Ocean Climate Indicators Workshop

August 27, 2012
San Francisco, CA

MEETING SUMMARY

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Cover Photo: Rocky shoreline just north of Año Nuevo.
Credit: Steve Lonhart, NOAA MBNMS

Table of Contents

Executive Summary

On August 27, 2012, thirty-six regional scientists and managers attended the invitation-only Ocean Climate Indicators Workshop to **provide input on physical and biological climate change indicators for the North-central California coastal region, from Bodega Head to Año Nuevo.** The workshop was a vital step in the two-year Ocean Climate Indicators Project.

Prior to the workshop, attendees (and 16 additional experts) completed an Indicators Survey to help rank a set of candidate physical and biological climate change indicators. Survey results formed the foundation for breakout group discussions at the workshop. Each breakout group *recommended* a set of priority indicators and assessed the *strengths, weaknesses, and potential data sources* for each. Indicators that were recommended by at least 3 breakout groups will be the focus of further evaluation.

Highest Priority Physical Climate Change Indicators:

⇒ Sea Surface Temperature
⇒ Sea Surface Salinity
⇒ Sea Level (mean and/or extreme)
⇒ Wave Height (mean and/or extreme)
⇒ Ocean Acidification (pH)
⇒ Dissolved Oxygen
⇒ Air Temperature (possibly other atmospheric measurements such as humidity and insolation)
⇒ Wind (alongshore or as part of an index)

Highest Priority Biological Climate Change Indicators:

⇒ Primary Productivity (Chlorophyll a, Phytoplankton Biomass, and/or Community Index)
⇒ Mid-Trophic Level Species Abundance, Biomass, and/or Phenology
  - Zooplankton
  - Macroinvertebrates
⇒ Aerial Extent of Habitat-Forming Organisms (e.g., Seagrass and Mussel Beds)
⇒ Seabird Diet, Foraging Effort, Breeding Success, and Timing of Breeding

Next Steps:

Utilizing the valuable input provided through the survey and workshop, the next steps of the Ocean Climate Indicators Project include:

1. Assess the relative strength and importance of the recommended climate change indicators with:
   a. Analysis of existing observations
   b. Regional climate model experiments

2. Finalize a set of physical and biological climate change indicators (by the end of January 2013).

3. Create two indicator reports: one outreach report for management and a detailed report for publication in a peer-reviewed scientific journal (by the end of March 2013).

4. Form a working group to:
   a. Define monitoring goals for the study region.
   b. Develop monitoring strategies based on the final indicators.
   c. Determine implementation timelines, partners, and funding requirements for each indicator.

5. In collaboration with the working group, finalize a monitoring plan and inventory that includes the goals, strategies, and implementation plan for each climate change indicator (by the end of September 2013.

Introduction

Impacts of climate change have been observed in physical and biological components of the North-central California coast, from Bodega Head in the north to Año Nuevo in the south. To better monitor, adapt to, and mitigate these impacts, the Gulf of the Farallones National Marine Sanctuary (GFNMS) is leading the two-year Ocean Climate Indicators Project in partnership with the U.S. Geological Survey (USGS). The project is focused on the development of climate change indicators for this region. Climate change indicators are measurable variables that can be used to determine the strength and impact of climate change in a region, and they can be physical (e.g. sea level or sea surface temperature) or biological (e.g. primary productivity or species phenology).

Although the project is based at GFNMS, advisors are scientists and managers from USGS, UC Davis Bodega Marine Laboratory, and Scripps Institution of Oceanography. This work is also a Bay Area Ecosystem Climate Change Consortium (BAECCC)-affiliated project, which ensures that there is coordination with agencies and organizations around the San Francisco Bay Area. Additional input is provided by regional scientists and managers that represent numerous universities, organizations, and regional, state, and federal agencies.

The Ocean Climate Indicators Project is part of the Postdocs Applying Climate Expertise (PACE) postdoctoral fellowship program, which is administered by the University Corporation for Atmospheric Research (UCAR) with significant funding from the NOAA Climate Program Office. The project extends from September 2011 – September 2013.

Key goals of the Ocean Climate Indicators Project are to:

- Create a set of clearly defined physical and biological indicators for climate change off the North-central California coast.
- Use collaboration with partner scientists, together with numerical computer modeling and data analysis, to maximize confidence in the chosen indicators and to increase the likelihood that regulators will adopt the indicators.
- Create an outreach summary report for management and a detailed report for publication in a peer-reviewed scientific journal.
- Form a working group to:
  - Define indicator monitoring goals for the study region.
  - Incorporate the climate change indicators into a collaborative monitoring inventory and plan that tracks the vulnerability of resources in the study region to climate change.

The Ocean Climate Indicators Workshop was organized with regional research scientists and decision-makers to collaboratively evaluate a pre-screened set of candidate physical and biological climate change indicators. The recommended priority indicators that resulted from the workshop will be further assessed before determining the final climate change indicators.

Workshop Goals

1. Reduce a list of candidate physical and biological candidate climate change indicators to a smaller set of recommended indicators.
2. Determine existing sources of data for the recommended indicators.

Workshop Structure

The Ocean Climate Indicators Workshop was held on August 27, 2012 at the Golden Gate Club in the Presidio of San Francisco, CA. Thirty-six regional research scientists and managers attended this invitation-only workshop. Prior to the workshop, thirty-five of the workshop attendees and sixteen other experts who could not attend the workshop completed an Indicator Survey to assess the relative importance of a set of candidate physical and biological climate change indicators.

After initial informational presentations to provide management context, attendees assembled into four pre-assigned breakout groups. Results from the Indicator Survey formed the foundation for breakout group discussions, during which each group determined priority physical and biological climate change indicators for further evaluation. Each breakout group intentionally included members with a variety of backgrounds and expertise to facilitate comprehensive discussions about the survey results.

These discussions were documented by note-takers in each breakout group. At the end of the breakout group discussions, each group presented their priority physical and biological climate change indicators. See Appendix A for the full workshop agenda and Appendix B for a list of workshop attendees and survey respondents.

Indicator Survey

Indicator Survey questions were created from the Indicator Selection Criteria, which was developed in close consultation with GFNMS management, project advisors, and other regional experts. The questions were intended to assess the relative strength of the most promising candidate physical and biological climate change indicators. Indicators were included in the survey after project advisors reviewed a list of over 100 candidate climate change indicators and identified the survey indicators as being particularly promising

Each survey question asked respondents to indicate their level of agreement with a set of statements, and the same statements were repeated for each candidate indicator. Each level of agreement was associated with a point value, with the exception of a "not sure" option, which was available for respondents who did not feel qualified to assess a given indicator or statement, or who felt that knowledge is inadequate to make assessment. Respondents were also invited to suggest additional physical and biological climate change indicators that they felt should have been considered in the survey. See Appendices C and D, respectively, for candidate climate change indicators that were included in the survey and the Indicator Survey questions.

Results from the Indicator Survey were used to create separate ranked lists of the physical and biological climate change indicators. Generally, indicators ranked low in ease of data collection, availability of existing data or potential for new data, and presence of proxies to provide sufficient information about each indicator. Some respondents without management experience were unsure about management actions that could be informed by changes in the candidate indicators. See Appendix E for complete survey results.

Informational Presentations

Introductory presentations served to provide management context for the climate change indicators, to provide an overview of the Ocean Climate Indicators Project, and to present the Indicator Survey results. Each presentation is summarized below and can be found on the workshop website at:
https://sites.google.com/site/gfnmsclimatechangeindicators/workshop/workshop-presentations

Management Context of Ocean Climate Indicators
Maria Brown, GFNMS Superintendent
Maria provided an overview of the legal authority and management obligations of GFNMS, and the ecological and economic significance of the North-central California coastal region. She also gave examples of how managers will likely use the climate change indicators.

Ocean Climate Indicators Project Overview
Benét Duncan, GFNMS
Benét gave a brief overview of the two-year Ocean Climate Indicators Project, presented a flowchart outlining each step of the project, and discussed the workshop goals and breakout group format.

Indicator Survey Results
Benét Duncan, GFNMS
Benét provided a review of the Indicator Survey questions and presented the survey results. Graphs showed the average survey score for each physical and biological indicator, and additional graphs showed the number of times that any additional indicators were suggested by respondents.

Breakout Groups

Following the morning informational presentations, workshop attendees divided into four pre-determined breakout groups, each with a mix of biological oceanographers, physical oceanographers, ecologists, and managers. Each breakout group was led by a designated facilitator, who ensured that the group discussed the Indicator Survey results and identified the most promising physical and biological climate change indicators.

To help focus discussions, breakout group facilitators were given the following set of optional questions to consider:

- Does the group agree with the order of ranking for the indicators?
- Does the group feel that any of these indicators should not be further considered?
- Do any of the "additional potential indicators" suggested in the Indicator Survey comments merit further discussion, or would the group prefer to not consider these? If additional indicators should be considered, evaluate them using the Indicator Survey questions.
- Do the indicators apply across multiple habitats, or do they only apply to specific habitats?
- Are the indicators realistic for what can be monitored?
- How feasible is it to monitor the indicator in the future?
- What is the relative importance of the indicator?

After deciding on the most promising physical and biological indicators, breakout groups were asked to answer the following questions:

- What are key strengths of each of the most promising indicators? Do they meet certain Indicator Survey statements especially well?
- What are key weaknesses of each of the most promising indicators? Do they fail to meet certain Indicator Survey statements?
- What are key sources of data for each of the most promising indicators? Are new data sources needed?

See Appendix F for a breakdown of the indicators recommended by each breakout group.

Consensus – Priority Indicators

Following the breakout group discussions, a representative from each group presented their recommended indicators. Indicators that were recommended by at least three of the four breakout groups were identified as broadly supported and will be the focus of future analysis. The final set of climate change indicators will come from these recommended indicators, or from the other climate change indicators that received support from multiple groups (Appendix F).

All groups agreed that biological indicators should be distributed across trophic levels, but the specific target taxa varied among groups depending on the habitat expertise represented in each group.

At least three breakout groups recommended the following priority physical and biological climate change indicators:

Physical Indicators:

- Sea Surface Temperature (3 groups)
- Sea Surface Salinity (3 groups)
- Sea Level (mean and/or extreme) (4 groups)
- Wave Height (mean and/or extreme) (4 groups)
- Ocean Acidification (pH) (3 groups)
- Dissolved Oxygen (3 groups)
- Air Temperature (3 groups) – possibly other atmospheric measurements such as humidity and insolation)
- Wind (alongshore or as part of an index) (3 groups)

Biological Indicators:

- Primary Productivity (Chlorophyll A, Phytoplankton Biomass, and/or Community Index) (4 groups)
- Mid-Trophic Level Species Abundance, Biomass, or Phenology (3 groups)
    - Zooplankton
    - Macroinvertebrates
- Aerial Extent of Habitat-Forming Organisms (i.e. Seagrass and Mussel Beds) (4 groups)
- Seabird Diet and/or Foraging Effort (3 groups) and Timing and Success of Breeding (4 groups)

Some workshop attendees emphasized the importance of carefully considering the timescale that management is concerned with to ensure that indicators are useful in making management decisions, and to use caution in directly attributing changes in an indicator to anthropogenic global climate change.

Next Steps

Utilizing the valuable input provided at the Ocean Climate Indicators Workshop, the priority next steps of the project include:

1. Gather available observational datasets for the priority climate change indicators.
2. Evaluate existing observational datasets to assess:

   a. The quality and availability of long-timescale data for an indicator.
   b. Any needed improvements in long-timescale data for an indicator.
   c. Observed long-term trends in an indicator, if available.
3. Determine which, if any, regional climate models have output that is available for further analysis.
4. Utilize statistical downscaling of output from larger (spatial) scale climate models to evaluate:
   a. Predictions of future changes in the priority physical indicators.
   b. The strength of a priority physical indicator's response to changing climate.
5. Finalize the set of physical and biological climate change indicators by the end of January 2013.
6. Develop indicator reports for management and for publication in a peer-reviewed scientific journal.
7. In consultation with a working group of regional scientists and managers, develop a comprehensive monitoring inventory and plan that incorporates the final physical and biological climate change indicators by September 2013.

Appendix A: Ocean Climate Indicators Workshop Agenda

Goals:

1. Reduce list of candidate physical and biological climate change indicators to a smaller set of finalist indicators.
2. Determine existing sources of data for climate change indicators.

Agenda:

8:30am-9:00am: Registration and refreshments

9:00am-9:45am: Workshop Begins

- Welcome
- Provide management context for indicators (Maria Brown, GFNMS Superintendent)
- Brief introductions
- Project overview
- Review meeting goals, agenda, and expectations for participants

9:45am-10:00am: Present survey results

10:00am-10:10am: Break - Divide into pre-assigned breakout groups

10:10am-11:45pm: Within breakout groups:

- Choose to discuss survey results about either physical or biological indicators. If physical indicators are the focus of discussions in the morning, the group will focus on biological indicators in the afternoon, and vice versa.
- Discuss if the group agrees on the order of ranking for the indicators.
- If additional indicators should be further considered (based on write-in option from Indicator Survey), complete survey questions for them.
- Decide on a list of the top 5-8 indicators.
- Discuss strengths, weaknesses, and data availability of the top indicators.

11:45pm-12:30pm: Lunch (provided)

12:30pm-1:50pm: Within groups:

Repeat the morning's discussions for whichever category of indicators was not discussed in the morning. If physical indicators were already discussed, then consider biological indicators in the afternoon, or vice versa.

1:50pm-2:00pm: Break - Reassemble in full group

2:00pm-3:15pm: Discuss each group's final list of indicators in full group

3:15pm-3:30pm: Wrap up

Appendix B: Ocean Climate Indicators Workshop Attendees & Respondents

Workshop Attendees

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Appendix C: Candidate Climate Change Indicators

The following candidate climate change indicators were included in the Indicator Survey. Respondents were asked to answer each Survey Question (below) for each of these candidate indicators. At the end of the survey, respondents were invited to suggest additional indicators that they felt should be considered at the Ocean Climate Indicators Workshop.

Candidate Physical Indicators:

1. Sea Level
2. Sea Surface Temperature
3. Air Temperature
4. Alongshore Wind Speed
5. Extreme and Mean Wave Height
6. Fog Frequency
7. Precipitation
8. Water Column Stratification, as measured by the temperature difference between the surface and the base of the 50m isobath.
9. Dissolved Oxygen at the base of the 50m isobath (used as a measure of upwelling).
10. Depth of the Oxygen Minimum Zone (used as a measure of upwelling).

Candidate Biological Indicators:

1. Ocean Water pH
2. Krill Abundance
3. Zooplankton Biomass
4. Phytoplankton Phenology, as measured by the timing of peak phytoplankton biomass.
5. Bull Kelp Spatial Extent and Relative Abundance
6. Timing of Seabird Breeding
7. Seabird Reproductive Success
8. Larval Recruitment
9. Shell Thickness of Calcifying Invertebrates
10. Relative Abundance of Calcifying Invertebrates
11. Primary Productivity
12. Abundance of Rocky Intertidal Macroinvertebrates
13. Tidal Height Distribution of Rocky Intertidal Macroinvertebrates

Appendix D: Indicator Survey Overview

The following questions were created from the Indicator Selection Criteria (see above), and are intended to assess the relative strength of a set of candidate physical and biological climate change indicators.

Survey Questions:
Indicate your level of agreement with the following questions (Strongly Agree, Agree, Disagree, Strongly Disagree, or Don't Know):
General Importance of Indicator:

1. Changes in this indicator will result in identifiable changes to the ecosystem.
2. Changes in this indicator can inform management actions by GFNMS and other regional managers.

Scale, Statistical Properties, and Reliability of Indicator Data:

3. Changes in this indicator can be detected at a spatial resolution appropriate to the study region.
4. Changes in this indicator due to climate change can be detected above the "noise" of other environmental variability.

Indicator Data Characteristics:

5. Reliable measurements of this indicator exist, or new information can be collected to develop reliable measurements of this indicator.
6. If measurements of this indicator are difficult to obtain, other datasets (i.e. proxies) could provide sufficient information about this indicator.
7. Data for this indicator can be collected without extensive training or specialized knowledge.

Survey Scoring:
All questions were asked for 10 candidate physical indicators and 13 candidate biological climate change indicators. These candidate indicators were chosen by project advisors from a large set of approximately 50 physical and 50 biological indicators.

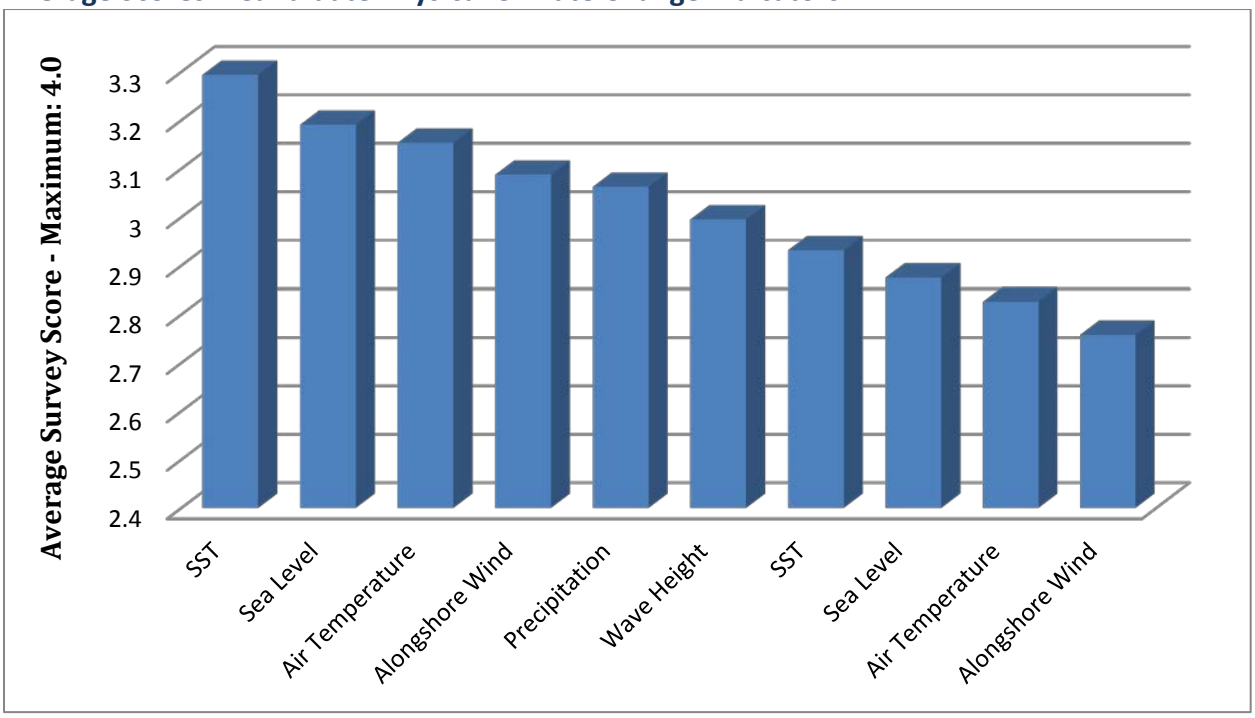
Point values were assigned to each possible level of agreement:
Strongly Agree – 4 points
Agree – 3 points
Disagree – 2 points
Strongly Disagree – 1 point
Don't Know – 0 points

The average score for each indicator was calculated as the average of all survey question scores for that indicator, taken over all survey respondents, with answers of "Don't Know" excluded from the averaging process.

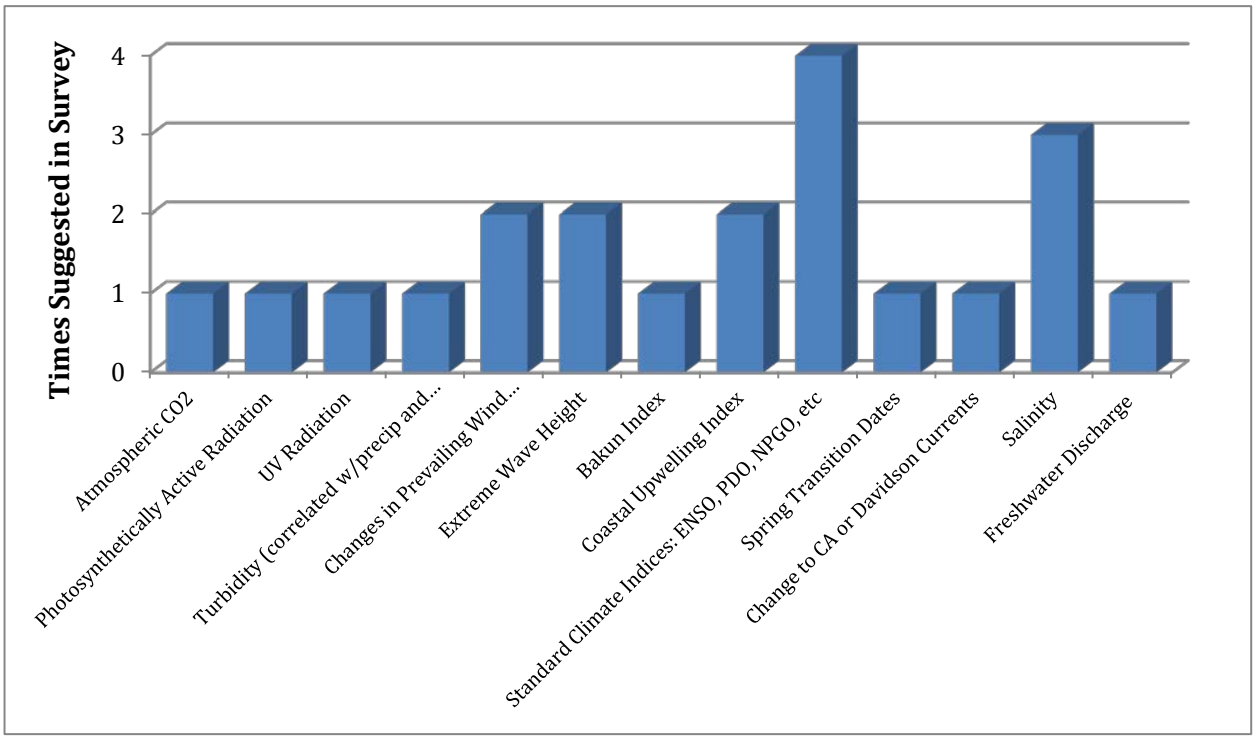
Appendix E: Indicator Survey Results

Candidate climate change indicators were ranked according to their average Indicator Survey scores. These scores, and the number of times that additional indicators were suggested by respondents, are presented in the graphs below.

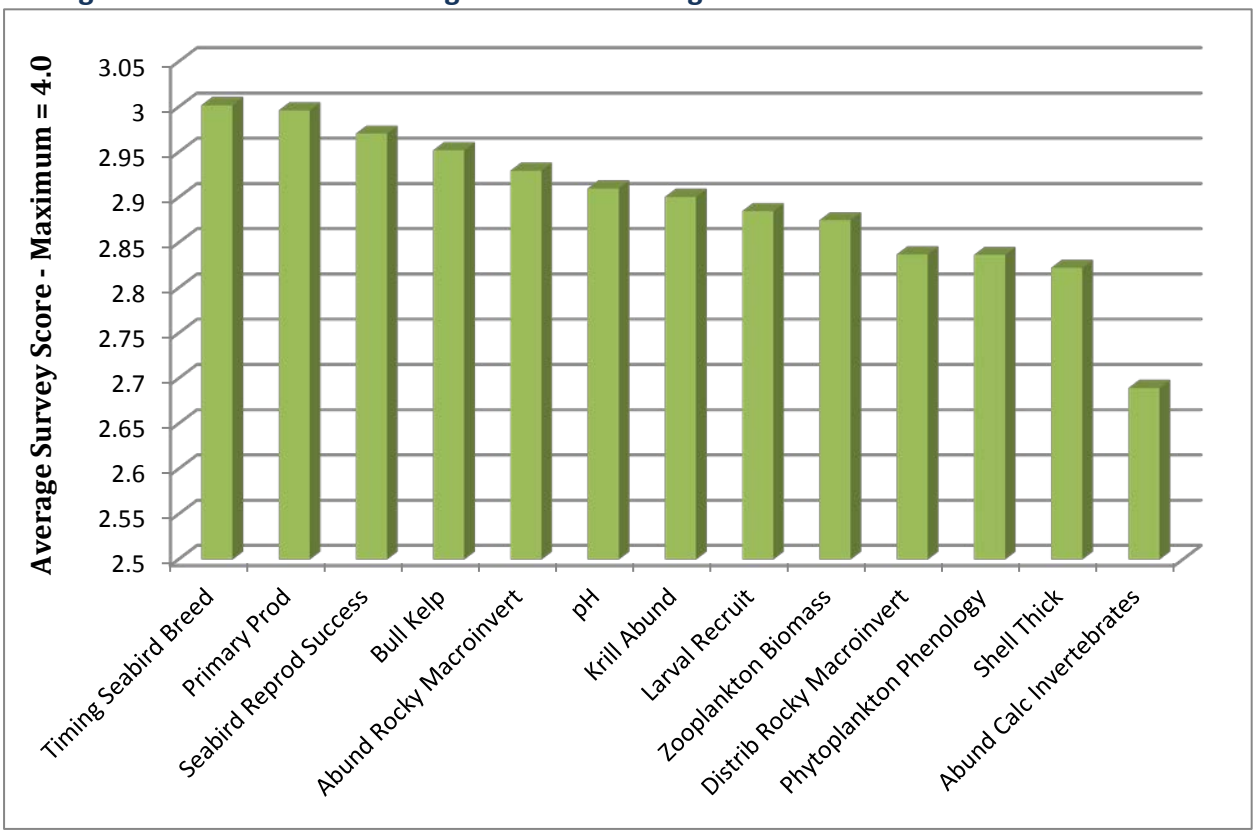
Average Scores – Candidate Physical Climate Change Indicators



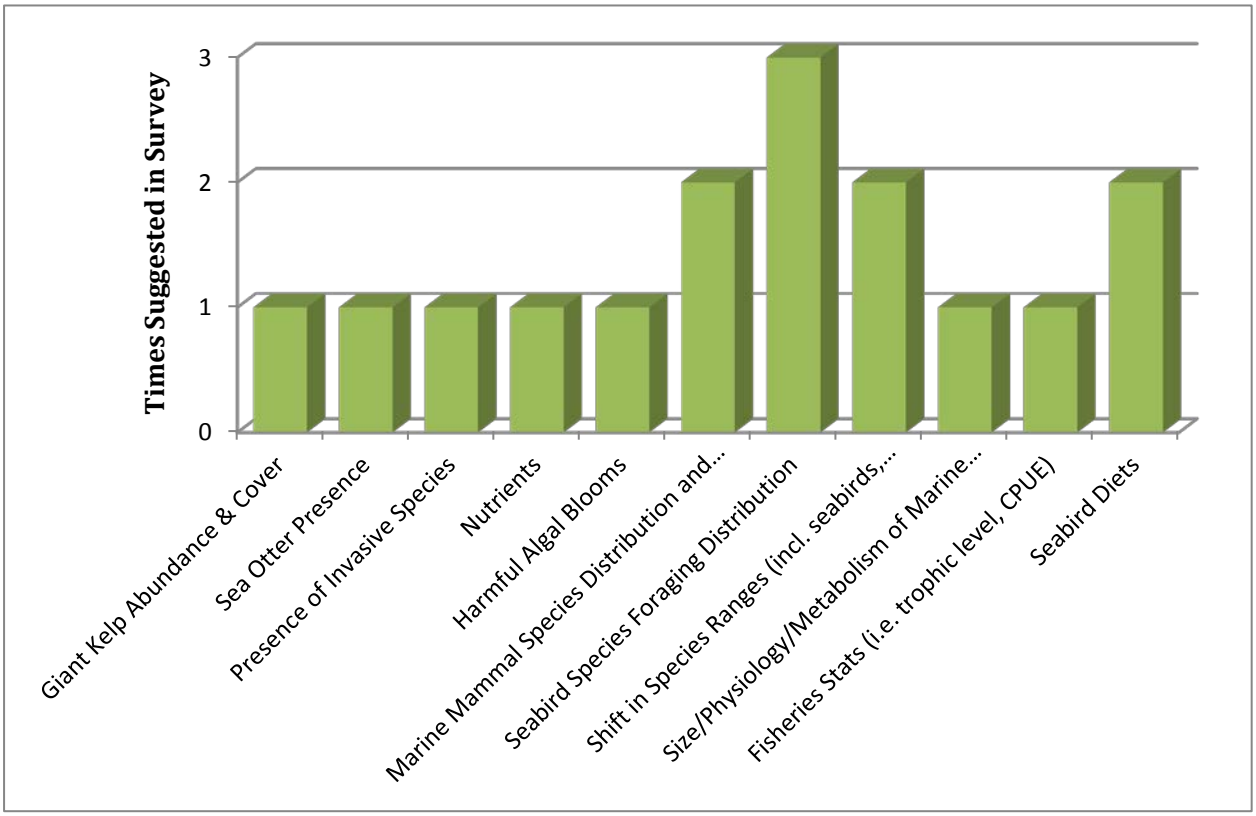
Additional Suggested Physical Climate Change Indicators



Average Scores – Candidate Biological Climate Change Indicators



Additional Suggested Biological Climate Change Indicators



Appendix F: Ocean Climate Indicators Workshop Results

The tables below summarize the priority physical and biological climate change indicators from the Ocean Climate Indicators Workshop breakout group discussions. Indicators that were recommended by three or more groups were considered to demonstrate consensus, and will be the focus of future analysis.

***Biological* Indicators**	**Recommended By (Group #)**	**Additional Notes**
Primary Productivity	1,2,3,4	Group 1: Especially pelagic habitat Group 2: Rate of productivity or biomass of algae or phytoplankton Group 3: Chlorophyll A or algae composition, possibly harmful algal blooms Group 4: Chlorophyll A
Seabird Reproductive Success	1,2,3,4	Group 1: Recommend combine all seabird indicators (reproductive success, timing of breeding, and diet/foraging) into an index, especially for pelagic birds.
Timing of Seabird Breeding	1,2,3,4	
Aerial Extent of Habitat-Forming Organisms	1,2,3,4	Group 1: Especially for intertidal habitats Group 3: As kelp abundance and spatial coverage Group 4: As macroalgae aerial surveys
Seabird Diet/Foraging Effort	1,2,4	Group 2: As part of seabird phenology, can also include nesting, migration, and recruitment.
Mid trophic level species abundance and/or distribution	2,3,4	Groups 3 and 4: Zooplankton abundance, biovolume, and/or species composition; Macroinvertebrate abundance, diversity, distribution, and/or presence of invasive species
Shell thickness and/or abundance of calcifying invertebrates	1,2	Group 2: As part of reproductive success of invertebrate recruitment
Species migration (latitudinal and by elevation)	1	Group 1: Especially intertidal habitat
Marsh and shorebird reproductive success	1	Group 1: Especially intertidal habitat
Marsh and shorebird predation	1	Group 1: Especially intertidal habitat
Blue whale distribution and timing	1	Group 1: Secondary recommendation, less important than others.
Upper trophic level species abundance (bird, mammal, or fish)	2	
Wild Cards – unexpected indicators that may come up in the future	2	Group 2: Example – gelatinous zooplankton in pelagic environments
pH	4	This indicator was originally placed in the list of Biological Indicators. The other three groups chose to move it to the list of Physical Indicators.

***Physical* Indicators**	**Recommended By (Group #)**	**Additional Notes**
Sea Level (mean and extreme)	1,2,3,4	Group 4: Consider sea surface height and coastal sea level
Wave Height (mean and extreme)	1,2,3,4	
Ocean Acidification (pH)	1,2,3	Group 2: Can consider this as part of a set of biogenic water properties
Dissolved Oxygen/Hypoxia	1,2,3	Group 2: Can consider this as part of a set of biogenic water properties
Air temperature	1,2,4	Group 1: Secondary recommendation, less important than others. Group 2: Can be part of a set of observations from standard meteorological station, including humidity and radiation.
Water temperature and salinity	2,3,4	
Wind	2,3,4	Group 2: Consider as part of a general index. Most specific effects are addressed by specific indicators. Group 4: Especially alongshore wind
Stratification	1,3	Group 1:Can be an index
Basin-scale indices (ENSO, PDO, NPGO)	1,4	Groups 1 and 4: Secondary recommendation, less important than others.
PAR – indicator of change in cloud cover	1,4	Groups 1 and 4: Secondary recommendation, less important than others.
Upwelling index	1	Group 1: This already exists
Insolation index	1	Group 1: To include fog, air temperature, and sunlight in intertidal, terrestrial, and estuarine habitats.
Timing of spring transition	1	Group 1: Secondary recommendation, less important than others.
Estuary sedimentation rate	1	Group 1: Secondary recommendation, less important than others.
Morphology	2	Group 2: Especially beach and estuarine habitats
Transport	2	Group 2: Due to currents and mixing
Freshwater discharge	3	Group 3: Instead of precipitation
Precipitation	4	
Retrospective indicator to put changes in physical state into understanding of ecosystem change	4	Group 4: This is used in fisheries management. Secondary recommendation, less important than others.