Workshop Summary Report

Washington Coast Marine Spatial Planning

Ecosystem Indicators Workshop

May 13, 2013
Montesano, WA

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Contents

Workshop Participants 3
Workshop Agenda 5
Outcomes for Ecosystem Indicators Workshop 5
Executive Summary 6
Summary of Presentations 7
Marine Spatial Planning: Washington Process Status & Background 7
Integrated Ecosystem Assessments and Ecosystem Indicators 7
A Draft Conceptual Model of Washington's Coast 7
Initial Selection and Evaluation of Potential Candidate Indicators 7
A Draft Process to Establish Ecosystem Indicators 8
Summary of Large Group Discussions 8
Conceptual Model Discussion 8
Ecosystem Indicator Criteria Discussion 10
Partnership Opportunity Discussion 14
Information Gaps Discussion 14
Next Steps Discussion 17
Appendix: Workshop Materials 19

Figure 1. Participant responses to criteria they like 11
Figure 2. Participant responses to criteria not to use 12
Figure 3. Participant responses to most important criteria 13
Figure 4. Participant responses to attributes requiring additional information 15
Figure 5. Participant responses to attributes with most agreement 16
Figure 6. Participant responses to attributes with least agreement 17

Workshop Participants

The intended audience for this workshop was resource managers and scientific experts, particularly those focused on ecosystem services and indicator development, and resource managers (local, state, tribal, and federal).

Name	**Affliation**
Ashley Malony	UW notetaker
Betty Renkor	Ecology
Brit Sojka	UW notetaker
Britta Timpana-Padgham	UW notetaker
Carol Bernthal	Olympic Coast National Marine Sanctuary
Charles Menza	NOAA Biogeography Branch
Chris Harvey	NOAA - NW Fisheries Science Center
Connie Sullivan	Hershman Fellow, Puget Sound Partnership
Corey Niles	WDFW, Coastal Marine Policy Lead
Eliza Heery	UW Notetaker
Elizabeth Tobin	UW Notetaker
Ed Bowlby	Olympic Coast National Marine Sanctuary
Felicia Olmeta-Schult	WSU notetaker
George Galasso	Olympic Coast National Marine Sanctuary
George Hart	DOD - Navy
Heather Reed	WDFW, Coastal Marine Resources Policy Coordinator
Helen Berry	DNR, Aquatics, nearshore
Ian Miller	Washington Sea Grant
Jan Newton	UW, NANOOS
Jeffrey Fisher	NOAA - SW Washington Branch Chief
Jennifer Hagen	Quileute Tribe, Habitat Biologist
Jennifer Hennessey	WA Department of Ecology
John Pierce	WDFW, Chief Scientist, Wildlife
John Stadler	NOAA Fisheries - Marine Habitat Coordinator (PMEP), Newport
Kara Cardinal	Hershman Fellow, The Nature Conservancy
Katie Krueger	Quileute Tribe
Katrina Lassiter	WA Department Natural Resources
Kelly Andrews	NOAA - NW Fisheries Science Center
Kristen Feifel	UW Notetaker
Laura Wigand	Hershman Fellow, WA Dept. of Health
Liam Antrim	Olympic Coast National Marine Sanctuary
Libby Whiting	Hershman Fellow, WA Department Natural Resources
Michele Culver	WDFW, Regional Director
Mindi Sheer	NOAA - NW Fisheries Science Center
Nick Bond	UW - climate

Parker MacCready	UW - oceanography
Paul Dye	The Nature Conservancy
Phil Levin	NOAA - NW Fisheries Science Center
Rich Osborne	ONRC, Research Consultant/ WCMAC Science Seat
Ron Warren	WDFW, Region 6 Fish Program Manager
Sara Breslow	NOAA - NW Fisheries Science Center
Scott Mazzone	Quinault Tribe
Scott Pearson	WDFW, Research Scientist, Wildlife
Stephan Kalinowski	WDFW, Region 6 Habitat Program Manager
Steve Fradkin	Olympic National Park
Terrie Klinger	UW - Benthic Ecology
Tim Battista	NOAA Biogeography Branch

Workshop Agenda

Outcomes for Ecosystem Indicators Workshop

- A presentation and discussion of status of work done on Integrated Ecosystem Assessments (IEAs) and indicators to-date and how it relates to developing a Marine Spatial Plan on Washington's coast.
- A presentation of a draft conceptual model of the coast and suite of potential indicators.
- An understanding of the definitions of ecosystem health, ecosystem services, and ecosystem models and how they relate to selecting good indicators. A presentation on current thoughts on the criteria for selecting indicators and discussion on criteria.
- A draft outline for a process to establish ecosystem indicators. An identification and prioritization of initial information gaps and partnerships for advancing ecosystem indicator work.

May 13, 2013
9 am – 4 pm

Montesano City Hall – Banquet Room
112 N Main Street
Montesano, WA

9:00 – 9:20	**Welcome and Introductions**
9:20 – 9:35	**Marine Spatial Planning: Washington process status & background** Jennifer Hennessey, Washington Dept. of Ecology
9:35 – 10:00	**Integrated Ecosystem Assessments and Ecosystem Indicators** Phil Levin, NOAA Northwest Fisheries Science Center
10:00 – 10:15	**Break**
10:15 – 11:45	**A draft conceptual model of Washington's Coast** Chris Harvey, NOAA Northwest Fisheries Science Center (30 min) Discussion on draft conceptual model (60 min)
11:45 – 12:15	**Lunch**
12:20 – 1:40	**Initial selection and evaluation of potential candidate indicators** Kelly Andrews, NOAA Northwest Fisheries Science Center (30 min) Discussion on criteria for indicators (45 min)
1:40 – 2:25	**A draft process to establish ecosystem indicators** Jennifer Hennessey, Dept. of Ecology (5 min) Discussion on partnerships, roles and process (40 min)
2:25 – 2:40	**Break**
2:40 – 3:40	**Identifying initial information needs and gaps** - discussion
3:40 – 4:00	**Summary and next steps**

Executive Summary

The state is doing preliminary work toward developing a Marine Spatial Plan for Washington's Pacific Coast. This includes work to compile and display a variety of ocean and coastal data, gather new data, evaluate the ecosystem, conduct outreach and engage stakeholders in the process.

Marine spatial planning (MSP) is a comprehensive and integrated approach to managing human uses and activities in the marine environment. MSP allows for coordination between all ocean and coastal users, draws upon the best available science, and creates an inclusive decision-making process that carefully considers economic, social, ecological and cultural interests. Washington adopted RCW 43.372 for marine waters planning and management in the state's marine waters. The law outlines the principles, process and key elements required for a marine spatial plan.

One of the required elements of a plan is an ecosystem assessment and development of ecosystem indicators:

> An ecosystem assessment that analyzes the health and status of Washington marine waters including key social, economic, and ecological characteristics and incorporates the best available scientific information, including relevant marine data. This assessment should seek to identify key threats to plan goals, analyze risk and management scenarios, and develop key ecosystem indicators. In addition, the plan should incorporate existing adaptive management strategies underway by local, state, or federal entities and provide an adaptive management element to incorporate new information and consider revisions to the plan based upon research, monitoring, and evaluation. [RCW 43.372.040(4)(c)].

On May 13, 2013, the state hosted an Ecosystem Indicators Workshop at the Montesano City Hall. This workshop helped the state get feedback on preliminary work done to understand the ecosystem on Washington's coast and evaluate potential ecological indicators as well as define a process and next steps for establishing coastal indicators. The workshop brought together scientists and resource managers to:

- Learn about the relationship of indicators to marine spatial planning on Washington's Pacific Coast.
- Learn about the status of work on Integrated Ecosystem Assessment for the California Current.
- Provide input on a draft conceptual model of the Washington Coast.
- Discuss potential candidate ecological indicators and criteria for evaluating indicators.
- Develop a process for establishing ecosystem indicators.
- Identify priority activities for advancing ecosystem indicator work.

Summary of Presentations

Marine Spatial Planning: Washington Process Status & Background

Jennifer Hennessey from the Washington State Department of Ecology (ECY) provided workshop participants with a background on Washington's marine spatial planning law (RCW 43.372), the major players in Washington state marine spatial planning, and the marine spatial planning process to date. She described the requirements in the law for an ecosystem assessment and the comprehensive process for establishing ecosystem indicators.

Integrated Ecosystem Assessments and Ecosystem Indicators

Phil Levin from the NOAA Northwest Fisheries Science Center (NWFSC) gave a presentation on his work with the California Current Integrated Ecosystem Assessment (IEA). Mr. Levin defined an IEA as a process to inform management decisions with a goal of minimizing ecosystem impacts while maximizing societal benefits. The process helps identify possible alternative futures and evaluate likely tradeoffs associated with management alternatives. Through an IEA, marine resource managers and scientists assess the cumulative effects of overlapping activities, the vulnerability of an ecosystem, or the impacts of broad scale ecosystem drivers such as climate change.

A Draft Conceptual Model of Washington's Coast

Chris Harvey from the NWFSC presented the workshop participants with a series of draft conceptual models for five types of coastal ecosystems in Washington. Conceptual models provide a framework for representing marine habitats, connecting societal goals to management actions, and tracking ecosystem responses to primary drivers. NWFSC developed conceptual models for a pelagic habitat, a seafloor habitat, a kelp forest, a rocky shore, and a sandy beach habitat. Each conceptual model displays food web connections, physical drivers, and human pressures. Mr. Harvey presented potential abiotic, biotic, and human indicators for each habitat and displayed theoretical impacts of climate change drivers (ocean acidification, increases in seasonal storms, decline of key species, sediment export, etc.) to the indicators.

Initial Selection and Evaluation of Potential Candidate Indicators

Kelly Andrews from the NWFSC discussed the process that he and his team used to select and evaluate potential candidates for ecosystem indicators. The team established a conceptual framework and selected key attributes that relate to general resource management goals for each habitat. Ecosystem indicators are empirically tractable metrics that serve as proxies for key attributes of natural and socioeconomic systems. One hundred eleven potential indicators for ecological components of Washington waters were identified through a literature review and rated according to specific evaluation criteria. Examples of highly-ranked indicators were displayed for each key attribute within each habitat (see Appendix) and mapped back to the conceptual models. Mr. Andrews requested input from workshop participants to identify missing

evaluation criteria and to determine appropriate weightings of evaluation criteria in order to complete the process of ranking and selecting a suite of ecological indicators.

A Draft Process to Establish Ecosystem Indicators

Jennifer Hennessey described the proposed process that the state could use to develop and establish ecosystem indicators. The Washington coast could use a framework similar to the work done to select indicators in Puget Sound. Scientists and resource managers would work together to develop and review products at each phase of the process. Ms. Hennessey described the steps of developing a conceptual framework and attributes, identifying indicators of each attribute, developing and evaluating appropriate metrics for each indicator, avoiding duplication, and reassessing indicators. She asked participants for feedback on the process, the best mechanism for scientific review and if a similar process is appropriate to develop social and economic indicators.

Summary of Large Group Discussions

Conceptual Model Discussion

After the presentation on the draft conceptual ecological models, small groups discussed their feedback on the models based on their expertise and knowledge of the systems. These groups then shared their general reaction and ideas for improving the conceptual models with the large group. Some unique results from the detailed small group discussions and individual worksheets are listed in bullets below.

- *What resonates about the conceptual model? What doesn't? Does it reflect the key processes on Washington's coast?*

  Participants generally liked the attempt at a bottom up and top down model and the broad scale, simplistic approach to the conceptual model because it could serve as a good communication tool. In terms of content, the physical drivers and the sand transport resonated across participant interest areas.

  Other major things that small groups discussed as resonating included:
  - Trophic level
  - Pelagic indicators
  - Good tool for indicators and gaps
  - Partitioning seascapes into systems
  - Sea fishing pressures included
  - Human pollution
  - Impacts on shellfish and plankton

  Individual worksheet unique results included:
  - Basic building blocks are present
  - Considers global scale drivers

- Habitat type seems generally accurate
- Top pressures are present
- Linking physical drivers to human uses

Workshop participants felt the following components of the conceptual model were lacking: varying pressures; static and not dynamic; detail, statistical representation; geographic variability (south coast not well represented); effects from the Columbia River, Puget Sound, Juan de Fuca eddy; and pressures and benefits of tourism and shoreline development.

Other major things that small group discussed resulted as not resonating included:

- Difficult to measure at a level that leads to predictability
- Analysis scale
- Scenario specific indicators may not be helpful
- Links to future actions and decisions
- Geographic processes that carve topography (and subsurface topography).
- Species abundance at different life stages

Individual worksheet unique results indicated that the following did not resonate:

- Estuaries
- Seasonality/climate variability
- Upland activity impacts
- Linking ecosystem effects with human drivers
- Linking models

- *What's missing from the conceptual model?*

In general, participants expressed that several major processes and datasets were missing from the conceptual model. Large scale events like hypoxia, harmful algal blooms, large carcass events, and human activities (shellfish harvest) were not included. Major components of ecosystem variation were also missing: seasonality, offshore islands as unique ecosystems, freshwater inputs, and water column structure. Finally, variation in habitat types, links between habitats, migration patterns, invasive species, freshwater habitat, and specific indicators were not addressed by the conceptual models.

Small groups also identified the following unique results:

- Estuaries
- Understory kelp
- Sediment dynamics and dredging
- Pelagic aquaculture
- Mining operations
- An uncertainty measurement
- Military activities
- Seabird colonies

- Scuba diving
- Wind energy and wave height

Unique results from individual worksheets included:

- The extent of human impacts
- Sediment supply
- Prioritization or weighing scale
- Economic indicators

- *What additional information do you/we need to revise the conceptual model?*

  The NWFSC prepared simple, draft conceptual models of the Washington coast. As the state further develops these models, participants asked that the state provide information about the use of the models and how they are connected to decision making. Participants suggested that the revised conceptual models include information about the relationships between pressures and drivers, species abundance and all extractive pressures.

  Other major themes from small group discussion included:

  - Statistically accurate measures
  - Ecosystem boundaries
  - Societal goals
  - Quantify relationships
  - Timing of runoff
  - Way to identify impactful pressures

  Individual worksheet unique results:

  - Interactions between habitat types

Ecosystem Indicator Criteria Discussion

The primary considerations used for this initial evaluation of draft potential indicators were:

1. Theoretically sound.
2. Relevant to management concerns.
3. Predictably responsive and sufficiently sensitive to changes in the specific ecosystem attributes.
4. Predictably responsive and sensitive to changes in specific management actions or pressures.
5. Linkable to scientifically defined reference points and progress targets.

The Appendix lists the primary considerations as well as a number of other potential criteria that could be used to evaluate indicators.

Participants then discussed their reaction to and feedback on these primary considerations, as well as the longer list of other potential criteria in small groups and shared their main ideas with the full group. Each participant was also asked to capture their individual responses and ideas on

worksheets. Unique results from the detailed small group discussions are listed in bullets below. The figures below display a summary of the individual results for each question.

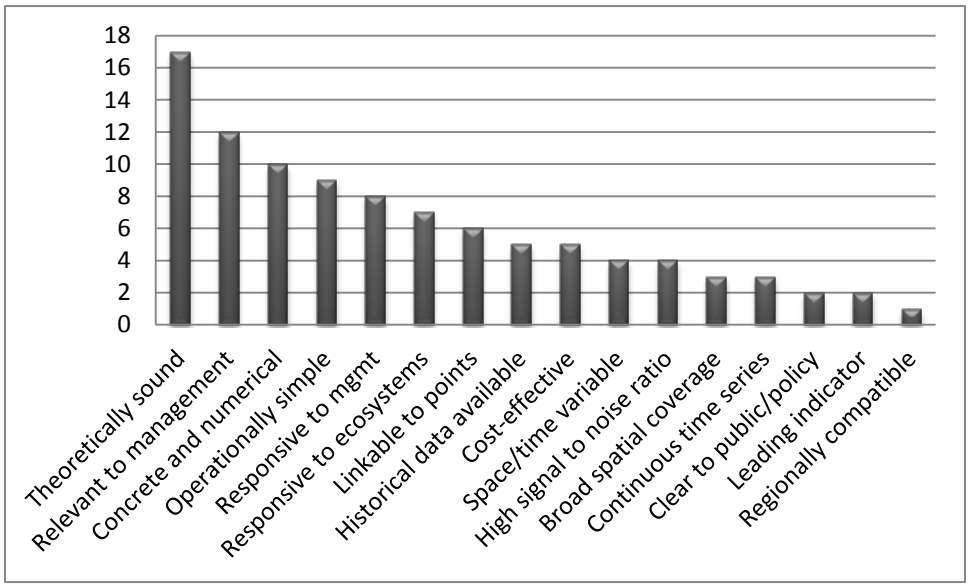
- *What criteria do you like or not like?*

  Of the primary considerations for draft indicators, participants felt that it was important to have indicators that are relevant to management concerns and generally responsive to changes. Additionally, workshop participants wanted indicators that would be:

  - Understood by public and policy makers
  - Cost-effective
  - Efficient multi-variable
  - Concrete and numerical
  - Supported by historical data
  - Operationally simple

  Unique results from small group discussion included:
    - Connected to management actions
    - Give a sense of current conditions

Figure 1. Participant responses to criteria they like



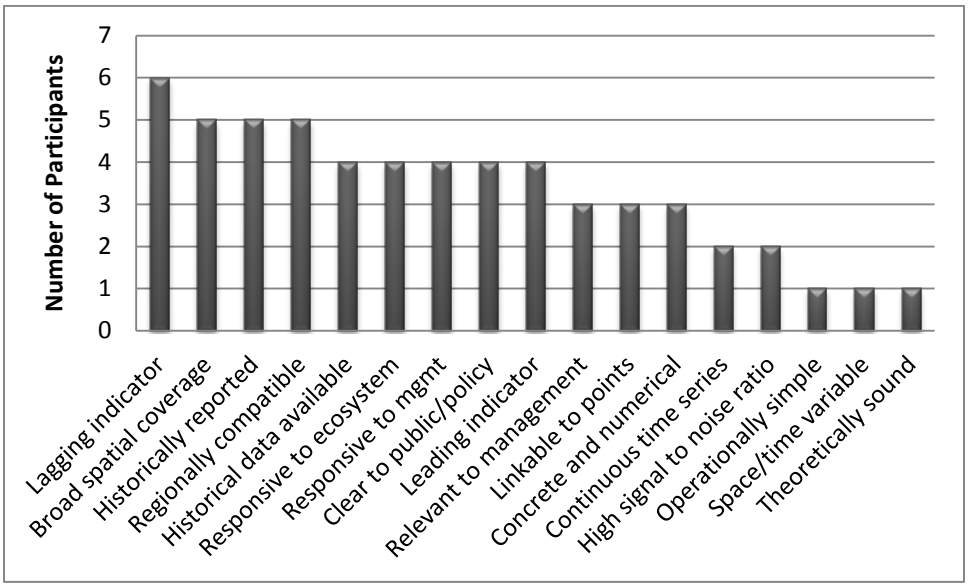
Workshop participants felt that some of the indicator criteria were arbitrary and others were unlikely to be used. These included: high signal to noise ratio, leading/lagging, regional compatibility, and historically reported. Participants would prefer to separate the public from policy makers in the criteria evaluating how easy an indicator is to interpret and communicate. They also felt that it was important to have indicators that are relevant to management concerns, but acknowledged, at the high level, the indicators would not

necessarily be responsive and sensitive to changes in management actions. This would require more refined development of performance measures as part of the plan.

Unique results from small group discussion included:

- 100+ years indicators
- Pollution on the outer coast is not a big issue
- Ranking is based on ecosystem attributes
- Need definition of reference points
- Need to test the models' connections and strengths

Figure 2. Participant responses to criteria not to use



- *What criteria are missing?*

Generally, workshop participants found the criteria to be lacking consideration for episodic events, repetition, compatibility with other human uses, unique information, limitations of data, and data comparability. The participants suggested addition a suite of criteria for adaptive management including consistence, compatibility, and connection to the model. Participants also thought that it was important to consider indicators based on their value to the public and opinions of scientific experts.

Unique results from small groups identified the following missing criteria:

- Weighing indicators
- Measure for catastrophic or episodic events

Unique results from individual worksheets included the following missing criteria:

- Cost-benefit analysis
- Definition of meaning in language (health, change, methods)
- Emphasis on long term value, support, and planning

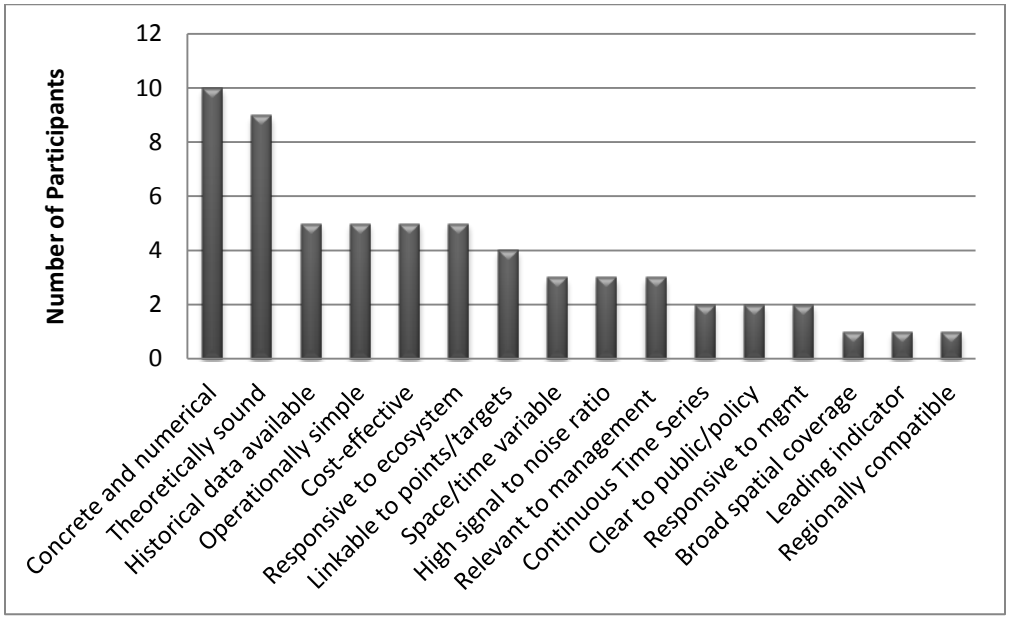
- *What criteria do you think are most important?*

  Of the primary considerations, the following were identified as the most critical criteria:
  - Theoretically sound
  - Relevant to management concerns (*if goals are defined*)
  - Predictably responsive and sufficiently sensitive to changes in specific ecosystem attributes
  - Linkable to scientifically defined reference points (*if targets are set*)

  Participants agreed that all of the data considerations for criteria were important such as: concrete and numerical, historical data or information available, operationally simple, broad spatial coverage, continuous time series, spatial and temporal variation understood, and high signal-to-noise ratio.

  Additionally, participants found that technical feasibility and the longevity in terms of affordability and practicality of the indicator were important. The figure below summarizes the individual worksheet responses and the small group discussion of this question.

  Figure 3. Participant responses to most important criteria



- *What indicators are missing from the initial list?*
  Few participants mentioned specific missing indicators in the large group discussion. However, participants felt that the spatial and temporal scale of indicators was missing and that the metrics for some of the indicators may not be appropriate, i.e. surface canopy as a measure for kelp forests. They also questioned whether indicators that are not measurable would be included in the list of indicators.

Missing indicators identified included phytoplankton communities and sediment core records. Specific to rocky shore habitats, wave action and tourism revenue were identified as missing indicators.

Unique results from small groups included:

- Visitor use
- Education as a human indicator

Individual worksheet identified the following unique results:

- Freshwater input from Columbia River plume and watersheds
- Estuary indicators
- Sediment core records or proxies
- Tracking phytoplankton communities
- Diseases

Partnership Opportunity Discussion

Participants were encouraged to write down the partnership opportunities that could contribute to the indicators process moving forward on a worksheet. They identified organizations or individuals with knowledge, expertise or resources as well as their potential roles in the process. The planning team also kept these individual worksheet responses team for later reference.

Workshop participants also used the individual worksheets to record ideas for improving the draft ecosystem indicator process. The following unique answers were provided:

- *What do you like best about the draft indicator process?*
  - Conceptual models available discussion
  - Managers and scientists together
  - The interaction and inclusivity of the workshop

- *What changes would you suggest for the draft indicator process?*
  - Clarify relationship between indicators and MSP
  - Incorporate more discussion of criteria and indicators

Information Gaps Discussion

Building on the previous discussions, participants were asked to identify attribute areas in the draft models that had more scientific agreement or disagreement and those that attribute areas that required additional data or analysis. Again, information was captured on individual worksheets, and in small and large group discussions.

- *Identify information gaps: What are some of the key attribute areas that need additional analysis or data?*

  Generally, participants found that the attribute areas were lacking consideration of space and time, specificity to Washington (especially ocean conditions) and positive indicators.

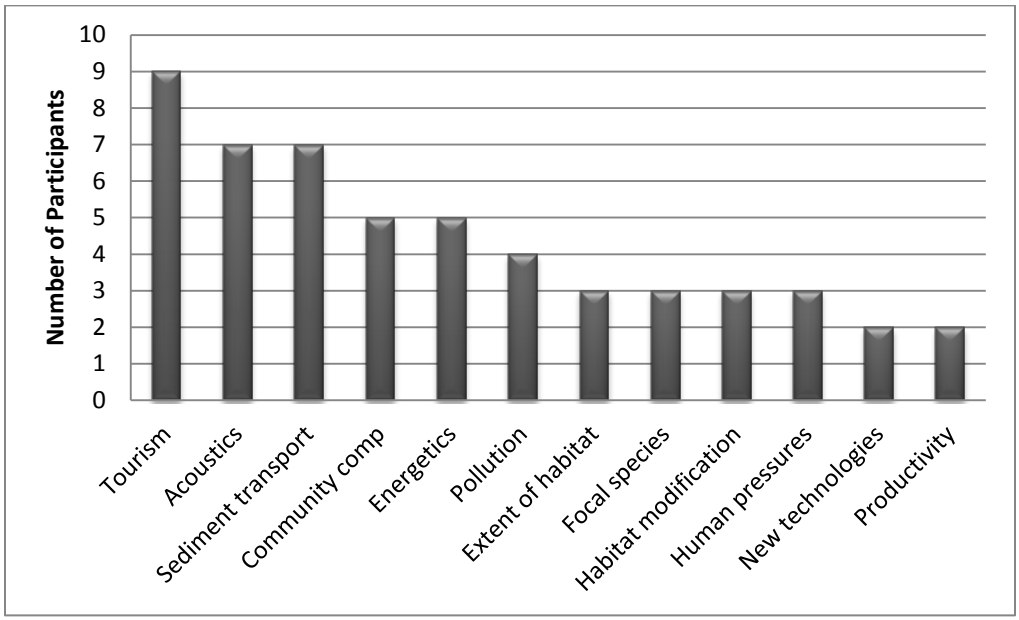
  Workshop participants felt strongly that additional data and analysis are needed for attributes relating to habitats and impacts from humans. Several anthropogenic attribute areas are lacking information: tourism, anthropogenic noise, climate conditions and carbon cycling related to climate change, atmospheric and pollution. Additionally, participants found that there are data needs for attributes relating to changes occurring in ecosystems including disease, invasive species, changing phenology and cumulative effects.

  Regarding habitat, participants discussed several attribute areas that need additional analysis and data: community composition, extent of coral and sponge habitat, focal species (specifically diets of sea otters), water column habitat, and the physical and biological condition of habitat. Additionally, participants thought that there is not enough data or analysis on sediment transport.

  Unique results from small group discussion included additional analysis on:
  - Physical and biological conditions of the habitat
  - Number of functionally redundant species

  The figure below summarizes the input on this question from individual worksheets.

Figure 4. Participant responses to attributes requiring additional information



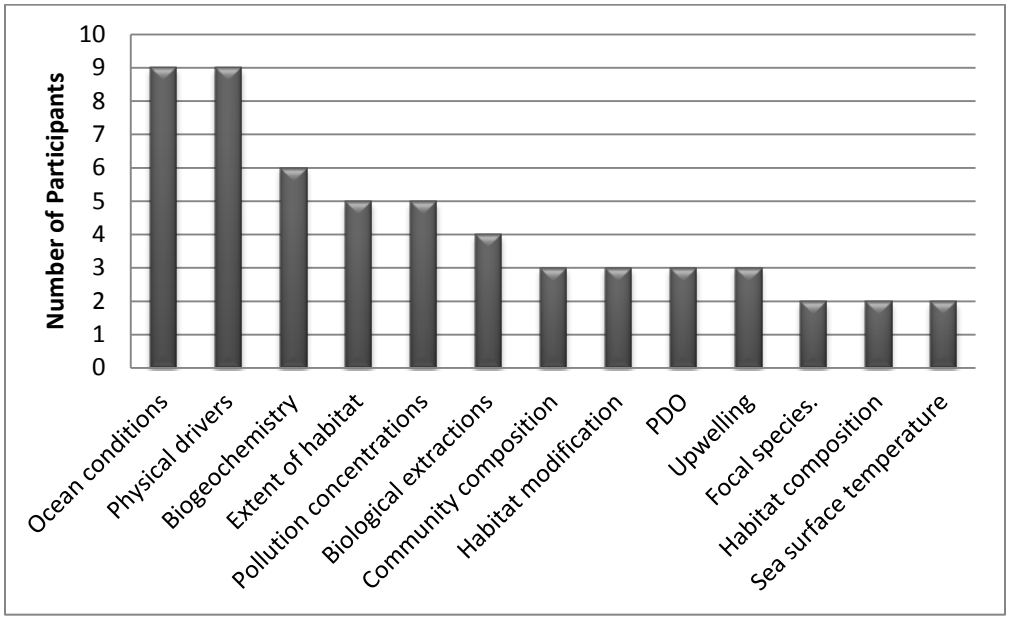
- *What are attribute areas that have solid scientific agreement?*

  Participants found that all of the key attributes were relevant, but utility depends on which indicators are used. They also agreed that attribute areas with good available data have solid agreement: physical drivers (upwelling and dissolved oxygen), ocean conditions, pollution, extraction, and focal species.

  Unique results from small group included:
  - Habitat and community composition
  - Extent of the habitat
  - Sea surface temperature
  - Biogeochemistry

  The figure below summarizes the input on this question from individual worksheets.

  Figure 5. Participant responses to attributes with most agreement



- *What are the attribute areas of greater disagreement that require further data or analysis?*

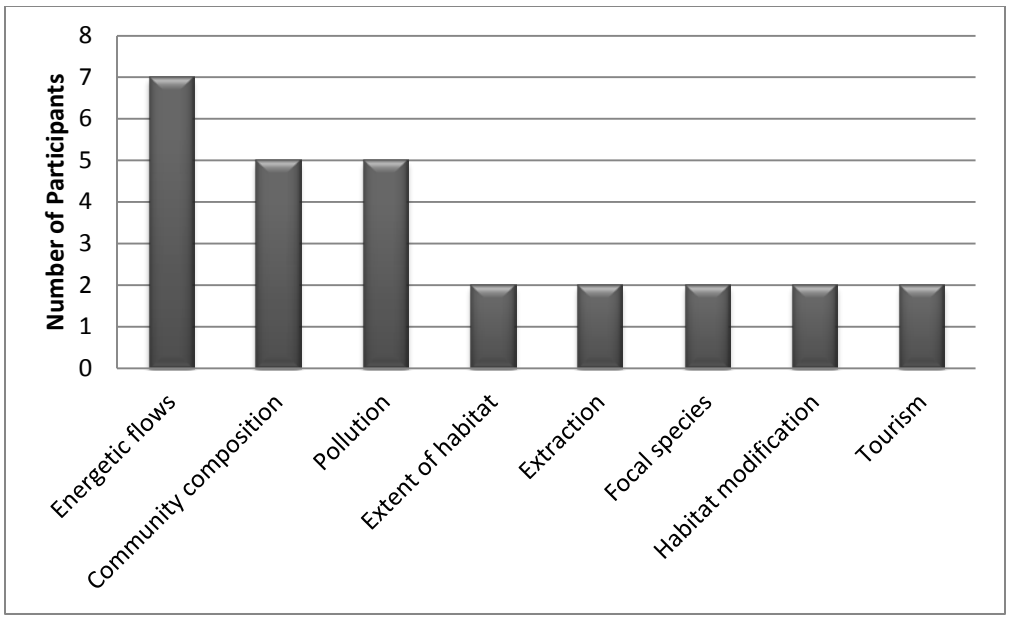
  Workshop participants found that solid scientific agreement may not be reached for attribute areas with insufficient data and that are not relevant to all ecosystems on the coast. These attribute areas include energetics and material flow, community composition, climate conditions, tourism, and pollution.

  Additionally, small groups identified the following unique results:
  - Energetics and material flows (deep sea cycles)
  - Ocean conditions (different kinds of upwelling events)

- Trampling (easy in small areas but difficult over large areas)
- Pollution (depends on species and toxicity levels)
- Diversity is difficult to measure
- Sediment movement

The figure below summarizes the input on this question from individual worksheets.

Figure 6. Participant responses to attributes with least agreement



Next Steps Discussion

- *What is the process we should use moving forward? How do we involve scientists in the development of ecosystem indicators for Washington's coast as we move forward? What are our best next steps?*

  Participants generally encouraged the state to continue to provide the opportunity for ongoing and in-depth feedback from scientists and managers on the development and selection of ecosystem indicators. At the same time, they were willing to defer much of work and recommendations to scientists such as on the weighting of criteria or quality of data for various indicators. They felt developing repository of materials would be helpful as would providing specific resources to help guide feedback (e.g. electronic, background materials and summary report from workshop).

  Participants expressed a need to continue contract with the NOAA Integrated Ecosystem Assessment team (NOAA Northwest Fisheries Science Center), establish a core group of people to work on indicators and provide opportunity for broader review from other groups. In addition, some felt bringing in graphic design expertise specific to

communicating with the public would help refine and optimize the information conveyed in the conceptual models.

Many participants felt it would be best to identify a core group of scientific experts across a range of disciplines to be the primary review group. They could be brought together remotely with conference calls and/or web technology (i.e. no need for in-person meetings) to work through more details for the indicators process.

Specific to the conceptual models, criteria and indicators, participants suggested doing a cumulative assessment across habitats and look for indicator redundancy – those that fill multiple needs. They also suggested exploring the tradeoffs of various data and data quality as well as the potential proxies for habitat modification.

Participants also suggested managers provide more depth on the predicted future drivers (human) to help constrain the conceptual models and indicators. In addition, they discussed the idea of using one piece to move through the whole process or selecting scenarios to help clarify how indicators fit with the problem statement as well as help focus additional needs (e.g. which habitats to focus on or whether there are other studies or research that might be useful).

Appendix: Workshop Materials

Potential indicators for seafloor habitats

Structural Element	Key Attribute	Indicator	Potential metrics
Habitat	Extent of habitat	Hard or mixed habitat	Areal coverage of hard or mixed habitat
		Biogenic habitat	Areal coverage of structure-forming invertebrates
Ecological components	Community composition	Diversity	Simpson diversity & Species richness (fish and inverts)
		Mean trophic level	Fish and invertebrates in bottom trawl survey
		Scavenger biomass	Biomass of scavengers (e.g., crabs, deposit feeders)
		Top predator biomass	Biomass of individuals with trophic level > 4.0
	Energetics & material flows	Productivity	Density/biomass of euphausiids
		Nutrient cycling	Dissolved nitrogen/phosphate concentrations
		Carbon cycling	Number of cycles
Physical drivers	Ocean conditions	Sea surface temperature	Pacific Decadal Oscillation (PDO)
		Upwelling	Spring Transition Index (STI)
	Biogeochemistry	Oxygen concentrations	Dissolved oxygen levels
		Ocean acidification	Aragonite saturation state
Human pressures	Biological extractions	Fishery/gathering removals	Commercial/recreational landings
	Habitat modification	Area disturbed	Area/distance disturbed by fishing gear, cable laying, and other benthic structures.
	Pollution	Pollutant concentrations	Heavy metals, inorganic/organic pollutants, nutrient runoff

Potential indicators for pelagic habitats

Structural Element	Key Attribute	Indicator	Potential metrics
Ecological components	Community composition	Diversity	Simpson diversity & Species richness (coastal pelagics, zooplankton, seabirds)
		Mean trophic level	Mid-water/surface species
		Northern copepod anomaly	Anomalies in the relative biomass of copepods with cold-water affinities
		Top predator biomass	Biomass of individuals with trophic level > 4.0
		Pinniped and seabird reproductive performance	Annualized # of pups/chicks
		Salmon smolt-adult survival	
	Energetics & material flows	Productivity	Remotely-sensed Chlorophyll a concentrations
		Nutrient cycling	Dissolved nitrogen/phosphate concentrations
		Carbon cycling	Number of cycles
Physical drivers	Ocean conditions	Sea surface temperature	Pacific Decadal Oscillation (PDO)
		Upwelling	Spring Transition Index (STI)
	Biogeochemistry	Oxygen concentrations	Dissolved oxygen levels
		Ocean acidification	Aragonite saturation state
Human pressures	Extractions	Fishery/gathering removals	Commercial/recreational landings
	Shipping activity	Areas disturbed	Spatial distribution/tracks of vessels.
	Pollution	Pollutant concentrations	Heavy metals, inorganic/organic pollutants, terrestrial nutrient runoff

Potential indicators for kelp forest habitats

Structural Element	Key Attribute	Indicator	Potential metrics
Habitat	Extent of habitat	Kelp forest cover	Areal extent of surface canopy
Ecological components	Community composition	Diversity	Simpson diversity & Species richness (fish and inverts)
		Mean trophic level	Fish and invertebrates in scuba surveys
		Scavenger biomass	Biomass of scavengers (e.g., crabs, deposit feeders)
		Top predator biomass	Biomass of individuals with trophic level > 4.0
	Energetics & material flows	Productivity	Kelp forest cover, Chlorophyll a concentration
		Nutrient cycling	Dissolved nitrogen/phosphate concentrations
		Carbon cycling	Number of cycles
	Focal species	Sea otter size & condition	Abundance and age structure
		Sea urchin size & condition	Density and size structure
Physical drivers	Ocean conditions	Sea surface temperature	Pacific Decadal Oscillation (PDO)
		Upwelling	Upwelling Index (UI)
		El Niño events	Northern Oscillation Index (NOI)
		Localized storms	Maximum wave height
	Biogeochemistry	Oxygen concentrations	Dissolved oxygen levels
		Ocean acidification	Aragonite saturation state
		Sedimentation	Sediment transport
Human pressures	Extractions	Fishery removals	Commercial/recreational landings
	Pollution	Pollutant concentrations	Heavy metals, inorganic/organic pollutants, nutrient runoff

Potential indicators for rocky shore habitats

Structural Element	Key Attribute	Indicator	Potential metrics
Habitat	Extent of habitat	Plant/algal cover	Areal extent of algae and surfgrass
		Habitat-forming inverts	Areal extent of mussel beds (spring, fall)
	Habitat composition	Substrate type	Diversity of substrate particle size (bench, boulder, rock, sand)
Ecological components	Community composition	Diversity	Simpson diversity & Species richness (algae and inverts)
		Mean trophic level	Benthic invertebrate density and stable isotope ratios
		Herbivore biomass	Biomass of grazers (e.g., urchins, limpets, chitons) (spring, fall)
		Suspension feeder biomass	Biomass of filter feeders (e.g., mussels, barnacles) (spring, fall)
	Energetics & material flows	Productivity	Surface Chlorophyll a
		Nutrient cycling	Dissolved nitrogen/phosphate concentrations
		Carbon cycling	Number of cycles
	Focal species	*Pisaster* pop. size & condition	Abundance and size structure (spring, fall)
Physical drivers	Ocean conditions	Sea surface temperature	Pacific Decadal Oscillation (PDO)
		Upwelling	Upwelling Index (UI)
		Sea surface height	Tidal gage data
	Biogeochemistry	Ocean acidification	Aragonite saturation state
	Climate conditions	Exposure stress	Biomass of filter feeders (spring, fall)
Human pressures	Habitat modification	Trampling	Shore attendance / visitation
	Pollution	Pollutant concentrations	Heavy metals, inorganic/organic pollutants, nutrient runoff

Potential indicators for sandy/gravel beach habitats

Structural Element	Key Attribute	Indicator	Potential metrics
Habitat	Extent of habitat	Plant/algal cover	Areal extent of wrack line
	Habitat composition	Substrate type	Diversity of substrate particle size (sand, gravel)
Ecological components	Community composition	Diversity	Simpson diversity & Species richness (inverts and fish)
		Suspension feeder biomass	Biomass of razor clams
		Scavenger biomass	Biomass of scavengers (e.g., sand fleas, crabs, deposit feeders)
		Seabirds	Seabird and shorebird diet
	Energetics & material flows	Productivity	Surface Chlorophyll a, Wrack deposition rate
		Nutrient cycling	Dissolved nitrogen/phosphate concentrations
		Carbon cycling	Number of cycles
Physical drivers	Ocean conditions	Sea surface temperature	Pacific Decadal Oscillation (PDO)
		Upwelling	Upwelling Index (UI)
		Sea surface height	Tidal gage data
		Wave energy	Slope of intertidal zone
	Biogeochemistry	Ocean acidification	Aragonite saturation state
Human pressures	Extractions	Fishery/harvest removals	Removals of razor clams, kelp
	Pollution	Pollutant concentrations	Heavy metals, inorganic/organic pollutants, nutrient runoff
	Sedimentation	Sediment (sand) input	Columbia River seasonal sediment export
	Tourism	Tourism revenue	GDP of tourism and recreation

Criteria used to evaluate potential indicators for the California Current Integrated Ecosystem Assessment

We follow the evaluation framework established by Levin et al. (2010a). We divide indicator criteria into three categories: primary considerations, data considerations, and other considerations. Ecosystem indicators should do more than simply document the decline or recovery of species or ecosystem health; they must also provide information that is meaningful to resource managers and policy makers (Orians and Policansky 2009). Because indicators serve as the primary vehicle for communicating ecosystem status to stakeholders, resource managers, and policy makers, they may be critical to the policy success of ecosystem-based management efforts, where policy success can be measured by the relevance of laws, regulations, and governance institutions to ecosystem goals (Olsen 2003). Advances in public policy and improvements in management outcomes are most likely if indicators carry significant ecological information and resonate with the public (Levin et al. 2010b).

Primary considerations (used in the Washington State Marine Spatial Planning evaluation)

Primary considerations are essential criteria that should be fulfilled by an indicator in order for it to provide scientifically useful information about the status of the ecosystem in relation to the key attribute of the defined goals. They are:

1. **Theoretically sound**: Scientific, peer-reviewed findings should demonstrate that indicators can act as reliable surrogates for ecosystem attributes.

2. **Relevant to management concerns**: Indicators should provide information related to specific management goals and strategies.

3. **Predictably responsive and sufficiently sensitive to changes in specific ecosystem attributes**: Indicators should respond unambiguously to variation in the ecosystem attribute(s) they are intended to measure, in a theoretically or empirically expected direction.

4. **Predictably responsive and sufficiently sensitive to changes in specific management actions or pressures**: Management actions or other human-induced pressures should cause detectable changes in the indicators, in a theoretically or empirically expected direction, and it should be possible to distinguish the effects of other factors on the response.

5. **Linkable to scientifically defined reference points and progress targets**: It should be possible to link indicator values to quantitative or qualitative reference points and target reference points, which imply positive progress toward ecosystem goals.

The remaining considerations and criteria are listed on the next page; we draw particular attention to the primary considerations here because they were the main basis by which the initial round of indicators was mapped onto the conceptual models we are presenting at the May 13th workshop.

Data considerations

Data considerations relate to the actual measurement of the indicator. Criteria are listed separately to highlight ecosystem indicators that meet all or most of the primary considerations, but for which data are currently unavailable. They are:

1. **Concrete and numerical**: Indicators should be directly measureable. Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments.

2. **Historical data or information available**: Indicators should be supported by existing data to facilitate current status evaluation (relative to historic levels) and interpretation of future trends.

3. **Operationally simple**: The methods for sampling, measuring, processing, and analyzing the indicator data should be technically feasible.

4. **Broad spatial coverage**: Ideally, data for each indicator should be available across a broad range of the California Current.

5. **Continuous time series**: Indicators should have been sampled on multiple occasions, preferably without substantial time gaps between sampling.

6. **Spatial and temporal variation understood**: Diel, seasonal, annual, and decadal variability in the indicators should ideally be understood, as should spatial heterogeneity and patchiness in indicator values.

7. **High signal-to-noise ratio**: It should be possible to estimate measurement and process uncertainty associated with each indicator, and to ensure that variability in indicator values does not prevent detection of significant changes.

Other considerations

Other considerations are meant to incorporate nonscientific information into the indicator evaluation process. Criteria may be important but not essential for indicator performance. They are:

1. **Understood by the public and policy makers**: Indicators should be simple to interpret, easy to communicate, and public understanding should be consistent with technical definitions.

2. **Historically reported**: Indicators already perceived by the public and policy makers as reliable and meaningful should be preferred over novel indicators.

3. **Cost-effective**: Sampling, measuring, processing, and analyzing the indicator data should make effective use of limited financial resources.

4. **Anticipatory or leading indicator**: A subset of indicators should signal changes in ecosystem attributes before they occur, ideally with sufficient lead time to allow for a management response.

5. **Lagging indicator**: Reveals evidence of a failure in or to the attribute.

6. **Regionally, nationally, and internationally compatible**: Indicators should be comparable to those used in other geographic locations, in order to contextualize ecosystem status and changes in status.

For the IEA, each indicator was evaluated independently according to these 18 criteria by examining peer-reviewed publications and reports. The result is a matrix of indicators and criteria that contains specific references and notes in each cell, which summarize the literature support for each indicator against the criteria. This matrix can be easily reevaluated and updated as new information becomes available.

Evaluation of indicators based on scores across the five "Primary considerations" criteria (highlighted values scored in the top quartile)

1. Population size for focal species

Monitoring population size in terms of total number or total biomass is important for management and societal interests. For example, abundance estimates are used to track the status of threatened and endangered species or other species of interest and help determine whether a species is recovering or declining. Accurate population biomass estimates of targeted fisheries species are used to assess stock viability and determine the number of fish that can be sustainably harvested from a region. While population size can be used to assess population viability, more accurate predictions of viability can be obtained by including the mechanisms responsible for the dynamics of the population. Population dynamics thus provide a predictive framework to evaluate the combined effect of multiple mechanisms of population regulation (e.g., birth and death rates, immigration, and emigration) to evaluate changes in abundance through time.

KEY ATTRIBUTE	INDICATOR	Sum of scores (5 is max)
Population size	Population numbers (using best method)	5
Population size	Population biomass (using best method)	5
Population size	Population growth rate	4.5
Population size	# groups < 40%; 25% spawning stock biomass (below/above recovery threshold)	4
Population size	Local Ecological Knowledge	4
Population size	Egg/larval abundance	3.5
Population size	Total harvest biomass; CPUE	2
Population size	Commercial landings biomass	2
Population size	Commercial landings numbers	2
Population size	Recreational landings biomass	2
Population size	Recreational landings numbers	2
Population size	Bycatch	0

2. Population condition for focal species

Whereas the preceding attribute is concerned with measures of population size, there are instances when the health of the population may be of interest. For example, monitoring changes in population condition may presage an effect on population size or provide insight into long-term population viability. The dynamics of many populations are better understood through knowledge of population conditions such as organism condition, age structure, genetic diversity, phenotypic diversity, and population structure. Impaired condition of any or all of these subcategories indicates biological resources at risk. In addition, monitoring changes in population condition can be used to infer changes in environmental conditions.

KEY ATTRIBUTE	INDICATOR	Sum of scores (5 is max)
Population condition	Age structure of populations	5
Population condition	Age at maturity	5
Population condition	Fecundity	5
Population condition	Spatial structure of population	5
Population condition	Mean length of species	5
Population condition	Genetic diversity of populations	4.5
Population condition	Size at maturity	4
Population condition	Condition factor (K)	4
Population condition	Rebuilding timeline	4
Population condition	Larval abundance	3.5
Population condition	Parasitic load	3.5
Population condition	Center of distribution (latitudinal or depth changes)	3
Population condition	Body growth	3
Population condition	Size structure of populations	2.5
Population condition	Cortisol/Vitellogenin	2
Population condition	Disease	2
Population condition	Diet	0

3. Community composition

This attribute represents the structure of the ecosystem, describing the individual components and the relative extent of their potential interactions. Our definition of community composition includes species diversity, trophic level diversity, functional group redundancy, and response diversity. Species diversity encompasses species richness or the number of species in the ecosystem, and species evenness or how individuals or biomass are distributed among species within the ecosystem (Pimm 1984). Trophic diversity refers to the relative abundance or biomass of different primary producers and consumers within the ecosystem (EPA 2002). Consumers include herbivores, carnivores or predators, omnivores, and scavengers. Functional redundancy refers to the number of species characterized by traits that contribute to a specific ecosystem function, whereas response diversity describes how functionally similar species respond differently to disturbance (Laliberte and Legendre 2010). For example, an ecosystem containing several species of herbivores would be considered to have high functional redundancy with respect to the ecosystem function of grazing, but only if those herbivorous species responded differently to the same perturbation (e.g., trawling) would the food web be considered to have high response diversity.

KEY ATTRIBUTE	INDICATOR	Sum of scores (5 is max)
Community composition (trophic level diversity)	Salmon smolt-adult survival rate (SAR)	5
Community composition (trophic level diversity)	Copepod species ratio (Cold vs. warm species)	5
Community composition (trophic level diversity)	Euphausiid biomass / richness	5
Community composition (functional redundancy)	Top predator B (trophic level > 4)	5
Community composition (trophic level diversity)	Proportion noncommercial species (unfished groups)	5
Community composition (trophic level diversity)	Pinniped annual reproductive performance	4.5
Community composition (trophic level diversity)	Crustaceans - Catch/Survey trends; larval surveys	4.5
Community composition (trophic level diversity)	Benthic invertebrate B	4.5
Community composition (trophic level diversity)	Zooplankton abundance/biomass	4.5
Community composition (species diversity)	Simpson Diversity	4.5
Community composition (species diversity)	Shannon Diversity	4.5
Community composition (species diversity)	Kempton's Q diversity	4.5
Community composition (functional redundancy)	Scavenger biomass	4.5

KEY ATTRIBUTE	INDICATOR	Sum of scores (5 is max)
Community composition (trophic level diversity)	Mean length, all species	4.5
Community composition (trophic level diversity)	Pinniped contaminant load	4
Community composition (trophic level diversity)	Forage fish biomass; species status & trends	4
Community composition (trophic level diversity)	Groundfish status & trends	4
Community composition (trophic level diversity)	Flatfish biomass	4
Community composition (trophic level diversity)	Zooplanktivorous fish biomass	4
Community composition (trophic level diversity)	Piscivorous fish biomass	4
Community composition (trophic level diversity)	Roundfish biomass	4
Community composition (trophic level diversity)	Demersal fish biomass	4
Community composition (trophic level diversity)	Pelagic fish biomass	4
Community composition (trophic level diversity)	Rockfish biomass	4
Community composition (trophic level diversity)	Juvenile rockfish index	4
Community composition (trophic level diversity)	Juvenile hake abundance	4
Community composition (trophic level diversity)	Salmon adult escapement	4
Community composition (trophic level diversity)	Seabird annual reproductive performance	4
Community composition (trophic level diversity)	Seabird diet (fatty acids, stable isotopes)	4
Community composition (trophic level diversity)	Jellyfish biomass; status and trends	4
Community composition (trophic level diversity)	Biodiversity Index (Hurlbert's Delta)	4
Community composition (trophic level diversity)	Taxonomic distinctness (average and variation in)	4
Community composition (trophic level diversity)	Number of Threatened Species (IUCN A1 criteria as modified by Dulvy et al 2006)	4

KEY ATTRIBUTE	INDICATOR	Sum of scores (5 is max)
Community composition (trophic level diversity)	Mean Trophic Index / Mean Trophic Level	4
Community composition (functional redundancy)	Detritivore biomass	4
Community composition (functional redundancy)	Herbivore biomass	4
Community composition (trophic level diversity)	Forage fish / jellyfish ratio	4
Community composition (trophic level diversity)	Piscivorous/Zooplanktivorous fish ratio	4
Community composition (trophic level diversity)	Pelagic / demersal fish ratio	4
Community composition (trophic level diversity)	Invertivore/Herbivore ratio	4
Community composition (trophic level diversity)	Finfish / Crustacean Biomass Ratio	4
Community composition (trophic level diversity)	Marine shorebird species status and trends	3.5
Community composition (functional redundancy)	Invertivore biomass	3.5
Community composition (trophic level diversity)	Trophic level of catch (Mean Biomass)	3.5
Community composition (trophic level diversity)	Cetacean species status & trends	3
Community composition (trophic level diversity)	Pinniped abundance / population trends	3
Community composition (trophic level diversity)	Pinniped biomass	3
Community composition (trophic level diversity)	Pinniped diet (fatty acids, stable isotopes)	3
Community composition (trophic level diversity)	Pinniped disease, death, mortality, bycatch	3
Community composition (trophic level diversity)	Marine seabird species status & trends	3
Community composition (trophic level diversity)	Seabird biomass	3
Community composition (trophic level diversity)	Seabird disease, death, mortality, bycatch	3
Community composition (trophic level diversity)	Squid - Humboldt	3

KEY ATTRIBUTE	INDICATOR	Sum of scores (5 is max)
Community composition (trophic level diversity)	Zooplankton/Phytoplankton ratio	3
Community composition (trophic level diversity)	Rockfish / Flatfish ratio	3
Community composition (trophic level diversity)	Slope size spectrum, all species	3
Community composition (trophic level diversity)	Integrative marine mammal index (multivariate)	2.5
Community composition (trophic level diversity)	Seabird contaminant load	2.5
Community composition (trophic level diversity)	Integrative seabird index (multivariate)	2.5
Community composition (trophic level diversity)	Total catch / Landings of target species	2.5
Community composition (trophic level diversity)	Total fishery removals of all species (bycatch as well)	2.5
Community composition (trophic level diversity)	Sea turtle status & trends	2
Community composition (trophic level diversity)	Total fishery removals of all species	2
Community composition (trophic level diversity)	Pinniped stress hormones	1.5
Community composition (trophic level diversity)	Seabird stress hormones	1.5
Community composition (trophic level diversity)	Coastal oyster condition index (WA)	0
Community composition (trophic level diversity)	Shellfish (bivalves - mussels, clams, oysters)	0

4. Energetics and material flows

This attribute represents ecosystem function and includes ecological processes such as primary production and nutrient cycling, in addition to flows of organic and inorganic matter throughout an ecosystem. Primary productivity is the capture and conversion of energy from sunlight into organic matter by autotrophs, and provides the fuel fundamental to all other trophic transfers throughout the ecosystem. Material flows, or the cycling of organic matter and inorganic nutrients (e.g., nitrogen, phosphorus), describe the efficiency with which an ecosystem maintains its structure and function.

KEY ATTRIBUTE	INDICATOR	Sum of scores (5 is max)
Energetics and Material Flows	Carbon cycling – number of cycles	5
Energetics and Material Flows	Production – phytoplankton biomass	4.5
Energetics and Material Flows	Production – Chlorophyll a	4.5
Energetics and Material Flows	Nutrient cycling – nutrient levels (dissolved inorganic nitrogen, silicate, phosphate, iron, etc...)	4.5
Energetics and Material Flows	Carbon cycling – respiration rate	3
Energetics and Material Flows	Carbon cycling – microbial decomposition / respiration rates	2.5
Energetics and Material Flows	Nutrient cycling – Nitrogen fixation rate, Nitrification/ denitrification rate, 15N ratios	2
Energetics and Material Flows	Nutrient cycling – Stratification - temperature, salinity; Thermocline depth	0.5
Energetics and Material Flows	Oxidation rate	0
Energetics and Material Flows	Carbon cycling – Particulate Organic matter (POM), Dissolved organic carbon (DOC)	0

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