Puget Sound Science Update

Draft April 12, 2011

Puget Sound Partnership
our sound, our community, our chance

Table of Contents

Editor's note

The Puget Sound Science Update is a represents the state-of-the-science supporting the work of the Puget Sound Partnership to restore and protect the Puget Sound ecosystem. The Puget Sound Science Update represents an advancement in the development and use of science to support Puget Sound recovery in two important ways. First, the content of the Puget Sound Science Update was developed following a process modeled after the rigorous peer-review process used by the Intergovernmental Panel on Climate Change (IPCC), in which small author groups produced draft assessment reports synthesizing existing, peer-reviewed scientific information on specific topics identified by policy leaders. These drafts were peer-reviewed before the final reports were posted. Second, the Puget Sound Science Update will be published on-line following a collaborative model, in which further refinements and expansion occur via a moderated dialog using peer-reviewed information. Content eligible for inclusion must be peer-reviewed according to guidelines.

In the future, there will be two versions of the Update available at any time:

(1) a time-stamped document representing the latest peer-reviewed content (new time-stamped versions are likely to be posted every 4-6 months, depending on the rate at which new information is added); and

(2) a live, web-based version that is actively being revised and updated by users.

The initial Update you see here is a starting point to what we envision as an on-going process to synthesize scientific information about the lands, waters, and human social systems within the Puget Sound basin. As the document matures, it will become a comprehensive reporting and analysis of science related to the ecosystem-scale protection and restoration of Puget Sound. The Puget Sound Partnership has committed to using it as their 'one stop shopping' for scientific information—thus, it will be a key to ensuring that credible science is used transparently to guide strategic policy decisions.

The Update is comprised of four chapters, and you will note that some are still at earlier stages of completion than others. Over time—through the process of commissioned writing and user input through the web-based system—the content of all four chapters will be more deeply developed. We are relying in part on the scientific community to help ensure that the quality and nature of the scientific information contained in the Update meets the highest scientific standards.

Preface

Who are the authors of the Puget Sound Science Update?

Leading scientists formed teams to author individual chapters of the Puget Sound Science Update. These teams were selected by the Puget Sound Partnerhship's Science Panel in response to a request for proposals in mid-2009. Chapter authors are identified on the first page of each chapter. Please credit the chapter authors in citing the Puget Sound Science Update.

What are the Puget Sound Partnership and the Science Panel?

Please visit psp.wa.gov to learn about The Puget Sound Partnership.

Please visit science panel web page to learn about the Science Panel.

Has the Puget Sound Science Update been peer reviewed?

The original chapters of the Puget Sound Science Update were subjected to an anonymous peer review refereed by members of the Puget Sound Partnership's Science Panel. Reviewers are known only to referees on the Science Panel and the Partnership's science advisor.

What is "content pending review"?

The future web presentation is intended to offer a venue for updating, improving, and refining the material presented in the Puget Sound Science Update. Suggested amendments and additions are presented as "content pending review" on each page when an editor, perhaps working with a collaborating author, has developed some new content that has not yet been formally adopted for incorporation into the section. As "content pending review," this content should not be cited or should be cited in a way that makes clear that it is still in preparation.

How can I contribute new material to the Puget Sound Science Update?

Please visit the Puget Sound Partnership website to learn about how you can help improve, update, and refine the Puget Sound Science Update, or send an e-mail to pssu@psp.wa.gov to get the process started.

How can I cite the Puget Sound Science Update?

We recommend citations this version in the following format:

[Authors of specific chapter or section]. April 2011. [Section or chapter title] **in** Puget Sound Science Update, *April 2011* version. Accessed from http://www.psp.wa.gov/. Puget Sound Partnership. Tacoma, Washington.

"Content pending review" of the Puget Sound Science Update has not been fully reviewed for publication. If you elect to cite this information, we recommend that you contact the named author(s) to cite as a personal communication or cite the web-presentation using the following format:

[Authors of pending material]. In prep. Content pending review presented in *[Section or chapter title]* **in** Puget Sound Science Update. Accessed from http://www.psp.wa.gov/. Puget Sound Partnership. Tacoma, Washington.

Chapter 1B. Incorporating Human Well-being into Ecosystem-based Management

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Section 1. Introduction

The Puget Sound Partnership is charged with identifying actions to protect and restore Puget Sound, and assessing the effectiveness of those actions. As part of its effort to fulfill these charges, the Partnership will identify indicators to monitor the ecological and human systems within the Puget Sound region. These indicators will help inform decision makers and the public about the health of Puget Sound.

In creating the Partnership, the Washington State Legislature identified six goals (State of Washington, 2007):

1. A healthy human population supported by a healthy Puget Sound that is not threatened by changes in the ecosystem;
2. A quality of human life that is sustained by a functioning Puget Sound ecosystem;
3. Healthy and sustaining populations of native species in Puget Sound, including a robust food web;
4. A healthy Puget Sound where freshwater, estuary, nearshore, marine, and upland habitats are protected, restored, and sustained;
5. An ecosystem that is supported by ground water levels as well as river and stream flow levels sufficient to sustain people, fish, and wildlife, and the natural functions of the environment;
6. Fresh and marine waters and sediments of a sufficient quality so that the waters in the region are safe for drinking, swimming, shellfish harvest and consumption, and other human uses and enjoyment, and are not harmful to the native marine mammals, fish, birds, and shellfish of the region.

The first two goals explicitly reference human well-being while the other goals have less direct references or can be indirectly connected to human well-being. Indicators that assess human well-being will therefore be needed to assess the effectiveness of any actions recommended by the Partnership in their Action Agenda (Puget Sound Partnership, 2008).

The use of indicators to track human well-being in previous ecosystem-based management efforts, however, is not common. Indicators connected to human well-being are most often used to measure the effects of social or economic policies and compare these effects across groups. Their use has therefore mostly focused on identifying and using a small set of indicators that covers a particular social or economic system (e.g.., housing or education) affected by the policy. Less common is their use when policy is primarily assessed first in terms of changes in ecological conditions and then only subsequently, if at all, in terms of changes in human conditions.

This report provides a framework for identifying, evaluating, and selecting indicators that track human well-being in the context of ecosystem-based management (EBM). It begins with a discussion of how human well-being can be integrated into EBM and used (in principle) as an over-arching metric by which to evaluate the effectiveness and impacts of management actions. We then give a brief overview of the concept of human well-being, a term that is difficult to define precisely, and discuss the nature of HWB indicators. The following section discusses methods for measuring human well-being and for assessing the links between changes in ecological conditions and changes in human well-being. Finally, the report outlines a framework for cataloging data and empirical studies, and for evaluating the nature and strengths of these links, in a manner that can assist the Puget Sound Partnership in its task of identifying and evaluating potential human well-being and other indicators.

Human Well-being and Ecosystem-based Management

Over the past decade, efforts have been made to expand our understanding of coupled social and ecological systems (Millennium Ecosystem Assessment, 2003; Liu et al., 2007; Walker et al., 2002). Governments at many levels have increasingly sought to base environmental management not just on political considerations, but on goals such as ecological health and resilience. Understanding how the two systems are linked is therefore important. The links between biophysical and human systems, and the support that the biophysical systems provide for human well-being, are both obvious and obviously important. The systematic measurement and assessment of the existence and importance of individual links, however, is less common than simple assertions that such links exist (Bowen and Riley 2003).

Crafting a picture of a linked natural-human system often takes place in the context of ecosystem-based management. In its early conception, EBM was defined to mean "focusing on ecological systems that may cross administrative and political boundaries, incorporating a ‘system' perspective sensitive to issues of scale, and managing for ecological integrity" (Endter-Wada, 1998). This initial definition was an ecologically centered view with human systems incorporated simply as political boundaries or more complexly as impacts on the system to be controlled or reduced (Figure 1).

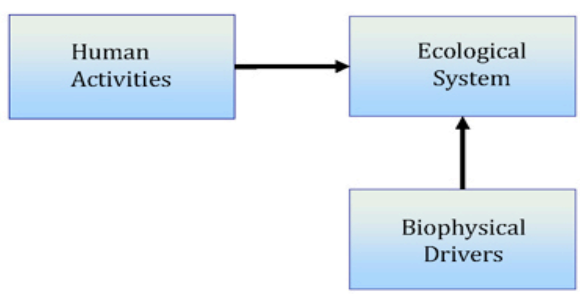

Figure 1: A simplistic view of an ecological system that is affected by but separate from human systems. Adapted from Redman, *et al.* (2004).

Although the purely ecocentric view still exists, there has been increasing recognition of the need to integrate humans and our social systems more completely into the EBM framework. The common approach to EBM has expanded to include the need to manage for the sustainability of human systems as well as ecological communities, to practice adaptive management, and to encourage broad-based involvement and collaboration in implementing EBM. As the term is employed in the Puget Sound region, EBM includes the management of ecosystems in ways that are inclusive of human needs and values, as reflected in the six goals listed in the previous section.

This section provides a conceptual model of how human well-being can be integrated into the Partnership's framework for conducting EBM. This model can also be used to craft a strategy for identifying and evaluating the connections between indicators, biophysical and human-based, and human well-being in the context of the Puget Sound Partnership's tasks. By including human well-being (along with human health) as an explicit goal, the Partnership acknowledges the importance of this integrated view. Including indicators that measure impacts to both the human and biophysical systems will therefore provide stronger support for an EBM effort such as the one being pursued by the Partnership (Bowen and Riley, 2003; Carr et al cite). Bringing HWB into an ecosystem-based management effort has potentially deeper implications, however. The Partnership goals can sometimes conflict with one another, and so the question arises of how to assess and evaluate such conflicts. The current Partnership approach is to compartmentalize the six goals and discuss them separately. Examples of this include the Partnership's Ecosystem Status & Trends document (Puget Sound Partnership, 2009a) and the Identification of Ecosystem Components and Their Indicators and Targets technical memorandum (Puget Sound Partnership, 2009b), where each goal is discussed separately. Connections among the systems represented by the goals are recognized, of course, but the question of how to resolve potential conflicts has not yet been addressed.

Separating ecological goals from human well-being is apparently one way of resolving a long standing tension between adopting a wholly ecocentric or wholly anthropocentric viewpoint in ecosystem-based management (Endter-Wada et al., 1998, for a discussion of this tension). Still, by setting the two sets of goals apart, the Partnership implicitly grants the ecological goals something in the nature of intrinsic value. That is, species, habitat, water quality, and water quantity have value for their own sake; or, it may be that some aspect of a particular goal has value because of its support for aspects of the other natural goals (e.g., the value of nearshore habitat may be derived from its support for certain species), but the goals so supported are still valued for their own sake.

Figure 2 gives a representation of this approach, where actions drawn from the Partnership's Action Agenda can be evaluated in terms of changes to one or more of the Partnership goals (Puget Sound Partnership, 2008). A problem with this construction is the difficulty it creates when intrinsically valued goals conflict with one another or, in this case, with human well-being (Justus et al., 2009). Little guidance is given about which goal should take precedence, and so the resolution of conflicts is hard to assess in a consistent, reasoned way. In contrast, viewing the values involved as instrumental creates an opportunity to evaluate goals with a common metric, because each goal is viewed as an "instrument" in achieving some higher, over-arching goal (Justus et al., 2009).

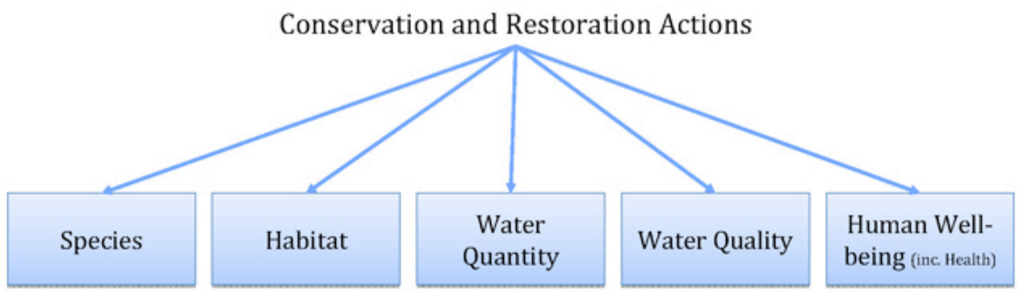

Figure 2: A framework for evaluating the effects of conservation and restoration actions on the Partnership's goals, where each goal is considered with a distinct set of metrics.

In the context of the Puget Sound Partnership, human well-being can be used as such an over-arching goal (Figure 3). Now, the ecological goals are viewed as instrumental in supporting human well-being, which then becomes in principle a common metric by which to assess management actions. "Instrumental" does not mean material or based solely on monetary values. As noted by Justus et al. (2009), something has instrumental value to the extent that it is "considered valuable by valuers" - that is, in the context of EBM, it is something that humans value about the environment. This includes values that are independent of consumption or the use of a resource, for example, and can even involve actions that are to the material detriment of the valuer.

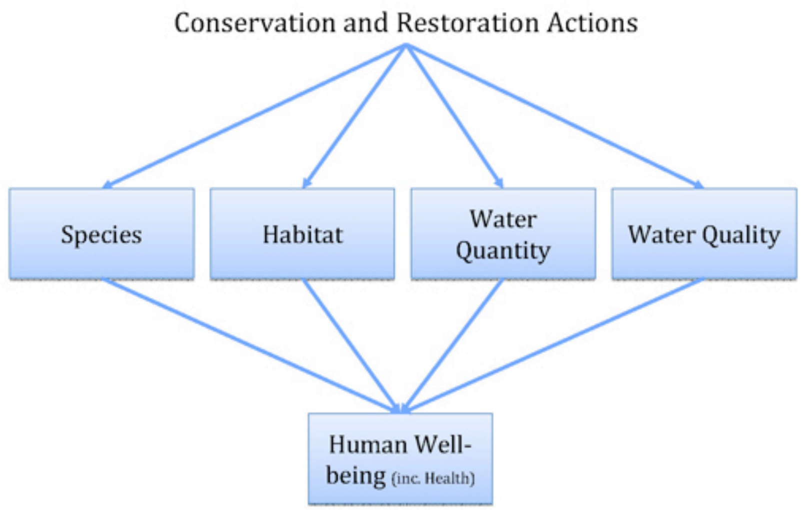

Figure 3: A framework for evaluating the effects of conservation and restoration actions on the Partnership's ecological goals using human well-being as a common metric.

Using this framework, it is straightforward to consider different types of links that connect the ecological goals to HWB, and therefore the different types of instrumental values. In Figure 4, the management objective is to improve the conditions covered by the Species and Water Quantity goals. These goals have direct connections to HWB but through possibly multiple types of values. Figure 5 illustrates a different case, where the ecological goal of Habitat provides indirect value to humans through its ecological connections to the Species and Water Quality goals. Assessing the value in this case would require an understanding of 1) the effect of the action on habitat; 2) the effects of habitat changes on species and water quality; and 3) the value to humans of the resulting changes in the conditions of those two goals.

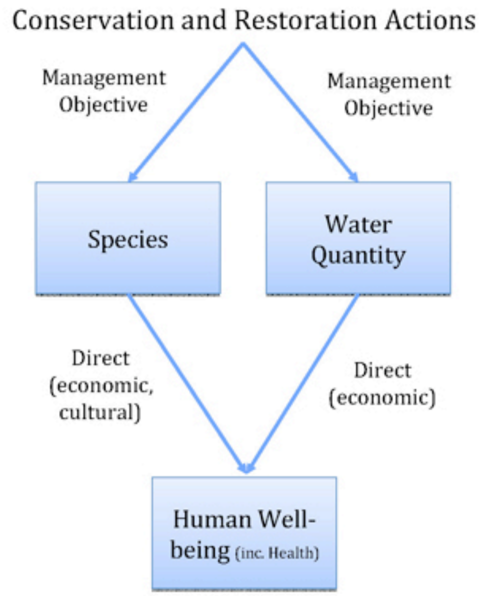

Figure 4: An example of how human well-being can be used as a metric to assess the effects of conservation and restoration actions that are directed at species and water quality.

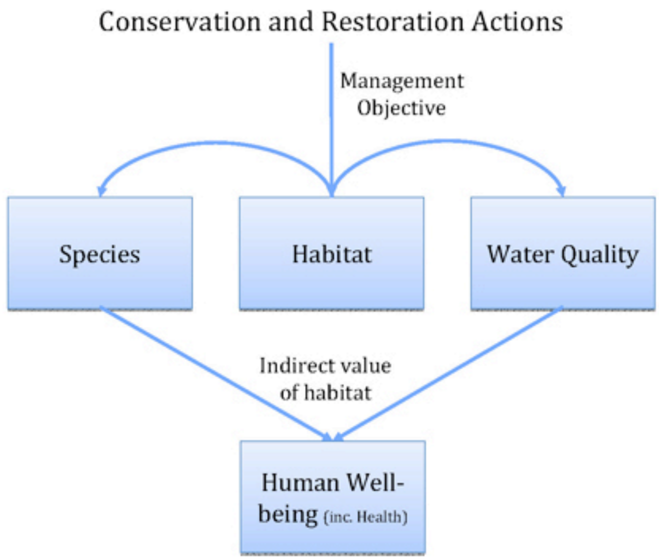

Figure 5: An example of how human well-being can be used as a metric to assess the effects of conservation and restoration actions that are directed at habitat, which in turn affects species and water quality and thereby affecting human well-being.

Creating the links between the Partnership's ecological goals and HWB also points to a more expansive view of the set of relevant indicators. Improving ecological systems is not the only way to improve human well-being (Millennium Ecosystem Assessment, 2005). Many factors support human well-being, only some of which are related to or derived from ecological systems. As Dasgupta (2001) notes, a society's total collection of capital is what supports its well-being. This capital is a diverse collection of traditional forms of capital (buildings and machines), "natural" capital (species and habitats), social capital (examples), and other forms. These forms of capital are partly substitutable for one another, and improvement in human well-being is then possible even if one or two components of total capital decrease (Millennium Ecosystem Assessment, 2005).

Figure 6 shows a simple way of expanding the focus of EBM to encompass other forms of capital that support HWB. In this simple illustration, Economic Activity and Social Conditions are treated as broader social goals because they support human well-being. They are not necessarily objectives for the Partnership's management strategies, however, but are certainly affected by them. Because they have strong links to HWB, assessing the effects on these areas will likely improve management, at least in the case where HWB is used as a common metric. Figure 7 illustrates this by presenting the case where an action improves Habitat by constraining Economic Activity. HWB is enhanced by the first effect through the improvements in the

Species and Water Quality goals, but the constraint on Economic Activity can produce an offsetting negative effect. Accounting for both types of pathways between actions and HWB is necessary to evaluate the total effect of an action.

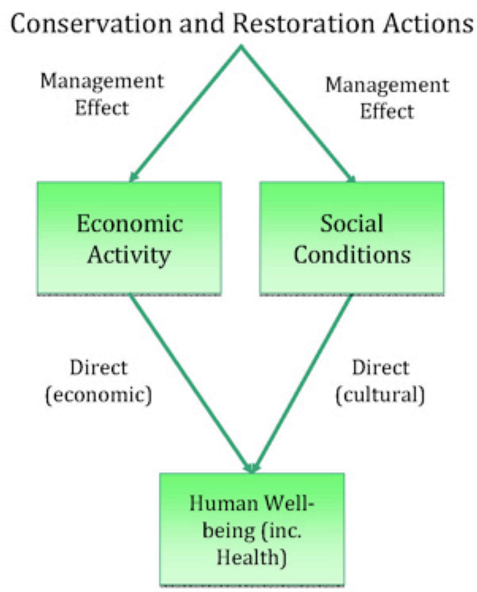

Figure 6: An example of how human well-being can be used as a metric to assess the effects of conservation and restoration actions that affect important components that support human well-being but which are not the objectives of management.

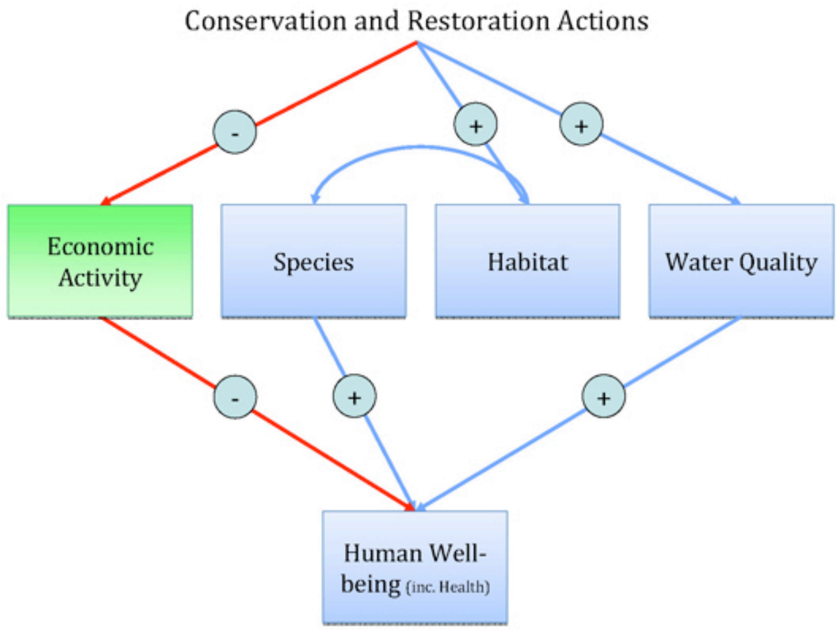

Figure 7: An example of how human well-being can be affected by conservation and restoration actions along multiple pathways.

The framework illustrated in this section can be used to set priorities for actions and help select indicators. The simplicity of the figures, however, masks the incredible number of all the possible pathways that connect HWB to the conservation and restoration actions proposed by the Partnership. The following two sections address this problem. In section 3, we discuss the nature of human well-being and the traditional indicators that have been used to track and register changes in well-being. In section 4, we consider ways in which the various pathways could be evaluated in terms of the "strength" of the connections. Much of that evaluation lies outside the scope of this report, as it involves identifying and evaluating ecological indicators. The discussion in that section considers different approaches for assessing the strength of connections between human well-being and environmental attributes that have direct effects on well-being.

Key Points: Human well-being is both a goal for the Puget Sound Partnership and a potential metric for assessing the effects of conservation and restoration actions that further all Partnership goals.

The Nature of Human Well-being

Human well-being is a broad concept, one that includes many aspects of our everyday lives. It encompasses material well-being, relationships with family and friends, and emotional and physical health. It includes work and recreation, how one feels about one's community, and personal safety. Precisely defining human well-being is difficult, however. Although it can be described, it lacks a universally acceptable definition and has numerous, and often competing, interpretations. As human well-being cannot be directly observed, it cannot be independently measured. And there are a host of terms -- quality of life, welfare, well-living, living standards, utility, life satisfaction, prosperity, needs fulfillment, development, empowerment, capability expansion, human development, poverty, human poverty, land and, more recently, happiness – that are often used interchangeably with human well-being (McGillivray and Clarke, 2008). Despite these difficulties, there is a large body of research covering the subject of human well-being. HWB research occurs in multiple fields such as psychology, medicine, economics, environmental science and sociology (Costanza et al., 2007). In recent times, human well-being has frequently been considered analogous with income and consumption levels. The reasoning goes something like this: humans consume materials and services to meet their needs and desires, and so increase their well-being; markets provide these materials and services; income allows individuals to obtain these market items; therefore, income can be equated with human well-being (Stiglitz et al, 2009). Using income or consumption as a proxy for well-being is problematic, however. Many material goods and services are not marketed; many of the determinants of human well-being are not resources but are circumstances or experiences that still have important connections to human well-being; and even a given market basket can produce varying amounts of HWB depending on the individual, so that some individuals can achieve a higher level of HWB with a market basket (i.e., income) smaller than others. Finally, income measured at the individual or national level overlooks distributional issues that can affect well-being (Stiglitz et al, 2009).

For this exercise, human well-being will be treated as having multiple dimensions. It refers to the degree to which an individual, family, or larger social grouping (e.g. firm, community) can be characterized as being healthy (sound and functional), happy, and prosperous. (Pollnac et al., 2006). The focus here, however, will be on individual well-being, although the determinants of an individual's well-being can include characteristics that include characteristics of family, community, nation, and so forth.

Similar to work done by natural scientists to describe ecological components that represent the system's overall biophysical health, social scientists have created broad categories or domains to draw general distinctions among different components of HWB. Within each domain is a set of subcategories or attributes that identify the specific components of HWB for that domain. There is no one generally agreed upon set of domains and attributes to describe HWB. In reviewing over 22 studies, Hagerty et al (2001) found the following seven domains to be broad enough to encompass most research frameworks: relationships with family and friends; emotional well-being; material-well-being; health; work and productive activity; feeling part of one's community; and personal safety (see also Cummins, McCabe, Romeo, and Gullone, 1994; Cummins, 1996).

The list of potential attributes is even longer, and no comprehensive list exists. Examples of attributes include items such as education; employment; energy; human rights; shelter, housing; health and health care access; income, income distribution, purchasing power; mobility; transportation; infrastructure; governing institutions; social participation; population; reproduction; leisure activities, sports participation and vacation time; spirituality; public safety and crime; traditional activities and cultural responsibilities; and more (Diener and Suh, 1997; Boelhouwer, 1999; Marks, 2007; Costanza, et a l., 2007; Flynn, 2002).

Domains and attributes are concepts that allow researchers to understand and broadly categorize information. Indicators are the actual measures that communicate information about the state of and trends in HWB for a given system. They are most useful when the cost of gathering information about the entire system is high, so that information must be simplified into a set of easily quantifiable attributes that represent the entire system. Indicators have been the subject of considerable discussion in both the natural and social sciences, in disciplines such as economics, sociology, anthropology, psychology, ecology, forestry and many others. Due to the broad array of disciplinary approaches, definitions, and applications, the formulation of indicators varies widely depending on which 'world view' is applied (Bowen and Riley, 2003). For example, the management community has focused on institutional measures of program performance while the ecological science community has worked to build indicators of the scope and scale of change in natural systems. The social science community has created social indicators to measure trends and changes in social systems.

Social indicators are societal measures that reflect people's circumstances in a given cultural or geographic unit. Land (1983) identifies three primarily uses for social indicators: monitoring (i.e., reporting for policy assessment), tracking (i.e., reporting for public enlightenment), and forecasting. Social indicators can focus on populations of interest such as the elderly, disabled, minorities, or women; or they can be used to track changes in geographic regions There are two types of social indicators for measuring human well-being: objective and subjective indicators (Diener and Suh, 1997; Costanza et al., 2007; Cummins, 2000). Objective indicators are those that can, in principle, be measured and verified in the "public domain," as expressed by Cummins (2000). Examples of objective social indicators include infant mortality, doctors per capita, and longevity (assessed for the health domain); and homicide rates, police per capita, and rates of rape (assessed for the personal safety domain). Objective indicator data can be gathered by observation or other forms of impersonal measurement, or by surveys that seek objective information from individual responses. The key feature of an objective indicator is the perspective: In principle, they measure attributes of human well-being that are publicly visible and have a uniform interpretation across individuals.

Objective social indicators help us understand how specific communities utilize resources or interact with the environment, but they do not measure how people feel about their place or their subjective experience influenced by the health of the environment. Subjective social indicators attempt to measure psychological satisfaction, happiness, and life fulfillment, which are private attributes of HWB in the sense of not being capable of independent observation and verification. By necessity, subjective social indicators are gathered through survey research instruments that ascertain the subjective reality in which people live. Sharpe (1999) describes this approach as "based on the belief that direct monitoring of key social-psychological states is necessary for an understanding of social change and the quality of life." Different domains lend themselves to being measured and tracked by different types of indicators. Material well-being and other basic economic attributes of HWB are amenable to being measured with objective indicators. These are often derived from data gathered by the U.S. Census Bureau or other government agencies. Even these domains, however, have important subjective elements, and so tracking both objective and subjective indicators will provide a more complete understanding of HWB and environmental considerations.

It is important to understand whether a social indicator has an unambiguous relation to HWB at either the individual or aggregate level, or whether it merely describes an attribute of HWB but without such a clear relation. If the first case holds, Land (1983) suggests that the indicator can then be used as a normative indicator, or one that can be directly tied to a social policy goal (Sharpe, 1999). The US Department of Health has defined normative welfare indicators in the following way:

"…a statistic of direct normative interest which facilitates concise, comprehensive and balanced judgments about the condition of major aspects of a society. It is, in all cases, a direct measure of welfare and is subject to the interpretation that if it changes in the 'right' direction, while other things remain equal, things have gotten better, or people are better off. Thus, statistics on the numbers of doctors or policemen could not be social indicators, whereas figures on health or crime rates could be (Land, 1983)."

The use of normative social indicators in this sense requires that society agree about what needs to be improved, that agreement exists on what "improved" means, and that it is meaningful to aggregate the indicators to the level of aggregation at which policy can be defined (Land 1983). Normative social indicators are most useful when indicators are used for policy monitoring, and they can be either objective or subjective in nature.

If an indicator does not have a clear policy relation, it can still be used as a descriptive indicator (Land, 1983), and can again be either objective or subjective in nature. As Land (1983) notes, descriptive social indicators focus on "social measurement and analysis designed to improve our understanding of what the main features of society are, how they interrelate, and how these features and their relationships change." This type of indicator may be related to social policy objectives, but is not restricted to this use (Sharpe 1999). Descriptive social indicators come in many forms, and can vary greatly in the level of abstraction and aggregation, from a diverse set of statistical social indicators to an aggregated index of the state of society.

As should be clear from the discussion above, human well-being is a complex concept, impossible to observe and measure directly, from the viewpoint of an objective observer. Nevertheless, there is broad agreement on important areas such as HWB domains, some of which can be connected to Partnership goals and objectives. Thus, identifying social indicators for the Partnership's efforts is a tractable task, although the basis for selecting a particular set of indicators is still daunting.

Key Points: Human well-being is difficult to define and measure from an objective point of view, but can be categorized in terms of its domains, such as material and emotional well-being, work and productive activity, and personal safety. Indicators connected to these domains can be objective or subjective in nature, and they can be normative (that is having an unambiguous relation to HWB) or descriptive.

The Determinants of Human Well-being

In this section, we consider how research on HWB and its determinants can illuminate the problem of selecting HWB indicators for ecosystem-based management. The focus is on methods that can and have been used to identify economic, social, and sometimes environmental factors that are correlated with and therefore likely to determine (in part) human well-being. These methods provide a way of assessing the connections between ecological and human systems, using human well-being as the metric by which to judge the strength of those links. The methods described below do not span the full set of potential ways of making such an assessment. In later versions of this document, the intent is to add, where warranted, other approaches.

The approach taken here is admittedly a reductionist view of human well-being and its determinants. First, we collapse the multiple domains or dimensions of human well-being into a single measure. While this measure is not observable directly, we use a framework that is based on either subjective, self-reported evaluations or inferred from observable behavior. Second, we assume that HWB can be expressed as a function of measurable, objective circumstances. There may be many other determinants, of course, that are not easily measured or even observable, but the challenge of selecting indicators for HWB can only be met if this second assumption holds.

With these assumptions, we can then formally represent HWB in the following way (Welsch and Kühling, 2009):

$HWB = F(M,X,D,Q,U)$

where HWB is an individual's stated well-being (the measurement of which is discussed below); M is the individual's income; X is a set of community or higher level "macro" factors that help determine HWB; D is a set of individual-level factors that help determine HWB; Q is a set of environmental conditions that determine the individual's HWB.; and U is a set of unobserved (or unmeasured) HWB determinants.

This equation provides a basis for formally and quantitatively assessing the links between a particular environmental quality attribute, Qi, and HWB:

$$dHWB = \frac{\partial F}{\partial Q_i} dQ_i$$

which provides a theoretical construct for evaluating what environmental quality attributes are connected to HWB (i.e., is $\partial F/\partial Q_i > 0$?) and to assess the strength of the connections (i.e., what is the magnitude of $\partial F/\partial Q_i$?) (Welsch and Kühling, 2009).

Below, we consider three general strategies for bringing this equation to life. The first, generally known as life satisfaction or "happiness" studies, starts with direct measurement of HWB and then analyzes objective factors that correlate with that measurement. The other two are different approaches used in economics based on the willingness of individuals to sacrifice one good (usually taken as income) for others, or a "willingness-to-pay" (WTP) approach. The first of these is based on the actual behavior of individuals, either observed directly or inferred through market prices. The second of the WTP approaches is based on the stated preferences of individuals regarding their willingness-to-pay for one situation relative to another. Each of these three approaches uses the equations above in one way or another to derive quantitative estimates of connections between HWB and its determinants.

1. Direct, Subjective Measurement of Human Well-being

The question of an individual's well-being can be addressed by taking a straightforward approach: Ask a person directly. The literature that has built up around this approach is generally known as life satisfaction or "happiness" studies. The types of measures used to assess HWB in this way fall into two categories: (1) measures that reflect an individual's self-reported well-being in a global or holistic sense; and (2) measures that reflect an individual's self reported well-being in the moment (Frey and Stutzer, 2002; Vitarelli, 2010).

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* Because the different components of *Q* are likely to have different units, it is more likely that this expression would be measured as an *elasticity*, or

$$e_i = \frac{Q_i}{HWB_i} \frac{\partial HWB}{\partial Q_i}.$$

An elasticity is a unitless number that measures the proportional change in the function with respect to a proportional change in one of its arguments.

This approach and methods to analyze life satisfaction and happiness originated in psychology but have been of found increasing interest to economists. The existence of several long-running, multi-national surveys provide a rich set of data for analysis (Frey and Stutzer, 2002):

- The General Social Surveys, which asks: "Taken all together, how would you say things are these days—would you say that you are very happy, pretty happy, or not too happy?" (Davis, Smith, and Marsden, 2001).
- The World Values Survey, which uses a ten-point scale and asks respondents: "All things considered, how satisfied are you with your life as a whole these days?" (Inglehart et al. 2000).
- The Eurobarometer Surveys, which covers all members of the European Union and asks respondents: "On the whole, are you very satisfied, fairly satisfied, not very satisfied, or not at all satisfied with the life you lead?" (Noll, 2008)

Other approaches use the answers to multiple questions to address life satisfaction, such as the Satisfaction With Life Scale (Diener et al., 1985), which is composed of five questions and rates life satisfaction on a scale from one to seven.

As is the case for all data gathered through surveys, this approach is prone to a host of possible errors. A person's self-reported global well-being can be influenced by moment-to-moment factors such as mood and immediate circumstances; it can also be affected by survey artifacts such as the order and wording of questions, the response scales used, and the selection of information given as context (Frey and Stutzer, 2002). Whether these factors produce systematic biases depends on how the data are used, as the potential problems are muted if their main use is not to compare levels in an absolute sense but rather to seek to identify the determinants of happiness.

With data on self-reported individual well-being, the framework above can be used to discern the determinants of HWB. The true level of HWB is modeled as a latent variable that is related to objective individual, economic, social, and environmental conditions, and the function above (usually in a linear form) can be estimated using ordered probit or logit regression (Welsch and Kühling, 2009). Among the most studied determinants is income (Hsieh 2003, Solberg et al 2002, Vera-Toscano et al 2006, Warr 1999, and many others). Across individuals within a given location, the general (and very robust) result is the people with higher incomes report higher levels of well-being (life satisfaction or happiness) - "income does buy happiness" (Frey and Stutzer, 2002).

Easterlin (1974, 1995, 2001), however, has found that while this result holds cross-sectionally, as incomes rise over time within a given area (such as a nation), everyone's self-reported well-being does not necessarily increase. This result has been supported by laboratory experiments that look at the effects of individuals' relative income on happiness (Smith et al. 1989, Tversky and Griffin 1991). Another interesting result comes from Alesina, et al. (2001), which found a strong negative relation between income inequality and happiness in Europe, but not in the United States. Another area related to income is unemployment, which many studies have shown to have strong, negative effects on well-being (Clark et al. 2001, Di Tella et al. 2001, Graetz 1993, Korpi 1997, Winkelmann and Winkelmann 1998).

Other individual circumstances play a strong role in determining self-reported well-being. A few areas are criminal victimization (Michalos and Zumbo 2000), housing and home-ownership (Diaz-Serrano 2006), and education (Hayo and Seifert 2003). Di Tella et al. (2001) show how inflation and unemployment both affect an individual's well-being; Frey et al. (2009) show how terrorism in France and the British Isles exerts a strong negative effect on subjective well-being; and Frey and Stutzer (2000), in a study of Swiss cantons, show how the institutional right of individual political participation via popular referenda exerts a strong effect on happiness.

This approach has also been used to examine the relations between environmental conditions and subjective well-being, as shown in Table 1 (Welsch and Kühling, 2009; Ferreira and Moro, 2010). While research on measuring subjective HWB directly and exploring its determinants is growing, the literature has not yet expanded to cover the broad set of ecological goals associated with the Partnership's efforts. Nevertheless, these studies and this method provide an interesting perspective on how links between ecological conditions and HWB can be assessed. If changes in these conditions have progressed to the point of having serious impacts on human systems, viewing the impacts through the lens of direct, subjective measurement of HWB would seem a fruitful avenue. Short of such changes, other methods (such as the ones discussed below) would seem more likely to provide a finer grained assessment of the links.

Table 1. Examples of studies using the direct, subjective measurement approach for estimating links between HWB and environmental quality	
Climate	Becchetti et al. (2007) Frijters and van Praag (1998) Rehdanz and Maddison (2005)
Droughts	Carroll et al. (2009)
Air pollution	Welsch (2002) Welsch (2006) Di Tella and MacCulloch (2007) Luechinger (2009)
Airport noise nuisance	van Praag and Baarsma (2005)
Flood hazards	Luechinger and Raschky (2009
Water pollution	Israel and Levinson (2003)

Revealed Preferences Methods

Standard economic theory is based on the assumption that observable choices made by individuals reveal their expected preferences. Individual utility is inferred from behavior, and is in turn used to explain the choices made (see Slesnick 1998 for an extended discussion). Behavior is therefore a way of inferring well-being, in that individuals are assumed to choose actions that are, from an ex ante perspective, the "best," or the actions that maximize their well-being. Criticisms of this approach, and particularly the equating of utility and well-being, are legion. One of the leading lines is Kahneman (1999; see also Kahneman and Krueger, 2006; Kahneman and Sugden, 2005; Kahneman, Wakker, and Sarin, 1997), who distinguishes between decision utility (which is what economists analyze) and experience utility, which is akin to the moment-to-moment well-being discussed above. He argues that if the two utilities differ in their implications for public policy, experience utility should be favored over decision utility. A common example given to support this stance is one that features smokers: they may decide to have a cigarette (decision utility), yet be better off if they don't (experience utility) (Read, 2004).

Nevertheless, although the revealed preference approach is not without its problems, it still offers a rich literature from which to draw, at least for the purpose of investigating links between environmental quality and human well-being. Below, we consider three methods that use actual behavior to assess the determinants of HWB: market-based approaches, hedonic analyses, and non-market behavior-based approaches.

Market-based Approaches

The most obvious way of discerning a link between environmental quality and human well-being is to look for environmental "goods and services" in the marketplace. Environmental resources are often inputs to market-based production processes. If so, their value can be measured directly, if the environmental resources are sold in a market; or inferred, if they are not themselves traded but the products they support are. Techniques for estimating the values in these cases are presented in standard benefit-cost textbooks (e.g., Zerbe and Bellas, 2006; Zerbe and Dively, 1994).

For example, Peters et al. (1989) examines the potential market value of non-timber forest products, such as fruits, latex, and tropical medicines, in a hectare of forestland. This value can be measured by calculating the net revenues per hectare from collecting these goods. Other studies use the costs of undesirable environmental change as a way of estimating the potential value of avoiding such change. Yohe et al. (1998) use the market value of land plus the cost of constructing protective sea walls to estimate the potential damage from sea level rise. The economic costs of climate change, and therefore the economic benefits of avoiding climate change, can also be estimated using this market perspective. Climate change will impact energy markets by shifting demand for energy resources, and the value of this shift can be used to infer these costs (Mansur et al., 2008). Similarly, a change in available water for an area through changes in climate can be valued using a demand model of water consumption in a watershed (Hurd et al., 1999).

The existence of markets for ecological goods and services provides an immediate pathway that connects ecological conditions to HWB. For Puget Sound, a potential source of relevant market-based data covers the commercial harvests of finfish and shellfish (Table 2) (Pacific States Marine Fisheries Commission , 2009). The volume of landings and the amount of revenues demonstrates the obvious value of these environmental goods. Exactly how these measures have or would respond to changes in the quality of their supporting habitat and other environmental conditions has not been the subject of systematic study, however.

Table 2. Examples of market landings and revenues in 2008 for species harvested in Puget Sound (Pacific States Marine Fisheries Commission, 2009)

Species common name	Aquaculture		Commercial (Non-tribal)		Commercial (tribal)	
	Landed weight (lbs)	Landed revenue ($)	Landed weight (lbs)	Landed revenue ($)	Landed weight (lbs)	Landed revenue ($)
Geoduck	4,122,429	$25,353,623	2,290,914	$6,188,422	3,197,846	$11,759,146
Chum Salmon			4,196,843	$3,552,228	4,689,451	$3,717,760
Manila Clam	7,149,458	$18,385,757	5,690	$10,811	788,595	$1,268,706
Dungeness Crab			2,837,020	$6,785,143	4,013,664	$10,198,513
Blue or Bay Mussel	2,963,216	$5,293,124			400	$600
Pacific Oyster	2,222,221	$7,498,498	21,238	$84,094	388,746	$1,253,802
Coho Salmon			205,236	$289,293	1,966,139	$3,389,613
Chinook Salmon			180,821	$566,347	1,387,001	$3,613,382

Hedonic Analyses

Market goods often have multiple characteristics but are sold as a bundle. Analyzing such goods to discern the implicit price of each individual characteristic is an approach known as hedonic analysis. An existing house, for example, contains many characteristics that come as a bundle: numbers of bedrooms and bathrooms, square footage, size of lot, type of energy used, and so forth. If the good is fixed to a certain location, the characteristics of the location also become part of the bundle. Again, for an existing house, such location-specific characteristics include the quality of public schools, proximity to jobs, transportation networks, and even environmental amenities, such as air and water quality or proximity to open space. Each of these characteristics is not explicitly priced, yet the price of the house varies systematically with variation in their levels. Two types of bundled goods are analyzed with this approach: housing (or more generally, property) and jobs (wages).

Hedonic property models collect data on the prices of home sales and housing characteristics, which can include environmental quality and amenities. The expectation is that "good" features of a location (e.g., air and water quality) will be reflected by positive implicit prices for those features, while "bad" features (e.g., toxic waste sites) will have negative implicit prices. Hedonic wage models are based on the assumption that a job is a bundle of characteristics, which cover workplace characteristics as well as location-specific characteristics, including environmental quality and amenities. Here, the expected direction of implicit prices is the opposite of that for hedonic property prices. "Good" features will have a negative implicit effect because workers are willing to accept lower wages in locations with such features; "bad" features are associated with higher wages for the opposite reason. Although hedonic wage models are primarily used in environmental economics to value mortality risk, there are some studies that incorporate a broader set of environmental quality measures.

Exactly how one bounds a "location" for hedonic analysis is important. Most studies are limited to urban areas that have well-defined boundaries, or to other geographic units (counties, census blocks, and so forth) that have similarly well-defined boundaries. The characteristics of the bundled good are then taken from the features found within these boundaries. In contrast, Schmidt and Courant (2006) consider proximity to "nice" places (national parks, lakeshores, seashores, and national recreation areas) in an hedonic wage model. They found that amenities outside the metropolitan area generate compensating wage differentials, as workers are willing to accept lower wages to live in proximity to accessible "nice" places.

The hedonic approach has been used to estimate the values, as reflected in property prices or wage levels, for several types of environmental quality attributes, as shown in Table 3. Examples of studies that examine attributes that are more connected to ecological systems are briefly reviewed below:

- Cho et al. (2009) examined amenity values of forest landscapes in the Southern Appalachian Highlands using a hedonic housing-price framework. Their results show that housing prices respond to the size and the density of forest-patches.
- Bin and Polasky (2005) used a hedonic property price method to estimate how wetlands affect residential property values in a rural area. They found that i) a higher wetland percentage within a quarter mile of a property, ii) closer proximity to the nearest wetland, and iii) larger size of the nearest wetland are associated with lower residential property values.
- Poor et al. (2007) investigated the value of ambient water quality throughout a local watershed in Maryland using a hedonic property value model, focusing on total suspended solids and dissolved inorganic nitrogen. Their results indicate that there is a substantial penalty imposed on property prices by higher levels of total suspended solids and dissolved inorganic nitrogen.
- Bark et al. (2009) examined homebuyers' preferences for nearby riparian habitat in the metropolitan Tucson study area and the data incorporated into a hedonic analysis of single family residential house prices. The results indicate that high quality riparian habitat adds value to nearby homes and that instead of indiscriminately valuing "green" open space, nearby homebuyers distinguish between biologically significant riparian vegetation characteristics.
- Bin et al. (2009) used data from the Neuse River Basin in North Carolina to provide empirical evidence on the effect of a mandatory buffer rule on the value of riparian properties. They found that a riparian property generally commanded a premium, but there was no evidence that the mandatory buffer rule had a significant impact on riparian property values when compared with the control group.
- Netusil (2005) uses the hedonic method to examine how environmental zoning and amenities are related to the price of single-family residential properties sold between 1999 and 2001 in Portland, Oregon. The type of environmental zoning and the property's location affected the price effect of environmental zoning, while the type of amenity and its proximity affected a property's sale price.
- Horsch and David (2009) use hedonic analysis to estimate the effects of a common aquatic invasive species--Eurasian water milfoil (milfoil)—on property values across an extensive system of over 170 lakes in the northern forest region of Wisconsin. Their

results indicated that property on lakes invaded with milfoil experienced an average 13% decrease in value after invasion.

- Halstead et al. (2003) applies the hedonic method to estimate the effects of variable milfoil on shoreline property values at selected New Hampshire lakes. Results indicate that property values on lakes experiencing milfoil infestation may be considerably lower than similar properties on uninfested lakes, but that the results are highly sensitive to the specification of the hedonic equation.
- Michael et al. (2000) used the hedonic approach to estimate the value for nine measures of water clarity for lakefront properties in Maine. They found that the value of water clarity varied across these measures, with the differences in implicit prices large enough to potentially affect policy decisions.

Table 3. Examples of studies using the hedonic approach for estimating links between HWB and environmental quality	
Air pollution	Anderson and Crocker (1971) Chattopadhyay (1999) Freeman III (1974) Graves et al. (1988) Harrison Jr. and Rubinfeld (1978) Murdoch and Thayer (1988) Nelson (1978) Nourse (1967), Zabel and Kiel (2000)
Water quality	Boyle et al., (1999) Leggett and Bockstael (2000) Poor et al. (2006) Epp and Al-Ani (1979) Gibbs et al. (2002) Halstead et al. (2003)
Noise	Hall et al. (1978) Nelson, J. P. (1982) O'Byrne et al. (1985) Taylor et al. (1982)
Solid waste sites	Havlicek et al. (1971) Reichert et al. (1992) Thayer and Rahmatian (1992)
Shore erosion protection	Kriesel et al. (1993)
Toxic waste sites	Kiel, K.A. (1995) Kohlhase (1991) Reichert (1997) Smith and Desvousges (1986) Smolen et al. (1992)

Non-market Behavior-based Approaches

For many recreational and other environmental experiences, there is no formal market that can be used to assess their value, either directly or indirectly as is done with the hedonic approach. If the experience requires some form of travel or other behavior that entails a cost (usually in terms of time), however, it is possible to infer how an individual values that experience in terms of their willingness-to-pay. The most common form of this approach is the travel cost method, which uses travel costs and visitation rates to a recreation site to estimate a demand function for that type of recreation (Clawson, 1959; Knetsch, 1963). Similar to the assumptions for hedonic models, the recreation "good" can be a bundle of characteristics, some of which are the environmental features important to the recreational experience. If data are available for visits to multiple sites with varying levels of those features, one can then estimate the contribution of a particular feature to the demand for that recreation, and from this estimate its value (Morey, 1981).

The travel cost method has been widely used to estimate the value of recreation. Loomis (2005) summarizes many of these studies for the purpose of assessing recreation values that could be applied to the U.S. National Forest system. Table 4 presents estimates from Loomis (2005) of seven different types of recreation, drawn from studies conducted in Oregon or Washington. As will be illustrated in the next section, the travel cost and other non-market behavior-based methods have been largely overtaken by the state preference approach. Nevertheless, there are some studies worth noting:

- Murray et al. (2001) estimated the value of reducing beach advisories in Great Lakes beaches located along Lake Erie's shoreline in Ohio. They found that the across all visitors, the average seasonal WTP to encounter one less advisory was approximately $28 per visitor.
- Egan et al. (2009) used a set of water quality measures developed by biologists in a study of recreation visits to 129 lakes in Iowa, and derived estimates of the willingness-to-pay for improvements in the water quality measures. The results demonstrated a significant WTP for water clarity as measured by the Secchi transparency, and that recreational trips decreased as concentrations of nutrients increased.
- Massey et al. (2006) and estimated the benefits of reducing water pollution for recreational fishing when fishing takes place at multiple locations. They found only small impacts from improving water quality conditions in Maryland's coastal bays alone, but that improvements throughout the range of the species could increase abundance and associated beneficial increased catch rates.
- Montgomery and Needelman (1997) also estimated the benefits of reducing water pollution for recreational fishing when fishing takes place at multiple locations. They estimated an annual benefit of $63 per capital per seasons from eliminating toxic contamination from New York lakes and ponds.
- Johnstone and Markandya (2006) derived economic values for river quality indicators, including chemical, biological and habitat-level attributes, by developing a model of angler behavior that linked these attributes to visitation rates. The models could then be used to estimate the welfare associated with marginal changes in river quality.

Table 4. Average recreation values based on studies from Oregon and Washington that use the revealed preference approach (Loomis, 2005)

Activity	Value per day ($2004)	Number of studies
Fishing	$41.98	5
Hiking	$23.98	5
Hunting	$35.27	5
Motorboating	$12.48	1
Swimming	$6.06	1
Wildlife viewing	$35.00	3

Stated Preference Methods

Stated preference methods rely on survey questions that ask individuals to make a choice, describe a behavior, or state directly what they would be willing to pay for specified changes in non-market goods or services. This approach is controversial because in most cases it is not possible to verify independently the answers given to the survey questions, although experimental work has been conducted to investigate this issue (Murphy et al., 2005). Stated preference methods are increasingly used in economic studies of environmental quality because they offer the opportunity to estimate the valuation for anything that can be presented as a credible and consequential choice. Because they do tie willingness-to-pay to a hypothetical act of payment, they do not require observations of actual behavior and so they are the only economic methods that can measure non-use values.

The stated preference method can take the form of a contingent valuation survey, which asks respondents directly about the monetary value of a particular commodity or environmental change (Mitchell and Carson, 1989). A second approach, and one that is increasingly common, is the choice experiment or conjoint analysis approach (Holmes and Adamowicz 2003). This survey method gives respondents a set of hypothetical scenarios, each depicting a bundle of environmental attributes supplied at a given level, where the levels vary across scenarios. Also included (in nearly all cases) is a monetary cost, often characterized as a payment to a fund, a tax, or some other payment mechanism. Respondents are asked to express their preferences by choosing the most preferred alternative, ranking them in order, or rating them on some scale. By examining the tradeoff between the environmental attributes levels and the payment amounts, the willingness-to-pay for the different attributes can be estimated.

Although this approach has focused mainly on environmental economic issues, it has also been used to address other, non-environmental issues, including violent crime (Atkinson et al., 2005);

urban amenities (Howie et al., 2010); broadband service (Tseng and Chiu, 2005); and public transit stop information (Caulfield and O'Mahony, 2009). Cook and Ludwig (2002) examined people's views of policies designed to reduce gun violence using a stated preference model. They asked respondents how they would vote on a policy that was described as having the potential to reduce gun violence by 30 percent. Stated preference questions were used to measure respondents' likelihood of using the high occupancy traffic lanes as a function of the toll level and time savings (Georgia State Road and Tollway Authority, 2005).

Stated preference studies are by far the richest literature for connecting environmental conditions to HWB, at least as measured in terms of individuals' willingness-to-pay. Examples are cited in Table 5, which lists stated preferences studies that have estimated the willingness-to-pay for protecting a species (Richardson and Loomis, 2009). Below, a few of the many other studies are summarized:

- Carson and Mitchell (1993) perform a single comprehensive CV analysis, asking a national random sample of U.S. households to value the change in water quality that results from moving from no pollution control to "swimmable" water quality nationwide. Their best estimate of annual benefits is $(1990) 29.2 billion.
- Lyon and Farrow (1995) assessed the incremental net benefits of additional water pollution control investments beyond 1990. They concluded that these programs could have net benefits less than zero, but significant uncertainties remained.
- Milon, J.W., and D. Scrogin (2005) estimated the benefits of restoring the Greater Everglades ecosystem in Florida. They cast the restoration in terms of ecological functions (water levels) and structural changes (species populations) and found higher WTP for the latter than the former.
- Bell et al. (2003) used a stated preference survey to determine the WTP for a local coho salmon enhancement program in four Washington and Oregon coastal estuaries. They estimate this WTP to range between $37 and $120, depending on a household's income and the type of program.
- Hall et al. (2002) measured the benefit of an improvement in the quality of rocky intertidal zones in southern California resulting from additional regulation enforcement and access limitations. They presented respondents with a hypothetical reduction in illegal collecting and onsite habitat disturbance, which would increase the abundance of intertidal organisms, and found an average WTP of $6 per family-visit.
- Viscusi et al. (2007) used the stated preference approach to estimate values for water quality ratings based on the US Environmental Protection Agency National Water Quality Inventory ratings. They found an average value of $32 for each percent increase in lakes and rivers in the region for which water quality was rated as "Good."
- Banzhaf et al. (2006) quantified the total economic value of ecological improvements to New York's Adirondack Park from a reduction in acid rain. They estimated the WTP for these improvements to range from $48 to $107 annually.

Table 5. Examples of studies that use the stated preference approach to estimate the economic non-use value of a species (Richardson and Loomis, 2008)

Arctic grayling	Duffield and Patterson (1992)
Atlantic salmon	Stevens et al. (1991)
Bald eagle	Boyle and Bishop (1987) Stevens et al. (1991) Swanson (1996)
Bighorn sheep	King et al. (1988)
Blue whale	Hageman (1985)
Bottlenose dolphin	Hageman (1985)
Gray whale	Hageman (1985) Loomis and Larson (1994)
Gray wolf	Duffield (1991, 1992) Duffield et al. (1993) Chambers and Whitehead (2003)
Humpback whale	Samples and Hollyer (1989)
Mexican spotted owl	Loomis and Ekstrand (1997) Giraud et al. (1999)
Monk seal	Samples and Hollyer (1986)
Northern spotted owl	Rubin et al. (1991) Hagen et al. (1992)
Northern elephant seal	Hageman (1985)
Peregrine falcon	Kotchen and Reiling (2000)
Red-cockaded woodpecker	Reaves et al. (1994)
Riverside fairy shrimp	Stanley (2005)
Salmon	Olsen et al. (1991) Loomis (1996) Layton et al. (2001) Bell et al. (2003)
Sea otter	Hageman (1985)
Silvery minnow	Berrens et al. (1996)
Squawfish	Cummings et al. (1994)
Steller sea lion	Giraud et al. (2002)
Striped shiner	Boyle and Bishop (1987)
Whooping crane	Bowker and Stoll (1988)
Wild Turkey	Stevens et al. (1991)

Summary

Given the flexibility of the stated preference approach, it is tempting to ignore the first two methods – direct, subjective HWB measurement and revealed preference approaches – and focus on the stated preference approach as the most fruitful, at least in terms of ongoing and future research. That approach can be difficult to apply for ecological systems, however, because presenting information on such systems in the context of a survey can be problematic (Boyd and Krupnick, 2009). For the first two methods, an individual does not need to understand or even be aware of entire system that connects ecological conditions and well-being. These methods are based on the actual experience of these conditions, however, because they use objective measurements of the "real" conditions as the basis for analysis. For stated preference surveys, the connections are explored by giving individuals information about various scenarios, which inevitably decompose the environment into a limited set of abstract conditions. This means that respondents do not experience the full set of "real" conditions, and so are likely to "fill in the gaps" in ways that present problems for gathering useful data (Boyd and Krupnick, 2009).

In any case, there is much more work to be done to relate changes in environmental conditions to changes in human well-being. (Stiglitz et al. 2009). One must be careful in drawing conclusion from the current literature, as the absence of evidence documenting the strength of a connection should never be taken as evidence of the absence of such a connection. Nevertheless, documenting such absences can identify potentially important areas for future research.

Key Points: Although human well-being cannot be observed directly, there are methods to assess the determinants of human well-being. Research has utilized these methods to investigate the strength of connections between economic, social, and environmental factors and HWB. There is still much work to be done, however, in documenting these connections, particularly those covering environmental factors in general and for Puget Sound in particular.

Linking Biophysical and HWB Indicators

In this last section, we briefly present a framework for establishing connections between potential indicators of ecosystem biophysical conditions and human well-being in Puget Sound. The framework also provides a way of characterizing existing and future studies and data that are relevant to an element of the set of potential HWB indicators.

1. Connections between biophysical and human-based indicators

Just as the Partnership's biophysical goals can be linked to human well-being, so too can biophysical indicators. In some cases, the component tracked by a biophysical indicator is directly connected to HWB. A component such as a species, for example, can be valued for its existence, even without any direct consumptive use (e.g., harvest) or non-consumptive activity (e.g., wildlife viewing). Some of the species in Table 4, for example, have little value other than this existence value, and so a measure of some aspect of that species' biological status could serve both as a biophysical indicator and as a normative indicator of human well-being. Estimates of WTP drawn from state preference studies that then measure existence value are one way of gauging the importance of such an ecological component. This provides a means of identifying a potentially useful indicator, independent of its qualities as a biophysical indicator.

At the other extreme, human well-being is sometimes derived purely from the direct consumption or harvest of an ecological component. The level and value of that use can be used as a normative HWB indicator, easily expressed in dollars if the use takes place in a market setting. In such a case, an indicator that tracks the actual level of consumption or harvest provides information on actual HWB, while an indicator that tracks the biological status of the ecological component provides information on potential future HWB.

This case presents an interesting complication that illustrates some of the nuances involved in introducing HWB into ecosystem-based management. Fishing provides an example relevant to Puget Sound. The harvest of a fish population is an activity that supports HWB, and so an indicator based on harvest levels is one that faithfully tracks HWB. If the harvest rate is unsustainably high, however, an indicator that tracks the status of the fish population will trend downward, which seemingly indicates a decline in HWB.

(For the purposes of this simple example, we assume that the fishery is "mature" in that the initial stock is at or below the level that would produce the maximum sustainable yield or growth rate. In that case, a harvest level greater than the growth rate is one that will lower the stock size and its growth rate, accelerating the stock's decline.)

How should these conflicting signals be interpreted? If a conservation action consists of rebuilding the fish population with a period of lowered harvest levels, both indicators will accurately reflect the effects of this action on HWB. In Figure 8 (top panel), the harvest level is initially above the sustainable level for the initial stock size, which we assume is the desired or target population level. HWB is correspondingly high, but not at a level that can be sustained indefinitely. At some point, restrictions on harvest are imposed for the purpose of rebuilding the stock. These restrictions reduce the current level of HWB, which then increases assuming the rebuilding period at some point allows harvest to increase gradually. Finally, harvest is maintained at a sustainable level after the stock is rebuilt, and (in this simplistic world) can be maintained at that level indefinitely.

The current level of HWB faithfully tracks the harvest level throughout these periods, and so a normative HWB indicator can be developed based on annual harvests. At the same time, the fish population dynamics foretell future HWB. In Figure 8 (bottom panel), the stock size decreases during the period of overharvesting to levels significantly below its initial, target level. During the rebuilding period, it increases, eventually reaching the target level, where it can be maintained indefinitely as long as the harvest level is sustainable. Again, these movements are faithful predictors of future HWB, and so a normative HWB indicator can be based on its level, recognizing that the information embedded in such an indicator is partly dependent on how the system is managed. This example underscores the complexities in interpreting biophysical indicators in terms of HWB, given the dynamic nature of ecosystems and the potential of natural capital to support current and future HWB.

In other cases, connections exist between ecological and human systems that support HWB along even more complicated pathways. Understanding these pathways is important to identifying potential indicators, evaluating their qualities, and understanding how to relate changes in their levels to changes in HWB. For example, the harvest example illustrated in Figure 8 focuses only on the HWB derived from the connection between a fish population and its harvest by humans. Such a population can be valued along multiple pathways, however, some of which are complementary to harvest while others potentially involve tradeoffs.

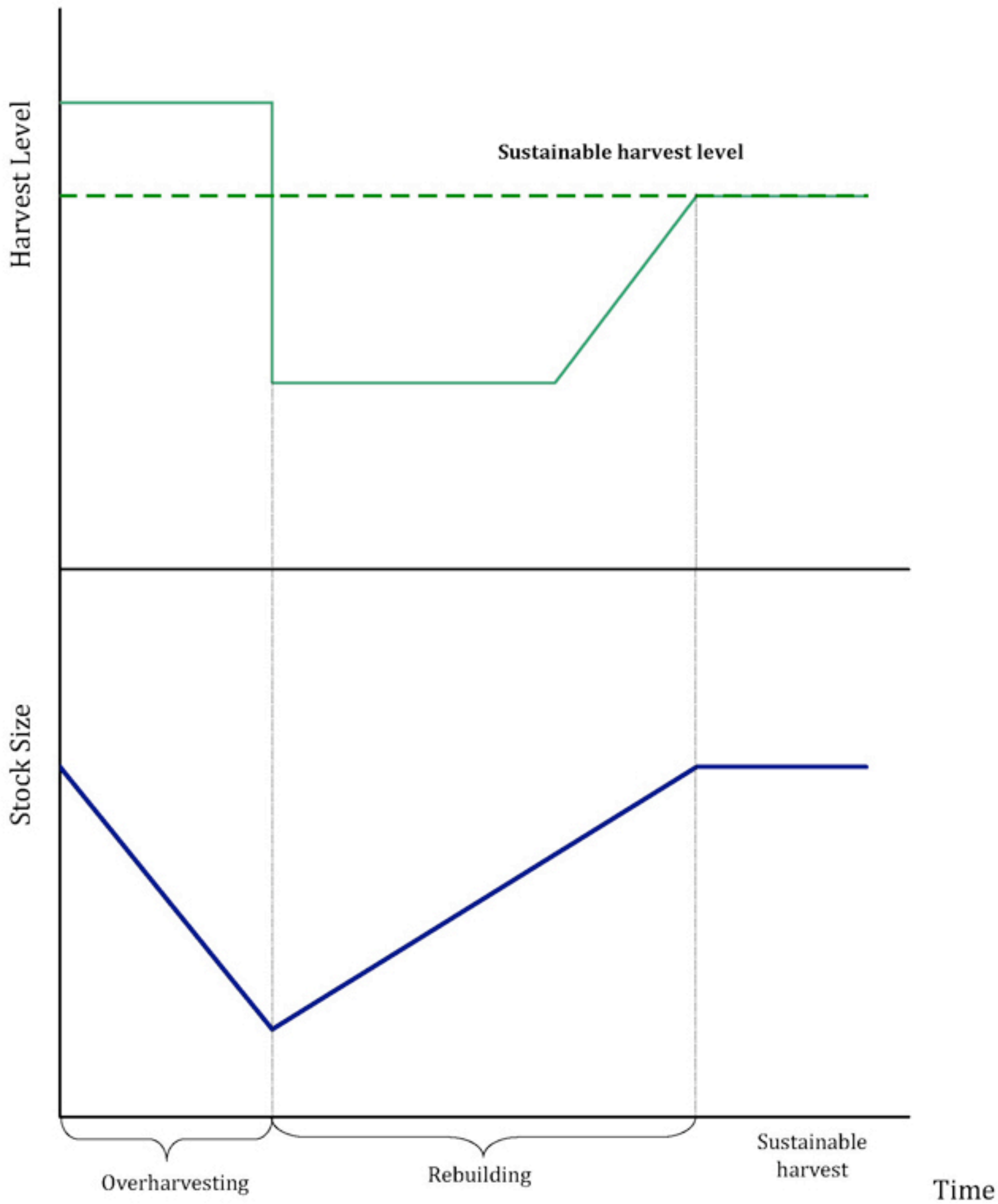

Figure 8 (upper panel): After a period of exceeding the sustainable level, harvest is reduced to allow the fish population to rebuild, and then is gradually increased to its sustainable level. These changes are mirrored by changes in current HWB.
Figure 8 (lower panel): Changes in the stock size accurately track potential future harvests and so can be used as an indicator for future HWB.

For example, Puget Sound coho salmon populations provide opportunities for recreational and commercial fisheries, some of which are conducted by Puget Sound tribes (Pacific Marine Fisheries Council, 2010, Tables B-39 and B-41). They are also prey for bald eagles (Stinson et al., 2007), an iconic species that has considerable economic value for wildlife viewing and existence value (Boyle and Bishop, 1987; Stevens et al., 1991; Swanson, 1996). In the Skagit

River basin, coho populations have experienced a loss in spawning and rearing habitat due to economic activities such as flood control, agriculture, and other activities (Stinson et al., 2007). Focusing on agriculture, we note that the Partnership has identified it as a "Low Threat" to ecosystem health (Puget Sound Partnership, 2009c). The Partnership has also identified "locally-grown food" in its Action Agenda as part of its five primary objectives, under the qualification that its production be "consistent with ecosystem protection" (Puget Sound Partnership, 2008). The cost and quality of agricultural production is an obvious contributor to HWB, as evidenced by its market value; moreover, there is some evidence that locally-produced food can command a higher WTP, other characteristics constant Darby et al., 2008). All of these connections create a complex set of pathways between potential biophysical and human-based indicators, and between those indicators and potential management actions (Figure 9).

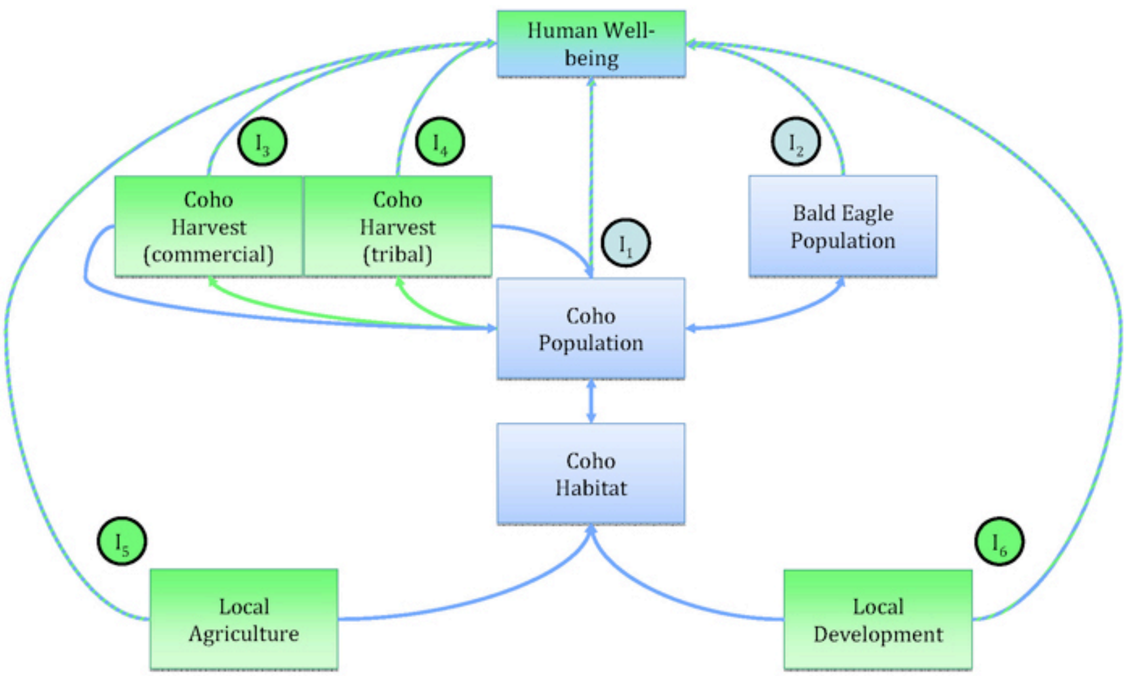

Figure 9: An example of the connections between biophysical and human-based components of the Puget Sound ecosystem, and between those components and human well-being. Identifying these connections can facilitate the identification and evaluation of biophysical and human well-being indicators.

In this system, HWB indicators could be based on

- Coho and bald eagle populations (I1 and I2). Bell et al. (2003) used a stated preference survey to determine the WTP for a local coho salmon enhancement program in four Washington and Oregon coastal estuaries. They estimate this WTP to range between $37 and $120, depending on a household's income and the type of program. Swanson (1996)

used a stated preference survey to determine the WTP of visitors to the Skagit River Bald Eagle Natural Area for bald eagle preservation. She found that visitors were willing to pay up to $350 for a 3005 increase in their population.
- Commercial Puget Sound coho harvest (all sources) and commercial, ceremonial, and subsistence tribal Puget Sound coho harvest levels (I3 and I4). As noted before in Table 2, Puget Sound coho populations are a valuable market commodity.
- Locally-based agricultural production (I5). Darby et al. (2008) used a stated preference survey to address whether consumers place a premium on "local" food distinct from other agricultural characteristics such as product freshness. They found that "local" does command a premium but found no difference between "in state" and "nearby" as the relevant geography for "local".
- Local development (I6). Because human well-being is supported by myriad forms of capital, not just natural capital (Millennium Ecosystem Assessment, 2005), measuring the contribution of land development to HWB and utilizing an appropriate indicator are important for EBM. This is an area for future work.

For broader purposes, one could use this approach for identifying connections and potential indicators to refine the Partnership's development of objectives and performance measures based on the Open Standards framework and its results chains (Puget Sound Partnership, 2009d).

Summary

Assessing the strength of connections between HWB and biophysical or human-based components of the ecosystem provides some guidance for EBM, then, in several ways. First, where sufficient evidence exists to indicate the strength of a connection, using any of the approaches described in the previous section, such evidence can highlight potential indicators associated with relatively strong connections. Second, the evidence can at least give some insights into the overall effect on HWB in cases where proposed management actions have multiple effects and potential tradeoffs. The evidence might indicate where such tradeoffs are likely to be "one-sided," in the sense of one value or connection being significantly stronger than any other; or it might indicate where such tradeoffs might be "closer," in that they involve multiple connections with some value but which move in opposite directions in response to a proposed action. And finally, collecting and cataloging evidence of this sort can highlight the (unfortunately many) areas where evidence is sparse, particularly for the connections among biophysical conditions, human behavior and values, and overall human well-being in the Puget Sound region. This can help set priorities for future social science research to support the Puget Sound Partnership's mission.

Key Points: The evidence on connections between environmental conditions and human well-being can be used to identify and evaluate potential indicators for the Puget Sound Partnership. Some biophysical indicators can also serve as human well-being indicators, or can be used in conjunction with HWB indicators to which they are connected. Evidence drawn from studies on HWB and environmental conditions can be used to assess the potential importance of the connections between the two, and so provide the Partnership with guidance on choosing relevant indicators.

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Figures

Table 1. Examples of studies using the direct, subjective measurement approach for estimating links between HWB and environmental quality	
Climate	Becchetti et al. (2007) Frijters and van Praag (1998) Rehdanz and Maddison (2005)
Droughts	Carroll et al. (2009)
Air pollution	Welsch (2002) Welsch (2006) Di Tella and MacCulloch (2007) Luechinger (2009)
Airport noise nuisance	van Praag and Baarsma (2005)
Flood hazards	Luechinger and Raschky (2009
Water pollution	Israel and Levinson (2003)

Table 2. Examples of market landings and revenues in 2008 for species harvested in Puget Sound (Pacific States Marine Fisheries Commission, 2009)

Species common name	Aquaculture		Commercial (Non-tribal)		Commercial (tribal)	
	Landed weight (lbs)	Landed revenue ($)	Landed weight (lbs)	Landed revenue ($)	Landed weight (lbs)	Landed revenue ($)
Geoduck	4,122,429	$25,353,623	2,290,914	$6,188,422	3,197,846	$11,759,146
Chum Salmon			4,196,843	$3,552,228	4,689,451	$3,717,760
Manila Clam	7,149,458	$18,385,757	5,690	$10,811	788,595	$1,268,706
Dungeness Crab			2,837,020	$6,785,143	4,013,664	$10,198,513
Blue or Bay Mussel	2,963,216	$5,293,124			400	$600
Pacific Oyster	2,222,221	$7,498,498	21,238	$84,094	388,746	$1,253,802
Coho Salmon			205,236	$289,293	1,966,139	$3,389,613
Chinook Salmon			180,821	$566,347	1,387,001	$3,613,382

Table 3. Examples of studies using the hedonic approach for estimating links between HWB and environmental quality

Air pollution	Anderson and Crocker (1971) Chattopadhyay (1999) Freeman III (1974) Graves et al. (1988) Harrison Jr. and Rubinfeld (1978) Murdoch and Thayer (1988) Nelson (1978) Nourse (1967), Zabel and Kiel (2000)
Water quality	Boyle et al., (1999) Leggett and Bockstael (2000) Poor et al. (2006) Epp and Al-Ani (1979) Gibbs et al. (2002) Halstead et al. (2003)
Noise	Hall et al. (1978) Nelson, J. P. (1982) O'Byrne et al. (1985) Taylor et al. (1982)
Solid waste sites	Havlicek et al. (1971) Reichert et al. (1992) Thayer and Rahmatian (1992)
Shore erosion protection	Kriesel et al. (1993)
Toxic waste sites	Kiel, K.A. (1995) Kohlhase (1991) Reichert (1997) Smith and Desvousges (1986) Smolen et al. (1992)

Table 4. Average recreation values based on studies from Oregon and Washington that use the revealed preference approach (Loomis, 2005)

Activity	Value per day ($2004)	Number of studies
Fishing	$41.98	5
Hiking	$23.98	5
Hunting	$35.27	5
Motorboating	$12.48	1
Swimming	$6.06	1
Wildlife viewing	$35.00	3

Table 5. Examples of studies that use the stated preference approach to estimate the economic non-use value of a species (Richardson and Loomis, 2008)

Arctic grayling	Duffield and Patterson (1992)
Atlantic salmon	Stevens et al. (1991)
Bald eagle	Boyle and Bishop (1987) Stevens et al. (1991) Swanson (1996)
Bighorn sheep	King et al. (1988)
Blue whale	Hageman (1985)
Bottlenose dolphin	Hageman (1985)
Gray whale	Hageman (1985) Loomis and Larson (1994)
Gray wolf	Duffield (1991, 1992) Duffield et al. (1993) Chambers and Whitehead (2003)
Humpback whale	Samples and Hollyer (1989)
Mexican spotted owl	Loomis and Ekstrand (1997) Giraud et al. (1999)
Monk seal	Samples and Hollyer (1986)
Northern spotted owl	Rubin et al. (1991) Hagen et al. (1992)
Northern elephant seal	Hageman (1985)
Peregrine falcon	Kotchen and Reiling (2000)
Red-cockaded woodpecker	Reaves et al. (1994)
Riverside fairy shrimp	Stanley (2005)
Salmon	Olsen et al. (1991) Loomis (1996) Layton et al. (2001) Bell et al. (2003)
Sea otter	Hageman (1985)
Silvery minnow	Berrens et al. (1996)
Squawfish	Cummings et al. (1994)
Steller sea lion	Giraud et al. (2002)
Striped shiner	Boyle and Bishop (1987)
Whooping crane	Bowker and Stoll (1988)
Wild Turkey	Stevens et al. (1991)

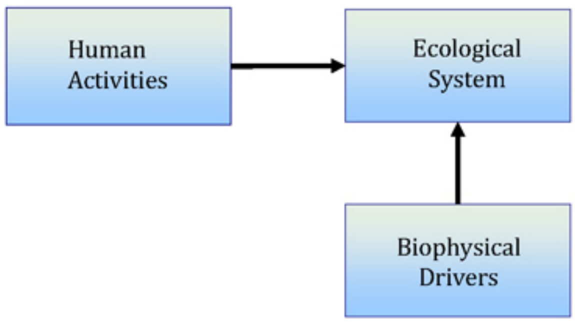

Figure 1: A simplistic view of an ecological system that is affected by but separate from human systems. Adapted from Redman, *et al*. (2004).

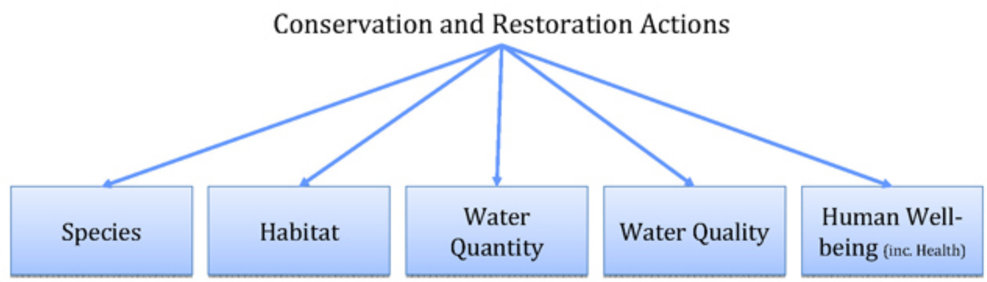

Figure 2: A framework for evaluating the effects of conservation and restoration actions on the Partnership's goals, where each goal is considered with a distinct set of metrics.

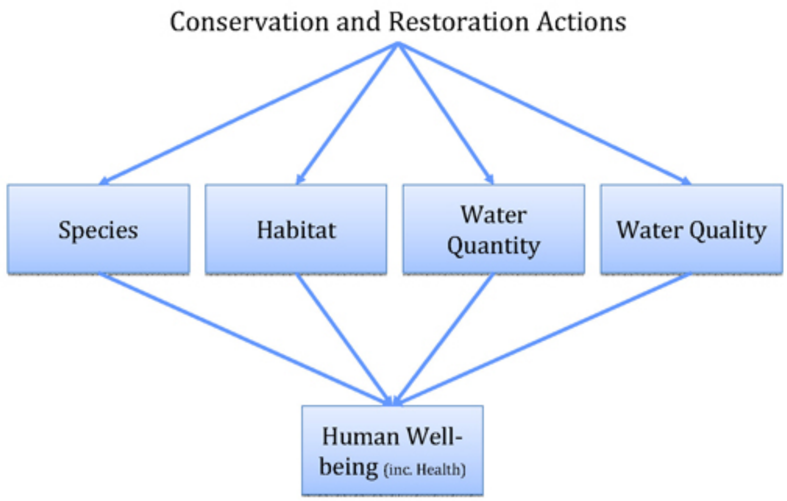

Figure 3: A framework for evaluating the effects of conservation and restoration actions on the Partnership's ecological goals using human well-being as a common metric.

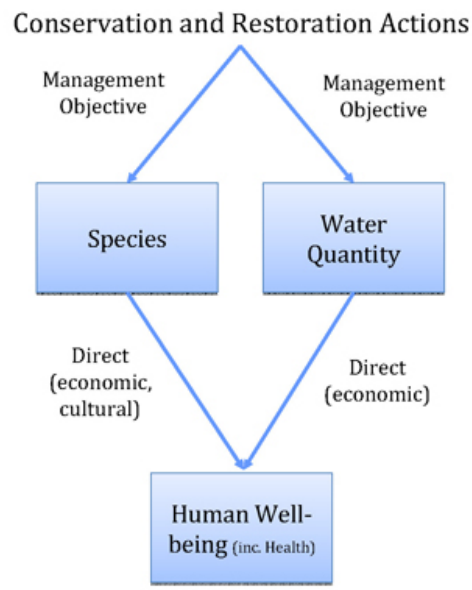

Figure 4: An example of how human well-being can be used as a metric to assess the effects of conservation and restoration actions that are directed at species and water quality.

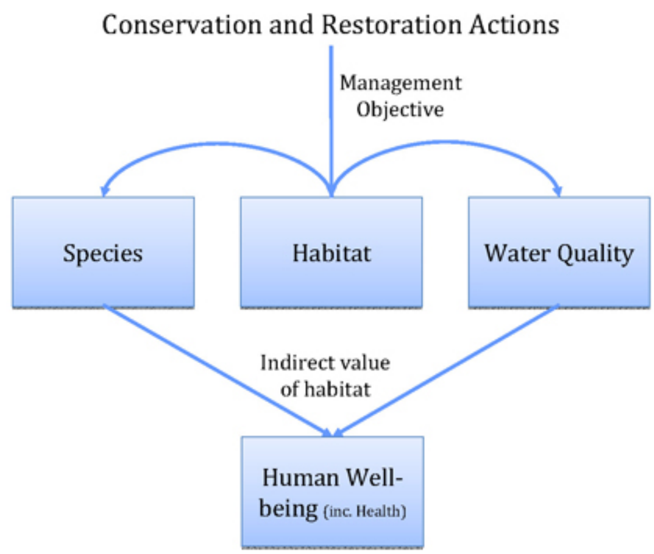

Figure 5: An example of how human well-being can be used as a metric to assess the effects of conservation and restoration actions that are directed at habitat, which in turn affects species and water quality and thereby affecting human well-being.

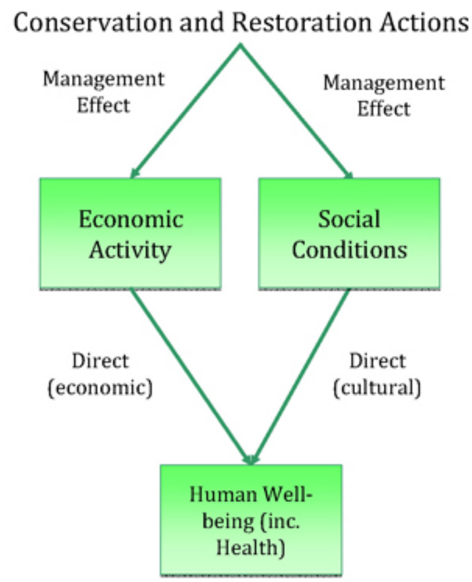

Figure 6: An example of how human well-being can be used as a metric to assess the effects of conservation and restoration actions that affect important components that support human well-being but which are not the objectives of management.

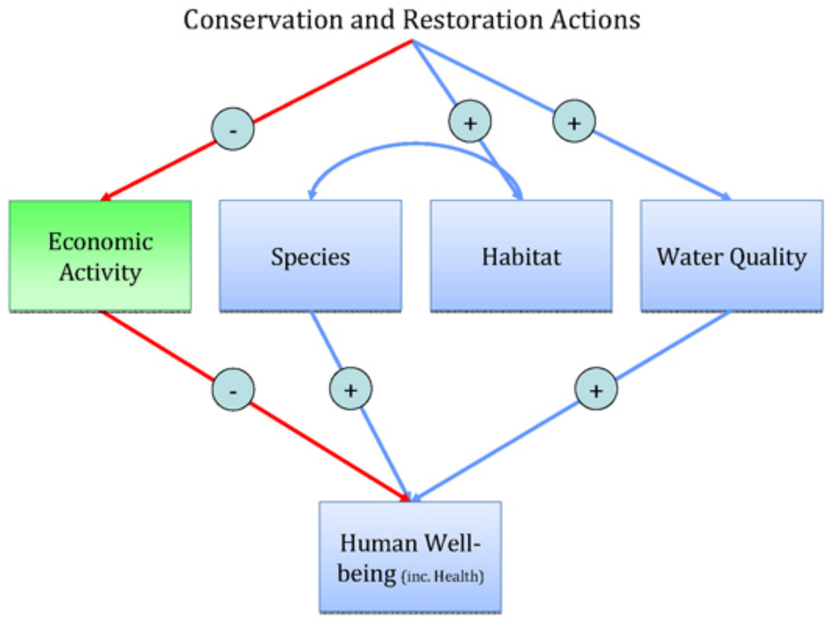

Figure 7: An example of how human well-being can be affected by conservation and restoration actions along multiple pathways.

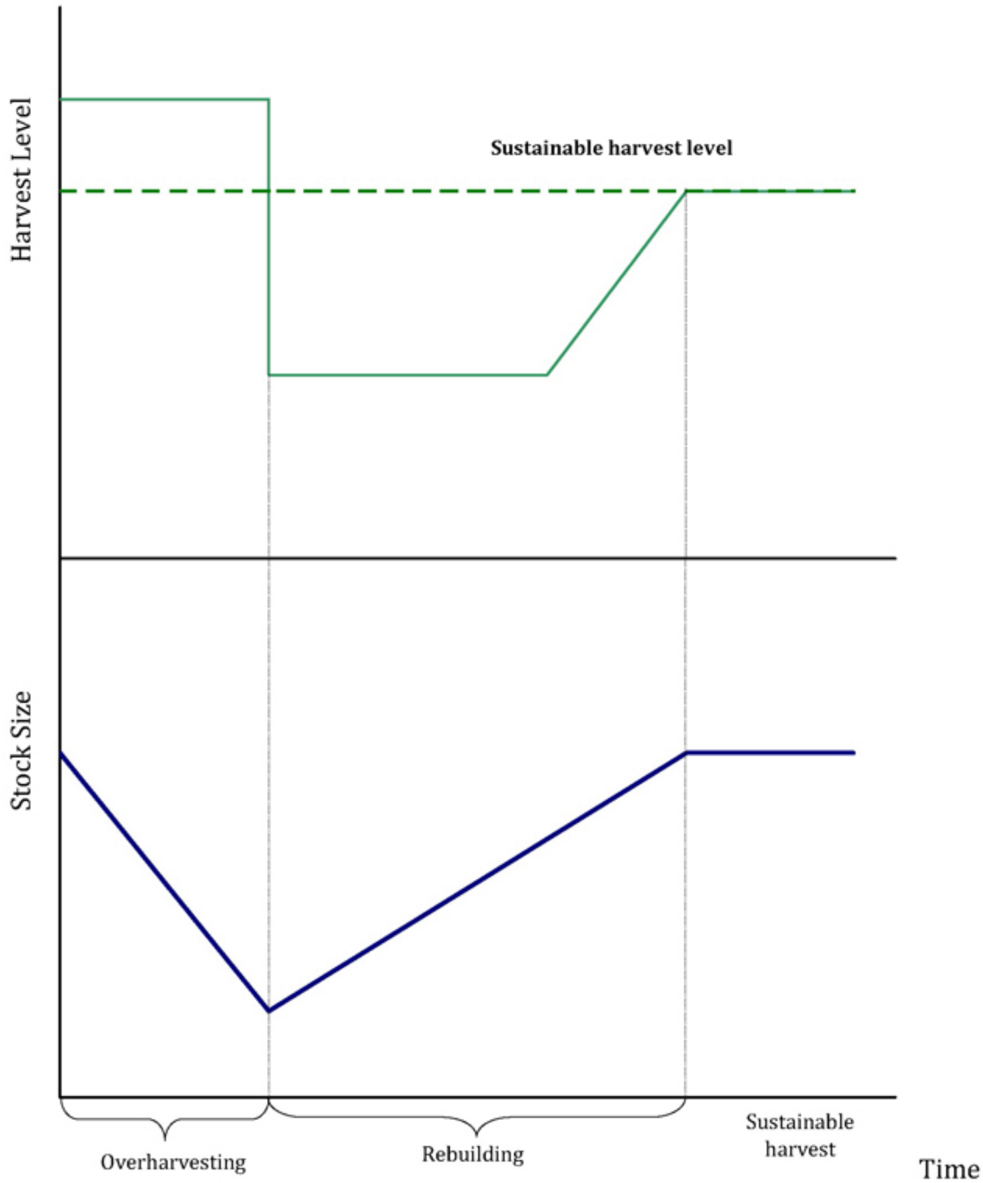

Figure 8 (upper panel): After a period of exceeding the sustainable level, harvest is reduced to allow the fish population to rebuild, and then is gradually increased to its sustainable level. These changes are mirrored by changes in current HWB.
Figure 8 (lower panel): Changes in the stock size accurately track potential future harvests and so can be used as an indicator for future HWB.

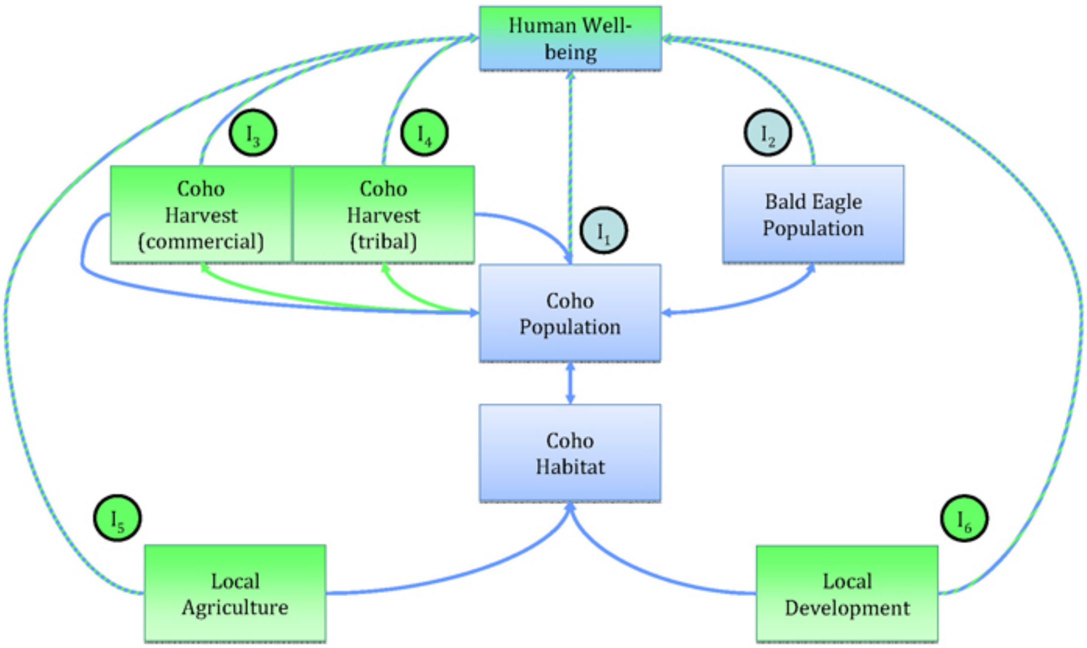

Figure 9: An example of the connections between biophysical and human-based components of the Puget Sound ecosystem, and between those components and human well-being. Identifying these connections can facilitate the identification and evaluation of biophysical and human well-being indicators.