Establishing Science-based Indicators for California's Oceans and Coasts

Recommendations to the Ocean Protection Council (OPC) from the

OPC Science Advisory Team

February 2024

About this Document

This report was produced by the California Ocean Science Trust (OST) and details scientific advice and recommendations from the Ocean Protection Council Science Advisory Team (SAT). The SAT was convened by OST on behalf of the California Ocean Protection Council (OPC) from April to October 2023.

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Introduction

The Ocean Protection Council (OPC) Strategic Plan goal 3.6.1 calls for the development of indicators for use in a State of California's Coast and Ocean Report Card by 2025 (hereafter referred to as Report Card). To address this need, the Ocean Science Trust (OST) convened the OPC Science Advisory Team (SAT) over the past year to provide recommendations, using best available science, for a suite of indicators that can annually provide insight into the health of California's coast and ocean. Recognizing the end goal of use in an annual report card, the intent is for these indicators to be both policy-relevant and scorable, when appropriate and feasible. While not necessarily tied to specific Strategic Plan objectives or targets, the indicators are necessarily broadly relevant to the priorities in the OPC Strategic Plan.

This report describes the SAT's combined recommendations for individual indicators for use in the Report Card. Collectively, these indicators are intended to reflect important aspects of California's many ocean and coastal features, including our state's diverse ecosystems and multitude of human uses. Importantly, these recommendations do not touch on a scoring approach necessary for the Report Card; making sense of data and trends for each, in a scientifically rigorous way, will require different approaches and considerations per indicator, and shall be explored and established beginning in 2024.

In addition to the indicator recommendations themselves, this report also describes the process taken to develop this list, highlights important science-based considerations for the development and, especially, interpretation of any indicator effort, and raises important questions for the state to consider in framing the goals of this initiative.

Key Recommendations

To support the development of the 2025 State of California's Coast and Ocean Report Card (Report Card), the Ocean Protection Council Science Advisory Team (SAT) established the following recommendations to develop science-based ocean and coastal indicators that will form the basis of the Report Card:

- Adapt the NOAA Coral Reef Monitoring Program (NCRMP) approach to develop indicators for California (Table E1);
- Adapt the West Coast Ocean Alliance (WCOA) approach as a starting indicator framework and align with ongoing West Coast efforts;
- Consider adopting the following suite of indicators as collectively representative of status and trends for California's coast and ocean health (Table E2);
- Develop additional climate-informed and policy-informed indicators, which will focus on the human-ecosystem nexus of climate change-driven impacts and track policy response and progress, respectively;
- Conduct routine human well-being surveys or other robust social scientific assessments to understand the importance of other indicators to coastal communities and to capture essential qualitative information to be integrated into the Report Card; and
- Beginning in 2024, explore opportunities to to fully develop, refine, and score indicators according to the following recommendations:
    - Establish thresholds for each indicator
    - Assess data availability, quality, and characteristics
    - Explore and establish appropriate scoring approaches based on available data and thresholds for each indicator
    - Develop visual tools to effectively communicate indicator grades

Table E1. SAT recommendations for developing indicators for California based on and aligned with the NCRMP process.

NCRMP Process Steps	SAT Recommendations
1. Create a conceptual framework	Adapt the WCOA approach as a starting indicator framework and align with ongoing West Coast efforts
2. Select indicators	Consider adopting the following suite of indicators as collectively representative of status and trends for California's coast and ocean health; develop additional indicators to address the climate crisis and and track policy progress
3. Define thresholds	Establish thresholds for each indicator (2024)
4. Calculate scores	Assess data availability, quality, and characteristics (2024)
	Explore and establish appropriate scoring approaches based on available data and thresholds for each indicator (2024)
5. Communicate results	Develop visual tools to effectively communicate indicator grades (2025)

Table E2. Components and indicators identified across each WCOA category (i.e. stressors, ecosystem health, and human use). Each component is provided along with a few examples of measurable indicators in parentheses.

Stressors		
• Ocean Acidification (aragonite saturation, pH) • Hypoxia (dissolved oxygen, number of monitoring platforms) • Warming (SST & temperature at depth, marine heatwaves) • Sea Level Rise (observed sea level, projections from climate models)	• Coastal Upwelling (mixed layer depth, habitat compression) • Coastal Cloudiness (cloud cover frequency) • Coastal Flooding (high-tide frequency, flooding days) • Beach Water Quality (pathogens, beach closures)	• Harmful Algal Blooms (dissolved toxins, fisheries closures & advisories) • Marine Debris (microplastics concentrations) • Toxics (toxins in predators) • Coastal Runoff (dissolved nutrient concentrations, bacteria & viruses)

<table>
<tr><th colspan="3">Ecosystem Health</th></tr>
<tr>
<td>● Kelp (canopy cover, biomass, density)
● Rocky Reefs (rockfish abundance, dissolved oxygen)
● Rocky Intertidal (mussel density)
● Seagrasses (area, biomass, density)
● Wetlands & Estuaries (habitat extent, oyster density)
● Soft Bottom (pismo clam abundance, water turbidity)</td>
<td>● Sandy Beaches (abundance of infauna & seabirds)
● Benthic fauna (crab abundance, coral range)
● Open Water (surface chlorophyll concentrations, krill abundance)
● Marine Mammals (cetacean mortality & strandings, pinniped productivity)</td>
<td>● Seabirds (seabird productivity & abundance)
● Fishes (stock status, forage fish biomass)
● Invasive Species (brown macroalgae extent, range shifts)
● Invertebrates (abalone abundance, mussel density)</td>
</tr>
<tr><th colspan="3">Human Use</th></tr>
<tr>
<td>● Sea Level Rise Planning (local coastal programs, adaptation plans)
● Ocean-related Employment (employment by sector, jobs, local businesses)
● Fisheries (landings, active fishing vessels)
● Recreational Fishing (angler trips, participants)
● Wastewater Discharge (amount of received wastewater)</td>
<td>● Aquaculture (commercial harvest, siting requests)
● Ports (non-fishing vessels, available slips & berths)
● Coastal Communities (revenue retained within communities)
● Energy (energy produced by offshore renewables, electrification of port infrastructure)
● Desalination (amount of potable water provided)</td>
<td>● Coastal Access (shoreline closures, percent of shoreline)
● Tourism (revenue, participants)
● Marine Recreational Activities (private vessel registrations, port vacancy rates, trips)
● Scientific Research
● Educational Activities
● Cultural & Spiritual Activities</td>
</tr>
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Current Indicator State of the Science

Environmental indicators provide understandable and simplified information on complex issues, phenomena, and conditions of the environment[1]. Indicators have become valuable and important in guiding policy decision-making by:

- Providing information on environmental problems, which enable consideration by decision-makers;
- Supporting policy development and decisions by identifying important factors, pressures, or threats to the environment; and
- Monitoring the outcomes or effects of policy decisions and actions.[2]

In environmental decision-making, there are several types of indicators that can be used and developed based on the intent and purpose of the indicator effort. For example, indicators may be more descriptive in nature and describe what is happening in or to the environment and to humans. In other cases, indicators may be more performance-based and developed to help monitor progress toward a desired state or outcome, such as a policy goal or target. Relatedly, indicators may also help to describe or assess the relationship between different components, such as environmental pressures and human activities.

There are multiple types of frameworks that can be used in indicator efforts depending on the intent and goal of such effort. The most common indicator frameworks are PSR (i.e. pressure-state-response), DSR (i.e. driving force-state-response), and DPSIR (i.e. driving force-pressure-state-impact-response) (Fig. 1). While differing slightly in complexity, all of these frameworks provide a conceptual understanding of how the environment and human systems are related in a causal chain manner, and are best used in cases where decision-makers need to gain a broad understanding of the status and trends of the environment in a comprehensive manner.[3] These causal chain frameworks include (1) forces that act on the environment, (2) changes that, as a result, take place in the environment, and (3) societal responses to those environmental changes.

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[1] Niemeijer & de Groot 2008
[2] Smeets & Weterings 1999
[3] Personal communication

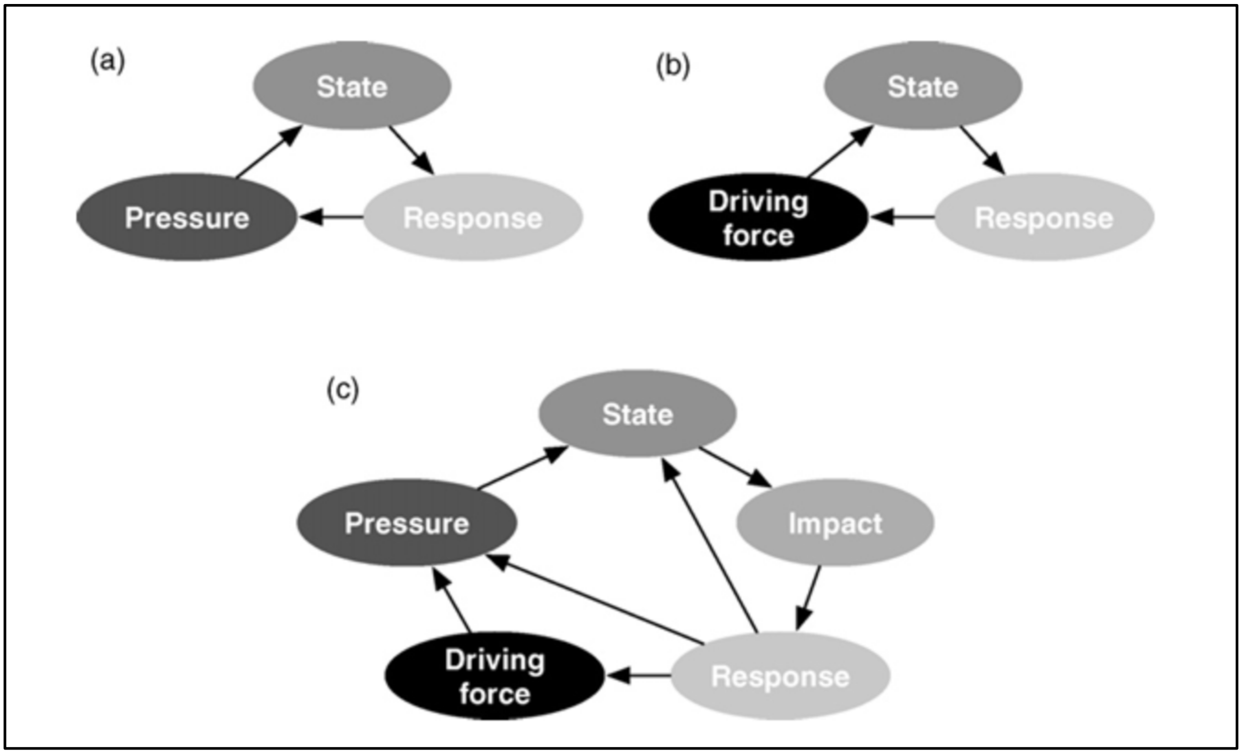

Figure 1. Causal chain indicator frameworks for (a) PSR, (b) DSR, and (C) DPSIR. Taken directly from Niemeijer & de Groot 2008.

While many indicator efforts may follow the general structure of these causal chain frameworks, final selection and inclusion of indicators is typically done on an individual indicator basis as opposed to jointly in a truly causal chain manner.[4] Three such examples of indicator efforts that follow the general structure of these causal frameworks, and have been successfully used to inform decision-making and management in the U.S. West Coast, include the 2022-2023 California Current Ecosystem Status Report (hereafter referenced as ESR), the 2015 Ecological Indicators for Washington State Report (hereafter referenced as NWFSC 2015), and the 2018 Status Report Scoring Methodology for Pacific Jurisdictions for NOAA's National Coral Reef Monitoring Program (hereafter referenced as NCRMP).[5,6,7]

All three of these efforts set out to assess the status and trends of their respective ecosystems and generally follow the same approach for arriving at a set of understandable indicators, including (1) identifying and selecting indicators, (2) analyzing indicator data to assess status and trends, and (3) presenting indicators to support interpretation and use. Each of these

[4] Niemeijer & de Groot 2008
[5] Harvey et al. 2023
[6] Andrews et al. 2015
[7] Donovan et al. 2018

efforts differs slightly in how they execute each of these steps. Notably, both the ESR and NWFSC 2015 report the direction and magnitude of change for each indicator (e.g. increasing, decreasing, or remaining stagnant) over a specified period of time. Where the NCRMP primarily differs from the ESR and NWFSC 2015 is in their presentation of those status and trends, where the direction and magnitude of change is re-interpreted into quantitative (i.e. percent change) and qualitative (e.g. Very Good, Impaired, Critical) interpretations of the status and trends. This additional step in the NCRMP process (Fig. 2) is used to support decision-making and management as this provides an easily understood indication of which components of the environment may require policy attention.

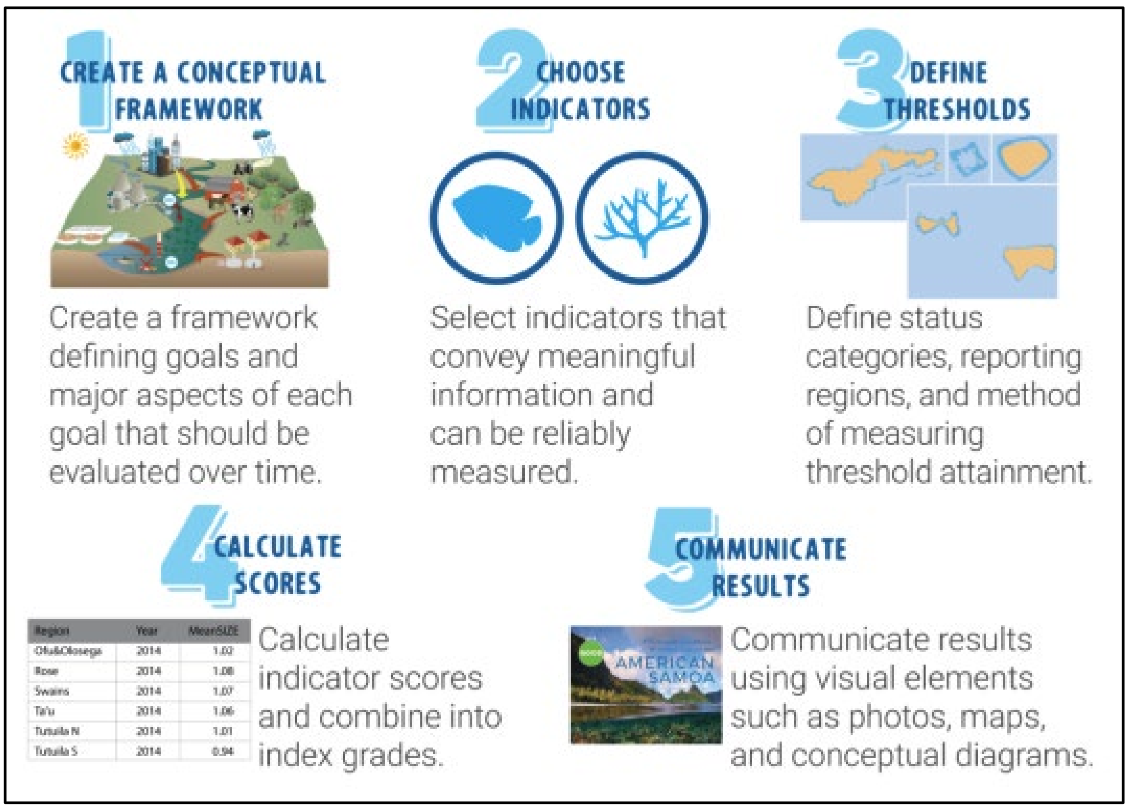

Figure 2. The 5-step process used to develop indicators for the NCRMP.

Currently, the West Coast Ocean Alliance (WCOA) is developing an ocean health report card, using a science-based indicator framework, for the contiguous U.S. West Coast.[8] The WCOA framework identifies and broadly categorizes key components - also known as priority attributes or aspects of our oceans and coasts (e.g. ocean acidification, kelp, marine mammals) - across three broad categories (i.e. stressors, ecosystem health, human use) that are synonymous with causal chain frameworks. WCOA will eventually identify measurable

[8] https://www.sccwrp.org/news/initial-phase-of-ocean-health-report-card-developed-for-california-managers/

indicators (e.g. canopy, abundance) to assess and track the status and trends for each component.

Process For Identifying And Selecting Indicators

Three SAT standing committees were convened in April 2023 to generate preliminary recommendations for California-specific indicators that track coast and ocean health. The standing committees convened were the Biodiversity, Climate, and Blue Economy committees; because OPC is separately developing equity-focused indicators, the Equity standing committee was not convened as part of this SAT effort.

Following the initial standing committee list generation, OST conducted individual interviews with each SAT member in May-July 2023. These conversations were intended to draw upon each individual member's specific expertise to refine the list of recommended indicators, as well as develop an overarching indicator framework. These conversations were augmented with additional interviews and resources from existing and previous ocean and coastal health indicator efforts, including WCOA, NCRMP, and ESR.

Previous and existing efforts were explored to identify additional components and measurable indicators that are specifically targeted for California. These efforts came from both within California (e.g. MPA Monitoring Program, OEHHA's Climate Change Indicators) and outside the state (e.g. Breslow et al. 2016, Biedenwig et al. 2014).[9,10] This search resulted in the compilation of several components and indicators of changing ocean conditions, pollution, ecosystems, species groups, and coastal economies.

Each SAT standing committee was reconvened in August 2023, to further refine the indicator framework and selection of individual indicators. Indicators were identified and selected according the following selection criteria:

- Indicators adequately represent ocean and coastal health;
- Indicators are scorable (i.e. they have available data and approaches for scoring); and
- Indicators are policy-relevant (i.e. they are generally relevant to OPC's Strategic Plan goals and other state priorities).

The input and recommendations from these meetings culminated in the framework and list of indicators presented in this report, which were finalized and vetted by the full SAT in October 2023.

[9] Breslow et al. 2016
[10] Biedenwig et al. 2014

Recommendations

This section details the SAT's recommendations for developing science-based indicators for the Report Card. These recommendations include an initial list of indicators as well as several initial recommendations towards a process for scoring indicators beginning in 2024.

Recommendation #1: Adapt the NCRMP approach to develop indicators for California

The goal of this effort is to develop scorable and gradable indicators to understand the health, status, and conditions of California's oceans and coast. To support decision-making and management, these indicators will need to be communicated in an understandable and meaningful manner. The NCRMP established a scientific approach for developing scorable indicators for coral reefs in a manner that is suitable for California's purposes. Recognizing this process as scientifically sound, the SAT adopted and adapted the NCRMP approach to arrive at a suite of science-based recommendations for developing indicators for California while staying aligned with the NCRMP approach (Table 1).

Table 1. SAT recommendations for developing indicators for California based on and aligned with the NCRMP process.

NCRMP Process Steps	SAT Recommendations
1. Create a conceptual framework	Adapt the WCOA approach as a starting indicator framework and align with ongoing West Coast efforts
2. Select indicators	Consider adopting the following suite of indicators as collectively representative of status and trends for California's coast and ocean health; develop additional indicators to address the climate crisis and and track policy progress
3. Define thresholds	Establish thresholds for each indicator (2024)
4. Calculate scores	Assess data availability, quality, and characteristics (2024)
	Explore and establish appropriate scoring approaches based on available data and thresholds for each indicator (2024)
5. Communicate results	Develop visual tools to effectively communicate indicator grades (2025)

Adapting the NCRMP approach to develop scorable indicators for the Report Card will entail the following steps, including work the SAT has already completed to launch this process:

Recommendation #2: Adapt the WCOA approach as a starting indicator framework and align with ongoing West Coast efforts

An important first step in developing scorable indicators is to develop a conceptual framework of the key environmental components that are aligned with the intent and goals of the indicator effort. Typically, these frameworks are developed by any combination of scientific experts, decision-makers, and/or community members. [11,12]

To begin the indicator framework selection process, the SAT adopted and adapted the WCOA framework and drew from existing efforts both within and outside California to consider additional components specifically relevant to California. Recognizing the existence of other ongoing science-driven West Coast-relevant indicator efforts, which may have overlap in data or approaches with the indicators recommended in this report, it is recommended that alignment with such efforts be facilitated where possible and relevant.

Recommendation #3: Consider adopting the following suite of indicators as collectively representative of status and trends for California's coast and ocean health

Indicators should reflect and convey meaningful information about the marine environment and, therefore, can be reliably measured using existing methods and data. The SAT recommends the following list that represents a limited set of components and indicators that best represent California's oceans and coasts without requiring assessment and tracking of the entire system (Table 2).

Table 2. Components and indicators identified across each WCOA category (i.e. stressors, ecosystem health, and human use). Each component is provided along with a few examples of measurable indicators in parentheses.

Stressors		
● Ocean Acidification (aragonite saturation, pH) ● Hypoxia (dissolved	● Coastal Upwelling (mixed layer depth, habitat compression) ● Coastal Cloudiness	● Harmful Algal Blooms (dissolved toxins, fisheries closures & advisories)

[11] Donovan et al. 2018
[12] Niemeijer & de Groot 2008

oxygen, number of monitoring platforms) ● Warming (SST & temperature at depth, marine heatwaves) ● Sea Level Rise (observed sea level, projections from climate models)	(cloud cover frequency) ● Coastal Flooding (high-tide frequency, flooding days) ● Beach Water Quality (pathogens, beach closures)	● Marine Debris (microplastics concentrations) ● Toxics (toxins in predators) ● Coastal Runoff (dissolved nutrient concentrations, bacteria & viruses)
Ecosystem Health		
● Kelp (canopy cover, biomass, density) ● Rocky Reefs (rockfish abundance, dissolved oxygen) ● Rocky Intertidal (mussel density) ● Seagrasses (area, biomass, density) ● Wetlands & Estuaries (habitat extent, oyster density) ● Soft Bottom (pismo clam abundance, water turbidity)	● Sandy Beaches (abundance of infauna & seabirds) ● Benthic fauna (crab abundance, coral range) ● Open Water (surface chlorophyll concentrations, krill abundance) ● Marine Mammals (cetacean mortality & strandings, pinniped productivity)	● Seabirds (seabird productivity & abundance) ● Fishes (stock status, forage fish biomass) ● Invasive Species (brown macroalgae extent, range shifts) ● Invertebrates (abalone abundance, mussel density)
Human Use		
● Sea Level Rise Planning (local coastal programs, adaptation plans) ● Ocean-related Employment (employment by sector, jobs, local businesses) ● Fisheries (landings, active fishing vessels) ● Recreational Fishing (angler trips, participants) ● Wastewater Discharge (amount of received wastewater)	● Aquaculture (commercial harvest, siting requests) ● Ports (non-fishing vessels, available slips & berths) ● Coastal Communities (revenue retained within communities) ● Energy (energy produced by offshore renewables, electrification of port infrastructure) ● Desalination (amount of potable water provided)	● Coastal Access (shoreline closures, percent of shoreline) ● Tourism (revenue, participants) ● Marine Recreational Activities (private vessel registrations, port vacancy rates, trips) ● Scientific Research ● Educational Activities ● Cultural & Spiritual Activities

The SAT reduced the broad set of indicators to a preliminary list of indicators that are policy-relevant and scorable using a combination of expert judgment and literature review. Using these two methods is a common approach for selecting indicators, but other efforts have also enlisted end users, decision-makers, and community participants to arrive at an indicator list.[13,14,15] Many of these potential indicators were identified from previous efforts (e.g. MPA Monitoring Program, ESR, and OEHHA's Climate Change Indicators report), and the SAT provided targeted guidance to limit these options into a set that could be feasibly scored for this effort. This preliminary list, therefore, includes multiple indicator options for each component. It is additionally important to note that while these components and indicators align with the WCOA framework, the SAT did not identify indicators in a causal chain manner, but rather identified indicators that were relevant to the broad categories (i.e. stressors, ecosystem health, and human use).

Going forward, the SAT recommends these indicators be further refined and revisited as appropriate scoring approaches are explored and decision-makers and end users are consulted to ensure these indicators are valuable, understandable, and actionable. During indicator refinement, experts should carefully consider how these indicators might be linked or related to better understand causality and correlation.

Recommendation #4: Develop additional indicators to address the climate crisis and and track policy progress

The indicators in Table 2 are broadly aligned with frameworks used in past and ongoing indicator efforts. As with those other efforts, the initial SAT-generated list of indicators has a focus on ecosystem structure and function, and on broad metrics of human use. Potentially lost in these indicators, however, is the story of the climate crisis California now finds itself in, and the state's efforts to address those challenges. Over the course of these standing committee discussions, it became increasingly apparent that a structure and function approach alone feels inadequate to meet this moment. As scientists representing a diverse range of specializations, all of which are significantly impacted by climate change right now, the SAT has a responsibility to create indicators that do not merely catalog the decline of our coasts and ocean, but that elucidates places where the state can focus solutions.

California's decision-makers recognize a similar responsibility, and have developed and implemented a wide range of policy responses to facilitate and enhance the resilience and adaptive capacity of our oceans and coasts. The Report Card concerned with the health of

[13] Donovan et al. 2018
[14] Niemeijer & de Groot 2008
[15] Biedenweg et al. 2014

California's coast and ocean should therefore also include more sophisticated indicators that can speak to the outcomes and progress of policy decisions.

The SAT therefore recommends identifying and developing additional (1) climate-informed indicators, focused on the human-ecosystem nexus of climate change-driven impacts; and (2) policy-informed indicators, designed to monitor and communicate policy response and progress. An example of each of these indicators include:

- **Fisheries Disruptions (climate-informed):** Rather than indicators such as landings or employment - the interpretation of which depend on human dimensions and policy goals, and may shift over time - tracking the number of disruptions could provide a score that better speaks to the challenges California's fisheries faced in a given year, as well as how well the state anticipated and addressed potential impacts.
- **Sea Level Rise Planning (policy-informed):** While tracking physical sea level rise measurements are an important stressor-related indicator (Table 2), the success of policies, planning, and infrastructure investment to address this stressor will be felt on a timetable of decades. A separate indicator that tracks the state of progress in SLR planning, such as Local Coastal Programs or Adaptation Plans, would allow for assessment of the state's readiness with enough time to course-correct as needed.

Recommendation #5: Conduct routine human well-being surveys or other robust social scientific assessments to understand the importance of other indicators to coastal communities and to capture essential qualitative information to be integrated into the Report Card

There is a potential danger inherent in any indicator effort of overly simplifying complex human and social information in lieu of more readily collected and quantified data. However, human well-being information can often be difficult or inappropriate to quantify or convert into metrics. While both quantitative and qualitative data are therefore useful for measuring different aspects of social indicators, qualitative data can often provide more robust insight into important aspects of human well-being, such as culture, identity, or intangible connections to nature.[16] For example, merely collecting employment data about California's fishing economy will say nothing about livelihoods or the cultural identities associated with that sector.

Furthermore, unlike biophysical indicators (e.g. the majority identified in Table 2), social indicators can be both *objective* and *subjective*, meaning they can also measure how people

[16] Breslow et al. 2016

perceive their own wellbeing; this perception is itself an important dimension of well-being.[17] Measuring these subjective indicators will likely require surveys and interviews. Finally, some measures of well-being may also be relatively invariant over shorter timescales[18], potentially making them challenging to fit into an annual report card structure.

To truly reflect all aspects of the health of California's coast and ocean, and achieve the goals of this initiative, the Report Card must also speak to these deeper human values. It is therefore recommended that routine coastal community well-being surveys or other robust social scientific assessments be conducted to augment the information available to the state via this report card effort.

[17] ibid
[18] Stiglitz et al. 2009

Future Work On Indicator Development

This document details the SAT's recommendations for developing indicators for the Report Card, including the SAT's completed work of identifying indicators and selecting an underlying framework. Beginning in 2024, OPC and OST will explore opportunities to provide and establish scientific guidance for continuing to develop, refine, and score indicators for the Report Card. Below, the SAT provides a suggested roadmap for initiating that scoring process, aligned with the NCRMP process.

Establish thresholds for each indicator

While not all indicators can follow the exact same approach, for the purposes of producing easily understandable scores, each indicator will need scientifically-derived and -supported thresholds against which current status and trends can be evaluated. These thresholds include (1) a reference point (also known as a baseline) and (2) assessment points (also known as breakpoints) to delineate a set of potential scores. Thresholds can come from a variety of sources, including the peer-reviewed literature, regulatory guidelines, reference sites, historical benchmarks, and expert judgment.[19]

Assess data availability, quality, and characteristics

In California, there is a wealth of projects, programs, and monitoring efforts that could provide the data for scoring. Identifying each specific data need, however, will in part be a function of the chosen scoring approach for each indicator; this process step is therefore closely linked to, and may need to happen simultaneously with, the scoring approach process step below.

There are also important considerations for the selection and use of data in any indicator effort. First, these existing efforts should be assessed to understand what data might exist to feasibly score and grade each indicator. For example, aragonite saturation is a reliable indicator of ocean acidification (OA), but little data currently exists to feasibly measure and track aragonite saturation. In contrast, there is ample pH data, which is another reliable ocean acidification indicator, that can therefore be more readily analyzed - thus making pH a potentially more suitable indicator of OA.

Second, both the geographic and temporal scales of these datasets should be carefully considered throughout the subsequent scoring process, as these scales will influence the final score. For example, toxin levels vary considerably across the state. Therefore, any single statewide score may risk masking the true variability across regions or locations. This is an

[19] Donovan et al. 2018

especially important consideration for revealing inequities across different social groups or other subpopulations where a policy response may be most needed.[20]

Explore and establish appropriate scoring approaches based on available data and thresholds for each indicator

Going forward, it will be important to establish scientific approaches for scoring each indicator based on data availability, quality, and characteristics. As noted in Recommendation #5, creating an approach to assign a grade or numerical score to an indicator is generally a more straightforward process for quantitative indicators with numeric values. However, some indicators may be more challenging to quantify (e.g. if ecosystem trends point to inconsistent conclusions), or are qualitative in nature (e.g. many human well-being indicators). In the coming year, OPC and OST will explore additional opportunities to establish scientifically-rigorous approaches for scoring and acquiring data for these indicators.

Develop visual tools to effectively communicate indicator grades

To facilitate understanding and interpretation of indicator scores, the final step in any indicator effort is to communicate results using visual tools (i.e. photos, maps, conceptual diagrams) that will adequately communicate the current status of each indicator. Ultimately, the California oceans and coasts indicators will be compiled into a Report Card, with the goal of scoring each indicator to support decision-makers and end users in interpreting those status and trends. This process itself will require expert guidance to ensure the information is communicated accurately and usefully.

[20] Daw et al. 2011

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