Washington Biodiversity Council
Biodiversity Assessment Framework

Draft Conceptual Model, Indicators and Metrics
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Final Version

Report of Efforts and Products

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EXECUTIVE SUMMARY

Few things are as complicated and difficult to describe as a living system. That's particularly true in Washington State, whose varied flora and fauna cover more than 170,000 square kilometers and more than half a dozen major ecosystem types.

But the very diversity that is so hard to describe is also a treasure. The state's biodiversity is central to the region's ecological health, an engine of the economy and dominant feature in our quality of life. Moreover, a variety of indicators already suggest that the biodiversity here is declining, as it is around the world. Eager to address this, the Washington Biodiversity Council identified in its Conservation Strategy the need to measure and monitor the problem with an eye towards guiding policies and practices.

At the Council's direction, we have developed a comprehensive, statewide tool to measure and monitor biodiversity – the Biodiversity Assessment Framework. We have done this by establishing a representative list of biodiversity indicators and using it as a proof-of-concept in one of the state's eight major ecosystem types, the wet or mesic forest. In the process, we feel we have created a thorough, robust tool that embraces the multifaceted nature of the state's biodiversity while offering a transparent, elegant system for analyzing and improving the state's natural systems.

The Framework has several strengths:

- It is based on state-of-the-science techniques in use around the world. In some ways, it improves on them.
- It is useful as a snapshot in time, but also serves as way to chart trends over time.
- Its indicators are selective enough to avoid being overwhelming, but broad enough to draw key ecosystem relationships.
- It incorporates not only natural features and systems, but also the human interface—practices that impact ecosystems and the services ecosystems provide.
- Like a body temperature or economic index, the Framework serves as an overall biodiversity index. Yet its component indicators are useful for a more systemic understanding and targeted efforts.

In short, the framework is a comprehensive, science-based assessment of the most important facets of Washington's biodiversity. It is the first of its kind for the state and a powerful tool for assessing the effects of targeted management efforts, evaluating conservation and management strategies, and adapting our efforts.

A Conceptual Framework

Some things come to mind quickly at the mention of biodiversity: numbers of species, or the variety of ecosystem types. By themselves, these living elements of the natural world can serve as rough indicators of biodiversity, like acres of forest, or the number of animals on the state list of at-risk species.

But if we only measure the number of certain things, it will be like taking the heartbeat of a patient without examining the processes affecting that heartbeat, whether it's heart congestion or distance running. For this reason, we chose to look as well at processes, like how species interact and influence each other, or how the health of ecosystems is affected by nutrient flows and natural disturbances.

We could have stopped there, and some assessments do.

But we went a step further and linked ecosystem health to human activity. The growing field of urban ecology, not to mention the Council itself, recognizes the value of this approach. Human activity affects the natural world. Sometimes we do this directly, be it through game management or timber harvesting. Other efforts, like environmental education and public engagement programs, are less direct.

Moreover, ecosystems provide us with a variety of services, the full value of which we are only now beginning to tabulate. An assessment framework that illustrates these benefits stands to be more complete while engendering a greater sense of stewardship among the citizenry. People can look at the assessment and see that, yes, biodiversity matters, and how, and that they can play a role in its conservation.

These four facets of biodiversity—ecological elements and processes, human involvement and ecosystem services—broadened our field of focus. But as a conceptual framework, they were invaluable in homing in on the most important indicators to consider.

Narrowing the Field

From the outset, the list of possible biodiversity indicators appeared infinite. We adapted a set of criteria that limited indicators to those that are scalable, scientifically sound, relevant, flexible, measureable and practical, and comprehensive. Our expert technical review panel also recommended indicators that might serve as an "early warning" of biodiversity changes or describe things particularly relevant to ecosystem services.

Still, our first pass at a list, drawn from the Council's conservation strategy and a broad range of local, national and international monitoring efforts, yielded 136 indicators. Our panel of experts helped winnow this list down to a more concise, comprehensive group of indicators, in large part by focusing on the conceptual framework. We cut that list by more than half by focusing on indicators relevant to a number of different processes and elements of biodiversity; those particularly important for biodiversity assessment, like keystone species; and those already being extensively measured, like water quality.

Proof of Concept

Through internal Council Science Committee reviews, we further limited the list to 30 indicators and applied them fully to the western mesic forests and partially to eastern shrubsteppe. These two diverse ecosystems cover more than half of the state of Washington. As a proof of concept, we evaluated metrics for how they related to our four main areas of focus. Elements of biodiversity included species richness and balance, landscape composition and configuration. Ecological processes included net primary productivity. Examples of the human-driven factors and activities impacting biodiversity included public and private lands under conservation protection, land use and changes in land cover. The ecosystem services we considered included food and fiber yields and carbon sequestration.

Through this we learned that a comprehensive, well-chosen framework of indicators can offer insights into an ecosystem's biodiversity. Some types of information are not available at the best level of detail; others will require expanded monitoring efforts, either through professional staff or networks of citizen scientists. But computing many of the indicators required minimal effort, particularly with the vast data-mining capacity of contemporary databases and the Internet. The prototype measures yielded insights about the value of specific practices, as well as an overall biodiversity benchmark, even when we use an inherently naïve summary in which all indicators are weighted equally. In future work, we expect to look at ways of giving greater weight to those indicators that have a proportionally larger effect on biodiversity.

A look at the mesic forest assessment shows that it is a versatile tool for getting both a quick snapshot of the ecosystem and a more nuanced view. Our initial estimates suggest that Washington's mesic forests are providing ecological and social functions at about 70 percent of their pre-statehood level. Breaking this down further, we find that measures of elements of biodiversity are also at about 66 percent of pre-statehood levels. Species diversity and abundance are at around 74 and 85 percent, respectively, while measures of landscape integrity are at only about 60 percent, reflecting the fragmentation of forests. Ecological process rates and levels are at roughly 79 percent of those observed in the past 5-20 years. Plant productivity is at almost 90 percent of the maximum recently observed, and average abundance of keystone species is at almost 72 percent. Human efforts supporting biodiversity are at about 65 percent of the maximum possible, with high levels of education and citizen engagement (roughly 80 percent) and persistence of forested land cover (89 percent), but less than 50 percent of the land under active conservation protection and use. Lastly, ecosystem services provided by mesic forests are at roughly 68 percent of recent levels: while game yields were particularly low (around 30 percent), provision of park and wildlife viewing amenities was quite high (around 90 percent).

The shrubsteppe analysis further demonstrated the versatility of the assessment, particularly in contrast with mesic forest. Overall, shrubsteppe is functioning at 60 percent of estimated pre-statehood levels, with moderately high overall native bird richness (68 percent), particularly for functional groups such as predatory birds (78 percent), but very low occurrence of conservation-relevant public lands (8 percent).

As the Council has noted in its conservation strategy, biodiversity is like a diversified stock portfolio, keeping our options "abundant and varied." Just as a stock portfolio has a balance sheet of investments and returns, the Biodiversity Assessment Framework gives us a measurement tool that will show the strengths and weaknesses of elements, processes, human effects and ecosystem services, as well as threats and improvements over time. It provides a current assessment of biodiversity compared to what we know of conditions at statehood, as well as a benchmark for future assessments. The contribution of the Biodiversity Assessment Framework lies in its comprehensiveness, its capacity to describe ecological conditions of wide-ranging importance, and its potential to serve as tool to guide our actions and investments into the future.

I. Objectives and Scope of the Framework

Biological diversity – the variety of life in all its forms – underpins a region's ecological health, impacts the services humans obtain from the natural world, and indicates the myriad ways people have influenced nature. Globally, biodiversity is declining. Moreover, a systematic monitoring of biodiversity – its elements, services and responses to human activities – is lacking. To address this need, the Washington State governor has created the Washington Biodiversity Council and charged it with developing a statewide program to measure and monitor biodiversity. The aims of this framework are to assess the status of biodiversity in Washington, provide legislative and management guidance, and inform and engage the citizenry in understanding the importance of biodiversity. Under contract and in consultation with the Council, the University of Washington has undertaken initial development of the framework.

The use of indicator measures, which is a necessary component for assessing the status of biodiversity (Orians and Policansky 2009), is the focus of the Biodiversity Council's efforts. Like economic indices, environmental indicators help researchers and managers identify and follow trends, particularly as measures are amassed over time (NRC 2000; MEA 2005; Heinz Center 2008). In the case of biodiversity monitoring and assessment, a select set of indicators can be used to describe a broader range of conditions affecting species and ecosystems (Hutto 1998). Additionally, correlations between species-, ecosystem- and landscape-centric indicators can be used in part to help identify important species-habitat relationships. Lastly, indicator measures can serve as a useful tool for assessing the effects of regional conservation and management strategies to evaluate their effectiveness and modify the efforts accordingly (Christensen 2003).

The Biodiversity Assessment Framework comprises the groundwork for the first comprehensive, science-based assessment of Washington's biodiversity and important factors that impact and are impacted by it. A thorough assessment must include indicators of not only ecological conditions, but also the interactions between human (i.e., socioeconomic and political) systems and the environmental processes they impact and upon which they depend. Thus, the framework consists of a set of indicators that collectively assess the statewide condition of biodiversity and the resources (human and biophysical) that affect it. It will provide information to the public and decision makers on the status of Washington's biodiversity, environmental factors that affect the quality of life for Washingtonians, and the level of engagement of government, nonprofits, and the private sector in taking action to conserve biodiversity. The intended use of the framework is to identify and guide legislative, policy and management priorities and objectives, as well as to provide a baseline for assessing the efficacy of such actions. At the same time, the communication objectives for the framework, combined with innovative use of citizen science to populate appropriate indicators, will promote public engagement in and hence greater stewardship of biodiversity.

Given its analytical underpinnings, the framework also significantly contributes to technical and scientific research on biodiversity assessment. Firstly, its component indicators and metrics are grounded in the state-of-the-science in natural resource indicator research. Secondly, it has at its core a conceptual model that explicitly recognizes the integral linkages between biodiversity and human well-being. Lastly, its comprehensive design offers the potential for guiding further research, conservation and management efforts. The framework is guided by and expands upon broader national and international approaches, such as that of the Convention on Biological Diversity (UNEP 2003) and the Millennium Ecosystem Assessment (MEA 2005), by addressing human-biodiversity interactions in an explicitly integrated, coupled human-natural systems perspective (e.g., Holling 2001; Cumming et al. 2006; Liu et al. 2007). Additionally, our comprehensive approach includes the assessment of not only species diversity, but also landscape and ecosystem conditions that support biodiversity.

This report describes in detail the draft indicators that comprise the biodiversity assessment framework and the metrics used to quantify them. We begin by discussing the scope and objectives of the framework. We describe the process of developing the framework and selecting indicators and metrics. We then present the indicators and metrics themselves. We detail our efforts to test the applicability of the indicators through an assessment of mesic forest ecosystems of western Washington and a partial assessment of eastern shrubsteppe. Lastly, we suggest some approaches for aggregating indicators to summarize the information within the framework and provide broad-level assessments of biodiversity status and trends.

II. Methodology for Developing the Assessment Framework

IIA. Interviews with Practitioners and Users

One of the first steps in the process leading to the development of the assessment framework was comprised of a series of interviews with stakeholders, potential users of the framework, experts in indicator methods, and members of the Council itself. These conversations, summarized in greater detail in Appendix A, guided the scope and content of the framework, and yielded suggestions for its future use. First and foremost, the interviews significantly shaped the guidelines and principles that would delineate the scope of the framework and the selection of indicators. Interviewees provided suggestions on the spatial scale(s) of assessment, recommending that indicator measures be provided at the level of watersheds or counties where feasible and appropriate. Such fine-scale measures could be most effective at guiding planning and management decisions, for instance. Relatedly, interviewees highlighted the importance of providing measures that would be important or useful in guiding such decisions. Specific emphasis was placed on coordinating with other indicator assessment efforts in state – particularly in identifying commonalities and parallels between the biodiversity indicators and those of Puget Sound Partnership, the Forum on Monitoring Salmon Recovery and Watershed Health, and the Washington Invasive Species Council. One suggestion also served as a significant impetus for shaping the conceptual model we ultimately adopted: the importance and usefulness of using causal linkages to identify and organize indicators.

Suggestions from interviewees also provided useful guidance on important indicators to include in the framework. A notable example is the assessment of keystone species status and trends, particularly with respect to the functional roles that they play in ecosystems (e.g., pollinators, predators, etc.). Two interviewees noted the importance that disturbance can play in determining ecosystem integrity and hence promoting biodiversity: in this context, they recommended indicators that not only describe disturbance trends but that also recognize disturbance as a vital, rather than solely destructive, process. Some interviewees provided suggestions regarding significant measures of terrestrial impacts on water quality – that is, upland landscape characteristics that support both terrestrial and aquatic biodiversity as well as humans. These included indicators of riparian characteristics and natural filtration of water supplies through municipal watersheds. Lastly, some practitioners suggested important and useful ways of considering ecosystem services, by including indicators of economically less tangible amenities for human well-being as well as direct and indirect provision of natural resources.

Finally, we gleaned from the interviews some important insights on how the assessment framework might be used, thereby further shaping our indicator selection process. Much of this capacity will require innovative methods for distilling the inherent complexity of biodiversity assessment into useful aggregate measures, as well as effective communication strategies. Again, information from the framework could be used to guide and prioritize policy, planning and management decisions. A number of potential users also noted the possibility that the “big-picture,” state- and regional-level scope of the framework could be used to guide more detailed, local-level assessment efforts. In this context, the Council’s assessment framework could serve a coordinating role in biodiversity assessment across the state. Lastly, users envisioned the framework as providing a useful means of benchmarking status and trends over time, much like the “State of Salmon in Watersheds” (GSRO 2008) reports.

IIB. Principles and Scope of the Assessment Framework

The literature on environmental indicators is vast. To define the scope of the assessment framework and narrow the universe of possible approaches, we adopted a set of principles that characterize its objectives, shape the criteria for selecting indicators, and define how the framework will be assembled and maintained. These consisted of the following:

- **Use the best available and appropriate science**
  Indicators should be grounded in basic science that justifies their use and identifies how trends in their values should be interpreted. This entails use of established indicators from the peer-reviewed literature as well as peer review of the framework itself.

- **Select a sufficient number of indicators, but no more than are necessary**
  The set should include the smallest number of indicators that effectively convey the status of species and ecosystems, ecosystem services, and human

engagement with and support of natural resources within Washington's major ecosystems (as described below). The indicators must collectively provide enough detail to be informative and guide policy and management action. A lack of parsimony would make the framework overly complex, diluting its usability and wasting scarce financial and human resources.

- **Conduct an objective assessment**
  The indicators should focus on quantitative measures of biodiversity status and trends in Washington, the processes that impact it, and the implications of such measures. Distilling the framework into a "grading" or "ranking" scheme would, by introducing value judgments into the framework, create an implied advocacy role that compromises the framework's objectivity.

- **Don't link indicators to specific policies or regulations**
  The framework should avoid linking indicators to specific policy and regulatory definitions, because policy and regulatory definitions, such as compliance levels and safe chemical concentrations, change with time. Adopting this principle further contributes to the framework's objectivity as described above.

- **Maintain and update separately from policy and decision-making efforts**
  A neutral body (much like the proposed Commission on Economic Indicators) is best suited for the implementation and maintenance of the framework and helps avoid introducing advocacy positions.

- **Create a process that allows for and embraces advances in technology and scientific understanding**
  Technological and scientific innovations like more detailed satellite imagery will provide improved abilities to measure biodiversity status with greater precision. To make the framework as adaptable a tool as possible, it should be flexible enough to incorporate improvements in knowledge as well as new data sources, while still maintaining continuity and comparability in its measures over time.

- **Use citizen science**
  Citizen science provides a means of collecting potentially significant amounts of data, particularly at broad spatial scales. It also offers an innovative approach to engage and educate the public about the importance of conserving biodiversity. Such efforts should be integrated into the framework development process by evaluating the types of data and indicators that citizen science can effectively address, rather than tailoring the selection of indicators to accommodate the use of such resources.

IIC. Criteria for Indicator Selection – Review of Potential Indicators

We used these principles in part to establish a set of criteria for selecting the list of candidate indicators. The following criteria were adapted from a set of guidelines posed by Andreasen et al. (2001) for creating a terrestrial index of ecological integrity, as well as those used by the National Research Council (NRC 2000) in developing ecological indicators at a national level and other published approaches (Barbour et al. 1995; Kurtz et al. 2001). We qualitatively evaluated for each candidate indicator whether it fit, or had the potential to fit, the following criteria:

1) is it quantifiable;
2) is it measurable and meaningful at multiple spatial and temporal scales;
3) is it especially necessary or relevant for measuring status and trends of biodiversity and the key ecological and human factors that affect it; and,
4) does it contribute to the comprehensiveness of the broader set of collective indicators?

Two additional criteria, recommended through an expert technical review panel, were also included. They are not relevant to all indicators but are useful in distinguishing among alternative indicators relevant to a given structure or function.

5) Is the indicator particularly sensitive to change, such that it can be used to provide an “early warning” measure of relevance to biodiversity (e.g., significant reductions in pollinator numbers)?
6) Does the indicator describe or measure something of particular relevance in terms of ecosystem services?

With these principles and criteria in mind, we conducted an extensive review of the peer-reviewed literature, as well as existing ecological indicator and scorecard frameworks, to explore the suite of possible indicators that might be included in the Washington biodiversity assessment framework. (Citations for those indicators selected for the final framework are included in Table 1; the full list of indicators identified and their associated references are provided in Appendix B.) We targeted in our search indicators that not only describe the condition of species and ecosystems, but also the ecological and socioeconomic processes that sustain (or impair) biodiversity and the ecosystem services that it (directly or indirectly) provides. We began our search using sample indicators suggested in the Washington Biodiversity Council’s Conservation Strategy (WBC 2007, Appendix C) as a guide. Given the Council’s unique needs and interests, we proposed and included some indicators not yet established in the published literature. Biodiversity monitoring efforts such as those proposed or initiated by the Convention on Biological Diversity (UNEP 2003), the European Environment Agency/European Union (EEA 2007), the Millennium Ecosystem Assessment (MEA 2005), and the Colorado Natural Heritage Program/Nature Conservancy (CNHP/TNC 2008) served as principal models for the indicators we selected for review. We also looked to broader environmental assessment frameworks for candidate indicators and monitoring approaches, such as those adopted by the National Research Council (NRC 2000), the Heinz Center for Science, Economics and the Environment (Heinz Center 2008), Sustainable Seattle (2008), and the King County, WA, Department of Natural Resources and Parks (King County 2008). Additionally, we focused on related efforts in Washington, particularly those of the Puget Sound Partnership and the Governor’s Forum on Monitoring Salmon Recovery and Watershed Health, to ensure interagency compatibility and prevent unnecessary redundancy among our respective approaches.

Our review resulted in an initial list of 136 potential indicators. Through a technical review workshop, comprised of a panel of experts in environmental indicators, major ecosystems in Washington, environmental economics and policy and ecosystem services, we initiated the process of winnowing the list to a more concise, comprehensive group of indicators. A key step in this process, and a significant outcome of the workshop, consisted of developing an integrated conceptual framework to identify those indicators most salient to assessing biological diversity.

IID. Integrated Conceptual Framework Linking Indicators of Biophysical and Human Dimensions of Biodiversity

Our process of selecting and organizing indicators began with ascertaining specifically what the assessment framework should measure. Naturally, at the most basic level, assessing the health of biodiversity entails measuring the status and trends of species and the ecosystems upon which they depend. Such an assessment may indicate the health of biodiversity (e.g., is species richness high?; are landscapes of a given ecosystem type sufficiently intact?; etc.), but it lacks information on what is affecting biodiversity status. Therefore, indicators are also needed that report on and assess the status of key processes – such as plant productivity, nutrient flows, and disturbance regimes – upon which species and ecosystems depend. Similarly, because biological diversity exists within the context of human actions that support, impinge and depend upon those resources, an understanding of relevant socioeconomic factors can also prove indispensible.

Our resultant conceptual model incorporates three categories of indicators reflecting the central components of structure and functioning that are relevant to biodiversity (Figure 1). Key interactions among these components, represented in Figure 1 by bi-directional connections between them, are also included. One set of interactions – ecosystem services provided directly or indirectly through biodiversity conservation – are specifically emphasized as a fourth category, and hence are represented as larger arrows.

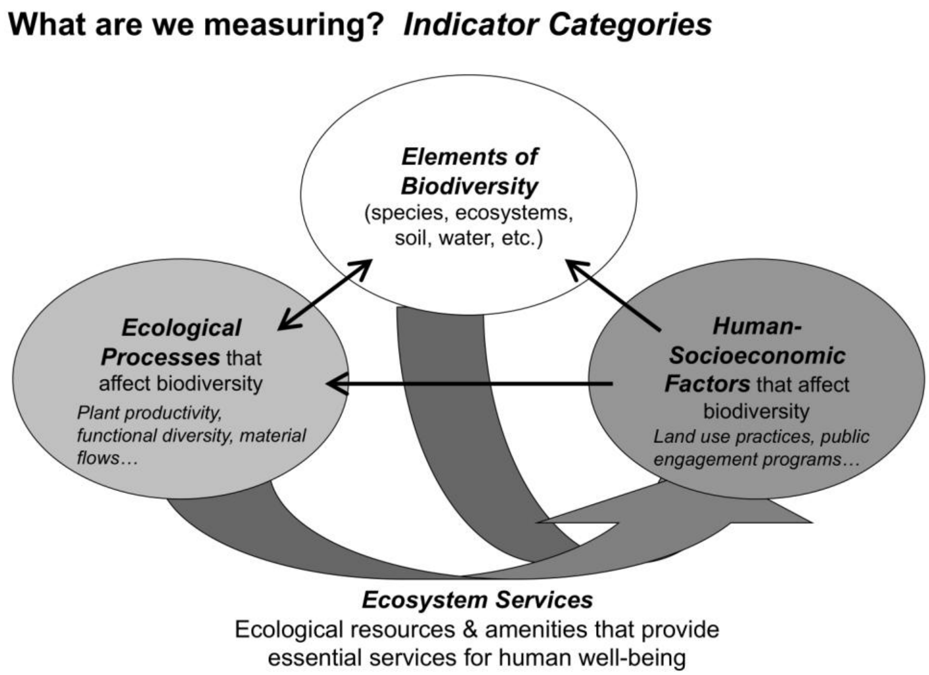


Figure 1. Conceptual Framework for biodiversity indicators.

Elements of Biodiversity – These include indicators describing the structural and compositional components of biodiversity. Such elements include distinct populations, species, and ecological communities, as well as ecosystem stocks (e.g., soils, nutrients, water), landscape patterns and other features that comprise the structural ecological components upon which species depend.

Key Ecological Processes that Affect and Support Biodiversity – These indicators describe processes that either promote or hinder biological diversity. One can think of the "Elements" indicators as nouns and the "Processes" as verbs. "Elements" describe the structural and compositional components of biodiversity; the "Ecological Processes" describe important ecological functions and interactions. Thus, for example, process indicators describe the functional roles that species play within ecosystems, rather than simply the diversity of species. Basic ecosystem processes, such as material flow rates, are also considered in the latter category.

Key Human-Socioeconomic Factors that Affect and Support Biodiversity – These indicators measure human engagement in promoting or hindering biodiversity, either directly or indirectly. Most such efforts consist of actions to conserve or create landscape conditions suitable for potential habitat – for example, lands set aside as national or state parks, as conservation easements, etc. However, the likely persistence of biodiversity is also reflected through indicators of public engagement in natural resource conservation, such as the number of environmental education and citizen science programs. Such engagement can directly relate to public perceptions of biodiversity's importance and potential level of commitment to conservation. This category also includes potential risk factors, such as land use/cover change and pollutant levels.

Ecosystem Services – Beyond the intrinsic ecological value of biodiversity are the services and amenities that humans derive from it (MEA 2005; Butler and Oluoch-Kosura 2006; Morrison et al. 2006; Tallis et al. 2008). Such services include provision of resources, ecological functions that support human needs, regulation of biotic and abiotic conditions that affect humans, and ecologically-based cultural amenities (MEA 2005; see also Morrison et al. 2006 for a parallel but alternate set of categories). To assess such services, this category is comprised of indicators describing amenities both directly (e.g., through recreational fish and game as well as food and fiber provision) and indirectly (e.g., through parks and greenspace, water filtration via natural vegetative cover, etc.) derived from biodiversity and those factors that support its persistence. Human stewardship and the resultant sustainability of biodiversity are considerably bolstered by conveying to policymakers and the citizenry how human well-being is fostered by and even dependent on the ecosystem services that are provided either directly or indirectly through biodiversity conservation (MEA 2005; Butler and Oluoch-Kosura 2006; Marcot 2007; Ruffo and Kareiva 2008; Tallis et al. 2009).

In this framework, ecosystem services and human-environment interactions are explicitly integrated into the broader context, and are addressed along with indicators of ecological structure and function (e.g., Alberti et al. 2003, 2007; Alberti and Marzluff 2004; Liu et al. 2007). This integration and interdependence is represented in Figure 1 by bi-directional connections between categories. This approach emphasizes the interdependence of humans on natural systems (through ecosystem services) and vice versa (through socioeconomic factors of human engagement) to directly address why we should care. The framework also highlights the importance of looking at the effects of actions and interactions. It allows us to not only assess the potential for mitigating negative impacts via regulations, but also to emphasize the potential for positive impacts via incentive programs. Such an emphasis on causal linkages is useful for decision-making and planning purposes.

To prioritize indicators and identify redundancies among indicators, we placed the 136 candidate indicators into the above four categories as appropriate. We then examined how indicators became linked to one another within the conceptual model of Figure 1 to describe important sets of functional relationships such as the following (see diagrams in Appendix C for more details): species/taxonomic diversity, iconic wildlife, process keystone species (pollinators), trophic keystone species (predators), soil/benthic productivity, plant communities and systems, disturbance regimes, water quantity, and water quality. These functional groups represent important causal linkages among indicators and provided a comprehensive basis for our selection and omission of prospective indicators (Neimeijer and deGroot 2008). We used the groupings to identify and then select indicators that fit the following criteria: 1) those that that occurred in three or more groupings and were thus broadly relevant to a number of different processes and elements of biodiversity; 2) those that were considered particularly important for biodiversity assessment, such as the status of keystone species; and 3) those that are already being extensively measured, such as water quality. Through this process we narrowed the set to 55 candidate indicators. We further reduced this set to a first-generation framework of 30 indicators via internal Council Science Committee reviews and tests of the indicators' applicability.

IIE. Scales of Measurement and Focal Ecosystem Types

Any assessment effort such as the biodiversity assessment framework must include an explicit consideration of spatial and temporal scales. The framework will provide measures of biodiversity status at two primary levels of spatial resolution. As a statewide assessment tool, the metrics in the framework will be scaled up to provide high-level indicators for the state of Washington. However, to capture the ecological and social characteristics unique to the diverse regions of the state, finer-scale assessments must underlie these state-level measures. At a minimum, the framework provides measures for indicators at the level of major ecosystem types of Washington (Figure 2): mesic forest, dry forest, shrubsteppe, cultivated, urban, alpine, marine, and freshwater (FGDC 2008). These ecosystem types, classified through remote sensing, are comprised of distinct coarse-level landscape characteristics that determine the species assemblages present and the dominant ecological and socioeconomic drivers that impact biodiversity across the state. Alternative measures, at the ecoregion level, are also feasible, with the nine ecoregions for Washington as delineated by the US Environmental Protection (U.S. EPA 2000) and modified by the Nature Conservancy and the Washington Natural Heritage Program. When possible and relevant, we also measure indicators at finer resolutions – at the watershed (Washington Department of Ecology Watershed Resource Inventory Areas: WRIA's) or county level – to provide an assessment of spatial variability within a given metric.

The time frames for measurement and reporting depend on a number of factors. Part of the objective of the framework is to use existing data sets to the fullest extent possible in populating the indicator measures. Thus, the temporal scale of the measures depends on the frequency of assessment of the respective data sources. Most of these data sets are updated at intervals appropriate for the specific measure of interest, in order to distinguish real trends from noise. Thus, for example, stream flow measures are typically reported on a daily basis to capture weather-related variability, species presence and abundance trends are measured annually, and land cover measures are typically updated at 2-5 year intervals. All such measures can then be effectively used to assess annual trends, which is the measurement interval of interest for the assessment framework. However, with regard to the reporting interval for the framework, the goal will be to provide biannual updates to the indicator measures in order to evaluate trends in biodiversity.

III. Outcomes – the Biodiversity Assessment Framework

IIIA. Indicators and Associated Metrics for Inclusion in the WA Biodiversity Assessment Framework

We suggest that the set of 30 indicators (Figure 3, and Table 1, column 1) comprises a parsimonious, minimally-redundant set of indicators for describing biodiversity, the ecological and socioeconomic factors that impact it, and the ecosystem services that it provides. The selection process also focused particularly on the measurability of indicators (Table 1, column 2). That is, each indicator must have one or more metrics that can be used to derive status and trends can be measured and interpreted. We also considered availability of data to populate indicators as part of our selection process. Sources included data produced by federal, state and local agencies, NGO's, private stakeholders, and academic institutions. Lack of available data would not necessarily preclude the usefulness of an indicator; however, data availability does influence an indicator's potential utility in the short-term. Hence, metrics, and in some cases the actual indicators used, were modified or prioritized based on what is currently quantifiable.

As noted above, indicators and metrics will be reported at the level of each of the major ecosystems in Washington (Figure 2). For some indicators, especially those that are species-based (e.g., iconic species, species trends as indicators of disturbance) or pertain to system-specific services, the metrics would change as appropriate for each ecosystem type. Additionally, other scales of reporting, such as at the state level, may be more appropriate for some metrics, particularly those related to human efforts and activities that are restricted to specific ecological or political boundaries. However, such differences among the metrics used for each system are minimal, and the indicators being used would not themselves vary significantly as a function of the major ecosystem types being assessed. The likely exception would be indicators to describe aquatic systems, for which some of those listed in Figure 3 would likely be irrelevant or would require alternate measures.

To begin to address our objectives for engaging citizen science in the framework, we also identified metrics that could serve as useful candidates for such efforts (Table 1, column 5). Some efforts are already included – data from the North American Breeding Bird Survey (BBS) are a prominent example – and in some instances offer the most promising opportunities for obtaining data in perpetuity for metrics (e.g., species presence/absence, and hence richness, phenological observations, etc.).

IIIB. Linkages with Related Efforts in Washington State

As noted in Table 1, we selected of a number of indicators that are also being used in international (UNEP 2003; MEA 2005; EEA 2007), national (NRC 2000; Heinz Center 2008), state-level (CNHP/TNC 2008; GSRO 2008), and regional (King County 2008; Sustainable Seattle 2008) environmental assessments. However, we also examined other state- and regional-level efforts underway in Washington for potential complementarity and synergy. We focused on two significant efforts in particular, those of Puget Sound Partnership (PSP) and the Governor's Forum on Monitoring Salmon Recovery and Watershed Health (a.k.a., the Monitoring Forum). Through discussions with representatives from each group and examination of their respective draft approaches, we identified indicators shared in common, in part or in whole, between their proposed efforts and those that comprise the biodiversity assessment framework. Table 2 illustrates those parallels, with 15 indicators in common with PSP's draft indicators and 6 in common with those of the Monitoring Forum. Identification of such synergies will allow for coordination between ongoing and future efforts of the Council, PSP and the Monitoring Forum. Additionally, the opportunity exists for significant collaboration between further development of the Council's framework, which includes significant assessment of terrestrial assessments, and that of PSP, which will provide valuable, detailed information on aquatic systems (see "Future Steps" below for further discussion of this).

We also anticipate coordination with efforts of an additional group, the Washington Invasive Species Council (WISC), as our respective efforts progress further. A key component of WISC's strategic plan consists of compiling data on and assessing the status of key invasives across the state (WISC 2009). Including measures of invasive species will be an important component of the framework, as reflected, for example, in Table 1d.

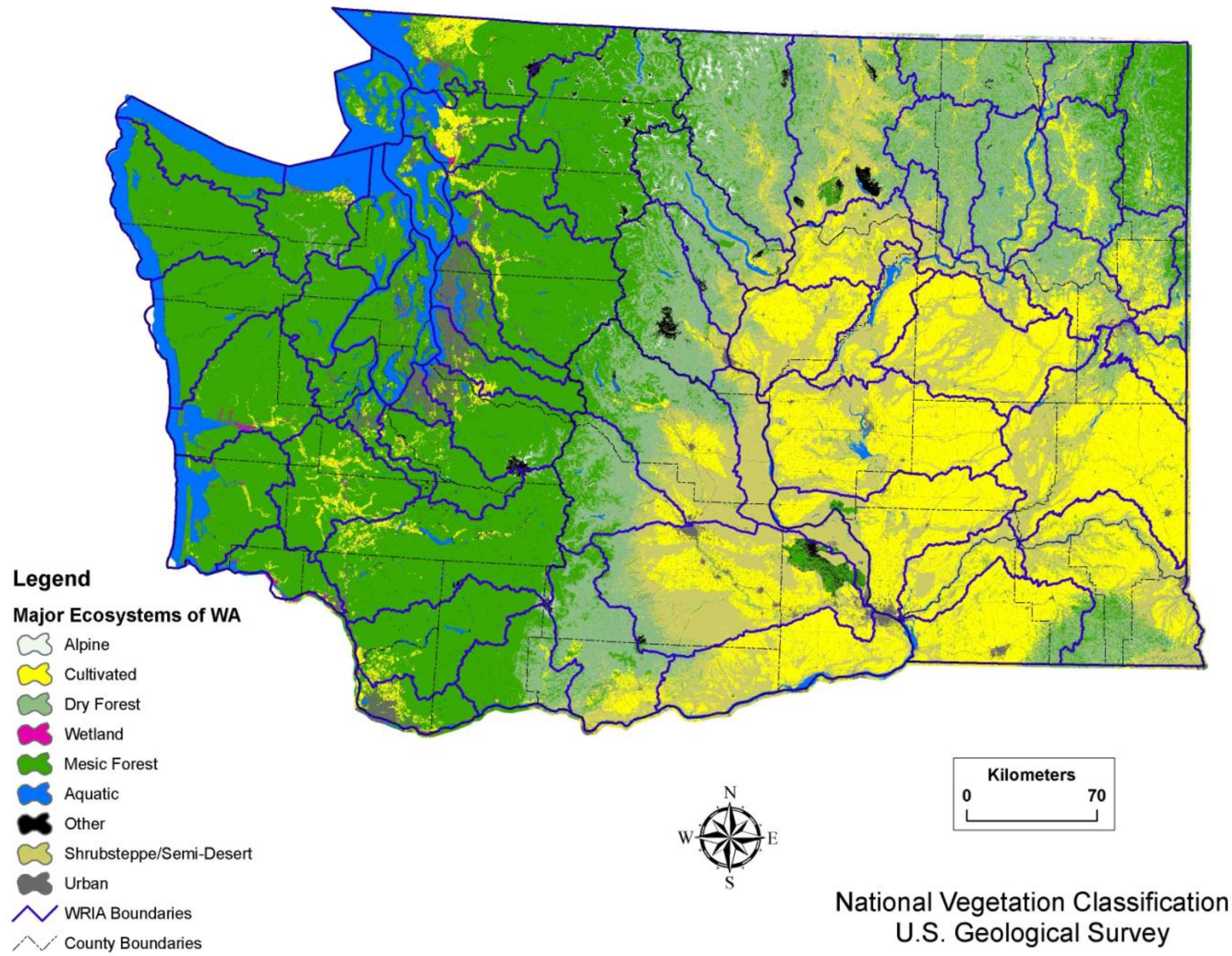


Figure 2. Major ecosystem types of Washington State, derived from the USGS National Vegetation Classification system (FGDC 2008). Indicators were identified and will be measured as relevant for each system type. Note that marine and freshwater systems, which would be considered separately, are represented in this map as a single "aquatic" class. Boundaries for finer-scales of measurement – WA Department of Ecology Watershed Resource Inventory Areas (WRIA's) and counties – are also displayed.

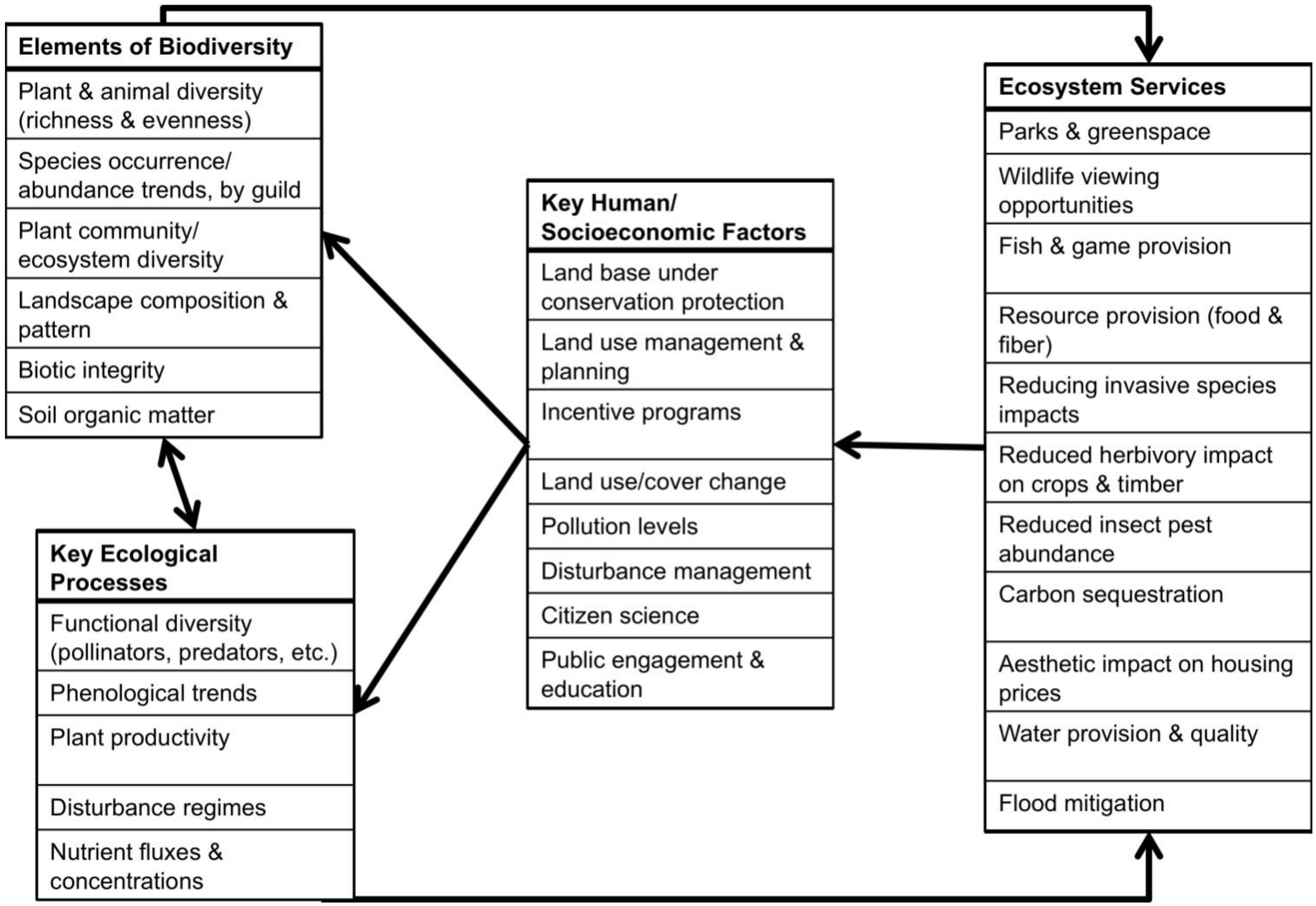


Figure 3. Selected indicators (30 in total) by indicator category. The diagram, which is schematically similar to the conceptual model in Figure 1, summarizes the first-generation indicators associated with each category. Further details for each indicator, along with associated metrics and references, are listed in Table 1.

Table 1. List of Indicators and Associated Metrics, by Indicator Category in Figure 1

1a: Elements of Biodiversity

Indicator	Metric(s)	Relevance	Reference(s)	Citizen Science Candidate
Plant & animal diversity	Measures by taxa (birds, mammals, plants, herptiles, fish, invertebrates), as available: • Relative richness • Relative balance/evenness (note: requires abundance data)	Richness (# of native species) & evenness (relative level to which each species is represented – a measure of species balance) – are most basic measures of biodiversity.	NRC 2000; MEA 2005; Hess et al. 2006; Pearman & Weber 2007; Roth & Weber 2008	Yes
Species occurrence/ abundance trends	• Iconic species • State-designated at-risk species, by taxa	• Iconic species have particular cultural significance, & hence important for public engagement; some such species (e.g., salmon) can be useful indicators for representing connections between systems (e.g., between uplands & marine). • Declining population trends of at-risk species could provide an early warning that there will be a change in species richness in the near future.	Hager 1998; Hutto 1998; UNEP 2003; Dent et al. 2005; MEA 2005; EEA 2007; Pearman & Weber 2007; WBC 2007; CNHP/TNC 2008; GSRO 2008; Heinz Center 2008; King County 2008; Roth & Weber 2008; Sustainable Seattle 2008	Yes
Plant community/ ecosystem diversity	• Distribution of native vegetation • Distribution and quality of WA NHP-identified critical and/or rare systems	• Aside from their contribution to overall biodiversity, plants are intrinsically important for food & habitat. • Measures relative to historical trends indicate significant changes in the distribution of plant species and communities.	NRC 2000; Turner et al. 2001; Moffatt & McLachlan 2004; Dent et al. 2005; Marzluff 2005; Alberti et al. 2007; Heinz Center 2008; Hepinstall et al. 2008	Yes
Landscape composition & pattern	• Percent cover • Largest patch index • Landscape diversity (Shannon landscape evenness index) • Contagion index (a measure of aggregation/	• Composition and spatial patterns of land cover (primarily vegetation) are broad-scale, relatively measured indicators of both habitat & ecosystem integrity. • Patch sizes & landscape diversity provide measures of relative dominance of specific land cover types.	NRC 2000; Lausch and Herzog 2002; McGarigal et al. 2002; UNEP 2003; Weller et al. 2003; Dent et al. 2005; Baker et al. 2006; EEA 2007; WBC 2007; CNHP/TNC 2008; Heinz Center 2008; King County 2008;	No

Indicator	Metric(s)	Relevance	Reference(s)	Citizen Science Candidate
	connectivity) • Riparian vegetation	• Contagion gives a rough measure of connectivity (or conversely, fragmentation). • Riparian vegetation, a specific metric of pattern, relates to both habitat provision & water quality.	Sustainable Seattle 2008	
Biotic integrity	• Index of Biotic Integrity (IBI)	IBI's serve as a measure not only of biological diversity, but of the status/intactness of ecosystems; benthic IBI's in particular are useful in measuring water quality.	Karr 1991, 1999; NRC 2000; Andreasen et al. 2001; UNEP 2003; Dent et al. 2005; EEA 2007; GSRO 2008; Heinz Center 2008; King County 2008; Sustainable Seattle 2008	Yes
Soil organic matter	• Soil organic matter (SOM)	Indicators of soil conditions, a basis for nutrient & water cycles, reflect ecosystem integrity, & also provide a rapid indicator of systemic changes.	NRC 2000; Heinz Center 2008	Yes

1b: Ecological Processes

Indicator	Metric(s)	Relevance	Reference(s)	Citizen Science Candidate
Functional diversity	• Pollinators/seed dispersers • Predators	• Pollinators & predators serve keystone roles in ecological processes (former) & trophic relationships (latter). • An assessment of the roles species play in ecosystem functions, & persistence of these functions, provides an indicator of both ecological integrity & resilience; low functional diversity ≈ impaired ecosystem functions.	Kearns et al. 1998; Marcot & Vander Heyden 2001; Ripple et al. 2001; Ripple & Beschta 2003, 2004; Hebblewhite et al. 2005; Hooper et al. 2005; Morandin & Winston 2006; Marcot 2007; Pearman & Weber 2007; WBC 2007; Hoehn et al. 2008; Kremen et al. 2007; Roth & Weber 2008; Steffan-Dewenter & Westphal 2008; Tallis et al. 2008; Whelan et al. 2008	Yes
Phenological trends	• Leaf-on/-off dates • Flowering dates • Timing of migrations	Seasonal trends & changes therein are indicative of systemic change, & can affect population persistence (e.g., changes in competition, food availability, etc.); offers in particular an important indicator of climate change impacts.	Stenseth & Mysterud 2002; Lawler & Mathias 2007	Yes
Plant productivity	• Net primary productivity (NPP)	Measures of plant productivity provide a broad-scale assessment of health & persistence of plant communities.	NRC 2000; Heinz Center 2008	No
Disturbance regimes	• Occurrence/abundance of disturbance-sensitive vs. –tolerant vs. –dependent bird species • Spatial extent of fire, insect outbreaks, floods & windthrows • Occurrence rates of floods • Occurrence rates of droughts	• Species & communities are adapted to (& in some cases dependent on) intrinsic disturbance processes; trends in bird species guilds are thus indicative of disturbance levels. • Significant changes in disturbance regimes can adversely affect species, ecosystems & human well-being. • Significant fluctuations in water volumes affect ecosystem functions, & the species & humans that depend on them: high levels → flooding, erosion; low levels → drought & water stress.	Hutto 1998; Turner et al. 2001; Folke et al. 2004; Moffatt & McLachlan 2004; MEA 2005; Marzluff 2005; WBC 2007; GSRO 2008; Heinz Center 2008; King County 2008; Sustainable Seattle 2008	No
Nutrient fluxes & concentrations	• WA Dept. of Ecology Water Quality Index (WQI)[1]	Abnormally high nutrient levels can result from (& hence be indicative of) significant increases in material	NRC 2000; UNEP 2003; Weller et al. 2003; MEA 2005; Groffman et al. 2006; EEA 2007; GSRO 2008; Heinz	Yes

Indicator	Metric(s)	Relevance	Reference(s)	Citizen Science Candidate
		deposition &/or vegetation losses; low water quality can result in impairment of downstream aquatic ecosystems (e.g., through eutrophication).	Center 2008; King County 2008; Sustainable Seattle 2008	

1) WQI is a composite annual index, ranging from 1-100, of temperature, pH, fecal coliform bacteria, dissolved oxygen, total suspended sediment, turbidity, total phosphorus, and total nitrogen; see http://www.ecy.wa.gov/programs/eap/fw_riv/docs/WQIOverview.html for further details.

1c: Key Human-Socioeconomic Factors

Indicator	Metric(s)	Relevance	Reference(s)	Citizen Science Candidate
Land base under conservation protection	• Distribution & extent of public & private lands amenable to biodiversity[1], & NGO/trust lands for biodiversity	Measures of public & private land holdings that are either implicitly or explicitly maintained for biodiversity reflect potentially available habitat for species, as well as preservation of key ecosystem functions; as such, they indicate human contributions to biodiversity conservation & ecosystem integrity.	La Tourrette & Luscombe 2002; EEA 2007; WBC 2007; GSRO 2008; Heinz Center 2008; Leu et al. 2008; Sustainable Seattle 2008	No?
Land use management	• Land cover composition of private land under growth management • Land cover composition of private land under critical area ordinances	Land use planning that limits urban/suburban development and protects critical areas (steep slopes, wetlands, etc.) can also preserve ecosystem integrity & provide intact habitat.	WBC 2007	No
Incentive programs	• Distribution/extent of private lands under forest stewardship certification	Locations where incentive programs are in place or restoration efforts underway can reflect human commitment to biodiversity; such information also might also prove informative to promoting further conservation opportunities.	La Tourrette & Luscombe 2002; UNEP 2003; EEA 2007; WBC 2007; GSRO 2008; Heinz Center 2008	No?
Land use/cover change	• Distribution/extent of land cover transitions	Broad-scale indicator of potential losses vs. gains in habitat, landscape integrity.	Turner et al. 2001; Lausch & Herzog 2002; Dent et al. 2005; Marzluff 2005; Alberti et al. 2007; EEA 2007; CNHP/TNC 2008; Heinz Center 2008; Hepinstall et al. 2008	No
Pollution level	• Levels of exposure to PCB's, PBDE, Dioxins, Pesticides	Measures of significant contaminants in the Northwest (R. Miniero, pers. comm.) indicate factors that can impact the health/integrity of species, ecosystems & humans alike.	Anderson et al. 2004; Daly & Wania 2005; Heinz Center 2008	No
Disturbance management	• Extent of fire suppression vs. controlled burn practices • Extent of natural pest management practices • Extent of flood mitigation	Can serve as potential indicator of human commitment to preserving ecosystem integrity through management practices that "mimic" natural regimes, vs. practices that may exacerbate disturbances.	WBC 2007	No?

Indicator	Metric(s)	Relevance	Reference(s)	Citizen Science Candidate
	• Extent of windthrow abatement (snag removal, stand maintenance)			
Citizen science[2]	• Distribution/extent & content focus of efforts within a given ecosystem type	Indicators on current citizen science programs can reflect both the specific interests and knowledge base of the general populace with respect to particular species types (e.g., birds) or ecosystem types (e.g., shorelines, wetlands); can also reflect potential opportunities for directly involving the broader public in measuring biodiversity indicators, particularly those for which there are data limitations or gaps.	Orr 1992; WBC 2007	Yes
Public engagement & education[2]	• Distribution/extent & content focus of efforts within a given ecosystem type	• Indicators of public engagement & environmental education can reflect both the specific interests and knowledge base of the general populace with respect to particular species types (e.g., birds) or ecosystem types (e.g., shorelines, wetlands). • Indicators illustrating current efforts at engagement can illustrate potential opportunities for further education (e.g., what is already working, what taxa, ecosystems, etc. are less well-represented).	Orr 1992; Audubon Washington 2004; WBC 2007	Yes

1) Lands comprised largely of remnant natural (e.g., forest) cover and constituting uses that either directly or indirectly provide favorable habitat for species was considered "amenable to biodiversity." In the case of public lands, the following designations were included: Experimental Forest, Fish Hatchery, Municipal Watershed, Nature Preserve, Non Designated Forest, Park, Park/Non-Wilderness, Recreation, Reserve, Seashore Conservation Area, Wilderness, Wildlife Area, Wildlife Refuge. For private holdings, land under timber management was of primary interest as being amenable to supporting biodiversity.
2) These indicators might be better/more appropriately measured at the state level, rather than by major ecosystem type.

1d: Ecosystem Services

Indicator	Metric(s)	Relevance	Reference(s)	Citizen Science Candidate
Parks & greenspace	• Usage rates for hiking, camping and other "wilderness" activities	Indicator reflects relationship between recreation benefits to humans on lands that also provide potential habitat.	Dent et al. 2005; MEA 2005; WBC 2007; Heinz Center 2008; King County 2008; Sustainable Seattle 2008	Yes
Wildlife viewing	• Participation rates	Reflects opportunities for public engagement & interest in biodiversity; simultaneously provides an estimate of where wildlife can be found.	Orr 1992; Audubon Washington 2004; WBC 2007	Yes
Fish & game provision	• Yields of fish & game species	Indicates direct "service" of biodiversity.	Dent et al. 2005; MEA 2005; WBC 2007; Heinz Center 2008; King County 2008; Sustainable Seattle 2008	Yes
Resource provision	Measures of yields as relevant to ecosystem type: • Timber yields • Crop yields • Commercial fisheries yields	Indicates direct "service" of biodiversity & ecosystem integrity.	UNEP 2003; MEA 2005; EEA 2007; WBC 2007; Heinz Center 2008; King County 2008; Sustainable Seattle 2008	Yes?
Reducing invasive species impacts	• Species/communities impacted • Costs of mitigation	Indicates the specific impacts of invasive species on ecosystem integrity & resilience, & the costs associated with these impacts; as such, measurements of the indicator over time describe the "service" provided by reductions in those impacts.	UNEP 2003; Dent et al. 2005; MEA 2005; EEA 2007; Heinz Center 2008	Yes
Reducing herbivory impacts	• Extent of damage by browsers & grazers	When linked with other indicators (e.g., predator trends, functional diversity), can illustrate how biodiversity contributes to system resilience (& how loss of diversity can reduce it).	Daily 1997; NRC 2000; Ripple et al. 2001; Ripple & Beschta 2003, 2004; Hebblewhite et al. 2005; Meyerson et al. 2005; Heinz Center 2008	Yes?
Reducing pest abundance	• Insect defoliation damage	When linked with other indicators (e.g., predator trends, functional diversity), can illustrate how biodiversity contributes to system resilience (& how loss of diversity can reduce it).	Daily 1997; NRC 2000; Meyerson et al. 2005; Heinz Center 2008	Yes?

Indicator	Metric(s)	Relevance	Reference(s)	Citizen Science Candidate
Carbon sequestration	• Measures of carbon uptake capacity	Estimation of vegetation-specific measures can indicate landscape-level contributions to climate change mitigation, & provide guidance for management decisions.	NRC 2000; Groffman et al. 2006; Lawler & Mathias 2007; Heinz Center 2008; Tallis et al. 2008	No
Aesthetic impacts on housing prices	• Hedonic valuation of land as function of natural land characteristics (e.g., remnant forest)	Reflects economic benefits of landscape aesthetics that also serve to promote biodiversity & ecosystem integrity.	Kaplan & Kaplan 1989; Bolitzer & Netusil 2000; Crompton 2001; Palmer 2004; MEA 2005; Wagner & Gobster 2007; WBC 2007; Kearney et al. 2008	Yes?
Water provision & quality	• Areal extent of municipal watershed lands (i.e., water from areas in natural land cover) • Amount of water derived from municipal watersheds	Can be used in conjunction with landscape measures to illustrate water quality benefits derived from maintaining ecosystem integrity.	UNEP 2003; Dent et al. 2005; MEA 2005; EEA 2007; GSRO 2008; Heinz Center 2008; King County 2008; Sustainable Seattle 2008	No
Flood mitigation	• Landscape pattern within FEMA moderate to high flood-risk zones	Indicator can illustrate flood & erosion mitigation benefits derived from maintaining landscape integrity.	Weller et al. 2003; Pypker et al. 2005; Brauman et al. 2007; WBC 2007; Cuo et al. 2008	No

Table 2. Complementarity with Puget Sound Partnership (P) and Monitoring Forum (M) Draft Indicators

Elements of Biodiversity	Key Ecological Processes	Key Human-Socioeconomic Factors	Ecosystem Services
Plant & animal diversity – (P)	Functional diversity – (P)	Land use/cover change – (P)	Parks & greenspace – (P)
Species occurrence/ abundance trends – (P)	Disturbance regimes (specifically river flow) – (P, M)	Pollution levels – (P)	Wildlife viewing opportunities – (P)
Landscape composition & pattern – (P, M)	Nutrient fluxes & concentrations – (P, M)		Fish provision – (M)
Biotic integrity – (P, M)			Resource provision – (P)
			Aesthetic impact on housing prices – (P)
			Water provision & quality – (P, M)
			Flood mitigation – (P)

<u>IIIC. Testing the Framework: Calculating Metrics for Mesic Forest and Shrubsteppe</u>

As a proof-of-concept for evaluating the effectiveness of indicators, we fully calculated metrics (where currently feasible) for mesic forests of western Washington and partially for the shrubsteppe of eastern Washington. We qualitatively assessed this "effectiveness," via consultation with the Council's Science Committee and expert peer-review, based on whether indicators and their associated metrics are sensitive to changing trends over time. Future work will require more robust quantitative sensitivity analyses as more measures for the state are computed (see "Future Steps" section below). Table 3 lists the "equations" used to calculate metrics for mesic forest. Metrics for each indicator were first calculated at the watershed or, where more appropriate based on the metric or data, county level, then averaged across all watersheds/counties within the mesic forest ecosystem. To provide normative measures that can more easily be aggregated, metrics were calculated as relative measures (e.g., number of species in watershed *x* relative to the total number of species potentially occurring in mesic forests, mean water quality index relative to 15-year maximum, etc.), ranging from 0-1, as described in column 3 of Table 3. Such normative measures have specific implications for the indicators that they define (Table 3, column 4). In a number of instances, values of 0 or 1 would be unlikely, if not impossible, outcomes (e.g., a relative richness of 0 would indicate that no species of a given taxa occur within the ecosystem of interest). Nonetheless, the relative measures provide a means of evaluating the relative condition of elements and processes, particularly as the indicators are measured over time. Future refinements of the framework will need to take into account metrics that potentially exhibit nonlinearities and non-normal distributions in their values.

One point to note is that the metrics incorporate different baselines in their relative calculation based on the context appropriate for that measure. Specifically, the metrics can be seen as falling within two particular classes (Figure 4): those measured relative to what is possible versus those measured relative to recent observed trends. For example, indicators of species richness, land cover types, lands under conservation protection, and so forth are measured as proportions of the total or maximum amount potentially occurring within a given region. Alternatively, indicators describing trends in plant productivity, water quality, and resource yields are quantified as measures of current conditions relative to recent historical trends over roughly the past 5-20 years depending on the available data. This difference in approaches largely corresponds to those indicators describing structural components of biodiversity, which are measured as amounts or quantities, versus process-based facets of biodiversity, which are generally measured as rates or estimates associated with a given time interval. In both instances, such relative measures provide built-in baselines for interpretation of status and, in the latter case, trends as well. Despite the differences in approaches, both provide an assessment of conditions as they currently stand, and against which future assessments can be evaluated. Additional comparative measures to be introduced from future efforts will include baselines derived from 1) comparisons with historical estimates (e.g., conditions at statehood) and 2) comparisons between the current and future iterations of the framework.

Table 3. Calculation of Relative Metrics and their Interpretation, by Indicator Category in Figure 1

3a: Elements of Biodiversity

Indicator	Metric(s)	Metric "Equation"[1]	Interpretation: 0 vs. 1
Plant & animal diversity	Measures by taxa (birds, mammals, plants, herptiles, fish, invertebrates), as available: • Relative richness • Relative balance/evenness (note: requires abundance data)	• (mean # of species observed per watershed) / (total # potentially occurring in system) • (Shannon Evenness) / (maximum Shannon index)	• 0 = no species present; 1 = all species present in all watersheds • 0 = no species present; 1 = all species present in equal abundance
Species occurrence/ abundance trends	• Iconic species • State-designated at-risk species, by taxa[2]	• northern spotted owl: 20-year mean annual growth rate (lambda; stable population = 1.0) • 1 - (# state at-risk species) / (total # potentially occurring in area)	• ~0 = population approaching (local) extinction; 1 = population stable or growing (truncated at 1.0) • 0 = all species present are at-risk; 1 = no at-risk species
Plant community/ ecosystem diversity	• Distribution of native vegetation • Distribution and quality of WA NHP-identified critical and/or rare systems[2]	• % composition of native vegetation types over total area • 1 – (% composition of critical system types over total area)	• 0 = no native vegetation remaining; 1 = all vegetation comprised of native species/communities • 0 = all plant ecosystems in critical status; 1 = no plant ecosystems in critical status
Landscape composition & pattern	• Percent cover • Largest patch index • Landscape diversity (Shannon landscape evenness index) • Contagion index (a measure of aggregation/connectivity) • Riparian vegetation	• % forest cover over total area • mean % of total watershed area covered by largest forest patch • mean Shannon landscape evenness index per watershed • mean contagion index (0-1) per watershed • % of area within 100m buffer of streams comprised of vegetation/tree cover	• 0 = no remnant forest cover within region; 1 = full forest cover within region • 0 = no remnant forest cover within region; 1 = region dominated by single forest patch • 0 = landscape dominated by only one cover type; 1 = all land cover types equally represented within area • 0 = all cover types disaggregated (highly fragmented); 1 = landscape completely aggregated, dominated by single cover type • 0 = no (forest) vegetation within 100m buffer; 1 = all 100m stream buffers maximally vegetated
Biotic integrity	• Index of Biotic Integrity (IBI)	• (mean IBI per watershed) / (maximum IBI observed in area)	• 0 = all watersheds maximally impaired (no biota left); 1 = mean IBI equal across all watersheds
Soil organic matter	• Soil organic matter (SOM)	• mean % SOM content	• 0 = no organic matter in soils; 1 = soil completely comprised of organic matter

1) Calculations specific to mesic forest system; will vary slightly (e.g., with respect to relevant species of interest) for other ecological systems.
2) Metrics indicate <u>declining</u> conditions, & hence are normalized with other metrics by subtracting from 1.

3b: Ecological Processes

Indicator	Metric(s)	Metric "Equation"	Interpretation: 0 vs. 1
Functional diversity	• Pollinators/seed dispersers • Predators	• rufous hummingbird & Clark's nutcracker: (abundance in 2008) / (maximum abundance over 20-year period) • cougar: (abundance in 2008) / (maximum abundance over 6 year period); bear: (abundance in 2008) / (maximum abundance over 10 year period)	• 0 = no hummingbirds/nutcrackers observed (impaired pollination/seed disperser function); 1 = abundance equal to maximum observed (relatively intact pollination/seed disperser function) • 0 = no top-level predators present; 1 = abundance equal to maximum observed
Phenological trends	• Leaf-on/-off dates[1] • Flowering dates[1] • Timing of migrations[1]	• 1 – (absolute difference in current day-of-year from previous *x* years' mean day-of-year / previous *x* years' mean day-of-year); # of years dependent on data available	• 0 = change in timing of event (either + or -) is equal to the mean day-of-year for the event (e.g., if leaf-on date changes by ±50 days relative to a mean of day 50); 1 = timing of event is equal to that observed over the previous *x* years
Plant productivity	• Net primary productivity (NPP)	• (mean forest NPP per watershed in 2008) / (9-year maximum forest NPP)	• 0 = no productive vegetation in region; 1 = NPP equal to maximum observed
Disturbance regimes	• Occurrence/abundance of disturbance-sensitive vs. –tolerant vs. –dependent bird species • Spatial extent of fire, insect outbreaks, floods & windthrows • Occurrence rates of floods[1] • Occurrence rates of droughts[1]	• Occurrence/abundance (abundance in 2008) / (maximum abundance over 20 year period) for development sensitive vs. tolerant (winter wren vs. Bewick wren: winter/(winter+Bewick)), cavity-dependent (hairy & pileated woodpeckers, brown creeper) & fire specialist species (black-backed woodpecker) • (mean area disturbed in 2008) / (maximum area disturbed over 10-20 years depending on data available) • 1 - ((peak river flow rates & volumes in 2007 - 15-year mean peak) / 15-year mean peak) if peak in 2007 > mean, 1 otherwise • 1 – ((15-year mean minimum flow rates & volume - minimum in 2007) / 15-year mean minimum) if minimum in 2007 < 15-year mean, 1 otherwise	• winter vs. Bewick: 0 = no winter wrens present (high land use development), 1 = only winter wrens, no Bewick present (low land use development); hairy & pileated: 0 = no woodpeckers present (lack of snags), 1 = woodpecker abundance equal to maximum observed (sufficient snags); black-backed: 0 = no fire damaged trees, 1 = abundance equal to maximum observed (sufficient fire damage for persistence) • 0 = no area disturbed within region; 1 = area disturbed equal to maximum observed • 0 = peak water flow & volume in current year is 100% greater than previous years' mean peak (indicating significant flooding) • 0 = minimum water flow & volume in current year is 100% less than previous years' mean minimum (indicating significant drought)
Nutrient fluxes & concentrations	• WA Dept. of Ecology Water Quality Index (WQI)[2]	• (mean WQI per watershed in 2007) / (15-year maximum)	• ~0 = all watersheds completely impaired; 1 = water quality measure equal to maximum observed

1) Metric indicates <u>declining</u> conditions, & hence is normalized with other metrics by subtracting from 1.

2) WQI is a composite annual index, ranging from 1-100, of temperature, pH, fecal coliform bacteria, dissolved oxygen, total suspended sediment, turbidity, total phosphorus, and total nitrogen; see http://www.ecy.wa.gov/programs/eap/fw_riv/docs/WQIOverview.html for further details. Note that a relative value of 0 does not occur with this metric.

3c: Key Human-Socioeconomic Factors

Indicator	Metric(s)	Metric "Equation"	Interpretation: 0 vs. 1
Land base under conservation protection	• Distribution & extent of public & private lands amenable to biodiversity[1], & NGO/trust lands for biodiversity	• % of total area within mesic forest comprised of public & private lands amenable to biodiversity, & comprised of NGO/trust lands for biodiversity	• 0 = no landholdings amenable to biodiversity are present; 1 = all land in public &/or private holdings amenable to biodiversity, &/or in NGO/land trust ownership
Land use management	• Land cover composition of private land under growth management • Land cover composition of private land under critical area ordinances	• % of total private mesic forest area outside of urban growth boundaries comprised of forest (vs. developed vs. cultivated land cover) • % of private area under critical area ordinances comprised of forest	• 0 = no forested area outside urban growth boundary (maximal development incursion); 1 = all area outside urban growth boundary comprised of forest • 0 = no forest cover in lands under critical area ordinances; 1 = all land within critical areas comprised of forest
Incentive programs	• Distribution/extent of private lands under forest stewardship certification	• % of total private mesic forest area under forest stewardship certification	• 0 = no forest stewardship certification lands present; 1 = all forest area under stewardship certification
Land use/cover change	• Distribution/extent of land cover transitions[2]	• 1 – (net % change in forest cover (losses minus gains) within mesic forest ecological system)	• 0 = all forest within region converted to other cover types; 1 = total area within region consists of forest
Pollution level	• Geographic distribution/extent of exposure[2]	• 1 - (mean concentration of pollutants in 2007 / prior 7 years' maximum)	• 0 = current exposure level equal to maximum observed; 1 = no pollutants present
Disturbance management	• Extent of fire suppression vs. controlled burn practices • Extent of natural pest management practices • Extent of flood mitigation • Extent of windthrow abatement (snag removal, stand maintenance)	• % of total mesic forest area under fire management • % of total mesic forest area under natural pest management • % of total mesic forest area under flood management • % of total mesic forest area under windthrow management	• 0 = no area within region under disturbance management; 1 = entire area covered by disturbance management efforts
Citizen science[3]	• Distribution/extent & content focus of efforts within a given ecological system	• (# of citizen science efforts underway in mesic forest) / (total # of citizen science efforts in WA)	• 0 = no citizen science programs within mesic forest ecosystem; 1 = all citizen science programs in state focused on mesic forest
Public engagement & education[3]	• Distribution/extent & content focus of efforts within a given ecological system	• (# of education efforts & community environmental programs focused on mesic forest) / (total # of efforts & programs in WA)	• 0 = no environmental education/community engagement programs within mesic forest ecosystem; 1 = all environmental education/community engagement programs in state focused on mesic forest

1) Lands comprised largely of remnant natural (e.g., forest) cover and constituting uses that either directly or indirectly provide favorable habitat for species was considered “amenable to biodiversity.” In the case of public lands, the following designations were included: Experimental Forest, Fish Hatchery, Municipal Watershed, Nature Preserve, Non Designated Forest, Park, Park/Non-Wilderness, Recreation, Reserve, Seashore Conservation Area, Wilderness, Wildlife Area, Wildlife Refuge. For private holdings, land under timber management was of primary interest as being amenable to supporting biodiversity.
2) Metric indicates declining conditions, & hence is normalized with other metrics by subtracting from 1.
3) These indicators might be better/more appropriately measured at the state level, rather than by major ecosystem type.

3d: Ecosystem Services

Indicator	Metric(s)	Metric "Equation"	Interpretation: 0 vs. 1
Parks & greenspace	• Usage rates for hiking, camping and other "wilderness" activities	• (outdoor recreation participation rates in 2006) / (prior 13-year maximum)	• 0 = no park usage in current period; 1 = park use in current period equal to maximum observed
Wildlife viewing	• Participation rates	• (participation rates in 2006) / (prior 10-year maximum)	• 0 = no wildlife viewing participation in current period; 1 = participation in wildlife viewing equal to maximum observed
Fish & game provision	• Yields of fish & game species	• (mean 2008 game harvest yield per management unit) / (maximum harvest yield in mesic forest)	• 0 = no game harvests (declining game populations); 1 = game harvests in current period equal to maximum observed
Resource provision	Measures of yields as relevant to ecological system: • Timber yields • Crop yields • Commercial fisheries yields	• (timber yields in 2002) / (5-year moving-window average yields over previous 20 years)	• 0 = no timber harvest yields; 1 = timber harvest yields in current period equal to maximum observed
Reducing invasive species impacts	• Species/communities impacted[1] • Costs of mitigation[1]	• 1 - (# of species/communities impacted / prior *x* years' maximum, depending on data availability) • 1 - ($ spent on invasive species mitigation in 2008 / prior *x* years' maximum, depending on data availability)	• 0 = # of species/communities impacted in current period equal to maximum observed; 1 = no species/communities impacted • 0 = $ spent on mitigation in current period equal to maximum observed; 1 = no mitigation expenses incurred
Reducing herbivory impacts	• Extent of damage by browsers & grazers[1]	• 1 - (areal extent of browsing damage in 2008 / prior 5 years' maximum)	• 0 = areal extent of browsing damage in current period equal to maximum observed; 1 = no browsing damage observed
Reducing pest abundance	• Insect defoliation damage[1]	• 1 - (areal extent of insect defoliation in 2007 / prior 5 years' maximum)	• 0 = areal extent of insect damage in current period equal to maximum observed; 1 = no insect damage observed
Carbon sequestration	• Measures of carbon uptake capacity	• (mean total carbon storage per watershed given current land cover) / (maximum sequestration level in mesic forest)	• 0 = no carbon sequestered within region; 1 = carbon storage at maximum for mesic forest throughout region
Aesthetic impacts on housing prices	• Hedonic valuation of land as function of natural land characteristics (e.g., remnant forest)	• (land values as function of proximity to & amount of nearby forestland) / (prior *x* years' maximum forest-land value trends)	• 0 = no impact of forest proximity on land value; 1 = current land value as function of forest proximity equal to maximum observed

Indicator	Metric(s)	Metric "Equation"	Interpretation: 0 vs. 1
Water provision & quality	• Areal extent of municipal watershed lands (i.e., water from areas in natural land cover) • Amount of water derived from municipal watersheds	• (mean area of municipal watersheds per person supplied) / (maximum area of watershed per person supplied) • (mean amount of water supplied by municipal watersheds per person) / (maximum amount of water supplied by municipal watershed per person)	• ~0 = no land within region used for deriving municipal water; 1 = mean per-person areal extent of watersheds equal to maximum occurring in region • ~0 = no water supplies derived from forested municipal watersheds; 1 = mean per-person water volumes derived from forested municipal watersheds equal to maximum occurring in region
Flood mitigation	• Landscape pattern within FEMA moderate to high flood-risk zones	• % forest land cover within flood zones in mesic forest region	• 0 = no forest cover (& hence higher flood risk) within flood zones; 1 = flood zones completely comprised of forest cover

1) Metric indicates declining conditions, & hence is normalized with other metrics by subtracting from 1.

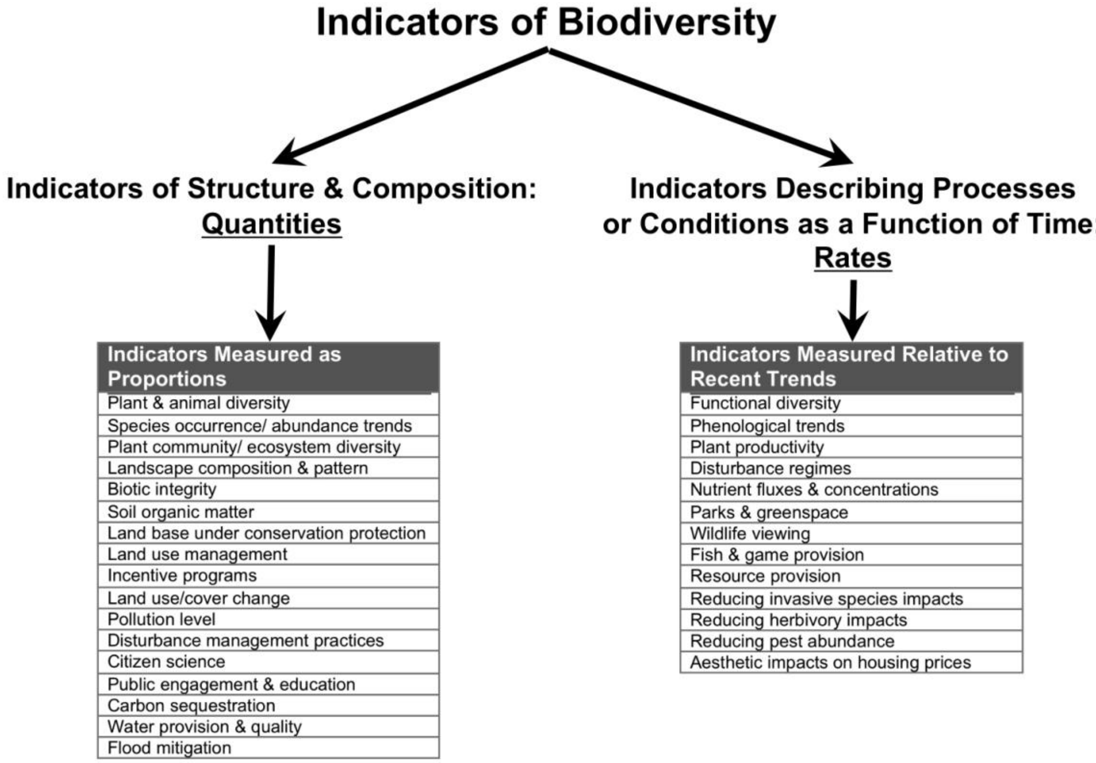


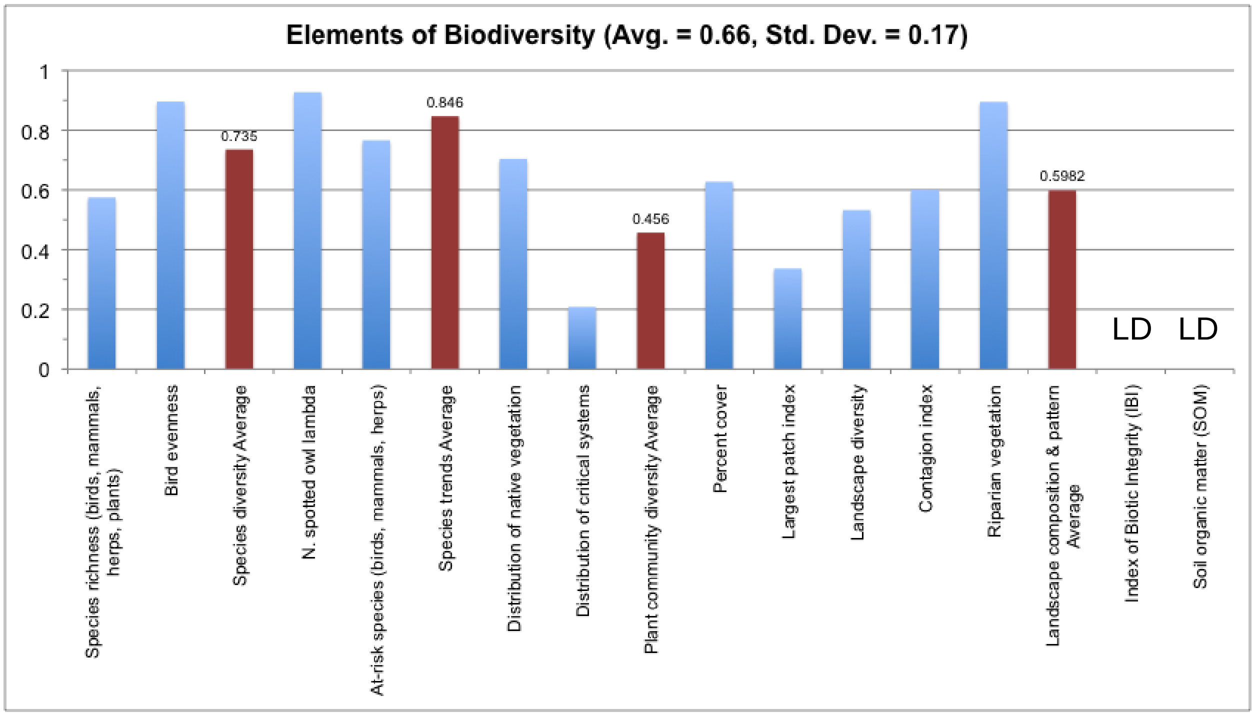
Figure 4. Indicators with metrics calculated relative to total possible versus relative to recent trends. The appropriate relative baselines for the various metrics depend on whether their associated indicators describe structural or compositional components of biodiversity, as opposed to those that describe processes or conditions specifically assessed at a given point in time.

Figure 5 illustrates the values for individual metrics (blue), as well as average indicator values (red), for mesic forests of western Washington. These values are based on currently available and obtained data. Metric values may change slightly as more, and potentially better, data are identified. The figures also reflect those indicators and metrics for which little or no data are presently available (or have yet been identified): biotic integrity, soil organic matter, phenological trends, disturbance management practices, herbivory impacts, and aesthetic impacts on housing prices. Though there is considerable knowledge regarding the types of invasive species present in Washington state, specific data on distributions, trends and related expenditures are still in the process of being compiled (WISC 2009), as indicated in Figure 5d.

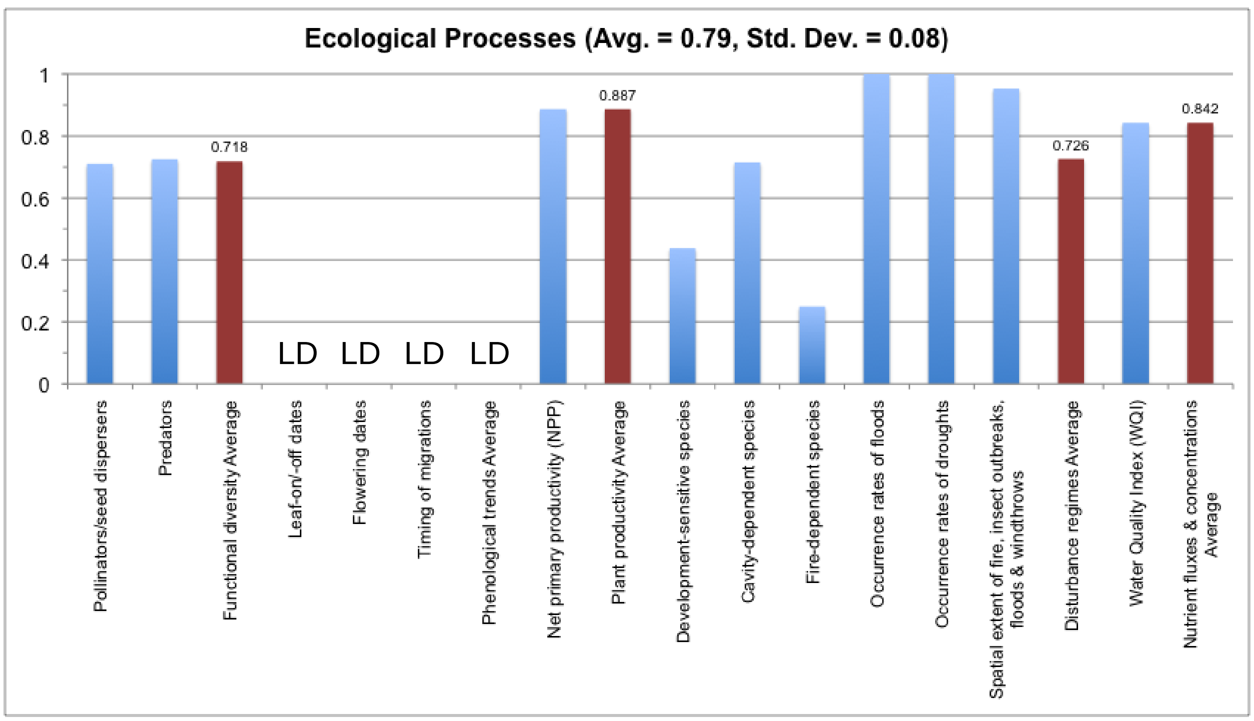
Based on the first-generation metrics, biodiversity in western mesic forests is moderately high (Figure 5a), as are the level of support of the ecological (Figure 5b) and human processes (Figure 5c) needed to sustain it and the ecosystem services it provides (Figure 5d). (See also the following section on aggregate measures.) Individual indicators vary significantly between high or low values, but average to approximately 0.7. Because of the way we calculated each metric (Table 3), this means that for some indicators, elements of biodiversity, human and ecological conditions, and ecological services are approximately 70% of the recent (5- to 20-year) average within Washington's mesic forest system: species trends, functional diversity, plant productivity, disturbance regimes, nutrient fluxes, pollution levels, park use, wildlife viewing, fish/game and resource provision, and insect pests. For other indicators, these values are a percentage of the total possible/observable within Washington's mesic forest system: species and community diversity, landscape composition and pattern, land base under conservation protection, land use management, incentive programs, land use/cover change, citizen science, public engagement, carbon sequestration, water provision, and flood mitigation.

Breaking the measures down further, the scores for the individual metrics indicate that the diversity of plants, animals and communities is relatively high (Figure 5a). Measures of forest landscape structure, however, seem to suggest significant levels of fragmentation, despite the fact that overall forest cover is still reasonably high. Forest cover in riparian buffers is very high, which may account at least in part for the high water quality measures (see Figure 5b). Overall functional diversity (Figure 5b) is relatively high for pollinators and seed dispersers, as well as for predators. Primary productivity exhibits relatively high levels as well. Disturbance levels are such that indicator species are not abundantly present (i.e., relatively high development intensity, low fire occurrence), although water flow conditions have remained outside of extreme low and high levels. With respect to the human dimensions relevant to biodiversity (Figure 5c), the indicators suggest high levels of public engagement and efforts that promote biodiversity. The areal extent of public, private and NGO land suitable for conservation purposes and under forest stewardship certification is marginal, but this does not entirely reflect conditions unsuitable for biodiversity in that significant natural cover remains. In fact, such lands may in fact be at close to the maximum possible, which would suggest that the extent is actually higher than suggested and hence the metric requires revision (see "Future Steps" below). The various ecosystem services are also generally high (Figure 5d); the exceptions are game yields, which is likely due to lower game populations than in previous years, and low mitigation of insect defoliation.

The diverse indicators within the mesic forest appear to track one another reasonably well. In general, a healthy diversity of biological elements is currently associated with a functional set of ecological and human processes, and is providing a strong set of ecological services. However, we recognize that these results largely give a baseline for current conditions: we will have a stronger sense of the robustness of indicators and metrics 1) when we have comparisons with other major ecosystems in the state, and 2) as we follow trends in the indicators over time, through future measures of the indicators and/or exploration of historic trends where data are available.

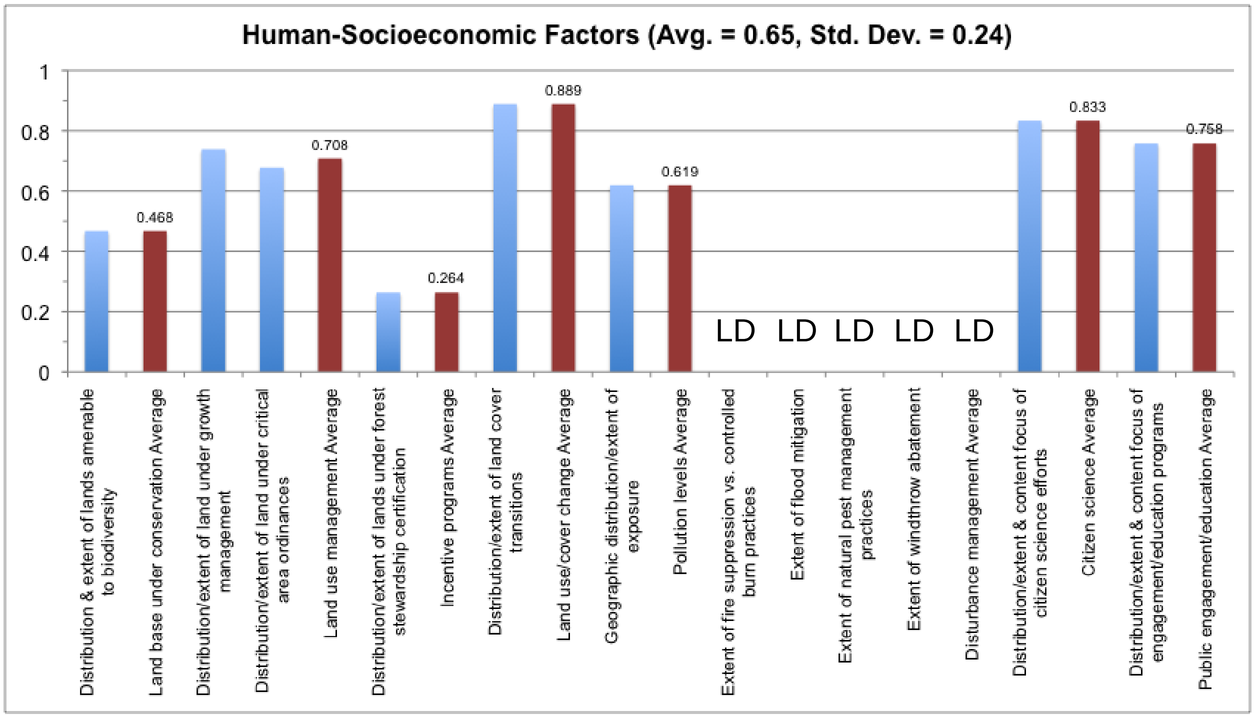


5a.

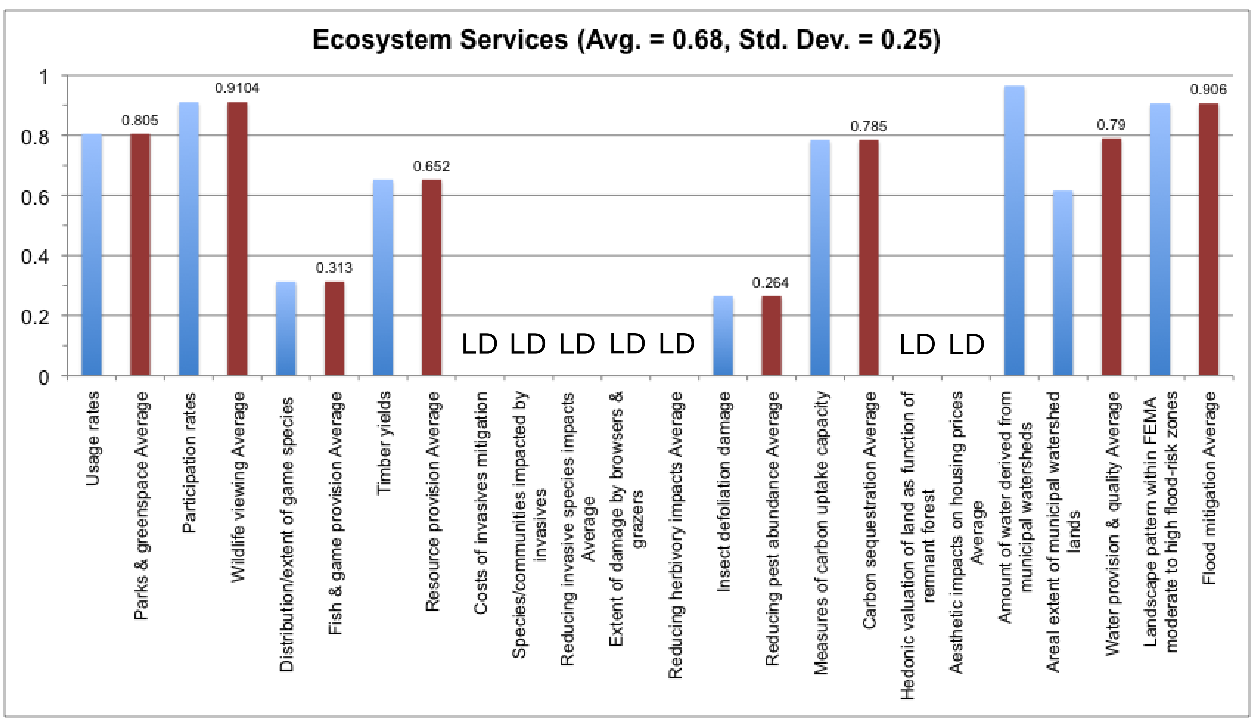


5b.

Figure 5. Indicator and metric values for mesic forests of western Washington. Blue bars give values for individual metrics, followed by red bars (and numerical labels) that give the average indicator value associated with the preceding metrics. Metrics and indicators labeled as "LD" are those for which insufficient data, if any, are currently available (or identified). Aggregated category values (in graph titles) are based on an average of the indicator values (red bars).



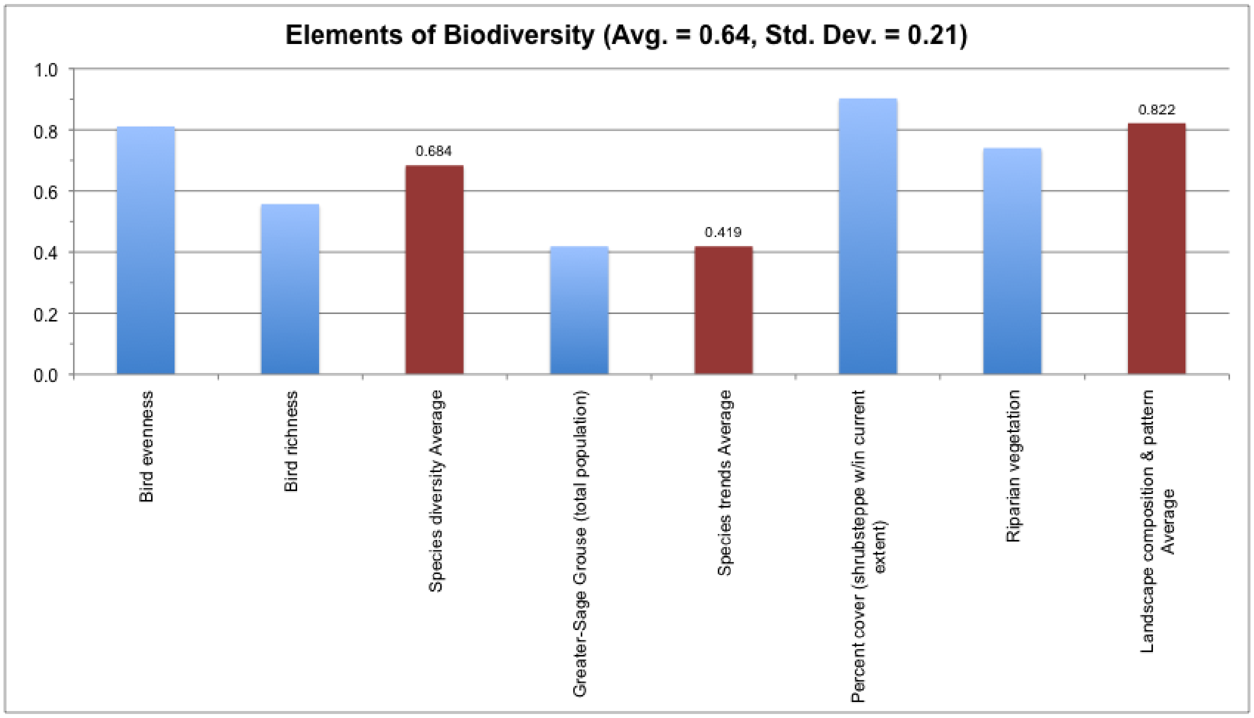
5c.



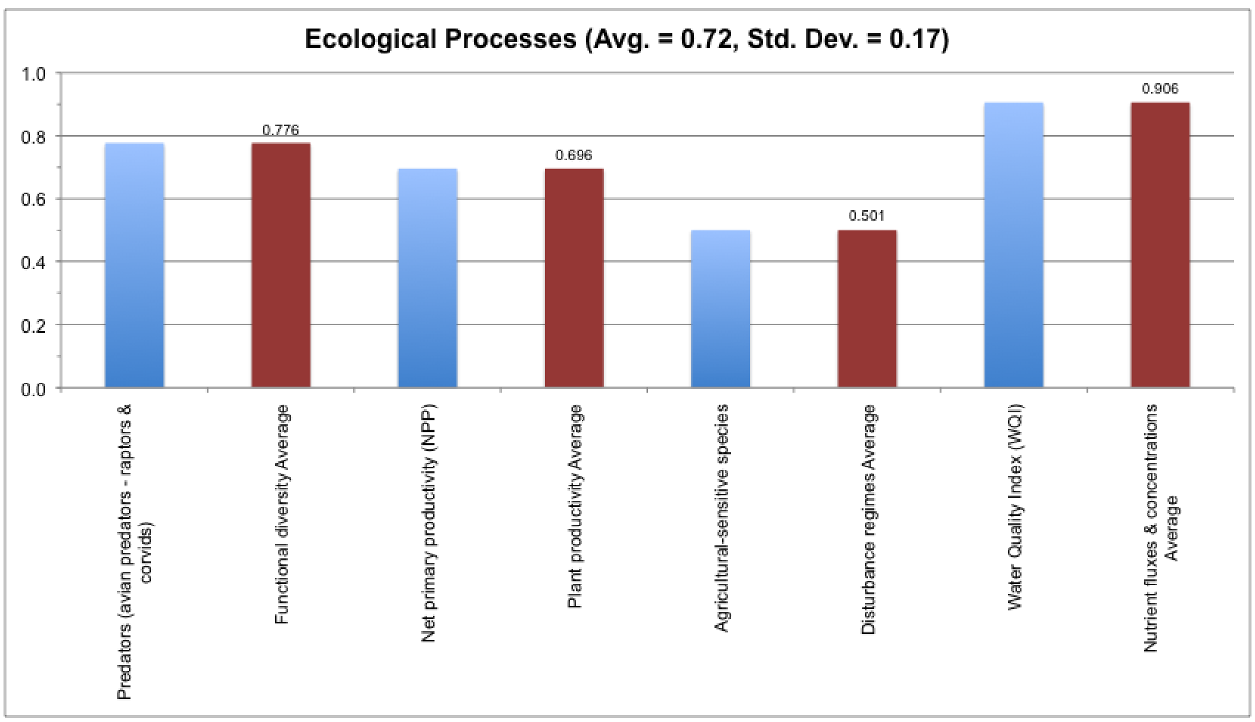
5d.

Figure 5 (cont.).

As illustrated here, the strength of the system-level measures lies predominantly in describing the status and trends of each system. However, a qualitative comparison of measures among major ecosystem types, such as that afforded through a partial assessment of eastern shrubsteppe, also provides information on the relative status of each system, and would collectively contribute to state-level assessments of biodiversity. Despite being incomplete at present, the shrubsteppe assessment yielded considerably lower estimates of status and trends, particularly for certain indicators (Figure 6). Bird diversity is comparable between the two systems, yet the relative amount of vegetation within 100 m of streams is considerably lower (Figure 6a). The percent actual shrubsteppe cover within the current ecosystem boundaries is relatively high, over 80%; however, it is important to note that the range of this system is only 47% of its historic range extent (Johnson and O'Neil 2001). Assessed ecological processes (Figure 6b) show relatively comparable trends to those within mesic forests, with very high water quality measures and only moderate trends in disturbance-sensitive species – in this system, species sensitive to agricultural land uses. Indicators of human-socioeconomic factors are considerably lower than in forests (Figure 6c), primarily to the much lower percentage of public land area in uses amenable to biodiversity; levels of pollutants are also somewhat higher. Lastly, measured ecosystem services provided by shrubsteppe are overall relatively lower in comparison to those of mesic forest (Figure 6d): estimated potential carbon sequestration is much lower, but mitigation of insect defoliation levels is relatively higher. Again, such comparisons of measures among ecosystem types both provide a relative assessment of those systems, while simultaneously allowing us to better test the sensitivity of the indicators to such differences among ecosystems. However, the latter evaluation of indicator sensitivities will require more complete assessments of the remaining ecosystem types and, quite likely, measures at future points in time (see "Future Steps" below).

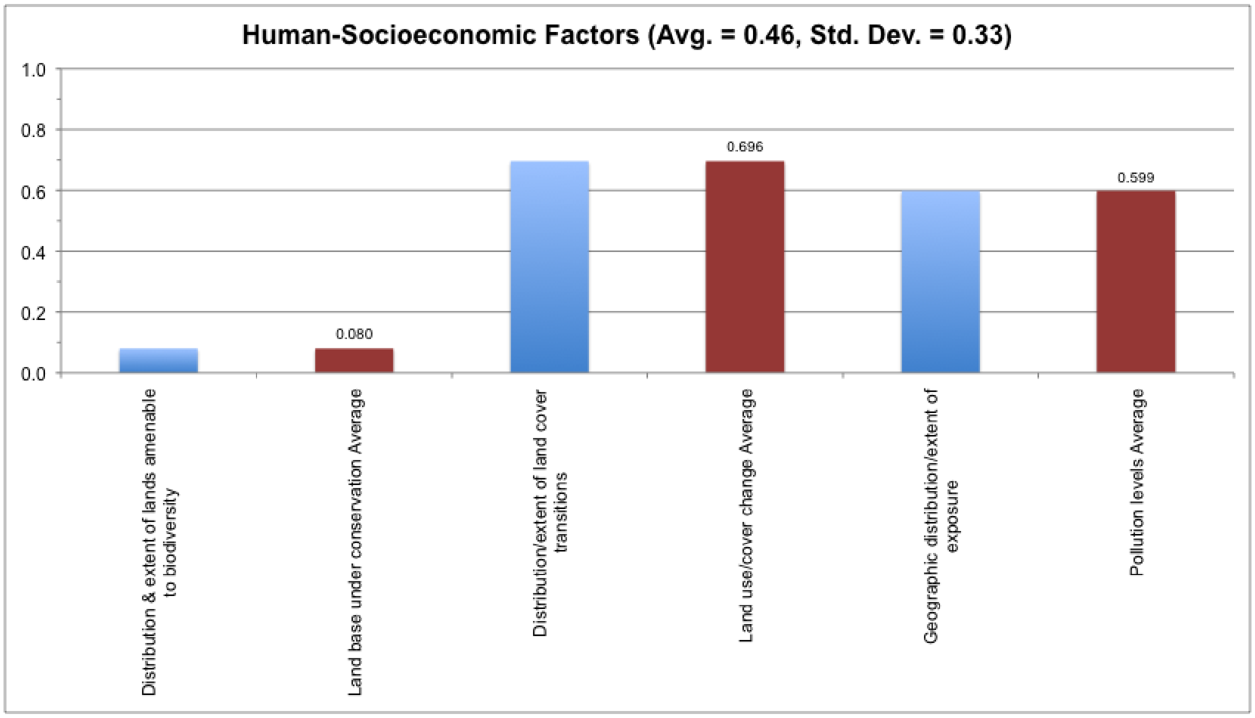


6a.

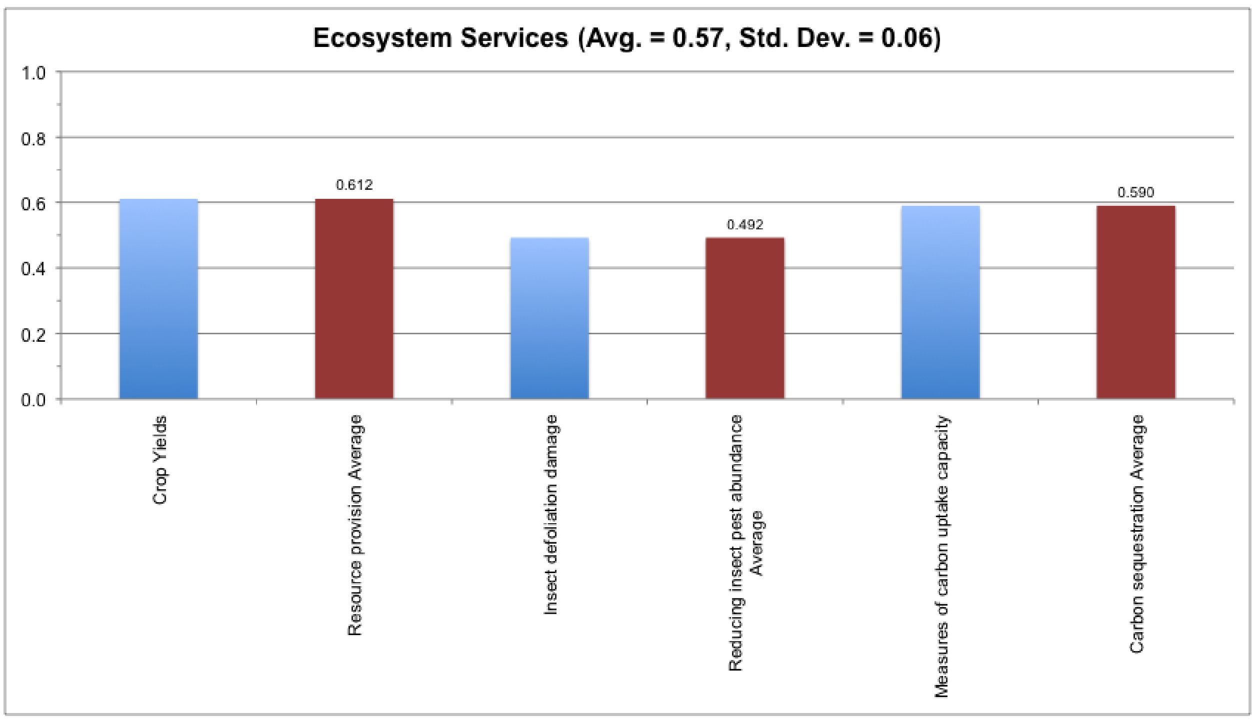


6b.

Figure 6. Indicator and metric values for shrubsteppe of eastern Washington. Blue bars give values for individual metrics, followed by red bars (and numerical labels) that give the average indicator value associated with the preceding metrics. Aggregated category values (in graph titles) are based on an average of the indicator values (red bars).



6c.



6d.

Figure 6 (cont.).

IIID. Aggregating Indicators: Possible Approaches to Assessing Higher-Level Measures

The indicators and metrics provide a detailed quantification of biodiversity status and the processes that support it. As noted previously, the individual indicators each describe facets of biodiversity health that can guide coarse-level conservation, monitoring and management strategies. However, only by looking (qualitatively, in the current iteration) at the interactions and connections among indicators can we assess broader system characteristics of integrity, resilience and sustainability. Additionally, such composite measures, derived by aggregating indicators within the framework, are necessary to make the information more accessible for non-technical audiences.

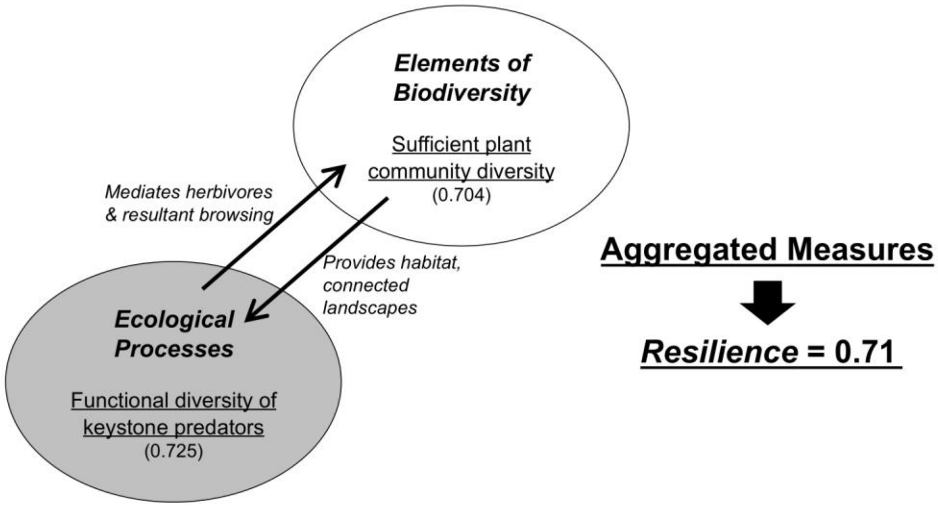
At present, we employ a simple approach to aggregating indicator measures: calculating relative values for metrics as noted above, and then adding these values together as appropriate (e.g., by indicator category). The current approach weighs all indicators equally; any weighting scheme would require additional statistical or scientific rationale beyond the scope of the current efforts. Future modifications to the framework will entail more sophisticated aggregation models.

We calculated a number of test aggregates, combining groups of indicators into higher tier measures. Aggregation by the four indicator categories (i.e., "Elements of Biodiversity," "Ecological Processes," "Human-Socioeconomic Factors" and "Ecosystem Services") is most straightforward: we calculated the average values of all metrics for a given indicator, then took the average of all indicators within that category. Figure 5 shows the aggregated values for the four indicator categories for mesic forests in western Washington, in addition to individual metrics and indicators. As would be expected based on the results for individual indicators (previous section), these aggregate category measures for western mesic forests track one another reasonably well. The results suggest that the moderately high integrity of ecological processes and human efforts in support of biodiversity (0.79 and 0.65, respectively) are bolstering – and in turn are bolstered by – moderately high levels of species, community and landscape diversity (0.66). Related ecosystem services in turn are relatively well maintained (0.68). Aggregating one step further – averaging across all indicator categories – gives biodiversity status in mesic forests of western Washington an overall value of 0.695 (SD = 0.067). These measures are in contrast with those presently available for eastern Washington shrubsteppe, with aggregate measures of 0.64, 0.72, 0.46 and 0.57 for "Elements of Biodiversity," "Ecological Processes," "Human Factors" and "Ecosystem Services," respectively, and a value of 0.596 (SD = 0.112) overall.

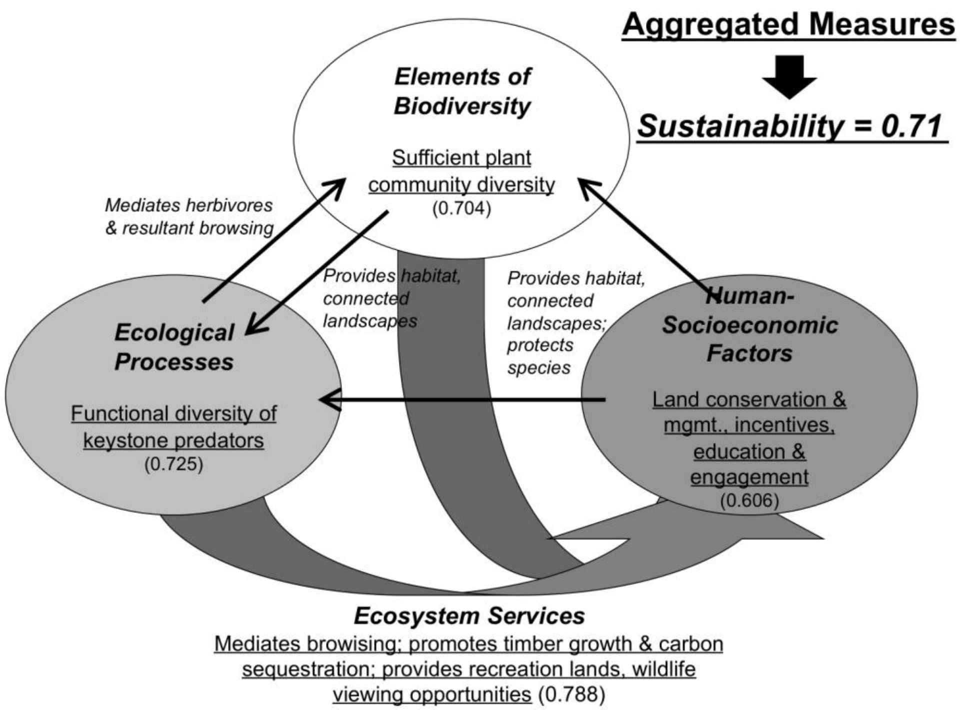
The breadth and flexibility of the assessment framework, however, permits a broad range of possibilities for aggregating indicators and their metrics, to evaluate other system properties and address the particular needs of a given user. One example of such aggregate measures includes an assessment of ecological resilience. Biological diversity both is affected by and plays a key role maintaining the functioning of ecological systems: richness of species, ecosystem and landscape structure and function adds robustness in the face of often widely varying conditions (Levin 1998, 1999; Peterson et al. 1998; Scheffer et al. 2001). This is particularly true in terms of climate and disturbance. In the context of the biodiversity assessment framework, combining indicators that describe the structural and functional components of ecological systems (i.e., the "Elements of Biodiversity" and "Ecological Processes" indicators, respectively) can be thought of as collectively assessing the resilience of major ecosystems within Washington. This is illustrated conceptually in Figure 7a. High functional diversity that includes sufficient predator populations, for example, can limit browsers and maintain sufficient plant community diversity (Ripple et al. 2001; Ripple & Beschta 2003, 2004; Hebblewhite et al. 2005). In turn, healthy plant communities can maintain resilience by providing habitat for species and mediating water and nutrient flows. Based on our current estimates, this aggregate would yield a moderate resilience measure of 0.71.

An assessment of ecological structure and function as described above provides an indication of a system's intrinsic biophysical resilience. Such an assessment is bolstered, however, by consideration of human-mediated drivers and interactions with which ecosystems are inextricably linked; as Levin (1998) notes, "Developing sustainable approaches to system use implies understanding what maintains resilience *and how human intervention might affect it*" (emphasis added). Human engagement in and understanding of the natural resources both upon which we depend and that our actions impact can lead to more effective strategies for conservation, management, resource usage and policy decisions (Cumming et al. 2006). Using Holling's (2001) definition, paying attention to and strengthening the linkages between biophysical and anthropogenic processes promotes <u>sustainability</u> (see also Levin 1998, 1999; Scheffer et al. 2001; Carpenter et al. 2001 use this coupled relationship as a broader definition for "resilience"). Within the context of the present framework, this operationally entails considering simultaneously the resilience of systems <u>and</u> human engagement in supporting – and in sustaining – ecological diversity as well as human well-being. To continue from the previous example (Figure 7b), policies, incentive programs and management strategies aimed at bolstering predator populations (Hebblewhite et al. 2005), along with public interest and education aimed at learning to coexist with such species, further helps to mediate trophic cascades; such efforts concurrently maintain ecosystem services, directly by preserving timber growth and indirectly by providing lands for outdoor recreation. The resultant aggregate measure for sustainability would thus also be 0.71.

The comprehensiveness of the framework allows users to focus on subsets of indicators that are most directly relevant to guiding their particular directives or objectives. For example, the indicators that describe status and trends of plant and animal species could individually and collectively inform strategies for agencies with a focus on species management or conservation (Figure 8). Alternatively, agencies and organizations whose focus is on land management – which ultimately can translate into quality habitat for supporting biodiversity – might focus their attention on land-relevant indicators. Conceptually, the indicators within the framework can be combined and summarized into subsets to identify trends most relevant to a particular audience's objectives and to derive stories that can best guide their actions and decisions.



7a.



7b.

Figure 7. Aggregating indicators for measures of resilience and sustainability. Measures for indicators (underlined labels) of ecological structure and function can be aggregated to provide measures of ecological resilience of Washington ecosystems (Fig. 7a). By integrating these measures with indicators describing human engagement (including socioeconomic factors supporting biodiversity and the ecosystem services derived from it), we can further assess the sustainability of the coupled human and natural systems (Fig. 7b). The example illustrated here describes the relevant interactions tied to the functional roles of predators as keystone species.

Species-Centric Indicators

Plant & animal diversity = 0.735
Species occurrence/abundance trends = 0.846
Plant community/ecosystem diversity = 0.456
Functional diversity (pollinators, predators, etc.) = 0.718
Plant productivity = 0.887

→ *Aggregate = 0.728*

Land-Centric Indicators

Landscape composition & pattern = 0.598
Plant productivity = 0.887
Disturbance regimes = 0.726
Land base under conservation protection = 0.468
Land use management & planning = 0.708
Incentive programs = 0.264

→ *Aggregate = 0.609*

Figure 8. Potential mission-specific aggregates of indicators. Agencies, NGO's and decision-makers whose purview is the conservation or management of species can focus their attention on indicators describing species-centered status and trends. Alternatively, users focused on land management can use indicators describing landscape conditions to guide their actions.

As noted above, one of our criteria for selecting indicators was to identify a select number that could be used for detecting critical changes in ecosystems – for example, indicators that exhibit critical thresholds (Levin 1998; Scheffer et al. 2001, 2009). Indicators such as levels of functional diversity, landscape connectivity, and nutrient loadings in watersheds provide such an assessment within our framework; Figure 9 illustrates how these can be considered individually and collectively to assess overall system intactness, particularly when measured over time. For many such indicators that exhibit, or be expected to exhibit, threshold behaviors, at what point the threshold occurs is often either not currently known (particularly given the challenges in identifying thresholds; Scheffer et al. 2001, 2009) or depends on more detailed contextual, system-specific information beyond the scope of the assessment framework. However, as future research reveals more about these threshold phenomena, such indicators and the implications of their measurements will become increasingly more valuable and informative. This will add to the framework's adaptability and ability to assess long-term trends.

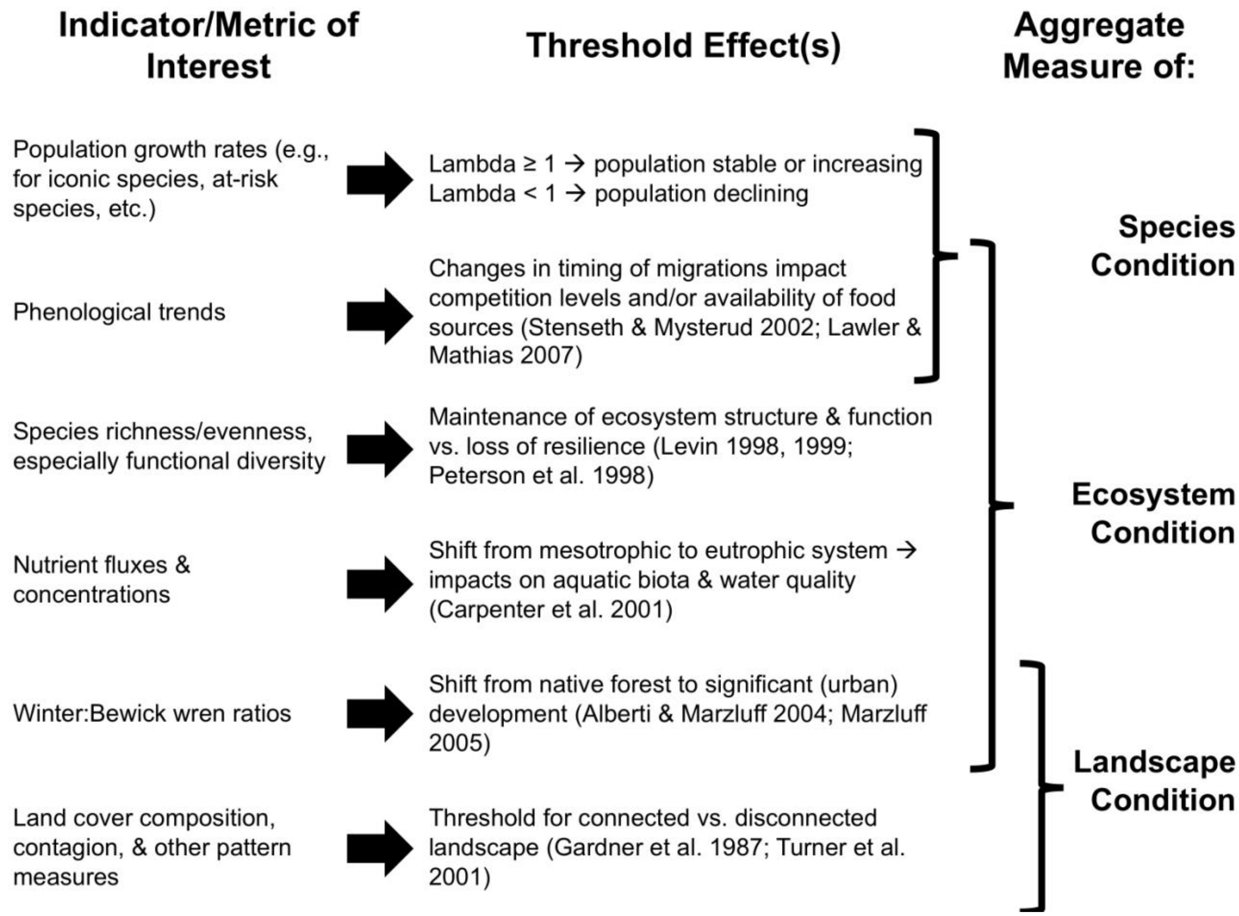


Figure 9. Aggregate measures for threshold phenomena. The assessment framework includes indicators that describe facets of biodiversity that are either known or expected to exhibit critical thresholds, such that shifts beyond those thresholds can result in dramatic ecosystem transformations. As research on and knowledge of threshold phenomena progresses, we can conceptually derive aggregate measures from these indicators that can then be used to describe significant changes in overall species-/population-, ecosystem-, and landscape-level conditions.

IV. Future Steps, and Concluding Remarks

The draft assessment framework documented here lays the groundwork for an inclusive and integrative assessment of biodiversity in Washington State. Though any assessment tool implicitly incorporates important ecological (and, in some instances, socioeconomic) linkages, our framework is unique in that it is explicitly organized around a conceptual model integrating pattern and process, structure and function, and human as well as biophysical components in its organization and content. By tracking chronic changes in status and trends, the indicators can serve as pointers to why such change is occurring, particularly given the comprehensive, causal linkages among indicators (Niemeijer and deGroot 2008; Orians and Policanski 2009). Such information in turn could serve to guide more targeted policy, management and research actions.

The draft metric formulas in Table 3, and the resultant values presented in Figure 5, serve as a demonstration of the capabilities of the assessment framework in terms of the measures it includes and the information it provides. Refinements to the indicators and metrics will include greater specificity with respect to variability in the measures, including confidence intervals and more information on the sampling extent for each. The scope and interpretability of measures will also be greatly enhanced by identifying historical baselines where available and relevant.

Future efforts hold the promise of greatly expanding the efficacy of the assessment framework. First and foremost, an assessment of the remaining ecosystems of the state will provide a more complete picture of status and trends across the state. Such an expansion of efforts will also allow us to identify those indicators that are less sensitive to differences across systems, those that are less appropriate for particular systems, and those that are current absent but necessary for a particular system. Relatedly, formal sensitivity analyses will be useful for further refining the indicators and metrics: we have thus far focused on qualitative assessments of sensitivity, particularly through peer review recommendations and discussions with the Council's Science Committee. The assessment of such sensitivities will also be influenced by the quality of data used to compute the metrics.

Related to this expanded assessment of the state's ecosystems is the opportunity for greater collaboration with Puget Sound Partnership. As noted in Table 2, half of our indicators have parallels in PSP's draft indicators. Despite this, the most significant potential shortcoming in the indicators' ability to provide uniform, compatible assessments across systems is the question of whether they can adequately describe aquatic (marine and freshwater) ecosystems. PSP is currently undertaking a process whereby they are refining their selection of indicators, and hence the set of indicators they will ultimately use to assess aquatic systems of Washington (T. Francis and S. Pearson, pers. comm.). Through regular meetings, updates and ongoing collaboration with PSP staff and consultants, we may thereby identify any limitations in our indicator framework and refine our abilities to measure significant trends in freshwater and marine ecosystems. Conversely, our framework, in its current or revised form, may serve PSP in deriving relevant assessments of terrestrial systems.

Feedback from the technical peer review yielded a number of recommendations regarding modification and/or simplification of the assessment framework. We present the specific recommendations in greater detail in an accompanying document summarizing the peer review results (Appendix D*)*. However, some general examples included the following. One suggestion was to focus largely on those indicators most directly descriptive of biodiversity – particularly those in the "Elements of Biodiversity" category. Human factors that have direct implications for biodiversity, such as those pertinent to land use, were also suggested as indicators to be emphasized. Other reviewers suggested moving ecosystem- and landscape-centered indicators from the "Elements of Biodiversity" category to a new or different category, given that these describe <u>conditions</u> of importance to biodiversity rather than elements of biodiversity (i.e., species) per se. A re-framing of the "Elements" category to reflect its original intent

– indicators that describe structural and compositional biophysical components of importance – may be a simple solution to this discrepancy. Implementation of these changes will require further consideration and consultation with the Science Committee, and the Council as a whole.

One of the most important future steps in revising the framework, both as described above and emphasized through reviewer comments, is the need to appropriately weight the indicators and metrics when deriving aggregate measures. Perusal of the indicators listed in Figure 3 makes it quite clear that some indicators, such as metrics of overall diversity, need to be weighted more heavily than others, such as trends for individual species. In addition, some metrics would be expected to exhibit nonlinear trends – that is, would provide “diminishing returns” at higher levels – as opposed to the linear relationships assumed in our normalized measures. Such examples might include levels of landscape connectivity (or rather its converse, fragmentation) or timber yields, which at higher levels are likely to result in lower biodiversity than at intermediate levels. As noted above, we made the simplifying assumptions of equal weighting and linear measures in order to focus our efforts on selecting and evaluating indicators and metrics. Devising appropriate weighting methods and refined metrics that more accurately reflect their statistical properties will require considerably more research and consultation with experts. In general, we envision refinement of the biodiversity assessment framework – the indicators, metrics and derivative aggregates – as an ongoing process.

Monitoring and hence further understanding ecological diversity and the manifold factors that impact it is by definition a complex task. The assessment framework was designed to be able to describe the essential structural and functional components that both define and impact biodiversity. However, to draw meaningful conclusions from the indicators, particularly in guiding policy and management decisions, the various indicators will need to be distilled in a manner that describes how they fit together to form a cohesive picture. The aggregate measures above illustrate some suggested avenues, but the comprehensive structure of the framework provides a capacity to answer a wide range of questions. In future efforts, we anticipate working closely with potential users to explore in greater detail the information they will need to glean from the framework in order to make informed and effective decisions. We are also examining optimal strategies for communicating the information that the indicators and the aggregates of interest provide. Initial discussions with Cascadia Consulting (Marc Daudon and Laila Parker) and Eric Sorensen, a freelance science writer, have yielded recommendations for convening communications and user-based focus groups and draft summary communication materials (i.e., the executive summary), respectively. Combined with refinements of the measures it includes, these next phases of development of the framework will enable us to better understand, monitor and become engaged with the rich natural heritage of Washington State.

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