lű ŀăƪă űKNJŜŜ ăƛΥLJƒŜ ǉdz happening in the environment? Why is it happening? What are we doing about it? (Hammond, Adriaanse, Rodenburg, Bryant, & Woodward, 1995).

The PSR framework (Figure 2) organizes indicators into three categories: pressure, state and response indicators. Pressure indicators measure the extent to which human pressures are acting on an ecosystem, while state indicators describe the condition of the ecosystem. Response indicators describe the management actions that seek to address the pressures placed upon the ecosystem by human activities.

This framework is based upon the idea that human activities exert pressure on the environment that result in changes in the state of the environment as a whole, as well as its individual parts. These changes often cause a societal response, which results in changing environmental policies or implementing management actions (OECD 1993). The central ideal is that societal responses affect the pressures by causing changes in the human activities that initially caused the environmental degradation, or even by direct changes to the degraded environment (OECD 1993). Response indicators have not been in use for as long as pressure and state indicators. Data availability and our limited understanding of potential and actual management outcomes often constrain the development of response indicators (OECD 1993, Watzin et al. 2005).

While tK Ŝ t { w ŦNJ ŀ Ƴ Ŝ ǿ ƻNJ ĭ Ω ă ƒ ƛ ʎ easy to understand, many feel it is limited ō Ŝ Ŏ ŀ dz ă Ŝ ƛ ű ƻ Ǿ ŜNJ ă ƛ ƳLJ ƒ ƛ Ŧ ƛ Ŝ ă characteristics and processes, and can be narrow in its evaluation scope (Bowen & Riley, 2003).

Climate Change and Land Use Impacts: Coos Watershed PSR

A coastal watershed, like the Coos, is a uniquely complex ecosystem because it encompasses a transition from freshwater and upland terrestrial ecosystems, to a mosaic of terrestrial, emergent wetland and tidal ecosystems, to coastal near shore marine ecosystems. In order to identify potential indicators the Coos pilot study area was conceptually broken down into smaller landscape classes (Dent, et al., 2005). The classes are: 1) Freshwater Aquatic & Riparian 2) Terrestrial 3) Estuarine Aquatic and 4) Near shore Marine.

The development of ecological indicators requires the interacting factors within ecosystem be conceptually modeled. The PSR concept model for an ecosystem can be very simple, focusing on the primary or secondary

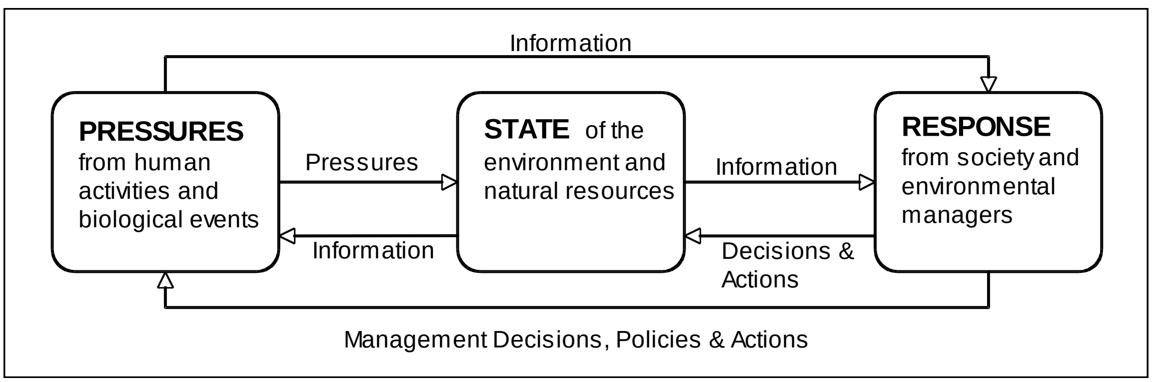

Figure 2: Pressure-State-Response Framework adapted from the OECD (1993).

interactions, or the models can be quite complex, incorporating many of the factors that are either impacting the system or being impacted within that ecosystem. The goal is to identify the environmental components, which are of greatest importance, both socially and scientifically, as integral drivers of the

Concept models must be easily understood by scientists and land managers, and incorporate enough information to facilitate the effective selection of the appropriate indicators for the ecosystem(United States Environmental Protection Agency (USEPA), 2008).

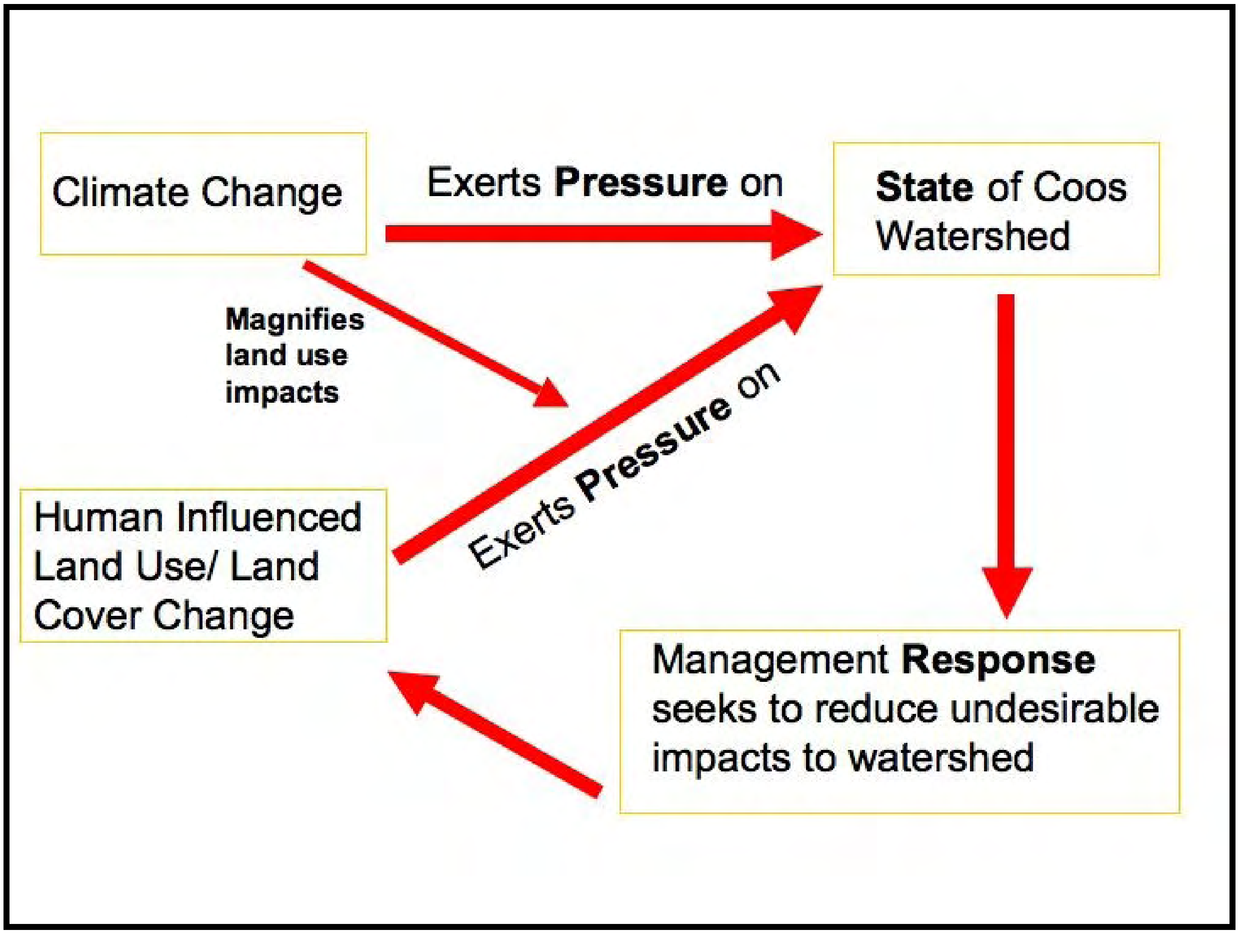

Figure 3: Climate Change and Land Use PSR diagram for Coos Watershed

(United States Environmental Protection Agency (USEPA), 2008). The PSR framework is often criticized for oversimplification of ecosystem complexity, as crucial factors can be overlooked or underestimated as to their influence or pressure on the system.

An overall PSR conceptual model was developed for the Coos Watershed (Figure 3) to broadly and simply depict the relationship between the ecosystem and the drivers of greatest concern to the Coos WA and SSNERR. In the Coos Watershed PSR model, the pressures are those forces related to climate change and human influenced land use changes. The state indicators are those that describe the condition of the watershed, while the response indicators measure the management or policy response to the state of the ecosystem.

Applied broadly, the PSR framework for the Coos Watershed predicts that not only will climate change have an impact on the watershed; it will also magnify any impacts from human land use changes. Typically, PSR models are a feedback loop, where management or societal responses exert influence on the initial pressures. In the Coos Watershed model, the response does not feed back to the climate change pressure. The scale of global climate change is so large that management actions at only the Coos Watershed level could not produce a direct and measurable effect on climate change.

As mentioned previously, this problem of scale has increased emphasis for managers and policy makers to focus on the adaptive capacity and resilience of ecosystems and social systems.

While the PSR model for the Coos Watershed can be conceptualized very broadly, the finer complexities and identification of specific indicators are not addressed in the broad model. Thus the potential indicators were identified at a smaller conceptual level in the individual landscape classes. Before potential indicators are selected however, guiding criteria for their selection should be established.

Step 3: Establish Indicator Criteria

Indicators programs must have guiding criteria by which to select potential indicators as part of the selection and evaluation process. Lack of rigorous procedures for selecting ecological indicators makes validation of the information provided by those indicators more difficult than when clear, transparent procedures are defined. Standard methods give legitimacy to the interpretation of ƛ ƴ Ř ƛ Ŏ change over Ω time. Thus, implementing a method and criteria for the prioritization and selection of ecological indicators allows for repeatability, avoids bias, and imposes discipline upon the selection process, ensuring that the selection of ecological indicators en-compasses management concerns and is transparent to the public, policymakers and other scientists (Dale & Beyeler, 2001).

Coos Indicators Program Guiding Criteria

Ecological Criteria:

Ecologically Relevant τ relates to essential components of the identified ecosystem.

Measurable τ can be quantified using a standard procedure with a documented performance and low measurement error.

Interpretable τ can distinguish acceptable from unacceptable conditions; natural variability understood or long term data available.

Integrative τ can be integrated with other ecosystem measurements over multiple scales.

Responsive τ responds to relevant stressors and causal linkages are established; and may offer an anticipatory signal of degradation.

Statistically Sound τ can be used to document trends and show significant differences.

It is important that indicators produce unique information in the context of the larger indicator program. Therefore, their selection should be based upon pre-determined criteria, and relevance to other priority indicators (Water Quality Guidelines Task Group 1996) that incorporate ecological, social, economic and organizational factors (Hunsaker et al. 1990). The literature discusses many criteria recommended for indicator selection, as well as a variety of approaches to using these characteristics (Kelly and Harwell 1990, Water Quality Guidelines Task Group 1996, Fisher 1998, Manley et al. 2000).

These approaches emphasize the need to balance technical, operational, and administrative considerations. The literature continues to stress the importance of available historical data, and the ability to be responsive to environmental pressures and informative even with considerable natural variation (Kurtz, et al., 2001).

Guiding Criteria for the Coos Watershed

By establishing guiding criteria for indicator selection, the process of identifying potential ecological indicators can be more transparent for the public, as well as more efficient for the monitoring organization. The guiding criteria proposed for The Partnership best represent what both organizations believe ecological indicators for the Coos monitoring program should achieve. In response to the need for criteria that address both the scientific and environmental management components of the Coos monitoring program, criteria are grouped in two categories: Ecological and Operational.

The ecological criteria are meant to guide the scientific soundness of the indicator selection process. The operational criteria are meant to guide and facilitate the evaluation of each

Coos Indicators Program Guiding Criteria

Operational Criteria:

Socially Relevant – indicator linked to public, government and scientist concerns.

Operationally Feasible – data collection methods are appropriate, feasible, and cost-effective to measure.

Synergistic – indicator integrates into other relevant indicator programs at various scales.

Appropriate Scale – spatial and temporal scales of measurement are scientifically justifiable and correspond to management concerns.

Related to Management Actions – allows for determination of current policy and adaptive management effectiveness.

Funding – monitoring of indicator is highly likely to be funded. No significant social, political, or logistical constraints.

operational feasibility in terms of organizational constraints. The operational criteria address management and implementation concerns.

Selection Strategy Using Weighted Criteria Scoring Matrix

The Partnership seeks to have a very transparent and efficient process for selecting indicators for their monitoring program. Guiding criteria selected for the Coos Indicators Program established specific characteristics, which potential indicators should possess, however the Partnership desired to have a process by which individual indicators could be ranked, thus ideally creating a straightforward means of selecting indicators for the program. ¢ 2 Ř 2 ű K ƛ ă Σ / 2 2 ă ² ! Ω ă ǿ for restoration projects was adapted to create a weighted scoring system for indicators (*See Appendices A-C*).

It could be argued that each indicator should fully meet each criterion in order to be included in the monitoring program, or that a linear additive method would be sufficient to score each indicator rather than weighting each criterion. It is possible however, that a potential indicator could be viewed as an essential indicator in the program, but perhaps it lacks historical data or the funding to monitor such indicator is not yet available. In this scenario, the Partnership identified the desire to be able to include this theoretical indicator in the potential indicator pool.

Each guiding criterion was weighted as a percentage of 1, and each criterion was assigned 0-4 points, of which any potential indicator could receive a whole number. The points would then be multiplied by the ŎNJƛ ű ŜNJƛ 2 ʎ Ω ă ate an overall K ű ű 2 Ŏ ŀ f Ŏ Ώ selection score.

The weight of each criterion was determined in a review process by the Partnership. The ecologically and socially relevant criteria were required characteristics. It was determined that an indicator lacking these characteristics should not be considered for the monitoring program.

Within the ecological criteria set, responsive; measurable; interpretable; and statistically sound were weighted highest because it is essential to be able to measure and interpret an ƛ ʎ Ř ƛ Ŏ ŀ ű 2NJΩă integrative was given the ă Φ lowest weight because while it is ideal for an indicator to mesh well with those being monitored by other organizations, the lack of this characteristic should not be overbearing in importance. Ŝ ƛ ∃ K ű Ŝ Ř ă Ŏ 2 NJ ƛ ʎ ∃ Ὑ ŀ ű NJ ƛ È

Within the operational criteria operationally feasible; related to management actions; and appropriate scale were weighted highest because the indicators should be feasible to measure and should be the appropriate scale and relevant to management actions in order to be in line with the objectives set forth by the Partnership. Synergistic and funding were ranked lower because the lack of these characteristics should not overpower the determination to include an indicator, but could are important factors in the selection of indicators.

The Partnership can use the weighted scoring system as a tool for the Technical Advisory Group (TAG) to prioritize potential indicators. In a selection scenario where potential indicators have been scored, the TAG could utilize the prioritization score to inform final selections.

> *To be useful, indicators must answer the questions being asked while being grounded in a conceptual framework that conveys not only what is being measured, but why and in what context.*
>
> *ʐU.S. EPA Indicator Development for Estuaries, 2008*

Step 4: Establish Public Values

Indicator programs often seek to set environmental policy and make environmental decisions, all of which rely on effective communication with policy makers and consideration of public values for an ecosystem (Schiller, et al., 2001). As part of this project and to take into consideration public values for the Coos Indicators Program, four preliminary community meetings were conducted for the Partnership in July 2009. In these meetings, indicators were explained and participants were asked to share their values for the watershed.

From these public meetings preliminary information about scientist and public interests was gathered. Figure 4 illustrates what values and interests were communicated by both the general public, local scientists and land managers. For example, both scientists and citizens identified issues such as climate change impacts, urbanization and industrialization, and salmon fisheries as issues of importance. Water quality and salmon fisheries are of particular importance because of the importance of salmon to the local economy. Thus the health of the salmon populations and the state of environmental conditions that affect salmon lifecycles are also important. The Coos WA and several Oregon state agencies work to restore water quality, stream and riparian buffer health with the aim to also improve the salmon population Ωhealth.

While it is necessary for effective indicators to be linked to public values, it also remains important that indicators are scientifically sound, as the guiding criteria demand. Scientists and land managers are involved in the process to ensure selected indicators are scientifically robust and well supported by quality, long term data. An effective indicators program, however will communicate with the public about the scientific and social importance of the

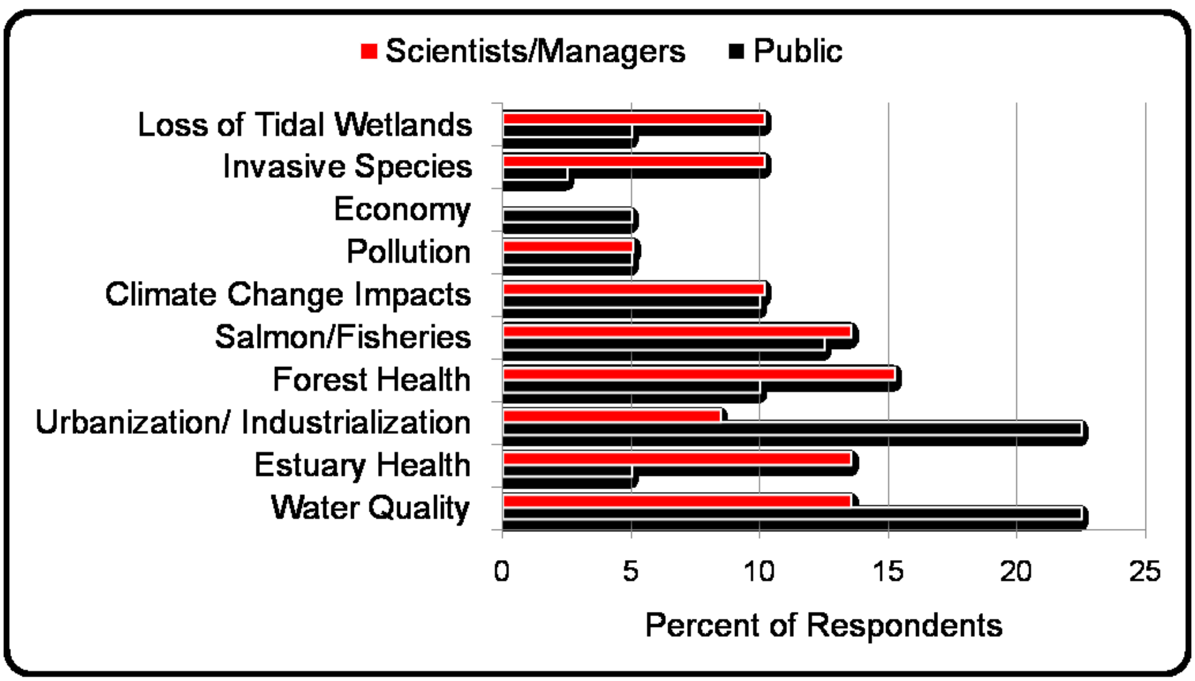

Figure 4: Scientist and Public Interests for Coos Watershed Condition

indicators being monitored. The complexity of many environmental issues and the manner in which scientists are used to communicating these ideas often make it difficult for the public to engage in the dialogue necessary to establish and address public values for an ecosystem. To adequately include societal values for an ecosystem in the development of indicators, the public and decision makers must be informed participants in the discussion of what is important for an indicator program and what should be measured (Schiller, et al., 2001).

Communicating Indicators & the Coffee Klatch Process

As part of its watershed assessment and restoration efforts, the Coos WA created a Coffee Klatch program, which seeks to engage the citizens of a watershed in a dialogue about ű K Ŝ ǿ ǀ ű ŜNJăKŜŘΩă KŜ ǀ ƚ ű K to improve and protect the waters KŜŘΩă condition. The Coffee Klatch process could also be adapted for use in establishing the values of scientists, policymakers, and the general public in an indicators development process.

Coffee Klatches are informal public meetings used to facilitate better relationships and greater communication with landowners and citizens. A series of meetings are held the in sub-basins of the larger Coos Watershed, where landowners are invited by Coos WA to meet for coffee and snacks to dialogue about the condition of their watershed and about their values and interests for its future. It is a process ű K ǀ ű ʎ ɣ Ŧ ⱬ NJ Ƴ ă / ⱬ ⱬ ă values ǀ ō ⱬ dz ű and needs, while providing citizens with a Ŏ K ǀ ɣ Ŏ Ŝ ű ⱬ ō Ŝ ű ű ŜNJ dz ɣ Ř ŜNJ ă and a chance to envision what the future might be like for their watershed. These meetings serve many purposes, but the main priorities are to open communication between the public and Coos WA, as well as to build understanding ǀ ɣ Ř ădzLJLJⱬNJű Ŧ ⱬ NJ / ⱬ ⱬ ă ² ! Ω ă while potentially creating a more unified vision for the watershed.

The aforementioned preliminary meetings held in July 2009 as part of this project were modeled on the / ⱬ ⱬ ă ² ! Ω ă / ⱬ Ŧ Ŧ Ŝ Ŝ process. Coffee Klatches could provide an excellent opportunity for The Partnership to inform and engage the public and policy makers in the Coos Watershed. The Partnership plans to adapt the Coffee Klatch process for use in the Coos Indicators program.

Indicators can fulfill the need to improve communication between scientists and the public, where decision-making is responsive to the science as well as the social feedback about management policies (Hammond, et al., 1995); however in the Coffee Klatch Process it will be necessary to strategically plan interactions between scientists and the public to facilitate information dissemination and dialogue of public values and indicator development. The Coffee Klatch Process would be best implemented with meetings for the general public or combined meetings of scientists, citizens, land managers, policy makers, and business leaders.

It will be useful for The Partnership to convene a series of technical advisory group (TAG) meetings for scientific input, as well as a series of Coffee Klatch meetings to gain public input. A scientist and land manager advisory group would be necessary in the evaluation of long-term data sets and in evaluating the conceptual model of ecosystem processes. More than one Coffee Klatch composed of the general public will be crucial to gauge public values. Another important Coffee Klatch is one focused on policy makers, business and industry representatives. This would offer perspective on policy and economic values related to the watershed. It is also recommended that a combined Coffee Klatch be held with citizens, scientists, policy makers and industry to communicate shared values, interests and efforts for the Coos Watershed Indicators program.

Schiller et al. found that a series of small meetings with the public also informed their efforts to communicate the information provided by an indicators program. From their series of meetings, the public shared that their interests were not in the scientific details of how each indicator would be measured, but rather what the measured information would tell them about environmental conditions (Schiller, et al., 2001).

Several methods have been used to communicate indicator performance to the public, recognizing that the ideal situation is where environmental goals, the management of resources and thus the establishment of ecological indicators is achieved through close communication between scientists, policy makers and the public (Harwell, et al., 1999). Environmental report cards or performance reports can take many forms, such as a simple color coding that informs the lay audience ø K Ŝ ű K Ŝ NJ ű K Ŝ ƛ ƴ Ř ƛ Ŏ ŀ ű ƍ NJ Ω ă ă ű ŀ ű dz ă ƛ ă ƛ ƴ ŀ NJ ŀ ƴ ∃ Ŝ characterized from good to poor. These reports might also include written summaries, graphs or tables that illustrate indicator performance.

It is recommended that The Partnership create a series of Coffee Klatch meetings composed of representatives of the public, scientists and policy makers to create a language and report format by which to most effectively communicate the status of Coos Watershed indicators. This process would be an iterative process with multiple meetings for each focus group.

That process includes steps similar to those used by Schiller et al., where the process would begin by identifying and understanding indicator names; then describing what each indicator measures and what information it provides; translating what information it provides into what the information tells the public about the environment; synthesizing multiple indicators into άcommon language έto communicate the status of the environment; and, finally testing ű K Ŝ ά Ŏ ƍ Ƴ Ƴ ƍ ƴ ƚ ŀ ƴ ∃ d indicators with the public and policy makers. The nature of this iterative process facilitates feedback from each stakeholder group (Schiller, et al., 2001). ¢ K Ŝ Ř Ŝ Ø Ŝ ƚ ƍ LJ Ƴ Ŝ ƴ ű ƍ Ŧ ƚ ŀ ƴ ∃ dz ŀ ∃ Ŝ έ ƛ ƴ Ř ƛ Ŏ ŀ ű ƍ NJ ă Ŧ ƍ NJ Č take place after indicators have been selected for the overall program.

Step 5: Evaluate Indicators Already In Use

The next step in the development process is to evaluate indicators that are already in use by other organizations or governments. To apply this step to the Coos Watershed Indicators Program, the goal was to provide The Partnership with examples of indicator programs that were similar in size and capacity, geographically or regionally relevant, or contextually related in regards to climate change and land use impacts. Programs established in Oregon and regionally were also given priority in the review of existing indicators because of the goal to select indicators that integrate into to regional monitoring and environmental assessment efforts.

A number of organizations within Oregon have already implemented or begun to establish indicator programs. Organizations such as the Oregon Watershed Enhancement Board, the Oregon Progress Board, the Pacific Northwest Aquatic Monitoring Partnership, and the Oregon Department of Forestry have each established ecological indicator programs under an array of objectives.

This section gives an overview of a couple Oregon indicator programs and a couple programs in use by other organizations in the Pacific Northwest. The programs briefly highlighted here were chosen because of their relevance to the Coos Watershed Indicators Program either because of objective similarities, program size and capacity, and indicator integration and synergy. The programs discussed here are the Oregon Plan for Salmon and Watersheds, the Oregon Progress Board, ű K Ŝ 9 t ! Ω ă -Georgia Basin program, Environmental Protection Indicators for California (EPIC), Pacific Northwest Aquatic Monitoring Partnership (PNAMP), and the Pacific Northwest Coastal Ecosystems Regional Study (PNCERS).

While a brief discussion of these programs is presented here, Appendix H provides more information about a variety of relevant indicator programs.

Oregon Plan for Salmon and Watersheds (OPSW)

In 2005, the Institute for Natural Resources at Oregon State University developed the Oregon Plan for Salmon and Watersheds (OPSW) τ a suite of potential indicators for the Oregon Watershed Enhancement Board (OWEB). The goal of OPSW is to restore watersheds and recover fish and wildlife populations to productive levels in an environmentally and socially sustainable manner (Dent, et al., 2005). The OPSW developed a list of priority indicators, also broken into ecosystem classes, which are listed below. The OPSW is a very relevant example for the Coos Watershed Indicators Program because the indentified indicators are ones with which the Partnership can integrate or supplement current monitoring efforts and monitoring databases.

Also, the Coos Watershed Association was established and is partially funded by the Oregon Watershed Enhancement Board, which works state wide. By integrating with OPSW indicators, the Coos Watershed Indicators Program could have access to other useful data sets, as well as provide reports for the Coos Watershed, which would help to inform a larger regional or statewide status and trends monitoring program through OWEB.

The following are the OPSW indicators within the identified ecosystem class. Each of the indicators described here are relevant to the Coos Watershed Indicators Program as determined by the application of the guiding criteria.

AQUATIC AND RIPARIAN ECOSYSTEMS

1. Anadromous fish abundance and distribution

2. Coldwater Index of Biotic Integrity (IBI) for fish and for macroinvertebrates (with the same data, native and nonnative species numbers and distributions can be reported for OPSW Indicator #15.)

3. Water Quality Index (WQI) (miles or percent of streams with rating of poor, fair, or good WQI)

4. Area, distribution, and types of riparian and wetland vegetation

5. Riparian function index based on vegetation and site capability (e.g., large wood recruitment, shade, and nutrient input) and wetland function index based on hydro-geomorphic (HGM) typing.

6. Physical aquatic habitat and estuarine habitat condition

7. Access to freshwater and estuarine habitat (miles of habitat accessible or limited; can be further analyzed by habitat quality)

8. Frequency of meeting instream water rights

TERRESTRIAL ECOSYSTEMS

9. Area, distribution, configuration, and types of cover for established ecological classes

10. Change in land use and land cover

ESTUARINE ECOSYSTEMS

11. Area, distribution, type, and change in area of tidal and submerged wetlands

12. Index of Biotic Integrity for estuaries

ECOSYSTEM BIODIVERSITY

13. Number of native plant and animal species and distribution over time (departure from potential)

14. At-risk species (aquatic, estuarine, and terrestrial; plant and animal)

15. Percent of nonnative invasive species (focus on subset of known species)

Oregon Progress Board (OPB)

The Oregon Progress Board (OPB) has developed statewide benchmarks for education, economy, environment and more. Many of the environmental benchmarks are based on or even utilize indicators already developed by other organizations such as the Oregon Department of Forestry.

The OPB has established 37 natural environment benchmarks, which address air quality, water quality, habitat quality, land cover, storm water, timber harvest, wildlife population health, invasive species, hazardous substances and municipal solid waste.

Many of these indicators are monitored by federal or state agencies, such as the U.S. Forest Service, Oregon Department of Fish and Wildlife, and the Oregon Department of Forestry. These indicators are useful because much of the information that goes into the OPB reports is gathered by these agencies at the local scale as well. Therefore, The Partnership could potentially access this data or work with these agencies to track and assess indicators like acres of freshwater or estuarine wetlands gained or lost, percent freshwater species at risk, or percent of forest land cover.

EPA: Puget Sound-Georgia Basin

The Puget Sound-Georgia Basin indicators program was established by EPA. The program places a large emphasis on citizen science outreach; however, the actual indicators are monitored by environmental professionals and are then reported to the public.

Among these indicators are forest cover and urbanization, measured as percent land cover change from or to these specific cover types. The Georgia Basin-Puget Sound program monitors human population health indicators, as well as fish and shellfish abundance, water quality, marine and freshwater wildlife abundance indicators (Transboundary Georgia Basin-Puget Sound Environmental Indicators Working Group, 2002).

Environmental Protection Indicators for California (EPIC)

In 2009, California published their work on establishing indicators of climate change for the state. Among the 27 indicators identified for the EPIC program are greenhouse gas emissions and carbon dioxide concentrations, annual average air temperature at regional, state-wide and local scales, as well as annual precipitation, large wildfires and changes in vegetation composition and distribution. The report classifies indicators according to whether data and monitoring programs already exist for the indicators (Office of Environmental Health Hazard Assessment (OEHHA), 2009).

EPIC is relevant to the Coos Watershed Indicators Program because of its focus on climate change impacts. While the data produced from these indicators may not be applicable for integration or use at the Coos Watershed scale, the indicators are excellent examples of measures which were prioritized and selected to track the impacts of impacts from climate change on the natural environment. Indicators such as annual precipitation, wildfire frequency, and vegetation composition and distribution have all been identified as potential indicators for the Coos Watershed. Therefore, the EPIC program could offer a valuable example for the selection of Coos Watershed indicators for climate change.

Pacific Northwest Aquatic Monitoring Partnership (PNAMP)

PNAMP is a partnership of several organizations in the Pacific Northwest, which focus on water quality issues. The purpose of the partnership is to provide a forum for coordinating state, federal, and tribal aquatic habitat and salmon monitoring programs (PNAMP, 2010).

In 2009, the Partnership identified six core indicators of watershed health and four core indicators for salmon populations. The core watershed health indicators are: water quality index, stream flow, sediment quality index, habitat quality (in-stream and riparian) index, Biological Health Index (in-stream), and land use/land cover (PNAMP, 2009). The core salmon indicators are measures of abundance: abundance of wild spawners; abundance of adults harvested; abundance of juveniles; and, abundance of hatchery spawners.

t b ! a t Ω ă Ǒ2NlŜ health ǿ indicators ŰŜNl are relevant to the Coos Watershed Indicators Program because many of these measures are ones that are currently monitored or could be monitored.

Monitoring information gathered on these core indicators in the Coos Watershed could also ƛ ƴ ű Ŝ ∃NJ Ⱶ ű Ŝ ǿ Ŝ f f ƛ ƴ ű ƻ t b ! a t Ω and Trends Monitoring (ISTM) project, where monitoring sites and information is recorded by partnering organizations in the region. / ƻ ƴ Ǿ Ŝ NJ ă Ŝ f ȅ Σ t b ! a t Ω ă L { ¢ a LJ valuable information to The Partnership in their efforts to establish a monitoring program or in choosing additional monitoring sites. ISTM catalogs monitoring sites, so that organizations can access who and what information is being collected at various sites in the region.

Pacific Northwest Coastal Ecosystems Regional Study (PNCERS)

The Pacific Northwest Coastal Ecosystems Regional Study (PNCERS) was a seven-year program funded by NOAA. It established social and environmental indicators for coastal watersheds with the aim of communicating with natural resource managers.

Among those indicators were measures such as revenue from fish catch; commercial oyster production in gallons per year; number of non-native invasive marine species; percent survival of salmon smolts to maturity; species diversity of water and shorebirds; rainfall in inches per year, streamflow and average annual air temperature (Parrish, Bailey, Copping, & Stein, 2003).

PNCERS also reported on human population trends, income, poverty and unemployment, as well recreation trends and pollution permitting. Information was gathered from a variety of sources and condensed into small reports that captured the status of the indicator in an accessible print format. Not only are the indicators relevant examples for the Coos Watershed Indicators Program, the format in which PNCERS communicated the indicators is also a relevant example. The diagrams used for the indicator reports were particularly simple and easy to comprehend. This highlights the need to establish a clear and comprehensible format for indicator communication to the public.

Step 6: Identify Potential Indicators

Based on a review of existing indicator programs, including the ones reviewed in the last section, as well as a review of data collected by Coos WA and SSNERR, a list of potential indicators for the Coos Watershed Indicators Program was developed and is listed in Appendix D in addition to a review of existing indicators listed in Appendix H.

This list of potential indicators is not exhaustive. The number of indicators and the specific measures presented in this list were chosen based on comparisons to other programs, as well as their estimated score using the weighted scoring matrix developed for this project.

The indicators are not presented in the PSR framework because the organizations using them did not use the PSR framework to develop their indicators program. The list is meant to offer examples of indicators being used by other programs, which are relevant to the Coos Watershed ecosystem and The t ŀ NJ ű ү Ŝ NJ ă K ƛ LJ Ω objectives.

The initial selection of the potential indicators was based on Ŝ ŀ Ŏ K ƛ ү Ř ƛ Ŏ ŀ ű ƻ NJ Ω ă dz ă programs Σ ŀ ă ǿ Ŝ ƚ ƚ incorporation ү Ř ƛ Ŏ ŀ ű ƻ in current monitoring efforts by Coos WA or SSNERR. The number of indicators was kept to 28 because of the estimated capacity of Coos WA to eventually measure these indicators watershed wide, and { { b 9 w w Ω ă ƚ ƛ Ƴ ƛ ű ă ō their focus on the South Slough watershed. Each indicator presented in Appendix D also had an estimated score within the top two priority designations.

Step 7: Establish Acceptable Levels

An often overlooked component in ecological indicator programs is the establishment of acceptable levels for each indicator that tell us when we should do something about the state of an indicator or ecosystem. Establishing acceptable levels Ŧ ƻ NJ ŀ ү ƛ ү Ř ƛ Ŏ ŀ ű ƻ NJ Ω ă that are scientifically rigorous and connected to public values is central to the effectiveness of an indicator program (Doren, Trexler, Gottlieb, & Harwell, 2009).

Ecologically, it requires an in-depth investigation and conceptualization of the components and processes that affect an ecosystem or a particular environmental condition. Ecosystems are complex and scientists do not know everything about how they work, so this often necessitates an adaptive approach (Doren, et al., 2009).

Socially, there are expectations for the services that an ecosystem will provide to a community, such as clean water or fish production. These expectations create the acceptable levels for indicators based on human desires for a certain state of naturalness or productivity in an ecosystem (Paetzold, Warren, & Maltby, 2009).

Ecological indicator monitoring programs often fall short of their objectives because acceptable levels for each indicator are not well defined both ecologically and socially (Watzin et al. 2005). Without an understanding of how an indicator naturally varies in an ecosystem and at what level the indicator is in an undesirable state, it is difficult to employ effective management actions.

Whether a suite of indicators is useful for land managers and policy-makers depends on defining those acceptable levels for each indicator, so that monitoring data can be interpreted and management actions adapted as necessary. This is particularly important for the Coos Watershed Indicators Program because of their use of the PSR framework, which defines response indicators separately to measure the effectiveness of management actions.

Ecological indicators are surrogates for specific environmental endpoints, such as water quality or biodiversity, and should be of value to the public. The selection of indicators depends on the identification of specific questions relevant to management or policy, which should be answered through the monitoring process (Noss, 1999). Therefore, acceptable levels should be specific statements of the desirable range of measured values for each indicator and those desirable ranges should reflect and be based upon management goals, scientific understanding, and social values (Watzin et al. 2005).

Identifying acceptable levels for indicators should ideally merge both a rigorous scientific review of available long-term data by a Technical Advisory Group, as well as an assessment of socially desirable ecosystem conditions (Smyth, Watzin, & Manning, 2007). Sometimes indicator levels can be established directly from minimum quality standards or legislative requirements set at the local, state or federal levels, however these levels must also connect to public values for the state of the ecosystem (Paetzold, et al., 2009).

In the next chapter, stream temperature is taken through the indicator development steps for the PSR framework as an example indicator. The indicator used to monitor acceptable levels for stream temperature in Oregon is the maximum 7-day average summer stream temperature. This measure exists and was established by scientists based on studies of elevated stream temperature impacts to the Salmonid lifecycle. Other stream temperature statistics may provide additional information about environmental change, the impacts of restoration efforts, or possibly the impacts of climate change. One additional statistic will be explored as possible indicator for monitoring stream temperature.

Chapter 4: Stream Temperature as an Example Indicator

Stream temperature was selected as an example indicator because of its influence on the health and survival of salmon populations. In the Pacific Northwest, salmon are culturally and economically significant. Salmon and other coldwater fish species in the United States are also at particular risk from the impact of land use and climate changes. A number of human activities threaten the health and survival of salmon species, but climate change coupled with those human activities is a growing source of stress (USGCRP, 2009). As air temperatures rise and changing land uses place more pressure on stream ecosystems, stream temperature becomes an increasingly important variable in the survival of coldwater fish species.

Coos WA and SSNERR have monitored stream ű Ŝ ϒ LJŜ NJ ŀ ű dzNJŜ ă ƛ ƴ Ŏ Ŝ Ŝ ŀ Ŏ Ƙ ƽ NJ Ǝ ŀ ƴ ƛ Î ŀ ű ƛ ƽ ƴ Ω ă inception. Coos WA has monitored stream temperature and implemented restoration activities throughout the Coos Watershed since 1995. These efforts were made with the goal of restoring salmon population health by improving habitat quality, improving fish passage, reducing sediment inputs, and reducing stream temperature.

Restoring appropriate stream temperatures can be difficult due to the complexity of stream ecosystems. Temperature regimes in rivers are determined by a dynamic set of factors that vary both within rivers and between different river systems. Land use history, topography, river discharge, sediment type, and climate conditions all play a role in the warming or cooling of stream water (Poole & Berman, 2001). The purpose of indicators, however, is to create a reduced set of measures that inform managers about the condition of the ecosystem (Smeets & Weterings, 1999). Stream temperature was selected as an example indicator to take through the PSR steps because of its importance ecologically and socially, and because this is a measure on which both organizations already focus much of their effort.

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Step1: Scale and Objectives

The smallest scale at which stream temperature would be assessed by The Partnership would be at the stream reach level. For this project, Willanch Creek was used as a case study to examine stream temperature as a potential indicator. Willanch Creek drains a total of 5,369 acres with a total of 33.8 miles of stream, which drain into Coos Bay. The Willanch watershed contains a range of ecosystems from estuarine to upland forests.

The objectives are those set out for the larger indicators program, which are:

1. Monitor the long-term impacts of climate and land use changes to a coastal watershed, the Coos Watershed.

2. Evaluate the effectiveness of management and restoration efforts through the use of indicators.

/ 2 2 ă management goals relative to stream temperature are to improve habitat quality by reducing stream temperature, among a host of other factors such as reducing sediment and improving fish passage.

Step 2: Set the Framework

To construct the stream temperature PSR diagram (Figure 5) current and historic pressures and management actions were considered. The pressure indicators were selected based on past and projected land use changes, as well as based on projected climate changes. The state indicators are stream temperature, area of potential fish habitat, and native anadromous fish abundance and health. These state indicators were chosen because of the impact temperature has on individual fish, and because the impact that a lack of cold water habitat has on a salmon population. Scientists believe that thermal refugia are

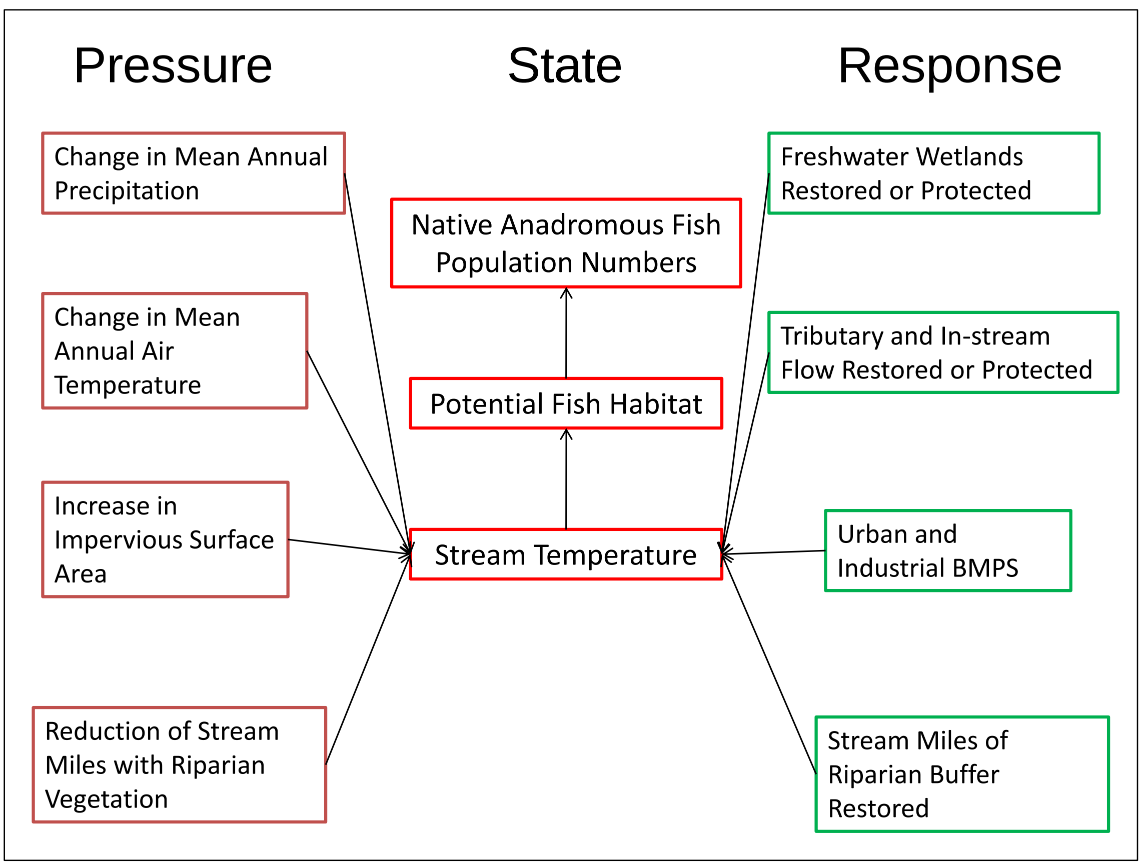

Figure 5: Stream Temperature PSR Diagram for Coos Indicators Program

essential to the survival of many aquatic species, and this is especially true of Salmonid species, which rely on pockets of cold water stream habitat when temperatures exceed tolerable levels (Torgersen, Price, Li, & McIntosh, 1999).

The response indicators were selected based on a review of current Coos WA management and restoration efforts and potential actions that could be employed and measured in response to the projected pressures related to climate change and land uses.

It is important to note that change in mean annual precipitation and mean annual air temperatures are pressures, for which Coos WA and SSNERR cannot create management actions that will directly affect these pressures. This is because the source of these pressures is at a much larger scale than that of the Coos Indicators program. The source is global τ global climate change. This is not to say that citizens, scientists, policymakers, and others in the Coos Watershed cannot take actions to address climate change at the local level, however at the local management level, The Partnership cannot implement management actions that will change mean annual precipitation or air temperature.

Their management actions can only seek to mitigate the effects by fostering resilience and adaptive capacity in the ecosystem. Among these actions are restoring tributary flows, restoring riparian vegetation, and restoring wetland and marsh areas to buffer instream flows.

Step 3: Guiding Criteria

When compared to the guiding criteria established for the Coos Watershed Indicators program, stream temperature scores well for both the ecological and operational criteria. Ecologically, stream temperature is strongly related to the other ecosystem components. It is measurable and in the Willanch case study, Coos WA has measured it for 15 years using a standard procedure. Stream temperature as an indicator can be complex when trying to distinguish natural variability within a stream due to thermal heterogeneity, however relative to the salmon lifecycle it is possible to distinguish between acceptable and unacceptable water temperatures. Stream temperature is responsive, can be used to document trends, and monitoring data can be integrated into larger watershed assessments.

In terms of the operational criteria, stream temperature is socially relevant because of its well established impact on the salmon lifecycle and the importance of salmon to ecosystem functions and the local economy. Data collection for stream temperature is feasible and synergistic. The spatial and temporal scale of measurement for stream temperature is appropriate, as is evidenced by the Willanch Creek case study. Stream temperature is appropriate to / ƻ ƻ ă ² ! Ω ă Ŏ ŀ LJ ŀ ō ƛ ƭ ƛ management efforts. / ƻ ƻ ă ² ! Ω ă Ŝ Ŧ Ŧ ƻ NJ monitor stream temperature and implement restoration actions is very likely to be funded through various avenues.

Step 4: Establish Public Values

As indicated in the preliminary public meetings held in July 2009, salmon are important to scientists and the general public. The number of responses identifying salmon as an important value for the watershed was nearly equal from both groups, and ranking third in the overall number of responses.

[illegible] cultural history. Before European settlers arrived in Coos Bay, the Willanch Creek sub-basin in particular was used by Native Americans to smoke fish caught in weirs (Coyote, 2010). Native American Tribes relied on salmon as a significant part of their diet and trade, and settlers to the Pacific Northwest also relied on salmon in the same fashion. Salmon have played a central role in the life and economy of the Pacific Northwest (Cone, 1995).

[illegible] recovery of populations mostly began in the 1970s and gained momentum over time with more organized efforts at the citizen and government levels. Efforts to protect and restore salmon fisheries continue today with programs at many levels and through many organizations, such as the Oregon Watershed [illegible] Watersheds (Dent, et al., 2005), which focuses on the goal of achieving healthy, sustainable basin and native fish populations.

The process of establishing public values would be an iterative process in which the public could communicate to The Partnership what information would be of greatest value to them. For example, stream temperature may be an indicator within the Coos Watershed Indicators Program; however the public may prefer to simply know whether salmon habitat and salmon populations are improving versus a more abstract report on stream temperature trends. It is this communication between scientists and the public that will shape how the Coos Indicators are communicated.

Step 5: Evaluate Indicators Already In Use

From a review of existing indicator programs, stream temperature was used as an indicator in each one reviewed for this project. While many [illegible] programs incorporated stream temperature as an indicator, it was most often combined as part of a larger water quality index. The complexity of factors affecting stream temperature and the thermal heterogeneity that often exists in streams are such that a water quality index may be seen as a more useful measure of stream quality or salmon habitat quality than stream temperature alone (Webb & Nobilis, 2007). The purpose of using stream temperature as an indicator varies with the objectives of each program.

In the example of the Willanch sub-basin, Coos WA monitored stream temperature separately, but in addition to a suite of aquatic habitat parameters, such as large woody debris, pool area and depth, riffle area, width to depth ratio, and entrenchment ratio. Stream temperature was an important measure of success for Coos [illegible] temperature with a goal of improving overall salmon habitat.

Step 6: Identify Potential Indicators

The selection of indicators depends on formulating specific questions relevant to management or policy, which are to be answered through the monitoring process (Noss, 1990). In the case of Willanch Creek, [illegible] stream temperature, reduce sediment, and improve fish passage thereby increasing and improving salmon habitat. Their second goal is to assess the effectiveness of their restoration actions. Therefore, the questions relevant to the use of stream temperature as an indicator in Willanch Creek are:

1. What is the natural variation of stream temperature in Willanch Creek?
2. Are the changes in the stream temperature regime in Willanch Creek from 1997-2009 due to the restoration activities implemented by Coos WA?

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Given resource constraints, the Partnership will not be able to measure every potential indicator related to stream temperature. Based on a review of literature and other programs, as well as an evaluation of the potential indicators using the weighted scoring matrix, the PSR diagram for stream temperature can be further simplified to a set of potential indicators (shown in Table 2) that would be most useful for The Partnership to monitor as part of their indicators program.

The potential indicators are based on land use history and potential climate change effects in the Willanch sub-basin, but also broadly for the Coos Watershed Indicators program. These indicators were chosen partly based on their use by other programs, such as the Oregon Plan for Salmon and Watersheds, the Environmental Protection Indicators for California, and the Puget Sound-Georgia Basin Indicators program, ǀ ӳ Ř ō Ŝ Ŏ ǀ dz ă Ŝ ƻ Ŧ ű K Ŝ ƛ NJ NJ Ŝ ƚ Ŝ management and restoration activities.

Table 2: Potential PSR indicators for Stream Temperature

Pressure	State	Response
Change in Annual Precipitation		Miles of tributary flow restored
Change in Annual Air Temperature Solar Radiation Intensity in Stream	Summer Stream Temperature Summer 7-day average maximum	Miles of Riparian Vegetation Restored
Number of improperly sized culverts		Number of culverts replaced

Other programs that provide temperature data at the proper scale and sampling resolution which may be useful contributions to stream temperature as indicator are: the Climate Leadership Initiative based at the University of Oregon, as well as temperature data collected by the U.S. Geological Survey, the Oregon Department of Fish and Wildlife, the U.S. Forest Service, the Bureau of Land Management, the Oregon Department of Environmental Quality, and the Oregon Department of Forestry.

Another valuable store of temperature and fish data is housed at StreamNet (www.streamnet.org), which is a searchable archive of data sets related to fish and water quality in the Pacific Northwest.

The next step in the process is to establish an acceptable level for an indicator; therefore, acceptable levels for stream temperature are examined in the next section.

Step 7: Establish Acceptable Levels for Stream Temperature

Due to the importance of salmon to stream ecosystems and to human economies, and based on what is understood about thermal stress on salmon, stream temperature thresholds are therefore based on the salmon lifecycle (ODEQ 2008). Acceptable levels for stream temperature in Oregon have been set by the Oregon Department of Environmental Quality (ODEQ) (Table 3) based on a review of the most current science and with input from EPA scientists (ODEQ 2008).

Elevated stream temperatures pose a significant physical threat to aquatic ecosystems; an effect that can be lethal to many organisms (Torgersen, et al., 1999). Stream water temperature is influenced by many factors, however scientists have done considerable work to understand what at levels stream temperature becomes lethal at the various stages of the salmon lifecycle. Table 3 describes the peak temperature for streams used for summer rearing and migration. This threshold is the uppermost point beyond which salmon will experience increased stress. This threshold was established by the Oregon Department of Environmental Quality after a review of the latest science. These levels are set by the Oregon government to protect salmon habitat and salmon fisheries.

Table 3: Oregon Summer Stream Temperature Standards adapted from ODEQ 2008.

Fish Usage	OR Temp. Standards: Summer 7 Day Avg. Max.
Salmon and trout rearing and migration	18 °C (64.4 °F)

Willanch Creek is considered potential salmon habitat for summer rearing and migration, and thus the 64 F threshold established by ODEQ can be applied to stream temperature monitoring efforts by Coos WA. In the next section, monitoring data for Willanch Creek is examined to further explore stream temperature, specifically the summer 7-day average maximum as an example indicator.

Tracking Stream Temperature Beyond the 7-Day Maximum

Coos WA has monitored stream temperature in Willanch Creek for 15 years, tracking changes in a number of stream characteristics. The summer 7-day average maximum is the measure of greatest importance because of the threshold set by ODEQ. This section explores a portion of the stream temperature data from Willanch Creek and considers whether there may be an additional indicator that could have a more direct bearing on management responses.

¢KŜ ²ƛƭƭŀƴŎK ŘŀűŀăŜű ƛă continuous data set for stream temperature and aquatic habitat inventory. When monitoring began in 1997, summer stream temperatures in several stream sections were well above the ODEQ threshold for Salmonid optimal summer rearing conditions.

Coos WA has monitoring data from 7-9 stream stations in Willanch Creek. These stream stations are placed in Willanch Creek at varying distances apart. There are two upper stations, which are used as reference stations because Coos WA has implemented no restoration activities in or above these reaches. The lower stations are all within reaches where restoration activities have taken place. The reference and restoration sections cover a 4-6 mile span as the crow flies to the mouth of Willanch Creek.

Over 15 years and after multiple restoration activities, stream temperatures have decreased to well below the ODEQ threshold of 64 F in most stream sections. All monitoring sites in the Willanch sub-basin were at acceptable levels in the last four years of data collection.

Coos WA has implemented a number of different restoration actions in Willanch Creek to reduce stream temperature, such as riparian vegetation planting, stream bank stabilization, culvert replacements, and reconnection of the stream to the floodplain.

Coos WA is interested in answering these aforementioned questions relative to stream temperature in Willanch Creek:

1. What is the natural variation of stream temperature in Willanch Creek?
2. Are the changes in stream temperature from 1997-2009 in Willanch Creek due to the restoration activities implemented by Coos WA?

Natural variation is important to understand when monitoring indicators because an identifiable, acceptable range must exist so that when measured levels are exceeded, stakeholders know when to respond.

Natural Variation

Natural variation of an indicator within an ecosystem distinguishes between the changes caused as a result of human activities and changes that reflect the natural fluctuations of the system. Long term research and data collection for an indicator are necessary to characterize its natural variation (Landres, 1992). The State of the Environment Report (SOER Science Panel 2000) explained that the extent to which an aquatic ŜŎƨăèăűŜϒΩă processes and characteristics reflect natural ranges is considered the best long-term indicator of aquatic ecosystem health.

Temporal variation and spatial variation are critical factors in the measurement of stream temperature. Temporal variation is change with time. Seasonal variation in stream temperature is an excellent example of temporal variation. Willanch Creek stream temperature data from 1997-2009 show a clear seasonal trend. The summer stream temperature data from Willanch Creek also appears to have declined over time.

Spatial variation is change over distance or position. In Willanch Creek, monitoring data from upstream stations to downstream stations shows a warming trend, meaning stream temperatures increase from upstream to downstream locations, as would be expected.

Many things affect stream temperature such as climate, stream flow, riparian vegetation, and channel structure. The influence of any one factor on stream temperature will also vary by location, distance and over time τ spatial and temporal variation (King, 2005). For example, the temporal variation of the linkage between air temperature and stream temperature will be very different depending on whether changes are examined over a day versus a year.

The process of examining natural variation is often overlooked or left uncompleted for indicator programs (Watzin, et al., 2005). This can be due to financial constraints or data limitations, as the evaluation of natural ranges can be a time-consuming and labor intensive process. The importance of historical data in this process is clear, however; to characterize natural variation, there must be sufficient data to support the ŀ ỵ ŀ ſ ề ă ƛ ă ƻ Ŧ ű K Ŝ ƛ ỹ Ř ƛ Ō ł ū ƻ NJ Ω ă fluctuation within the ecosystem over time.

Willanch Natural Variation

Thermal variation within a stream is influenced by many factors. Some of those factors are air temperature, solar insolation, precipitation, groundwater and interstitial flows, tributary connectivity, and large woody debris. This analysis examines one of those factors by looking at the relationship of air temperature and stream temperature in Willanch Creek.

Daily summer stream temperature and daily summer air temperature data from 2004-2009 (2005 and 2008 air temperature data were not collected) were averaged to obtain average monthly maximum temperatures. Corresponding monthly values were then plotted against each other. Summer was considered to be the months of July through September. Average monthly maximum stream temperatures for each monitoring reach were plotted over time. The average monthly maximum air temperatures collected by a weather station located in the Willanch sub-basin were also plotted over time.

The analysis showed seasonal variation in both air temperature and stream temperature. While air temperatures in the Willanch sub-basin showed a small increasing trend from 2004-2009, air temperature data collected from the NOAA weather station at the North Bend Regional Airport showed a decreasing trend in mean annual air temperatures from 1980-2009 (Appendix G).

When plotted against each other (Figure 6), the coefficient of variation for each year indicated the relationship between air temperature and stream temperature was not strong. This suggests that changes in stream temperature did not significantly correspond with changes in air temperature.

The analysis completed here is not meant to fully characterize the natural variation of stream temperature in Willanch Creek. While the relationship between stream temperature and air temperature was not statistically significant because of the small sample size, stream temperature and air temperature are related as they must be to some extent.

Maximum monthly stream temperatures seem to follow maximum air temperatures to some degree, but a wide variety of other factors may also be in control of stream temperature. Factors such as solar radiation, stream flow, and sediment are a few of the components that affect stream temperature and could be used for a more complex analysis with appropriate data collection.

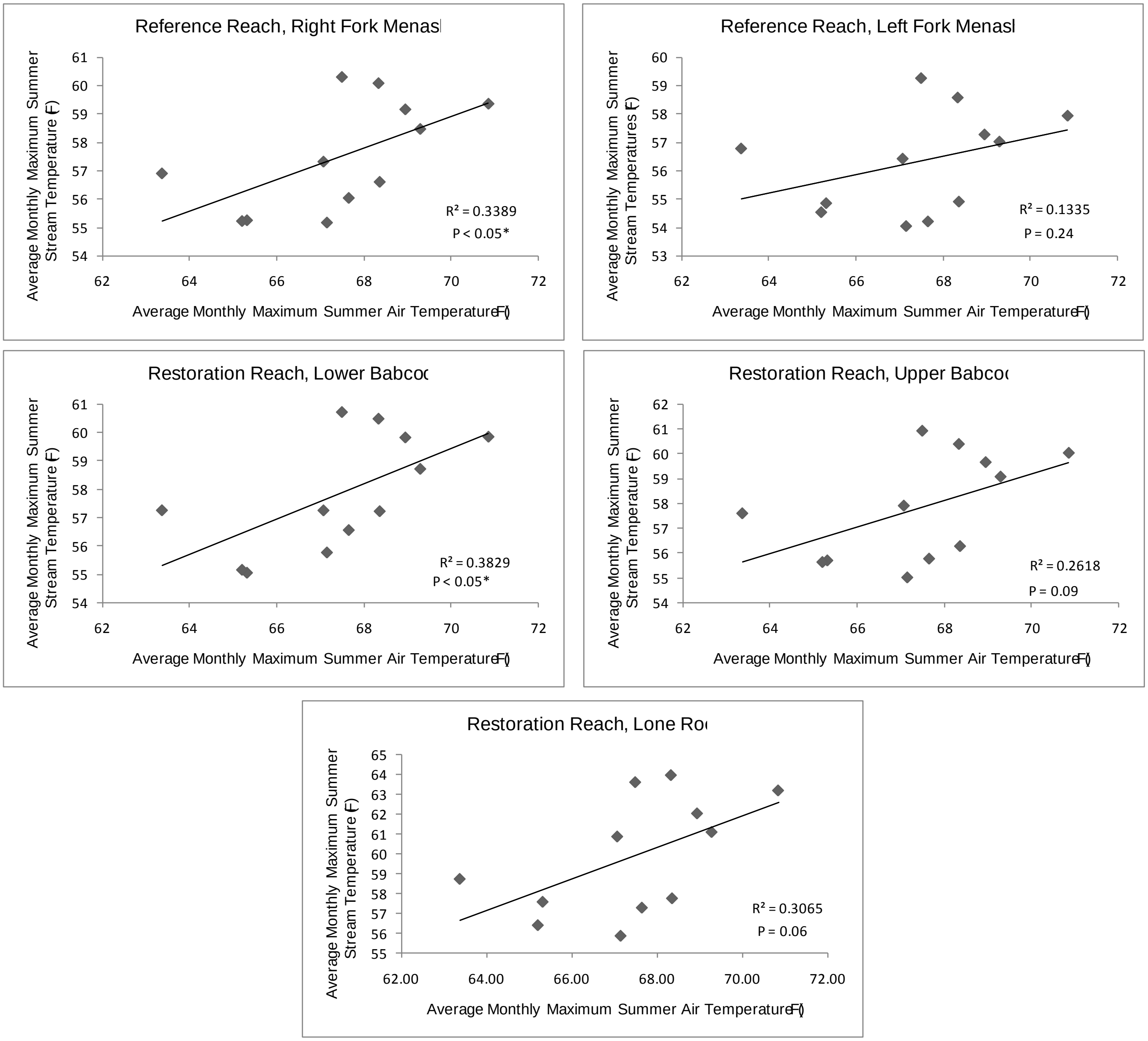


Figure 6: Linear regression for five monitoring stations on Willanch Creek. Results are from the analysis of summer stream and air temperature data from 2004-2009. Air temperature data were available only for 2004-2009 therefore the corresponding timeframe was used for the stream temperature data. An asterisk indicates statistical significance, although a test of significance is difficult for this analysis because the data are not linear due to unavailable data for several years and missing data points.

Restoration Impacts on Stream Temperature

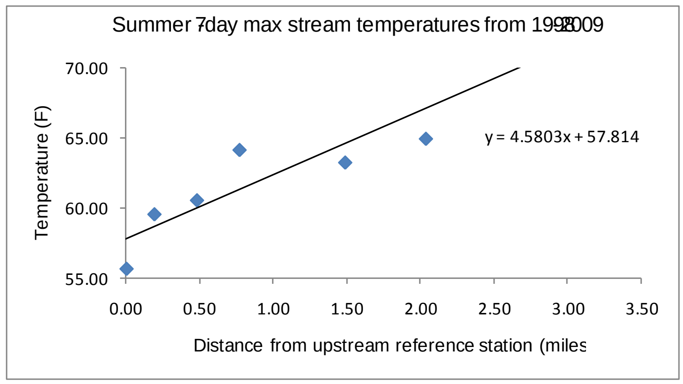
Using the available monitoring data from 1997-2009 collected by CoosWA, a simple assessment of the stream temperature trend was completed. The goal of this assessment was to gauge the impact of restoration activities on stream temperature in Willanch Creek over time.

Over the past 15 years, Coos WA has been monitoring stream temperature and paying attention to one measure in particular τ the 7-day average maximum stream temperature. This is the potential indicator examined here because ODEQ has established a threshold for this measure based on the salmon lifecycle and the impact of elevated stream temperatures on fish mortality.

Thus, this assessment used the 7-day average maximum as the statistic of interest, and evaluated the rate of change of this indicator over the monitored stream distance for each year. The rate of change for each year was plotted to assess the trend over time.

For each year, the 7-day average maximums were plotted for each stream station against distance from the most upstream reference station. As was expected, each exhibited a positive slope, with increasing temperatures from upstream to downstream. Figure 7a illustrates the analysis for 2009 as an example of how data from each year 1998-2009 was completed.

From 1998-2009 (1997 was omitted for lack of data points), the rate of change of the 7-day average maximums over distance decreased, meaning that from the upstream to downstream location, the 7-day average maximum stream temperature was decreasing over time for the entire monitored stream section (Figure 7b). This suggests that the 7-day maximum summer stream temperature has decreased at all stream monitoring stations since 1998. The 7-day maximum stream temperature has decreased over time.



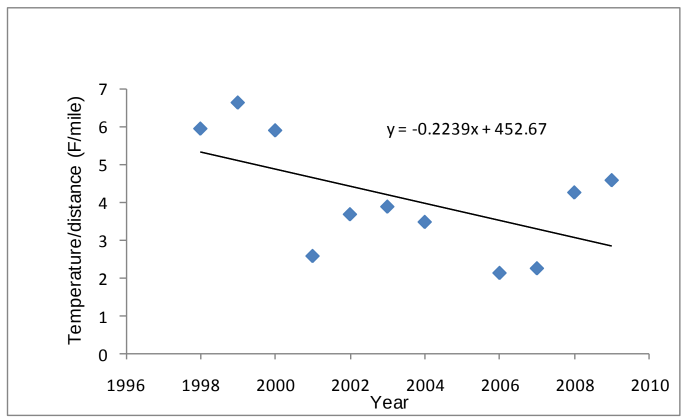


Figure 7a: 2009 Summer 7-day average maximum stream temperatures from the most upstream reference station to the downstream stream station. E a c h y e a r ô s t e m plotted in this manner. The slope for each year was noted.

Figure 7b: Slope for the summer 7-day maximum stream temperature each year, 1998-2009, was plotted, showing a decreasing trend over time. From 1998-2009 the rate of temperature change within the monitored section of Willanch Creek decreased.

This new indicator is thus slightly modified from the original 7-day average maximum. Instead, it is the slope of the yearly summer 7-day average maximum stream temperature over the monitored stream distance, which is a surrogate for time. ¢KŜ ƛƴŘƛŎŀűƧNJΩă change in degrees/mile.

The decreasing trend shown in Figure 7b ădz∃∃Ŝăűă ű Krestoration activities ² ! Ωă may be reducing stream temperature warming as water moves from the Menasha monitoring station downstream. These are promising signs for CoosW ! Ωă NJŜăűƧNJŀűƛƧƴ ŜŦŦƧNJűă

While this is positive evidence, a causal relationship between the decline in stream warming and the Coos WA restoration program cannot be inferred because these are field measurements and not an experiment. Stream temperatures are the result of multiple climatic, hydrologic, and land-use/land-cover factors in watersheds (Webb & Nobilis, 2007). These include geography, groundwater inputs, solar radiation and air temperature, as well as increasing human disturbances such as global warming and land use changes (Kaushal, et al., 2010). However, in the absence of other logical reasons for this decline, it seems reasonable to continue to monitor this indicator as a possible measure of the effect of Coos ² ! Ωă NJŜăűƧNJŀűƛƧƴ ŜŦŦƧNJűăΦ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The 7-day average maximum as a measure ƛƴűŜ∃NJŀűŜă øŜťť øƛűK monitoring strategies; however, a measure that is less isolated may give a better indication of űKŜ ăűNJŜŀΥΩă űŜΥLJŜNJŀűdzNJŜ ƛ ... Such a measure could look at stream warming by monitoring the maximum daily rate of stream warming from the upstream monitoring station to the downstream station. If the daily rate of stream warming declines over time, this could help to assess both the effectiveness of management efforts, as well as measure a ăűNJŜŀΥΩă NJŜăƛťƛŜƴŎŜ ű Ƨ temperatures.

Stream Temperature as an Indicator

While a clear causal relationship cannot be drawn between management actions and resulting stream temperature, the analysis, provides an example of how The Partnership might be able to examine stream temperature as an indicator.

A comprehensive analysis would incorporate the evaluation of stream flow, solar radiation, land use/land cover change, groundwater infiltration, a more complete data set for air temperature and stream temperature, in addition to other factors such as long term shifts in climate oscillations such as the Pacific Decadal Oscillation (Durance & Ormerod, 2007). An analysis of this type is not possible at all sites (Likens, 1991), and it may be outside the scope and feasibility of The tŀNJűƴŜNJăKƛLJΩă resources.

The influence of stream temperature and air temperature on ecological systems supports their use as indicators to track and predict the impacts of climate and land use change on stream ecosystems (Kaushal, et al., 2010). The use of indicators will be a valuable tool for The Partnership to track and communicate with stakeholders about the status and trends of the Coos Watershed Ωă ăűNJŜŀΥ . ŜŎƧăèă

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Chapter 5: Conclusions & Overall Recommendations

The Coos Watershed Association and the South Slough National Estuarine Research Reserve formed a partnership to create an ecological indicators program. This program would be charged with monitoring the impacts of climate and land use changes to the Coos Watershed. To launch this effort, the Partnership chose Pressure State Response as the indicator development framework and then identified the coastal frontal watershed as the pilot study area in which to start the process of developing ŀ ȳ ƛ ȳŘƛŎŀ ű ƨNJă LJNJƨ ƎNJŀ ƳΦ ¢ƘŜ ŧ ŀNJű ƴŜNJă Ƙƛ LJΩ ă objectives are:

1) To monitor the long-term impacts of climate and land use changes to the Coos Watershed through the development of an ecological indicators program.
2) To evaluate the effectiveness of management and restoration efforts through an adaptive management process informed by an ecological indicators program.

The CoosWA and SSNERR partnered with the Field Naturalist program at the University of Vermont to provide additional research for the development of the Coos Watershed Indicators Program. The goals of this project were:

1. Apply the PSR framework to the Coos Watershed Indicators pilot study.
2. To identify applicable ecological indicators already in use through a literature review and examination of existing indicator programs.
3. To use stream temperature an example indicator by taking it through the PSR process.

Coastal communities around the world are already experiencing the impacts climate and land use changes (Canning & Mote, 2007). Greater focus is being placed on how to track and respond to the impacts of climate change, as well as how to manage coastal ecosystems to increase their resilience to climate changes (Gibbs, 2009). ¢ƻ Ŧŀ Ŏ⅄ƒ⅄ǘŀǘŜ ¢ĶŜ tŀNJǘƴŜNJăĶ⅄LJΩă program development, seven key steps were identified from the PSR development process and examined as part of this project for the Coos Watershed.

There are many organizations worldwide that are using indicators to track changes in coastal ecosystems. The organizations presented in this document mostly reflect the Pacific Northwest Region because examples that more closely resemble the local setting of the Coos Watershed may prove more useful in addressing climate change and land use impacts for the Coos Indicators Program. Indicators suggested here were chosen based on their applicability to the Coos Watershed, their relevance to ¢ĶŜ tŀNJǘƴŜNJăĶ⅄LJΩă current data collection efforts, and their evaluation through the weighted scoring system adapted for Coos Watershed Indicators Program.

The next section focuses on recommendation for The Partnership concerning data collection and communication. Recommendations are made based on a review of other indicator programs, and a review of the stream temperature data collected by the Coos Watershed Association.

Recommendations

Data Collection

Recommendations for The Partnership are focused on data collection and communication. Through a review of the monitoring data collected by CoosWA, it may be helpful to have a clear Quality Assurance-Quality Control (QAQC) protocol for stream temperature data collection. There is abundant information available about QAQC methods; however several key recommendations are focused on here.

First, it may be helpful for the partnership to identify 3-4 essential stream stations and implement a rigorous QAQC process for only those stations. This would assure consistently complete, quality data for a set of points along each monitored stream.

In Willanch Creek, these points might be a Menasha Left Fork, Babcock Lower, Lower Lone Rock, and Tidegate, as they are named by CoosWA. These four points would cover the key locations. Ensuring that monitoring stations are not placed at the confluence of tributaries is also essential.

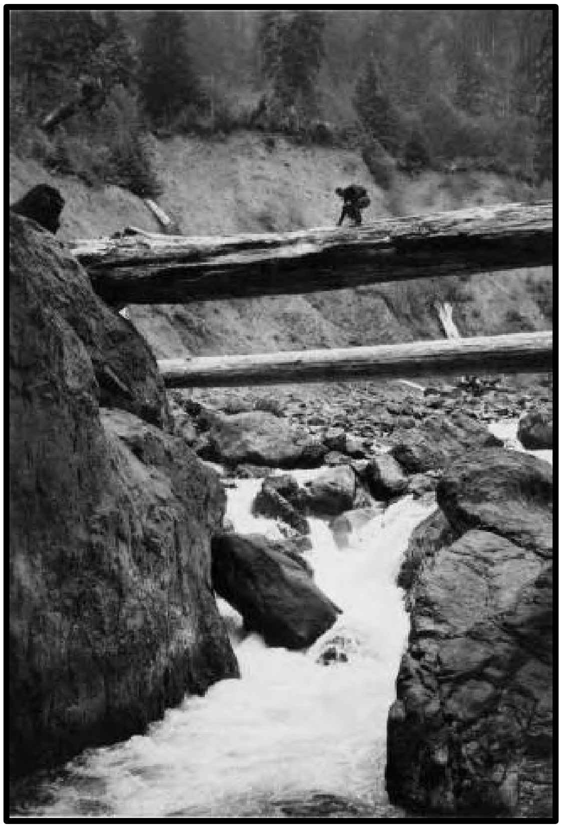
Second, a review of the stream data uncovered some questionable outliers. This could be due to malfunctioning data collectors. One method to address this problem is to place two temperature units at the same location. This allows the manager to check the accuracy of the units against each other, and also offers some data collection assurance should a unit fail or become lost.

Lastly, the most sensitive way to analyze stream temperature data is to look at the temperature change at a spatial scale over time, therefore accurate and consistent locations for the temperature stations is crucial to the long-term analysis of stream temperature. Fewer stations can make management of those stations more feasible for The Partnership, requiring fewer resources while ensuring consistent, quality data collection.

Communication

The second overall recommendation is focused on communicating indicators to the community. It is important to engage stakeholders throughout the process to create community support of and trust in an indicators program (Rhoads, Wilson, Urban, & Herricks, 1999). This engagement will also help to shape the indicators program by influencing the selection of potential indicators, the development of monitoring efforts and the communication of indicators to the public (Schiller, et al., 2001). It can also be used to help establish acceptable levels for indicators, linking those indicators to scientific and social values (Smyth, et al., 2007).

It is not expected that indicators will be chosen solely on either public or scientist input (Schiller, et al., 2001). The guiding criteria for the indicators program will facilitate the selection of indicators that are scientifically sound and connected to social values; however because the act of selecting and measuring indicators involves a human cognitive and cultural action of observing the environment, indicator information often implicitly reflects the values of those who develop and select them (Schiller, et al., 2001). Thus, to communicate indicators to the public, it is important that the community of stakeholders be involved in the process of selecting and expressing indicators.



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The Partnership aims to create an indicators program that tracks the status and trends of the Coos Watershed, but also that also informs adaptive management efforts. It is also important that stakeholders be involved in the adaptive management process either through communication or by direct involvement because although adaptive management may be considered a scientifically sound approach, it is often socially discounted (Mclain & Lee, 1996).

It is recommended that The Partnership hold Coffee Klatches for stakeholder focus group throughout the various stages of the development process. It would be most helpful to hold meetings at the beginning to launch the concept of indicators; then at Step 3 to establish stakeholder values, followed by meetings at Step 6 to select potential indicators, identify a common language and method of communication. Finally, another meeting should be held after the indicators have been selected and launched. There should be separate meetings for scientists, policy makers and the general public, and then combined meetings should also be held to develop the common language for the indicators, to communicate the overall progress of the development, and to receive feedback.

The joint public and scientist meetings should facilitate the translation of indicators into a common language. For example, scientists may be interested in a suite of indicators that relate to the health of the salmon population, however the public may not have an interest in water temperatures, and rather they would like to know whether salmon fisheries are doing well or not.

¢ K Ŝ / ƨ ƨ ă ² ! Ω ă / ƨ has been a successful method bridging communication gaps between scientists, land managers and the public. The Coffee Klatch should not only be used during the development of ecological indicators, but its use should be continued as an integral part of communicating the status and trends of the Coos Watershed to the community.

Finally, addressing land use and climate change impacts in a coastal watershed are growing priorities as increasing pressure is placed on communities. The Partnership cannot assess and address these impacts without the support, participation and trust of citizens and policy makers in the Coos Watershed. It will require a community-based effort to identify and address climate and land use change impacts, and to adapt to the changes the Coos Watershed faces. An effective indicators program that incorporates and connects the community is a crucial first step in the process of addressing climate change at the local level.

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Appendix A: Ecological Criteria and Weighted Scoring Rubric

Ecological Criteria			Score				
Weight	**Criterion**	**Statement**	**0**	**1**	**2**	**3**	**4**
Required	[1]**Ecologically Relevant**	relates to essential components of the identified ecosystem	An ecological indicator must be relevant to the essential components of the ecosystem being monitored. With this ecological relevance, the indicator lacks purpose in the monitoring program and any associated actions may not produce any feedback to influence the pressures affecting the indicator.				
25%	[4]**Responsive**	responds to relevant stressors and causal linkages are established or supported; indicator offers an anticipatory signal of degradation	may not respond to relevant stressors and causal linkages are not supported by data; not anticipatory	may respond to secondary stressors, but not primary stressor; linkage not clear; anticipatory quality not clear	anticipatory, but responds to secondary stressors primarily	not anticipatory, but response to relevant primary stressors is suggested by data	responds to relevant stressors; causal linkages established; anticipatory
30%	[1,3]**Measurable**	can be easily quantified using a standard procedure with documented performance and low measurement error	not easily measured; no identified procedure or procedure with high error	procedure available, but performance has inconsistent error; procedure not easy to	procedure available, but performance not established; and method fairly easy to	can be quantified easily by an established procedure with medium measurement	can be quantified by an established, high-performance method
25%	[2]**Interpretable**	able to distinguish acceptable from unacceptable conditions or ranges; natural variability is understood or long-term data is available for analysis of natural variance	unacceptable levels not established; natural variability unknown;long-term data not available	unacceptable levels unknown; natural variability unknown; long-term data available, but poor	unacceptable levels not well-established; natural variability not well understood; good long-term data	unacceptable levels not established; natural variability estimated; good long-term data	unacceptable ranges established; natural variation known; good long-term data
5%	[3]**Integrative**	indicator can represent or integrate with other ecosystem measurements over multiple spatial, temporal and biological scales	does not integrate with other ecosystem measurements on any scale	limited integration with other measurements at limited scales	integrates with a few measurements at multiple scales	limited integration with other measurements on multiple scales	integrates with other measurements on multiple scales
15%	[1]**Statistically Sound**	able to document trends and show significant differences in data available or potentially collected for the indicator	data shows no trends or significant differences	no long-term daa exists for this ecosystem, but has been collected in other locations	long-term data exists, but is not organized and analyzed	long-term data not yet establsihed, but current data suggests signficant differences	long-term data shows clear trends and significant differences

Appendix B: Operational Criteria and Weighted Scoring Rubric

Operational Criteria			Score				
Weight	**Criterion**	**Statement**	**0**	**1**	**2**	**3**	**4**
Required	[1]**Socially Relevant**	Indicator is linked to concerns or values of the public, the government, and other community stakeholders	To be part of an indicator monitoring program, an indicator must be linked to stakeholder values, which maybe established from public values, government policy or from other community stakeholders, such as land managers, experts, etc.				
25%	[2]**Operationally Feasibile**	Data collection methods are appropriate and feasible considering available personnel and equipment; cost-effective to measure	Data collection not feasible for available personnel and equipment;not cost-effective	Data collection method not feasible for personnel; not likely cost-effective	Data collection is feasible for personnel; equipment not available; may not be cost-effective to purchase	Data collection is feasible for personnel; equipment not available but feasible; cost-effective	Data collection methods are feasible for available personnel and equipment; cost-effective
15%	**Synergistic**	Indicator integrates into other relevant ecological indicator programs already established at national, state, regional and basin scales	Indicator does not integrate with other ecological indicator programs	Indicator integrates with basin scale indicators	Indicator integrates with regional and basin scale indicators	Indicator integrates with state and regional scale indicators	Indicator integrates into many other ecological indicator programs at many scales
20%	[2]**Appropriate Scale**	Spatial and temporal scale of measurement are scientifically justifiable and correspond to management concerns	Spatial and temporal scale not justified; does not correspond to management concerns	Spatial and temporal scale not justified; corresponds to management concerns	Spatial or temporal scale not justified; corresponds to few management concerns	Spatial and temporal scale justified adequately; corresponds to most management	Spatial and temporal scale justified; corresponds directly to management concerns
25%	[2]**Related to Management Actions**	Allows for the determination of current policy effectiveness and adaptive management	Does not have the capacity to evaluate policy or management actions	Not significantly related to current management actions; not wel-suited for adaptive management	Loosely related to management actions; could be used for adaptive management	Can be used to evaluate limited policy or management actions; fairly well-suited for adaptive management	Can be used to evaluate multiple policy or management actions; well-suited for adaptive management
15%	[3]**Funding**	Monitoring of indicator is highly likely to be funded. There are no significant social, political, or logistical constraints to funding the monitoring program for this indicator	Indicator not likely to be funded; significant social, political and logistical constraints	Indicator funding unlikely due to social and political constraints; known source	Indicator funding possible; social or political constraints that may be addressed; known source	Indicator funding possible; a logistical contraint that can be addressed; known source	Indicator funding is likely; no constraints should hinder funding; known source

Appendix C: Scoring Sheet

Indicators are given a score from 4 to 0 representing the likelihood of the indicator to meet each criterion. 4 = Meets criteria with no obvious limitations; 3 = likely to meet with a minor limitation; 2 = possibly will meet with 2-4 minor or major limitations; 1 = likely won't meet because specified limitations are numerous and significant; 0 = unknown status or very unlikely to meet criteria because of specified limitations. Each criterion has a weighted multiplier, which is applied to the score for each indicator to produce an overall weighted rank. Under indicator class would be 1) Aquatic and Riparian Freshwater, 2) Terrestrial, 3) Estuarine Aquatic, and 4) Near shore Marine. These classes are an organizational tool. Although each criterion could be seen as a required characteristic for an indicator, this weighted scoring system was adapted to provide a [illegible] organizations. Ideally [illegible] every indicator would meet each of these criteria to fullest degree, however with data limitations, resource limitations and incomplete knowledge; a prioritization tool may help experts to decipher what indicators would be most rigorous. Although this prioritization tool offers transparency for the final selection of indicators, rigorous analysis and conceptualization of indicators within the PSR framework could provide enough efficiency and transparency for the selection process.

		Ecological Criteria								Operational Criteria								Weighted Operational Score	Weighted Ecological Score
	Criterion points	Required	0-4	0-4	0-4	0-4	0-4			Required	0-4	0-4	0-4	0-4	0-4				
	Criterion weight		0.25	0.3	0.25	0.05	0.15				0.25	0.2	0.25	0.15	0.15				
Indicator Class	Ecological Indicator	Ecologically relevant	Responsive	Measurable	Interpretable	Integrative	Statistically sound	**Raw Score**	**Weighted Score**	Socially relevant	Operationally feasible	Appropriate scale	Related to management actions	Synergistic	Funding	**Raw Score**	**Weighted Rank**		

Appendix C (a): Prioritization Coding

Once potential indicators have been given their final weighted score, each criterion can be coded as to the implications for action by the monitoring organization. Again, this coding allows for transparency in the selection process and also facilitates clear communication about the choices that were made during the selection process. As much as this tool could be used for prioritization, it could also be used as a means of record keeping, again making transparency and adaptive techniques important parts of the process. The creation of a clear method for selecting and prioritizing indicators also allows more stakeholders to be involved in the process.

Priority	Implications for Indicator and Action
	Indicator scored above 2 in both categories. It is ecologically relevant; operationally feasible; linked to stakeholder concerns; high priority for funding; long-term data analysis already shows significant trends and differences; indicator may also be anticipatory.
	Indicator scored above 2 in the ecological category, but scored below 2 in the operational category. This indicator should be considered for implementation, as it would likely be funded; Education and outreach should be undertaken to build understanding and support for this indicator.
	Indicator scored below 2 in the ecological category, but would be operationally feasible (score above 2 in operational) and is connected to public values. It may be hard to fund a monitoring program for this indicator based on scientific concerns.
	Indicator scored low in both categories, or received a zero for one or more low weighted criteria; potential indicator should be considered only if limitations can be addressed.
	Indicator scored low in both categories, or received a zero for one or more highly weighted criteria; potential indicator should not be conisdered for a monitoring program.

Appendix D: Potential Indicators for Coos Watershed

This section proposes a suite of potential indicators based on the Coos Watershed ecosystem, social values, and evaluation of indicators in use by other programs, and an evaluation of indicators using the weighted scoring matrix adapted for the Coos program. Pressure-State-Response diagrams were not created for each of these indicators, rather these are suggestions based on review of existing indicators from other programs, however they have been classified as pressure, state or response indicators, indicated by a P, S, or R beside the indicator. The potential indicators were organized into 4 classes for ease of organization and conceptualization of the ecosystem.

Freshwater Aquatic and Riparian

1. Stream Water Temperature

2. Riparian shade: S

3. Oregon Water Quality Index τ OWQI: S

4. Frequency of water rights engaged: P

5. Summer streamflow: P

6. Miles of stream riparian area restored: R

Terrestrial

1. Annual Precipitation: P

2. Changes is plant or animal distribution: S

3. Number of invasive species identified: S

4. Impervious surface area in watershed: P

5. Rate of sprawl τ high, low impact development, and fragmentation: P

6. Average air temperature: P

7. Changes in zoning and development policies:R

8. Invasive species eradicated: R

9. Change in forest fire frequency: S

Estuarine Aquatic

1. Salinity gradient change: P

2. Eelgrass bed distribution: S

3. Invasive species number and distribution: S

4. Acre-days of shellfish harvest opportunities:S

5. Density of harvestable shellfish: S

6. Area of restored eelgrass beds and salt marsh: R

7. Percent of estuary with chlorophyll-a violation according to standards: S

8. Number of days with shellfish contamination warnings: S

Nearshore Marine

1. Sea level change: P

2. Sea surface and subsurface temperature: S

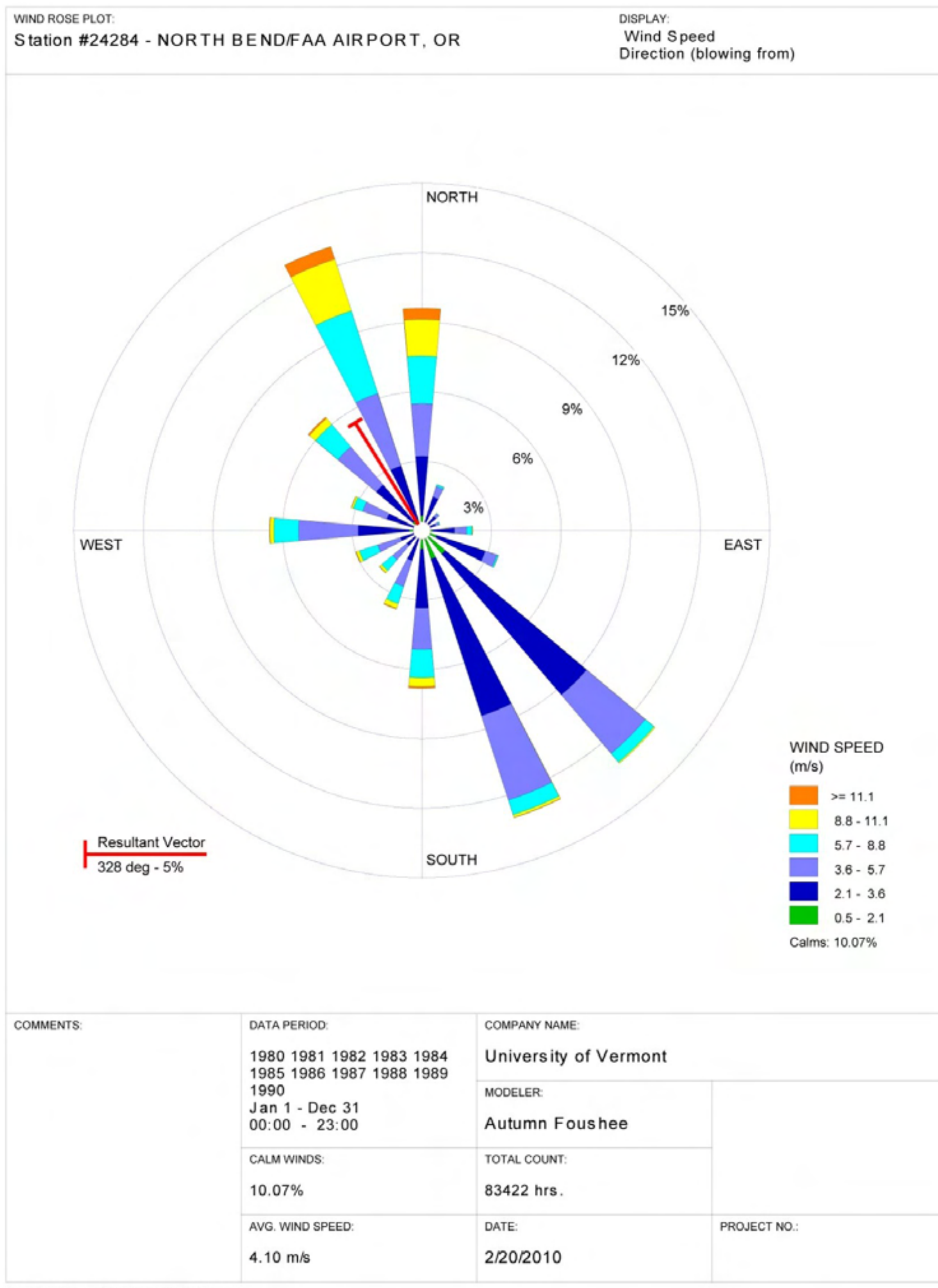
3. Anadromous fish returns: Sand fishing limits:R

4. Rockfish production: Sand limits: R

5. Coastal Upwelling Index: S

Appendix E: Wind Rose Analysis

This wind rose was created from resultant wind speed and direction data collected from 1980 to 1990 at the North Bend Regional Airport. The wind rose shows how much of the 10-year period the wind blew with a specific speed from a specific direction. The average wind speed for the time period was 4.1 meters/second. The wind blew from the northwest or southeast primarily and usually had a speed of 8.8 meters/second or less. With more complete data, an analysis could be easily completed to evaluate changes in wind speed and direction over longer periods of time. Wind roses are popular for ease of communication. The plot was created using the WRPLOT View software from Lakes Environmental.



Appendix F: Annual Average Precipitation

Precipitation data from 1902-1980 was gathered from the North Bend Regional Airport to compare local trends to regional climate change trends and projections. According to the U.S. Global Change Research Program reports that precipitation in the Pacific Northwest region has increased by 10 percent since 1916, however local precipitation data indicates a decline in mean annual precipitation from 1902 to 1980.

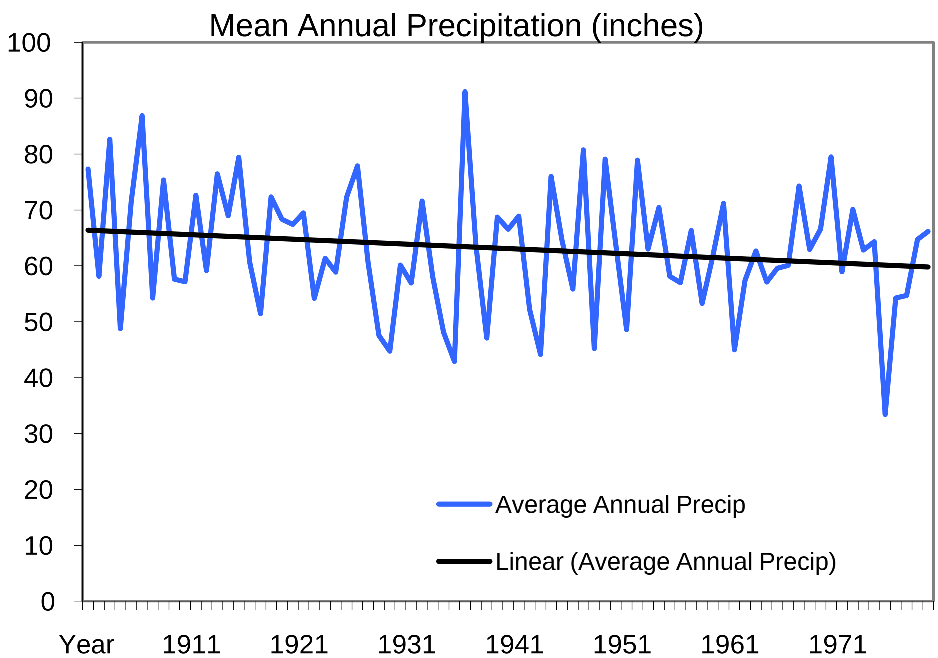


Figure 8: Mean Annual Precipitation at North Bend Regional Airport

Appendix G: Mean Annual Air Temperature

According to the U.S. Global Change Program, average annual air temperatures over the past decade have increased from 2-4 F across the Pacific Northwest Region, however local data from the North Bend Regional Airport for the past 30 years shows a decline in average annual air temperature. The year 2010 was excluded from this analysis because the year was not yet complete. The data set available from the North Bend Regional Airport did not include air temperature data before 1980; however, data are now being collected by a NOAA weather station within the pilot study area. These data could be used to further evaluate local climate changes compared with regional changes and predictions. With more robust stream temperature data, it may be possible to evaluate the impact of air temperature trends on stream temperatures. It could be possible that the declining air temperature trend may be driving the declining stream temperatures elsewhere in the Coos Watershed.

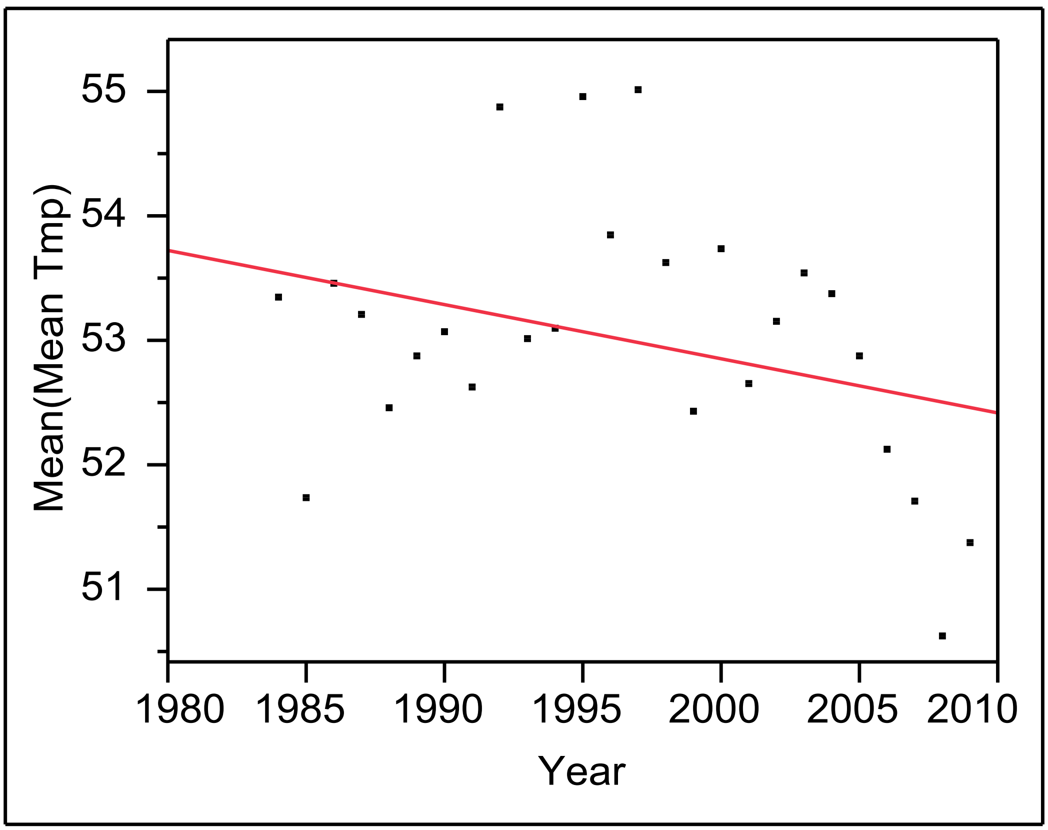


Figure 9: Mean Annual Air Temperature at North Bend Regional Airport, North Bend, OR