mpa MONITORING ENTERPRISE

CALIFORNIA

Innovative Approaches to Monitoring

Monitoring Climate Effects in Temperate Marine Ecosystems

A test-case using California's MPAs

JANUARY 2012

About this Document

This report has been prepared by EcoAdapt for the MPA Monitoring Enterprise. The MPA Monitoring Enterprise, a program of the California Ocean Science Trust, is tasked with developing and implementing monitoring of California's emerging statewide MPA network. While climate change is not explicitly incorporated into the goals and objectives of California's MPAs, future evaluations of MPA performance will occur in the context of a changing climate and associated changing oceanographic environment. Moreover, MPA monitoring in California provides a framework that can be applied to inform the climate change management dialogue. A statewide network of MPAs, in which other anthropogenic stressors are reduced, provides a large-scale, natural laboratory to understand how climate changes manifest in ocean ecosystems. Thus, this presents a timely opportunity to develop and recommend an approach to most efficiently and effectively augment MPA monitoring to provide additional information. This information should aid in the interpretation of MPA monitoring results but also can be designed to inform the management dialogue around potential climate change effects on marine ecosystems and adaptation or mitigation measures.

The Monitoring Enterprise engaged EcoAdapt to develop and recommend an approach to supplement MPA monitoring with climate change monitoring that can track climate change effects

Citation: *Monitoring climate effects in temperate marine ecosystems*. MPA Monitoring Enterprise, California Ocean Science Trust, Oakland, CA. February 2012.

About the MPA Monitoring Enterprise

The MPA Monitoring Enterprise was created in 2007 to lead the design and implementation of scientifically rigorous, impartial and cost-effective monitoring of the network of marine protected areas established in California under the Marine Life Protection Act.

Working at the boundary between science and management, we are pioneering scientific and practical assessments of the changing condition of ocean ecosystems and the performance of MPA networks, and developing innovative approaches for sharing monitoring results so that decision-makers and stakeholders have timely, credible information for making sound management decisions. We work closely with the California Department of Fish and Game and the California Ocean Protection Council and engage scientists and stakeholders to ensure monitoring is based on the best available science, reflects public interests and meets management needs.

CALIFORNIA OST Ocean Science Trust
Connecting Science to Ocean Management

The MPA Monitoring Enterprise is a program of the California Ocean Science Trust, a non-profit organization established pursuant to the Coastal Ocean Resources Stewardship Act of 2000 to provide scientific guidance to the state on ocean policy issues. More information about the MPA Monitoring Enterprise can be found at www.monitoringenterprise.org.

Monitoring climate effects in temperate marine ecosystems

A test-case using California's MPAs

January 2012

Acknowledgements

Sincere thanks to Lara Hansen and the team at EcoAdapt for their collaborative approach, great discussions and hard work in developing this report. We thank all the participants in the International Marine Conservation Congress 2011 Focus Group ‘Monitoring resilience to climate change in temperate marine ecosystems’ for a valuable discussion that launched this project. We also thank Mark Carr, Carolyn Lindquist and Chris Harley for their constructive feedback and input into draft versions of the report. This work was made possible by the support of the California Ocean Protection Council and the Resources Legacy Fund Foundation.

SUMMARY

Changes to atmospheric and oceanographic conditions, including increased temperatures (air and water), ocean acidification, sea level rise and altered ocean currents, may affect temperate marine ecosystems. Some species will likely be able to adapt to these impacts and even thrive under new conditions, while others may be adversely affected, resulting in ecologically significant biological, phenological, or community shifts. While these potential changes present a challenge for managing coastal resources, we have the opportunity to address this challenge with the tools we currently use.

This report recommends an approach to efficiently and effectively augment MPA monitoring to provide additional information that can inform the management dialogue around potential climate change effects on marine ecosystems and adaptation or mitigation measures. This report explicitly focuses on approaches for monitoring the potential impacts of climate change on marine ecosystems (e.g. rocky intertidal, kelp and shallow rock). While we recognize that climate change will likely impact human uses, both consumptive (e.g. fishing, crabbing) and non-consumptive (e.g. tidepooling, SCUBA diving), consideration of monitoring these effects is not covered in this report.

The MPA Monitoring Enterprise has developed a framework for MPA monitoring in California to ensure that monitoring efficiently and effectively assesses MPA performance and provides information to support future MPA management decisions. This framework, that was developed to assess the progress of California's regional networks of MPAs in meeting the goals of the Marine Life Protection Act (MLPA), adopts an ecosystem-based approach to assess the condition of marine ecosystems. While climate change is not explicitly incorporated into the goals and objectives of California's MPAs, future evaluations of MPA performance will occur in the context of a changing climate and associated changing oceanographic environment.

This document offers a suggested framework for augmenting MPA monitoring efforts in order to inform our understanding of climate change effects and increase the effectiveness of adaptive MPA management in light of climate change. It contains recommendations for efficiently incorporating climate change monitoring following a three-tiered design in order to provide scalable implementation options for managers that can track climate change impacts and provide 'alerting signals' for California's marine ecosystems.

The first, most basic, approach for incorporating climate change into MPA monitoring is through the identification of species that are currently identified in MPA monitoring plans that may also inform our understanding of climate change effects. This report identifies these species, suggests what aspects of climate change are likely to affect them and predicts how these species may respond. If resources are available, MPA monitoring can be augmented through the addition of new metrics for species already being monitored (e.g., measuring mussel depth, in addition to percent cover) or through the addition of new species for monitoring. Finally, new areas of research are identified that take advantage of the 'natural laboratory' created by a network of MPAs. These research areas can advance our understanding of how climate change may affect marine ecosystems and be used to evaluate the efficacy of management actions.

MONITORING CLIMATE CHANGE EFFECTS IN TEMPERATE MARINE ECOSYSTEMS

Technical Report
October 2011

Prepared for:
MPA Monitoring Enterprise
California Ocean Science Trust
Oakland, California, USA

Prepared by:
Alex Score, Rachel M. Gregg, and Lara J. Hansen

EcoAdapt™
Meeting the challenges of climate change

PO Box 11195 Bainbridge Island, WA 98110 USA

Table of Contents

Purpose

Temperate marine ecosystems are likely to change in response to altered atmospheric and oceanographic conditions, including increased temperatures (air and water), ocean acidification, sea level rise and altered ocean currents, including coastal upwelling. Some species will likely be able to adapt to these impacts and even thrive under new conditions, while others may be adversely affected, resulting in ecologically significant biological, phenological, or community shifts. Existing evidence suggests that climate change may result in the loss of sandy beach habitat and wetland systems, saltwater intrusion to aquifers, and declines of kelp forests and some fish stocks in California. While these potential changes present a challenge for managing coastal resources, we have the opportunity to address this challenge with the tools we currently use. This report recommends an approach to efficiently and effectively augment MPA monitoring to provide additional information that can inform the management dialogue around potential climate change effects on marine ecosystems and adaptation or mitigation measures.

Climate Change in Temperate Marine Ecosystems

Of the climate changes and impacts most likely to affect nearshore temperate marine ecosystems, the following – sea level rise, increased air and sea surface temperatures, increased intensity and frequency of storms, decreasing pH, and altered circulation patterns – may be most effectively informed through MPA monitoring. It is important to note that many physical characteristics (e.g., sea level rise, sea surface temperature, circulation patterns, wave height, etc.) are already monitored by other programs and agencies. Many of these programs have long-term and ongoing spatial and temporal data that, when combined with the ecological monitoring conducted for MPAs, can both identify the ecological consequences of changes in these oceanographic conditions and facilitate better evaluation of the performance of California's network of MPAs[1]. More information on these impacts, including existing monitoring programs, is provided below.

Sea Level Rise

Sea level rise is principally caused by thermal expansion and increases in freshwater input,[2] and can be exacerbated by El Niño Southern Oscillation (ENSO) events.[3] Under medium to medium-high greenhouse gas emission scenarios (B1 and A2 IPCC scenarios) mean sea levels are projected to rise from 1.0 to 1.4 meters by the year 2100 along the California coast.[4] Sea level rise is anticipated to result in coastal inundation, beach erosion, flooding, and saltwater intrusion to low-lying areas, such as coastal wetlands,[5] and may ultimately cause changes in habitat availability and types.[6] Monitoring programs in place that track sea level rise include Cal-Adapt and the Integrated Ocean Observing System (IOOS).

---

[1] Carr et al. 2011
[2] Heberger et al. 2009
[3] Cayan et al. 2006

[4] Cayan et al. 2009
[5] Heberger et al. 2009
[6] Harley et al. 2006

Increased Air and Sea Temperatures

Elevated mean sea and air temperatures and extreme events will become more common in the region.[7] Increased temperatures can directly manifest as thermal stress in temperature-sensitive species and can change local salinity. Species will likely respond differently to these compounding factors, but changes in species ranges, community structure, phenologies (i.e. seasonality of life cycle events), and increased incidences of disease and establishment of invasive species are expected.[8] Monitoring programs in place that track air and sea surface temperatures include the California Nevada Applications Program (CNAP), Integrated Ocean Observing System (IOOS), and Western Regional Climate Center.

Increased Intensity and Frequency of Storms

More intense storms and extreme weather events may be expected with climate change and may be enhanced by naturally occurring ENSO events.[9] Storms can cause direct physical damage to coastal ecosystems, especially coastal wetlands, estuaries, intertidal zones, and kelp forests. Indirect damage due to changing intensity and frequency of storms can be just as important as direct impacts. For example, sediment inputs from land based erosion and runoff may cause increased turbidity, thus smothering estuarine, coastal and offshore benthic communities by sediment deposition. Storm intensity and frequency may be exacerbated by sea level rise resulting in shoreline erosion and increased nearshore turbidity.[10] The National Weather Service Climate Prediction Center currently monitors for these kinds of events.

Ocean Acidification

The oceans are absorbing large amounts of anthropogenic carbon dioxide (CO2), resulting in chemical reactions that lower ocean pH and acidify ocean water. Decreased pH levels can result in the decline of available calcium carbonate, which is needed for the development of many species, including calcareous algae, zooplankton, shellfish, and larval fishes,[11] and can cause population and trophic shifts.[12] Ocean acidification can also affect biological processes (e.g., fertilization, development, metabolism) in a variety of species.[13] The PMEL Carbon Dioxide Program monitors pH levels in at select monitoring sites in the region.

Altered Circulation Patterns

Ocean circulation patterns are driven by winds and thermohaline circulation, influencing currents and upwelling. Climate change will interact with naturally occurring climate cycles such as the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO).

---

[7] Cayan et al. 2008, Moser et al. 2009
[8] Stachowicz et al. 2002, Harley et al. 2006
[9] Moser et al 2009
[10] Flick 1998, Peterson and Schwing 2008

[11] Hauri et al. 2009
[12] Doney et al. 2009
[13] Portner and Reipschlager 1996, Kikkawa et al. 2003, Ishimatsu et al. 2004, Kurihara and Shirayama 2004, Kurihara et al. 2007, Michaelidis et al. 2007

These interactions can cause significant changes in ocean productivity, shifts in distribution of nutrients and organisms, altered larval dispersal, and modification in food webs.[14] Monitoring programs in place that measure ocean circulation patterns include the Integrated Ocean Observing System (IOOS) and Southern California Coastal Ocean Observing System (SCCOOS).

MPA Monitoring in California

The MPA Monitoring Enterprise has developed a framework for MPA monitoring in California to ensure that monitoring efficiently and effectively assesses MPA performance and provides information to support future MPA management decisions.

The top level of the monitoring framework is the set of Ecosystem Features chosen to collectively represent and encompass a region, such as the South Coast and North Central Coast regions. For example, 10 Ecosystem Features have been identified for the South Coast region and these include rocky intertidal ecosystems, kelp and shallow rock ecosystems, and estuarine and wetland ecosystems, among others. As described in the monitoring plans:

> *The Ecosystem Features provide the focus for two core MPA monitoring elements: 1) assessment of ecosystem condition and trends, and 2) evaluation of specific MPA design and management decisions. Assessment of ecosystem condition and trends will track the state of marine ecosystems, including human activities, in each region, and how they change over time inside and outside the MPAs. Evaluations of specific MPA design and management decisions, such as MPA size and spacing, will examine the effects of these decisions on Ecosystem Features. Collectively, the two core monitoring elements will provide information to assess progress in achieving MPA goals, and facilitate future adaptive management decisions.*[15]

The MPA monitoring framework that was developed to assess the progress of California's regional networks of MPAs in meeting the goals of the Marine Life Protection Act (MLPA),[16] and which is described in the North Central Coast and South Coast MPA Monitoring Plans, adopts an ecosystem-based approach to assess the condition of marine ecosystems. While these plans identify metrics that can be used to both monitor MPA performance and track climate change impacts, there is also an opportunity to consider additional metrics or new research questions that may augment MPA monitoring in support of advancing understanding of climate change impacts and testing the efficacy of proposed management and planning approaches under the challenges of climate change.

MPA Monitoring in a Changing Climate

Two of the primary purposes for MPA monitoring are assessing progress towards MPA goals and evaluating the effectiveness of management actions. Increasingly, these goals include broad ecosystem-level protections; thus monitoring includes measuring key aspects of the structure and

---

[14] Bakun 1990, Gaylord and Gaines 2000, Behrenfeld et al. 2006, Peterson and Schwing 2008

[15] Additional details are available on the Monitoring Enterprise website at www.monitoringenterprise.org

[16] California Marine Life Protection Act, Statues 1999, Chapter 10.5 of the California Fish and Game Code, section 2850-2963.

function of coastal and marine ecosystems. Implicit in this is the need to understand changes in the physical and biological environment through tracking changes through time. Recent approaches to natural resource management include calls for adaptive management, whereby the effectiveness of management actions are evaluated and, if needed, adjusted in response. Information collected to assess ecosystem condition and in support of adaptive management can also be useful for evaluating and adapting to climate change, but it requires explicit consideration of climate change in the monitoring framework.

A useful way of approaching the role of climate change in MPA monitoring is to consider the types of decision support that are required for effective MPA management; these include: informing decisions, evaluating decisions, and increasing understanding to support future decisions.

Informing decisions

Climate change has implications for the *existing decisions* that need to be made within current monitoring approaches and management mandates, such as where species of concern are located or how water quality may affect MPA success. It may also result in *emerging decisions*, such as how to consider ocean acidification or changing upwelling patterns, issues that historically have not been a concern of marine managers. There may also be the need for decisions on how to enact rapid responses to episodic conditions such as hypoxia or storm related events.

Evaluating decisions

Climate change adaptation and monitoring provides the opportunity for adaptive management, including *evaluating decisions* and *testing assumptions*. Evaluating the efficacy of management decisions in the face of climate change requires the inclusion of MPA monitoring metrics that are sensitive to the effects of climate change. Monitoring results can also suggest ecosystem indicators that are sensitive to changes in ocean conditions associated with climate change. Determination of the management and monitoring actions taken in response to climate change is based on assumptions regarding the nature of marine ecosystems and climate change. Designing monitoring that tests the predicted ecosystem responses based on these assumptions is equally important. MPA monitoring can show if species and ecosystems, both their structural and functional attributes, are responding to changes in oceanographic conditions as predicted.

Increasing understanding

The effects of a changing climate may result in unforeseen changes to coastal and marine ecosystems. This uncertainty underscores the need for monitoring programs designed to collection information that documents the condition of and tracks the changes in marine ecosystems. This information can be used to deepen our understanding of climate change effects, improve our ability to adaptively manage MPAs in the face of these changes and inform the development of biophysical and coupled socio-ecological models to make future predictions and reduce uncertainty.

Integrating Climate Change into Monitoring

While monitoring and management for climate change is often implemented as a separate endeavor from existing monitoring efforts, this approach misses the opportunity to efficiently leverage resources and to use the information collected to inform other management mandates. Effective monitoring and management are contingent on full integration of metrics and frameworks that are climate-informed[17]. Not doing so decreases the likelihood of separating the impacts of climate change that are negative from the beneficial impacts of MPAs due to the reduction of other impacts.

Incorporating consideration of climate change into MPA monitoring is not a complex endeavor requiring expensive technical capacity. The key element required is integrating climate change into the underlying perception of condition for the system being monitored. Much of the work can be done using existing metrics, new metrics for already monitored species, or existing metrics on new species.

A first step is to identify species that are already being monitored and consider their vulnerabilities to climate change. This may include predictions of how these species are expected to respond to climate-related changes. For example, these predictions may identify altered abundance, size frequency, or density as potential responses. In *Tier 1* below, we suggest species identified as candidates for MPA monitoring in the existing monitoring plans that may also provide useful information to inform our understanding of climate change effects.

A next step is to identify the predicted climate change concerns for an individual MPA or region, and identify additional metrics to assess these concerns in order to inform effective management in the face of climate change. This may include adding a new metric for a species currently being monitored (e.g., fecundity, incidence of disease, range shift) or adding new species that may be expected to experience a range shift or change in abundance. We provide some examples in *Tier 2*, below.

Finally, monitoring provides the opportunity to advance our understanding of how climate change may be affecting marine ecosystems through identification of new research areas. In *Tier 3* we explore some of the new elements that might become part of a monitoring plan given the reality of climate change.

California's MPAs offer an opportunity to increase the data and information available to support the development of climate change-informed marine and coastal management and adaptation strategies. This is especially true of no-take reserves, which are often described as 'living laboratories' where it is possible to evaluate climate change effects in the absence of extractive human uses. Additionally, MPA monitoring will allow us to test the efficacy of both MPAs and adaptation approaches under the challenges of climate change.

This document offers a suggested framework for augmenting MPA monitoring efforts in order to inform our understanding of climate change effects and increase the effectiveness of adaptive

[17] Carr et al. 2011

management in light of climate change. It contains recommendations for efficiently incorporating climate change monitoring following the three-tiered design applied in the North Central Coast and South Coast MPA Monitoring Plans in order to provide scalable implementation options for managers. The three tiers include the following to track climate change impacts and provide 'alerting signals' for California's marine ecosystems:

- Tier 1. Existing climate change indicators within the North Central Coast and South Coast MPA monitoring plans that provide information on climate change
- Tier 2. Candidate climate change metrics that may be added to the MPA monitoring plans
- Tier 3. Candidate new framework elements for climate change monitoring

What can climate change monitoring in a MPA monitoring framework provide?

- Assessment of the human and ecological dynamics in the ecosystem, including testing model predictions of human and ecological responses to environmental changes
- Data to better design management and planning actions to address climate change concerns
- Test of the efficacy of management and planning actions taken to address climate change

TIER 1. EXISTING METRICS WITHIN THE NORTH CENTRAL COAST AND SOUTH COAST MPA MONITORING PLANS THAT PROVIDE INFORMATION ON CLIMATE CHANGE

The MPA monitoring framework was applied to develop the North Central Coast and South Coast MPA Monitoring Plans. Both plans adopt an ecosystem approach with indicators that provide information on ecosystem condition, including human uses. The framework includes two core elements for monitoring MPAs: 1) Assessing Ecosystem Condition and Trends, and 2) Evaluating MPA Design and Management Decisions. Several features of the existing monitoring plans provide useful information on climate change effects. The following are the ecological components in both the North Central Coast and South Coast Monitoring Plans that provide useful information on climate change effects in MPAs. While climate change is likely to affect patterns of human uses, the focus of this report is on the ecological aspects of MPA monitoring.

1. ECOLOGICAL INDICATORS OF ECOSYSTEM CONDITION AND TRENDS

Several of the recommended ecological indicators in both the North Central Coast and South Coast MPA monitoring plans may be useful to monitor climate change effects (Table 1). These include species indicators that are sensitive to temperature thresholds and may exhibit biological responses in abundance, distribution, size structure, and range shifts. It is expected that some species ranges may shift farther north range due to thermal stress and tolerance limits. Other changes in the climate regime that will result in a biological response include ocean acidification, sea level rise, changes in upwelling intensity and timing, increased severity of storms, and changes in wave heights and patterns. These will result in changes in size structure, habitat availability, food supply, and larval dispersal.

Other responses to climate change effects may include more complex community shifts caused by ecological interactions, such as changes in predator-prey interactions, decreased reproductive success, increased disease incidence, and invasion of non-native species. For instance:

- Ocean acidification and increased temperature may result in increased abundance of ochre sea stars *(Pisaster ochraceus*). These sea stars are keystone species and increased abundance may result in increased predation pressure on the California sea mussel (*Mytilus californianus*).[18]
- Increased sea and air temperatures may also result in reduced growth rates and reproductive success. For example, owl limpets (*Lottia gigantea*) are sensitive to thermal stress; therefore, decreased abundance and size frequency may occur in the southern ranges of limpet populations.[19]
- Increased ocean temperatures and turbulence in shallow waters will likely cause shifts in depth distribution of fishes[20].
- Increased temperatures may also increase incidences of diseases and invasions by non-native species. An increase of withering syndrome disease in black abalone is expected with increasing temperatures.

2. EVALUATION OF MPA DESIGN AND MANAGEMENT DECISIONS

Evaluating the effectiveness of MPA design and management also provides an opportunity to track climate change effects. In particular, through questions related to MPA size and shape, as well as spacing of MPAs, we may improve our understanding ecosystem responses to climate change. New questions that may be answered while monitoring for existing Tier 1 metrics in the plans that may also inform the evaluation of climate effects in MPAs include the following:

- Do MPAs reduce impacts from non-climatic stressors (e.g. pollution, water quality, consumptive and non consumptive uses)?
- Do MPAs increase resilience of the ecosystem (ability for the ecosystem resist and recover from disturbance)?
- Do MPAs protect areas and species that seem more resistant and adaptable to climate change effect?
- Do MPAs protect resilient populations that are able to ensure replenishment, viability, and genetic diversity?

[18] Gooding et al. 2009, Harley 2011
[19] Harley and Rogers-Bennett 2004
[20] Perry et al. 2005, Dulvy et al. 2008

- Do MPAs protect areas and species least expected to be impacted by climate change?
- How does MPA size and spacing allow for connectivity and species range shifts in response to climate change effects?

Table 1. Existing MPA monitoring metrics that can be used to detect climate change effects.

The MPA Monitoring Framework (see Appendix 2) provides two implementation options: Ecosystem Feature Checkups (orange boxes) use simplified monitoring protocols to take best advantage of partnerships with citizen-science monitoring programs; Ecosystem Feature Assessments (green boxes) use more resource-intensive monitoring methods designed for implementation by government agency and research institutions. The following table provides existing monitoring metrics for both options that may provide additional information on climate change effects. This table may be read as:

"If monitoring for Focal Species/Indicator Metric), (Climate Change) may manifest through (Plausible Biological Change/Range Shift)."

TIER 1: FOCAL SPECIES/INDICATORS METRICS	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT	MLPA REGION	
			North Central	South
Black abalone (*Haliotis cracherodii*) abundance and Size Frequency[21]	• Increased air and sea temperature • Ocean acidification	• Reduced abundance due to thermal stress and disease • Stunted growth due to ocean acidification	✔	
California sheephead (*Semicossyphus pulcher)* abundance, size frequency, and sex ratio[22]	• Increased sea temperature	• Increased abundance and size • Northern range shift		✔
Cassin's auklet (*Ptychoramphus aleuticus*) breeding success[23]	• Changes in upwelling intensity and timing • Increased air and sea temperature	• Reduced population abundance due to changes in food supply • Reduced reproductive success	✔	✔
Dungeness crab (*Cancer magister*) abundance[24]	• Increased sea temperature • Changes in upwelling intensity and timing	• Reduced abundance due to thermal stress	✔	
Eelgrass (*Zostera marina*) areal extent[25]	• Increased sea temperature • Ocean acidification • Storm impacts	• Increased abundance and growth due to increased available dissolved CO_2 and increased sea temperature. • Reduced growth due to storm damage and turbidity	✔	✔

[21] Field et al. 2000
[22] Lenarz et al. 1995
[23] Mazur and Milanes 2009, Wolf et al. 2010
[24] Botsford 2001
[25] Björk et al 2008, Palacios and Zimmerman 2007

TIER 1: FOCAL SPECIES/INDICATORS METRICS	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT	MLPA REGION	
			North Central	South
Marine birds abundance[26]	• Changes in upwelling intensity and timing • Increased air and sea temperature	• Reduced due to changes in food abundance and composition	✔	✔
Mussel bed cover (*Mytilus spp.*)[27]	• Increased sea temperature • Storm frequency • Ocean acidification	• Reduced due to thermal stress and increased predation by *Pisaster sp.*	✔	✔
Ochre sea star (*Pisaster ochraceus)* abundance and size frequency[28]	• Ocean acidification • Increased sea temperature	• Increased abundance and size frequency	✔	✔
Owl limpet (*Lottia gigantea*) abundance and size frequency[29]	• Increased sea temperature • Ocean acidification	• Reduced abundance due to thermal stress • Increased fragmentation of local populations	✔	✔
Pinniped abundance (colony size) (harbor seal, California sea lion, northern elephant seal) [30]	• Sea level rise	• Reduced abundance due to loss of haul out sites.	✔	✔
Purple sea urchin (*Strongylocentrotus purpuratus*)abundance and size frequency[31]	• Ocean acidification • Increase sea temperature	• Reduced abundance and size frequency	✔	✔
Red abalone (*Haliotis rufescens*) abundance and size frequency[32]	• Increased sea temperature • Ocean acidification	• Reduced abundance due to thermal stress and disease • Stunted growth due to ocean acidification	✔	
Red sea urchin (*Strongylocentrotus franciscanus*) abundance and size frequency[33]	• Ocean acidification • Increased sea temperature	• Reduced abundance and size frequency	✔	✔
Rock crab (*Cancer spp.)* abundance and	• Changes in upwelling intensity	• Northern range shifts	✔	✔

[26] Sydeman et al. 2001
[27] Harley and Rogers-Bennett 2004, Harley et al. 2006, Harley 2011
[28] Gooding et al. 2009
[29] Cheung et al. 2009
[30] Adams et al. 2009
[31] Harley and Rogers-Bennett 2004
[32] Rogers-Bennett et al. 2010
[33] Harley et al. 2006, O'Donnell et al. 2009

TIER 1: FOCAL SPECIES/INDICATORS METRICS	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT	MLPA REGION	
			North Central	South
size frequency[34]	and timing • Increased air and sea temperature			
Abalone (*Haliotis spp.*) density and size structure[35]	• Increased sea temperature • Ocean acidification	• Reduced density and size structure due to thermal stress and disease • Stunted growth due to ocean acidification	✔	✔
Areal extent of surface kelp canopy (*Nereocystis luetkeana*)[36]	• Increased severity of storms • Wave height and patterns • Increased sea temperature	• Reduced areal extent • Lower density • Expansion of bull kelp (*Nereocystis luetkeana*) into traditionally giant kelp dominated systems	✔	
California sheephead (*Semicossyphus pulcher)* density, size structure, and sex ratio[37]	• Increased sea temperature	• Increased abundance and size • Northern range shift		✔
Purple sea urchin (*Strongylocentrotus purpuratus*) density and size structure[38]	• Ocean acidification • Increased sea temperature	• Reduced density and size structure	✔	✔
Kellet's whelk (*Kelletia kelletii*) density and size structure[39]	• Increased sea temperature	• Northern range shifts		✔
Red sea urchin (*Strongylocentrotus franciscanus*) density and size structure[40]	• Ocean acidification • Increased sea temperature	• Reduced density and size structure	✔	✔
Giant kelp (*Macrocystis pyrifera*) areal extent[41],	• Increased severity of storms • Wave height and patterns	• Reduced areal extent • Lower density • Lower annual productivity • Bull kelp (*Nereocystis luetkeana)* range shift, moving into giant kelp (*Macrocystis pyrifera*)dominated systems		✔

[34] California Department of Fish and Game 2001
[35] O'Donnell et al. 2009
[36] Springer et al. 2010, Byrnes et al. 2011
[37] Lenarz et al. 1995
[38] Gooding et al. 2009
[39] Zacherl et al. 2003
[40] Harley and Rogers-Bennett 2004, O'Donnell et al. 2009
[41] Byrnes et al. 2011, Reed et al. 2011

TIER 1: FOCAL SPECIES/INDICATORS METRICS	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT	MLPA REGION	
			North Central	South
Sea star (*Pisaster spp. and Pycnopodia helianthoides*) density and size structure[42]	• Ocean acidification • Increased sea temperature	• Increased density and size structure	✔	✔
Hydrocoral density[43]	• Increased sea temperature • Ocean acidification	• Reduced density	✔	✔
Cover of foliose red algae[44]	• Increased sea temperature • Sea level rise	• Increased algal cover	✔	✔
Cover of fucoids (fleshy brown algae)[45]	• Increased sea temperature • Sea level rise	• Increased algal cover	✔	✔
Areal extent of pickleweed (*Salicornia virginica*)[46]	• Sea level rise	• Decrease in areal extent • Loss of habitat	✔	✔
Colony size and fledging rate of sea birds[47]: • Brandt's cormorant • Pelagic cormorant • Pigeon guillemot • Common murre	• Sea level rise • Increased sea temperature • Changes in upwelling intensity and timing • Changes in circulation patterns	• Shifts in food supply	✔	✔
Rock crab (*Cancer spp.*) density [48]	• Increased sea temperature • Ocean acidification	• Decrease in density	✔	✔
Total abundance of rockfish larvae[49]	• Increased sea temperature • Changes in upwelling intensity and timing • Changes in circulation patterns	• Decrease in abundance • Shifts in spatial patterns of recruitment • Shifts in species ranges	✔	✔
Total YOY (young-of-the-year) rockfish	• Increased sea temperature	• Reduced abundance	✔	✔

[42] Harley et al. 2006
[43] Cheung et al. 2009
[44] Barry et al. 1995
[45] Heberger et al. 2009
[46] Heberger et al. 2009
[47] Sydeman et al. 2001
[48] Leet et al. 2001
[49] Moser et al. 2000

TIER 1: FOCAL SPECIES/INDICATORS METRICS	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT	MLPA REGION	
			North Central	South
abundance[50]	• Changes in upwelling intensity and timing • Changes in circulation patterns	• Shifts in spatial patterns of recruitment • Shifts in species ranges		
Pismo clam (*Tivela stultorum*) density and size structure[51]	• Increased sea temperature	• Reduced density and increased mortality due to thermal stress		✔
Sand crab (*Emerita analoga*) density and size structure[52]	• Changes in upwelling timing and intensity • Increased sea temperature	• Increased abundance • Northern range shifts	✔	✔

[50] Soto 2002
[51] Revell et al. 2011
[52] Sorte et al. 2001, Revell et al. 2011

TIER 2. CANDIDATE CLIMATE CHANGE METRICS THAT MAY BE ADDED TO THE MPA MONITORING PLANS

Several ecological metrics could be added to existing monitoring plans in order to track climate change effects in MPAs. In some cases these metrics are new metrics of existing monitored species; in other cases they are metrics for new species (Tables 2 and 3). Developing Tier 2 components requires vigilance on the part of those monitoring to recognize novel species that are not traditionally seen, yet have shifted into the region and are therefore not identified on any list of species to monitor. One of the recurring tenets of the study of climate change effects is to "expect surprises." In monitoring this could translate into "notice surprises."

Point Conception in Santa Barbara County is a major biogeographic boundary point, delineating some species' northern or southern range limits. Given the range patterns associated with historic climatic conditions for these species, observed changes can serve as climate change indicators by monitoring presence/absence and percent coverage within the existing MPA framework.[53] Below are examples of climate-sensitive species with range limits at Point Conception that could be used in the North Central Coast and South Coast Monitoring Plans to track climate change impacts.[54] These examples include species already monitored through climate-sensitive metrics, already monitored species with additional metrics that are climate-sensitive, and additional species. Additional details and metrics can be found in Table 3 (North Central Coast) and Table 4 (South Coast).

<u>North Central Coast Candidate Climate Change Indicator Species to be Included in the MPA Monitoring Plan</u>

Plausible decrease in species of:

- California anadromous salmonid species abundance and size frequency
- Dungeness crab abundance and size frequency
- Pinniped population and breeding success
- Rockfish density

Plausible increase in species of:

- Dolphin fish, billfish, and schooling fish, such as mackerel, bonito and sardine abundance
- Treefish, kelp rockfish, California sheephead, kelp bass, giant kelpfish, range extensions

<u>South Coast Candidate Climate Change Indicator Species to be Included in the MPA Monitoring Plan</u>

Plausible decrease in species of:

- Blue fin tuna abundance and size frequency
- Spider crab abundance and size frequency

[53] Blanchette et al. 2008
[54] Radovich 1961, California's Living Marine Resources and their Utilization 1992, Shaw 2008

- California spiny lobster abundance and size frequency
- Owl limpet cover
- Giant kelp and other shallow kelps
- Any fishes (and other species) with cold water affinity whose southern range limit extends into southern CA and is temperature-dependent[55]

Plausible increase in species of:

- Tropical species that may be expanding their ranges farther poleward, such as pelagic red crabs (can also be found in Northern regions, during ENSO events), bottlenose dolphins (established populations after the '82/83 ENSO event), and many species of fish, including hammerhead sharks, bonefish, Mexican barracuda, cutlassfish, puffers, and porcupinefish.
- Bull kelp (due to increased storm removal of giant kelp)

Many proposed monitoring species occur across the California coast and some of those provide good monitoring metrics for climate change. Examples of candidate monitoring metrics for inclusion in either the South Coast or the North Central Coast regions for climate change (although the pattern of change may be different) include:

- Cassin's auklet (*Ptychoramphus aleuticus*) nest abandonment rates
- Krill abundance
- Marine bird nesting success (density and fledging rate)
- Mussel shell integrity (thickness and size) and size frequency (*Mytilus spp.*)
- Mussel bed height (*Mytilus spp.*)
- Mussel larval concentration and integrity (*Mytilus spp.*)
- Ochre sea star (*Pisaster ochraceaus*) larval concentration
- Owl limpet (*Lottia gigantea*) larval concentration and density
- Pelagic red crab (*Pleuroncodes planipes*) presence
- Sea urchin *(Strongylocentrotus purpuratus and S. franciscanus*) larval concentration
- Abundance of intertidal nudibranch (*Phidiana hiltoni*)
- Abundance of subtidal gastropods (*Calliostoma ligatum*)
- Distribution and concentration of phytoplankton (relative proportion of diatoms and dinoflagelates) and zooplankton.

[55] Holbrook et al. 1997

Table 2. Additional North Central Coast MPA monitoring metrics that can be used to detect climate change effects

This table may be read as:

"If monitoring for Focal Species/Indicator Metric), (Climate Change) may manifest through (Plausible Biological Change/Range Shift)."

TIER 2: ADDITIONAL MPA MONITORING METRICS TO BE CONSIDERED	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT
ADDITIONAL METRICS FOR SPECIES ALREADY MONITORED		
Black abalone (*Haliotis cracherodii*) disease occurrence (withering syndrome)	• Increased sea temperature	• Increased incidence of disease • Reduced abundance due to thermal stress and disease • Reduced recruitment
Black abalone (*Haliotis cracherodii*) larval concentration and recruitment	• Increased sea temperature	• Reduced abundance
Cassin's auklet (*Ptychoramphus aleuticus*) abandonment rate of nest	• Changes in upwelling intensity and timing • Increased air and sea temperature	• Reduced reproduction success to changes in food supply
Dungeness crab (*Cancer magister*) larvae	• Increased sea temperature	• Reduced recruitment due to larval sensitivity to higher temperatures
Marine bird nesting success (density and fledging rate)	• Changes in upwelling intensity and timing • Increased air and sea temperature	• Reduced reproduction success due to changes in food abundance and composition
Mussel shell integrity (thickness and size) and size frequency (*Mytilus spp.*)[56]	• Ocean acidification • Increased sea and air temperature • Sea level rise	• Reduced mean size • Reduced shell integrity
Mussel larvae (*Mytilus spp.*) concentration[57]	• Ocean acidification • Increased sea and air temperature	• Reduced recruitment
Mussel bed height (*Mytilus spp.*)[58]	• Increased sea and air temperature • Sea level rise	• Thermal stress restricting mussels to the lower levels of the shore
Ochre sea star (*Pisaster ochraceus*) larvae	• Ocean acidification	• Increased recruitment

[56] Gaylord et al. 2011
[57] Gaylord et al. 2011
[58] Menge et al. 2008

TIER 2: ADDITIONAL MPA MONITORING METRICS TO BE CONSIDERED	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT
concentration	• Increased sea temperature	
Owl limpet (*Lottia gigantea*) larval concentration	• Increased sea temperature	• Reduced fertilization success
Sea urchin (*Strongylocentrotus purpuratus* and *Strongylocentrotus franciscanus*) larval concentration	• Ocean acidification • Increased sea temperature	• Reduced recruitment
Red abalone (*Haliotis rufescens*) larval concentration	• Ocean acidification • Increased sea temperature	• Reduced reproduction success and recruitment
YOY and juvenile rockfish composition and concentration	• Increased sea temperature • Changes in upwelling intensity and timing • Changes in circulation patterns	• Reduced abundance
Anadromous salmonid abundance and size frequency	• Increased sea temperature • Increased severity of storms	• Range shift out of the region • Reduced hatching success
California sheephead (*Semicossyphus pulcher)* abundance[59]	• Increased sea temperature	• Range shift into the region
Garibaldi (*Hypsypops rubicundus*) abundance[60]	• Increased sea temperature	• Range shift into the region
Krill abundance	• Changes in upwelling intensity and timing • Increased air and sea temperature	• Changes in krill abundance and distribution
Novel species	• Increased sea and air temperature • Changes in upwelling intensity and timing • Changes in circulation patterns	• Range shift into the region
Nudibranch (*Phidiana hiltoni*) abundance[61]	• Increased sea temperature	• Range shift into the region
Opaleye (*Girella nigricans*)[62]	• Increased sea temperature	• Range shift into region
Phytoplankton (diatom and dinoflagellate) and zooplankton composition, concentration, timing	• Increase sea temperature • Ocean acidification • Changes in upwelling intensity and	• Altered composition and timing • Range shifts

[59] Lenarz et al. 1995
[60] McGowen 1993, Field et al. 1999
[61] Goddard et al. 2011
[62] McGowen 1993

TIER 2: ADDITIONAL MPA MONITORING METRICS TO BE CONSIDERED	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT
and distribution[63]	timing • Changes in circulation patterns	
Pelagic red crabs (*Pleuroncodes planipes*) presence[64]	• Increased sea temperature	• Range shift into the region
Rock wrasse (*Halichoeres semicinctus*)[65]	• Increased sea temperature	• Range shift into the region
Schooling fish (e.g. mackerel, bonito, sardines) abundance[66]	• Increased sea temperature	• Range shift into the region
Subtidal gastropod (*Calliostoma ligatum* and *Kelletia kelletii*) abundance[67]	• Increased sea temperature	• Increase in abundance
Treefish (*Sebastes serriceps*) abundance	• Increase sea temperature	• Range shift into the region

[63] California Natural Resources Agency 2009
[63] Goericke et al. 2007
[64] Aurioles-Gamboa 1992, Lluch-Belda et al. 2005
[65] McGowen 1993
[66] Lea and Rosenblatt 2000, Lluch-Belda et al. 2005
[67] Barry et al. 1995

Table 3. Additional South Coast MPA monitoring metrics that can be used to detect climate change effects

This table may be read as:

"If monitoring for Focal Species/Indicator Metric), (Climate Change) may manifest through (Plausible Biological Change/Range Shift)."

TIER 2: ADDITIONAL MPA MONITORING METRICS TO BE CONSIDERED	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT
ADDITIONAL METRICS FOR SPECIES ALREADY MONITORED		
Abalone (*Haliotis* spp.) disease occurrence (withering syndrome)	• Increased sea temperature	• Increased incidence of disease • Reduced abundance due to thermal stress and disease • Reduced recruitment
Abalone (*Haliotis* spp.) larval concentration and recruitment	• Increased sea temperature	• Reduced abundance
California sheephead (*Semicossyphus pulcher)* spawning sites[68]	• Increased sea temperature	• Northern range shift and changes in site fidelity
Cassin's auklet (*Ptychoramphus aleuticus*) abandonment rate of nest	• Changes in upwelling intensity and timing • Increased air and sea temperature	• Reduced reproduction success to changes in food supply
Marine bird nesting success (density and fledging rate)	• Changes in upwelling intensity and timing • Increased air and sea temperature	• Reduced reproduction success due to changes in food abundance and composition
Mussel shell integrity (thickness and size) and size frequency (*Mytilus spp.*)[69]	• Ocean acidification • Increased sea and air temperature • Sea level rise	• Reduced mean size • Reduced shell integrity
Mussel larvae (*Mytilus spp.*) concentration[70]	• Ocean acidification • Increased sea and air temperature	• Reduced recruitment
Mussel bed height (*Mytilus spp.*)[71]	• Increased sea and air temperature	• Thermal stress restricting mussels to the lower levels of

[68] Topping et al. 2006
[69] Gaylord et al. 2011
[70] Gaylord et al. 2011

TIER 2: ADDITIONAL MPA MONITORING METRICS TO BE CONSIDERED	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT
	• Sea level rise	the shore.
Ochre sea star (*Pisaster ochraceus)* larvae concentration	• Ocean acidification • Increased sea temperature	• Increased recruitment
Owl limpet (*Lottia* gigantea) larval concentration and density	• Increased sea temperature	• Reduced fertilization success • Range shift out of region
Sea urchin (*Strongylocentrotus purpuratus* and *Strongylocentrotus franciscanus*) larval concentration	• Ocean acidification • Increased sea temperature	• Reduced recruitment
ADDITIONAL SPECIES TO MONITOR FOR CLIMATE CHANGE		
Blue fin tuna (*Thunnus orientalis)* abundance and size frequency	• Increased sea temperature	• Range shifting north from region • Altered migration patterns
Krill abundance	• Changes in upwelling intensity and timing • Increased air and sea temperature	• Changes in krill abundance and distribution
California Moray eel (*Gymnothorax mordax*) reproduction	• Increased sea temperature	• Presence of early-stage larvae
Novel species	• Increased sea and air temperature • Increased severity of storms • Ocean acidification • Changes in upwelling intensity and timing • Changes in circulation patterns	• Range shift into the region
Nudibranch (*Phidiana hiltoni*) abundance[72]	• Increased sea temperature • Changes in upwelling intensity and timing	• Range shift out of the region
Phytoplankton (diatom and dinoflagellate) and zooplankton composition, concentration, timing	• Increase sea temperature • Ocean acidification • Changes in upwelling intensity and timing	• Altered composition and timing • Range shifts

[71] Menge et al. 2008
[72] Goddard et al. 2011

TIER 2: ADDITIONAL MPA MONITORING METRICS TO BE CONSIDERED	CLIMATE CHANGES	PLAUSIBLE BIOLOGICAL CHANGE/RANGE SHIFT
and distribution[73]	• Changes in circulation patterns	
Pelagic red crabs (*Pleuroncodes planipes*) presence[74]	• Increased sea temperature	• Range shift into the region
Spider or Sheep crab (*Loxorhynchus grandis)* abundance and size frequency	• Increased sea temperature	• Range shift out of the region
Subtidal gastropod (*Calliostoma ligatum*) abundance[75]	• Increased sea temperature	• Increase in abundance
Subtropical/Tropical fish (e.g. hammerhead sharks, bonefish, Mexican barracuda, cutlassfish, puffers and porcupinefish) abundance	• Increased sea temperature	• Range shift into the region

[73] California Natural Resources Agency 2009
[73] Goericke et al. 2007
[74] Aurioles-Gamboa 1992, Lluch-Belda et al. 2005
[75] Barry et al. 1995

TIER 3: CANDIDATE NEW FRAMEWORK ELEMENTS FOR CLIMATE CHANGE MONITORING

Some of the effects of climate change in MPAs may go beyond factors that can be detected with existing monitoring species and metrics. Because climate change effects are likely to be ubiquitous in marine and coastal systems it may be prudent to fully integrate climate change into MPA monitoring and management. In Tier 3 we provide a perspective on the types of new framework elements that can facilitate this integration. These elements can drive an iterative process of identifying new implications of climate change for MPAs, improving monitoring, and improving management.

One important area for considering climate change in MPAs is the interactive nature of climate change with existing environmental challenges. There is still insufficient scientific knowledge to determine how MPAs will respond to the impacts of multiple climate stressors compounded by non-climatic stressors. Non-climatic stressors, such as land use practices, fishing, habitat degradation, disease, non-native or invasive species, and pollution may interact with and possibly exacerbate the impacts of climate change. Monitoring programs should consider other impacts and plausible interactions. A new monitoring framework to provide information on climate change effects in MPAs should include analysis of climate change variables, temporal and spatial tracking of patterns and ecological change across ecosystems, disturbance response monitoring, and coordinated information sharing and analysis.

As a first step, adding essential oceanographic and climatic variables to MPA monitoring can increase the information available to inform the climate change management dialogue[76]. There is ample opportunity to include climate change monitoring within MPA management and link MPA monitoring to several existing climatic and oceanographic monitoring programs in California, such as the Integrated Ocean Observing System, National Weather Service Climate Prediction Center, and the California Climate Data Archive. Essential oceanographic and climate measurements needed to interpret MPA monitoring results include:

- Temperature (air and water)
- Ocean chemistry (ocean acidification, salinity, O_2)
- Currents and circulation
- Upwelling
- Shoreline mapping (sea level rise)
- ENSO and PDO events
- Wave height and patterns
- Storm events
- Precipitation

[76] Carr et al 2011

MPA monitoring can provide the opportunity to further our scientific understanding of the linkages between ecological indicators and physical factors (e.g., climatic, atmospheric, oceanographic) as they relate to climate change. MPA monitoring that is reflective of climate change and attempts to capture the effects and response of those changes will be a key step in supporting MPA management, but it will also help develop a suite of information that will be useful in filling some of the information gaps about climate change and MPAs. This section focuses on additional questions that may require new research projects or development of new methods. For each focus area, information is provided on what might be required to implement supplemental monitoring.

FOCUS AREA 1. MPA EFFECTS ON ECOSYSTEM AND SPECIES RESILIENCE

Information Need: California's marine and coastal ecosystems are impacted by non-climatic stressors, such as fishing, coastal development, and water pollution. MPAs provide an opportunity to assess how populations respond to climate change in the absence of some of these pressures. There is still considerable scientific debate about how to empirically measure resilience. However, approaches that compare rates of ecosystem change in areas with and without identified anthropogenic stressors may shed light on the interactions between MPAs, climate change, and ecosystem resilience.

- Question 1. Which MPAs and ecosystem features are most resilient to climate change impacts?

  Potential Approach: Compare species composition and density in no-take reserves to other MPAs and surrounding areas to serve as a baseline for resilience. Monitor areas during and after an episodic event (e.g. severe storm, ENSO year) to determine which ecosystems and MPAs were able to resist and/or recover from change. Develop a model to forecast climate change effects in California's MPAs.

- Question 2. Can MPAs serve as reference sites for climate change impacts? Are communities inside MPAs more resilient to climate change effects than those outside MPAs?

  Potential Approach: Conduct assessments to determine the effectiveness of management actions that reduce localized stresses (e.g., fishing) and compare to outside areas. Compare rates of changes in community structure in areas isolated from local anthropogenic stresses that can serve as reference sites for the ability of MPAs to enhance resilience to climate change.

Information Need: Understanding of the interaction between climate change and ecosystem structure and function of MPAs.

- Question 1. Do MPAs protect climate-sensitive species in specific geographic ranges?

  Potential Approach: Monitor climate-sensitive species abundance and composition within specific ranges over the long term. Compare between MPAs along the network gradient.

- Question 2. Do MPAs protect species in areas that may serve as climate refugia?

  Potential Approach: Identify and monitor existing MPA locations that serve as nursery, spawning, or foraging habitats (e.g., eelgrass beds, kelp forests, estuaries, wetlands) that may act as refugia for climate-sensitive species.

FOCUS AREA 2. OCEANOGRAPHIC CLIMATE CHANGE VARIABLES AND EFFECTS ON MPAS

Information Need: Understanding of spatial and temporal effects of sea level rise in coastal and marine areas relative to low-lying habitats.

- Question 1. Will species be able to shift or relocate to new areas as sea level rise results in inundation of wetlands, beaches, and other nearshore habitats?

  Potential Approach: Model sea level rise and associated impacts on community structure. Identify methods to accommodate species and habitat movement through migration corridors.

- Question 2. Will species move higher in the intertidal zone?

  Potential Approach: Monitor for changes in species distribution up intertidal gradients relative to historic sea level and with reflection on modern sea level.

- Question 3. What coastal habitats will be most vulnerable to sea level rise?

  Potential Approach: Record extreme storm events and wave conditions (height and patterns) and coastal erosion rates to determine areas most vulnerable to sea level rise.

Information Need: Understanding of the effects of altered sea surface temperature on marine species and habitats. Increasing temperatures are projected to cause phenological and community shifts, increased risk of invasive species establishment, altered photosynthetic and metabolic rates, and increased risk of disease.

- Question 1. Will species abundance or range change in response to increasing sea surface temperatures?

Potential Approach: Monitor for presence or absence of native species to detect range shifts and invasive species establishment. Coordinate information sharing with other monitoring programs, such as the California Department of Fish and Game's Marine Invasive Species Program and the Multi-Agency Rocky Intertidal Network (MARINe).

- Question 2. Will relative species abundance change in response to increasing sea surface temperatures?

  Potential Approach: Monitor composition and areal extent of plants and algae [e.g., giant kelp (*Macrocystis pyrifera*) and beach wrack] and abundance of known temperature-sensitive species [e.g., Sea stars (*Pisaster* spp., *Pycnopodia helianthoides*) and abalone (*Haliotis* spp.)]. Analyze historical sea surface temperature and future temperature projections to determine which species may be most vulnerable or resistant to thermal stress; species with high levels of vulnerability may serve as early warning signals of change.

Information Need: Understanding climate impacts requires monitoring of the many aspects of climate and a wide range of biological, chemical, and physical responses. Putting climate change impacts in the context of multiple stresses requires an integrated analysis.

- Question 1. How will ocean acidification affect marine species?

  Potential Approach: Conduct systematic monitoring of ocean pH and alkalinity along with monitoring of mussel bed cover and species abundance and size frequency (e.g., black abalone, purple sea urchin, rock crab) to identify and track early indications of difficulties in calcification or of decreased prey availability due to increasing CO_2 in the ocean.

- Question 2. How will larval transport be affected by predicted changes in ocean circulation?

  Potential Approach: Develop standardized approaches to modeling and monitoring techniques to facilitate the links between monitoring efforts to climate and ecological/biological response models. Model future larval recruitment and future circulation patterns driven by climate change.

- Question 3. How will primary productivity be affected by predicted changes in coastal upwelling?

  Potential Approach: Monitor for phenological shifts in marine species (e.g., seabirds, marine mammals) that time breeding and migration patterns to coincide with upwelling. Utilize existing SeaWiFS data.

Information Need: Knowledge of cross-scale interaction of species composition and climate change impacts, including changes in sea surface and air temperatures, ocean acidification, physical oceanography, and sea level rise.

- Question 1. How will climate factors influence MPA performance?

  Potential Approach: Utilize climate modeling information and derivative products in order to forecast ecological and population responses at regional and local levels. Place climate change impacts in the context of multiple stresses in order to distinguish climate change influences. Streamline collection of data at certain spatial and temporal resolutions and support ground truth measurements.

FOCUS AREA 3. ATMOSPHERIC AND CLIMATIC VARIABLES AND EFFECTS ON MPAS

Information Need: Research into effects of extreme or anomalous events on species and habitats in marine and coastal areas.

- Question 1. What impact will changes in precipitation and increasing frequency and intensity of storms have on species and habitats in MPAs?

  Potential Approach: Monitor sedimentation rates caused by increased precipitation that may smother nearshore eelgrass and seagrass beds. Record level of damage or destruction to kelp holdfasts and mussel beds after storm events and compare to other data over time.

- Question 2. What impact will increasing air temperatures have on species and habitats in MPAs?

  Potential Approach: Monitor species abundance, composition, and presence/absence to detect range and community shifts, invasive species establishment, and disease occurrence.

Information Need: Naturally occurring climatic variability, such as inter-annual El Niño Southern Oscillation (ENSO) and inter-decadal Pacific Decadal Oscillation (PDO) events, characterized by warm and cool phases and changes in sea surface temperatures and wind patterns, need to be considered in monitoring climate change parameters. These events result in alterations to plankton distribution and fish abundance and cause range shifts in marine species.[77]

---

[77] Sagarin et al. 1999, Brosnan and Becker 2005, Helmuth et al. 2006, Hilbish et al. 2010

- Question 1. What are "natural" versus anthropogenic events?

  Potential Approach: Differentiate between ENSO/PDO events (single or decadal time frame) and anthropogenic events (long-term trend) in order to determine episodic events versus long-term changes. ENSO/PDO events can be used to forecast future climate change impacts on biological indicator species in MPAs.

FOCUS AREA 4. CLIMATE ANALYSES AND DATA INTEGRATION

Information Need: Rescaling of climate information to suit regional to local scale analyses.

- Question 1. How can climate information be used in regional and local scales to determine climate change effects in MPAs?

  Potential approach: Develop descriptive downscaled models of large-scale climate variability data (e.g., ENSO, PDO) to assess ecosystem response. Downscaled models should include large-scale circulation data, currents, coastal upwelling, sea temperatures, sea levels, and winds.

- Question 2. How can large-scale climate variability be linked to biological response in MPAs?

  Potential approach: Create a climatological baseline of modeled climatic data including *in situ*, moored buoy, and modeled data for the region. Link this information to local knowledge of the ecosystem and ecosystem variability to understand historical climate conditions at regional and local scales.

Information need: Temporal and spatial tracking of climatic patterns and ecological changes across ecosystems.

- Question 1. Will climate change affect MPAs in different ways across temporal and spatial scales?

  Potential approach: Monitor for community and range shifts between MPAs. Analyze seasonality and climatic factors while considering ecological responses over time and space.

FOCUS AREA 5. EPISODIC EVENTS, RAPID RESPONSE, AND LONG-TERM EFFECTS ON MPAs

Information Need: Long-term monitoring protocols might not capture episodic events necessary to evaluate extreme disturbance events. A disturbance response monitoring protocol would be useful.

- Question 1. How can episodic climate change events affect MPA ecosystems?

  Potential approach: Need to be able to track local disturbance events that might not be picked up by long-term monitoring protocols. Developing a disturbance response monitoring protocol would be useful in tracking episodic events such as ENSO/PDO, algal blooms, extreme precipitation events, or extreme heat waves to determine the impact to MPA ecosystems and could be used in long-term climatic effects analyses. Develop a regional rapid response monitoring protocol and action network. Standardize training, data management, and communications plan.

FOCUS AREA 6. COORDINATION AND INFORMATION SHARING ACROSS MPAS

Information Need: Although coordination and information sharing are incorporated into the North Central Coast and South Coast monitoring plans, communication of climate change-specific monitoring protocols, methods, and results is critical to success. Coordination, sharing, and analysis of data between regions (both within and outside MPAs) are needed to track climate change impacts and range shifts of indicator species. There should be special recognition that there will be a lag effect (e.g., time between change and response to change).

- Question 1. How are "indicator species" responding to climate change impacts?

  Potential Approach: Analyze indicator species data within individual MPAs, between specific MPAs, and throughout the entire network of MPAs periodically to assess changes and signals. Consider which indicators are likely sources of early detection (such as the intertidal nudibranch, *Phidiana hiltoni*, and sub-tidal gastropods, *Calliostoma ligatum* and *Kelletia kelletii*) and adjust temporal and spatial monitoring schemes to allow for early detection. For example, in coral reef systems this has meant shifting monitoring to track warm water events to detect bleaching and disease progression.

- Question 2. What additional benefit could be gained from collection and analysis of data?

  Potential approach: Coordinate a centralized data analysis team to track climate status and trends and communicate with the monitoring teams. Develop a centralized data bank accessible by all MPAs.

- Question 3. How will monitoring results be communicated among regions and to interested stakeholders, including scientists, managers, and decision makers?

  Potential Approach: Develop a MPA working group with representatives from all areas to analyze results and disseminate information back to their home area. Use regular inter-MPA communications (newsletters, listservs, discussion groups) and novel communications (georeferenced online database information portals, special conferences, webinars) to share findings from monitoring analyses.

CONCLUSION

With the onset of global climate change, there may be many unanticipated effects. Monitoring programs should be flexible enough to allow detection and recording of anomalous events; these may be informative measures of the effects due to climate change. Tracking climate change impacts on MPA performance will be challenging even with the inclusion of indicator species within the existing monitoring frameworks and other climatic, atmospheric, and oceanographic factors. Modeling climate impacts to ecosystem features can be a useful solution in addressing the complex and interwoven aspects of climate change.

Monitoring MPAs to determine how effective they are in the face of climate change will be important for determining how to improve management and siting. The monitoring suggestions presented in this framework, as well as others that will be developed as the effects of climate change become evident, will be useful in improving California's MPAs.

Many of the same tools that are used for MPA monitoring today are useful for assessing the effects of climate change and working to envision management responses. There are, however, many opportunities for expanding the monitoring toolkit by learning how to use old tools in new ways and adding new tools. Additionally there is much to learn by looking at the results of monitoring in a new light, especially to identify early indicators and leverage network wide comparisons.

REFERENCES

Adams, D., D. Press, M. Hester, H. Nevins, D. Roberts, B. Becker, H. Jensen, E. Flynn, M. Koenen, and S. Allen. 2009. San Francisco Bay Area Network pinniped monitoring protocol. Natural Resource Report NPS/SFAN/NRR—2009/170. National Park Service, Fort Collins, Colorado.

Aurioles-Gamboa, D. 1992. Inshore-offshore movements of pelagic red crabs *Pleuroncodes planipes* (Decapoda, Anomura, Galatheidae) off the Pacific coast of Baja California Sur, Mexico. Crustaceana 62(1):71-84.

Barry, J. P., C.H. Baxter, R.D. Sagarin, and S.E. Gilman. 1995. Climate-related long-term faunal changes in a California rocky intertidal community. Science 267(5198):672-675.

Behrenfeld, M.J., J.T. Randerson, C.R. McClain, G.C. Feldman, S.O. Los, C.J. Tucker, P.G. Falkowski, C.B. Field, R. Frouin, W.E. Esaias, D.D. Kolber and N.H. Pollack. 2006. Biospheric primary production during an ENSO transition. Science 291(5513):2594-2597.

Björk M., F. Short, E. Mcleod, S. Beer. 2008. Managing Seagreasses for Resilience Climatic Change. IUCN, Gland, Switzerland.

Blanchette, C.A, .C.M. Miner., P.T. Rainondi, D. Lohse, K.E. Heady, and B.R. Broitman. 2008. Biogeographical patterns of rocky intertidal communities along the Pacific coast of North America. Journal of Biogeography 35:1593-1607.

Botsford, L. W. 2001. Physical influences on recruitment to California Current invertebrate populations on multiple scales. – ICES Journal of Marine Science 58: 1081–1091.

Brosnan, D.M. and C.J. Becker. 2005. El Niño Southern Oscillations (ENSO) and Their Impacts on Marine Populations. In Volume 4: Habitat Conservation Plans of Headwaters Habitat Conservation Plan/Sustained Yield Plan Volume 4 Habitat Conservation Plans. http://resources.ca.gov/headwaters/hcp/v4/v4pbs6.pdf

Byrnes, J.E , D. C. Reed, B.J. Cardinale, K.C. Cavanaugh, S.J. Holbrook and R.J. Schmitt. 2011. Climate-driven increases in storm frequency simplify kelp forest food webs. Global Change Biology doi: 10.1111/j.1365-2486.2011.02409.x.

California Natural Resources Agency, Climate Action Team. 2009. California Climate Adaptation Strategy: A Report to the Governor of the State of California in Response to Executive Order S-13-2008, 2009.

California's Living Marine Resources and their Utilization. 1992. Published by the Sea Grant Extension Program, Department of Wildlife and Fisheries Biology, University of California, Davis, CA 95616.

Carr, M.H., C.B. Woodson, O.M. Cheriton, D. Malone, M.A. McManus, and P.T. Raimondi. 2011. Knowledge through partnerships: integrating marine protected area monitoring and ocean observing systems. Frontiers in Ecology and the Environment 9:342-350.

Cayan, D, Bromirski, P, Hayhoe, K, Tyree, M, Dettinger, M, and R. Flick. 2006. Projecting Future Sea Level. Report for California Climate Change Center. http://www.energy.ca.gov/2005publications/CEC-500-2005-202/CEC-500-2005-202-SF.PDF

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham and R. Flick. 2009. Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment. California Climate Change Center, publication #CEC-500-2009-014-F, 64 pages, August 2009.

Cayan, D.R., E.P. Maurer, M.D. Dettinger, M. Tyree and K. Hayhoe. 2008. Climate Change Scenarios for the California Region. Climatic Change 87(supplement 1):21-42.

Cheung, W. W. L., B.W.Y. Lam, J.L. Sarmiento, K. Kearney, R. Watson and D. Pauly. 2009. Projecting global marine biodiversity impacts under climate change scenarios. Fish and Fisheries 10:235-251.

Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas. 2009. Ocean acidification: the other CO_2 problem. Annual Review of Marine Science. 1:169-193.

Dulvy, N.K., S.I. Rogers, S. Jennings, V. Stelzenmuller, S.R. Dye and H.R. Skjolda. 2008. Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. Journal of Applied Ecology 45:1029-1039

Echavarria-Heras, H.A., E. Solana-Arellano, and E. Franco-Vizcaíno. 2006. The Role of Increased Sea Surface Temperature on Eelgrass Leaf Dynamics: Onset of El Niño as a Proxy for Global Climate Change in San Quintín Bay, Baja California. Bulletin, Southern California Academy of Sciences 105(3):113-127.

Field, C.B., G.C. Daily, F.W. Davis, S. Gaines, P.A. Matson, J. Melack, and N.L. Miller. 1999. Confronting Climate Change in California: Ecological Impacts on the Golden State. Union of Concerned Scientists, Cambridge, MA and Ecological Society of America, Washington, DC.

Field, C. et al. 2000. U.S. National Assessment of Potential Consequences of Climate Variability and Change: Potential Consequences of Variability and Change on Coastal Areas and Marine Resources 461.

Flick, R.E. 1998. Comparison of California tides, storm surges, and mean sea level during the El Niño winters of 1982–1983 and 1997–1998. Shore and Beach 66(3):7–11.

Gaylord, B. and S.D. Gaines. 2000. Temperature or transport? Range limits in marine species mediated solely by flow. American Naturalist 155:769–789.

Gaylord, B., T. M. Hill, E. Sanford, E.A. Lenz, L.A. Jacobs, K.N. Sato, A.D. Russell and A. Hettinger. 2011. Functional impacts of ocean acidification in an ecologically critical foundation species. Journal of Experimental Biology 214: 2586-2594.

Goddard, J.H.R, T. M. Gosliner, and J. S. Pearse. 2011. Impacts associated with the recent range shift of the aeolid nudibranch *Phidiana hiltoni* (Mollusca, Opisthobranchia) in California. Marine Biology 158:1095–1109. doi:10.1007/s00227-011-1633-7.

Goericke R, E. Venrick, T. Koslow, W. Sydeman, F. Schwing, S. Bograd, W. Peterson, R. Emmett, J. Lara, G. Castro, J. Valdez, K. Hyrenbach, R. Bradley, M. Weise, M. Harvey, C. Collins and N. Lo. 2007. The State of the California Current, 2006-2007: Regional and Local Processes Dominate. 48:33-66. http://www.calcofi.org/newhome/publications/

Gooding, R.A., C.D.G. Harley and E. Tang. 2009. Elevated water temperature and carbon dioxide concentration increase the growth of a keystone echinoderm. Proceedings of the National Academy of Science [USA] 106(23):9316-9321. doi:10.1073/pnas.0811143106.

Harley, C.D.G. 2011. Climate change, keystone predation, and biodiversity loss. Science. 334:1124-1127.

Harley, C. and L. Rogers-Bennett. 2004. Effects Of Climate Change And Fishing Pressure On Exploited Invertebrates. CalCOFI Reports 45: 98-110.

Harley, C. and L. Rogers-Bennett. 2004. The potential synergistic effects of climate change and fishing pressure on exploited invertebrates on rocky intertidal shores. CalCOFI Reports 45: 98-110.

Harley, C. D. G., A. Randall Hughes, K.M. Hultgren, B.G. Miner, C.J.B. Sorte, C.S. Thornber, L.F. Rodriguez, L. Tomanek, L. and S.L. Williams. 2006. The impacts of climate change in coastal marine systems. Ecology Letters 9:228–241.

Hauri, C., N. Gruber, G.-K. Plattner, S. Alin, R.A. Feely, B. Hales and P.A. Wheeler. 2009. Ocean Acidification in the California Current System. Oceanography 22(4):60-71.

Helmuth, B., N. Mieszkowska, P. Moore, and S.J. Hawkins. 2006. Living on the Edge of Two Changing Worlds: Forecasting the Responses of Rocky Intertidal Ecosystems to Climate Change. Annual Review of Ecology, Evolution, and Systematics 37:373 -404.

Heberger, M., H. Cooley, P. Herrera, P. H. Gleick, and E. Moore. 2009. The Impacts of Sea-Level Rise on the California Coast. California Climate Change Center.

Hilbish, T.J., P.M. Brannock, K.R. Jones, A.B. Smith, B.N. Bullock, and D.S. Wethey. 2010. Historical changes in the distributions of invasive and endemic marine invertebrates are contrary to global warming predictions: the effects of decadal climate oscillations. Journal of Biogeography 37: 423–431. http://climate.biol.sc.edu/Publications/wethey22010.pdf

Holbrook, S.J., R.J. Schmitt, J.S. Stephens Jr. 1997. Changes in an assemblage of temperate reef fishes associated with a climate shift. Ecological Applications 7: 1299-1310.

Ishimatsu, A., T. Kikkawa, M. Hayashi, K. Lee and J. Kita. 2004. Effects of CO_2 on marine fish: larvae and adults. Journal of Oceanography 60:731–741.

Kikkawa, T., A. Ishimatsu and J. Kita. 2003. Acute CO_2 tolerance during the early developmental stages of four marine teleosts. Environmental Toxicology 18: 375–382.

Kurihara, H. and Y. Shirayama. 2004. Effects of increased atmospheric CO_2 on sea urchin early development. Marine Ecology Progress Series 274:161–169.

Kurihara, H., S. Kato, and A. Ishimatsu. 2007. Effects of increased seawater pCO_2 on early development of the oyster *Crassostrea gigas*. Aquatic Biology 1:91–98.

Lea, R.N. and R.H. Rosenblatt. 2000. Observations on fishes associated with the 1997-98 El Niño off California. California Cooperative Ocean Fisheries 41:117-129.

Leet, W.S., C.M. Dewees, R. Klingbiel, and E.J. Larson (eds.) 2001. California's Living Marine Resources: A Status Report. California Department of Fish and Game (ANR Publication #SG01-11).

Lenarz, W.H., D.A. Ventresca, W.M. Graham, F.B. Schwing, and F. Chavez. 1995. Explorations of El Niño events and associated biological population dynamics off Central California. CalCOFI Reports 36:106-119.

Lluch-Belda, D., D.B. Lluch-Cota, and S.E. Lluch-Cota. 2005. Changes in marine faunal distributions and ENSO events in the California Current. Fisheries Oceanography 14(6):458-467.

Mazur, L. and C. Milanes. 2009. Indicators of Climate Change in California. California Office of Environmental Health Hazard and Assessment.

McGowen, G.E. 1993. Coastal ichthyoplankton assemblages, with emphasis on the Southern California Bight. Bulletin of Marine Science 53:692–722.

Menge, B.A., F. Chan, and J. Lubchenco. 2008. Response of rocky intertidal ecosystem engineer and community dominant to climate change. Ecology Letters 11:151-162.

Michaelidis, B., A. Spring, and H.O. Portner. 2007. Effects of longterm acclimation to environmental hypercapnia on extracellular acid-base status and metabolic capacity in Mediterranean fish *Sparus aurata*. Marine Biology 150:1417–1429.

Miller, A. K. and W. Sydeman. 2004. Rockfish response to low-frequency ocean climate change as revealed by the diet of a marine bird over multiple time scales. Marine Ecology Progress Series 281:207-216.

Moser, H.G., R.L. Charter, W. Watson, D.A. Ambrose, J.L. Butler, S.R. Charter, and E.M. Sandknop. 2000. Abundance and distribution of rockfish (*Sebastes*) larvae in the Southern California Bight in relation to environmental conditions and fishery exploitation. CalCOFI Rep. 41:132-147.

Moser, S. C., G. Franco, S. Pittiglio W. Chou and. D. R. Cayan. 2009. The Future Is Now: An Update on Climate Change Science, Impacts, and Response Options for California. California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2008-071

O'Donnell, M.J., L.M. Hammond, and G.E. Hofmann. 2009. Predicted impact of ocean acidification on marine invertebrate: elevated CO_2 alters response to thermal stress in sea urchin larvae. Marine Biology 156:439-446.

Palacios, S.L. and R.C. Zimmerman. 2007. Response of eelgrass *Zostera marina* to CO_2 enrichment: possible impacts of climate change and potential for remediation of coastal habitats. Marine Ecology Progress Series 344:1-13.

Perry, A.L., P.J. Low, J.R. Ellis and J.R. Reynolds. 2005. Climate change and distribution shifts in marine fishes. Science 380: 1912-1915.

Peterson, W. and F. Schwing. 2008. California Current Ecosystem. *In* Osgood, K. E. (editor). 2008. Climate Impacts on U.S. Living Marine Resources: National Marine Fisheries Service Concerns, Activities and Needs. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS- F/SPO-89, 118 p.

Portner, H. O. and A. Reipschlager. 1996. Ocean disposal of anthropogenic CO_2: physiological effects on tolerant and intolerant animals. In Ocean Storage of Carbon Dioxide. Workshop 2—Environmental Impact (B. Ormerod and M.V. Angel, Eds.). IEA Greenhouse Gas Rand Programme, Cheltenham, UK.

Radovich, J. 1961. Relationships of Some Marine Organisms of the Northeast Pacific to Water Temperatures. Fish Bulletin 112, 62pp.

Reed, D.C., A. Rassweiler, M.H. Carr, K.C., Cavanaugh, D.P. Malone and D.A. Siegel. 2011. Wave disturbance overwhelms top-down and bottom-up control of primary production in California kelp forests. Ecology 92:2108–2116.

Revell, D.L., Dugan, J.E., and Hubbard, D.M., 2011. Physical and ecological responses of sandy beaches to the 1997–98 El Niño. Journal of Coastal Research, 27(4): 718–730. West Palm Beach (Florida), ISSN 0749-0208.

Rogers-Bennett, L, R.F. Dondanville, J. D. More and L.I. Vilchis. 2010. Response of Red Abalone Reproduction to Warm Water, Starvation, and Disease Stressors: Implications of Ocean Warming. Journal of Shellfish Research 29(3):599-611.

Ruiz,G.M, J.T. Carlton, E.D. Grosholz, and A.H. Hines. 1997. Global Invasions of Marine and Estuarine Habitats by Non-Indigenous Species: Mechanisms, Extent, and Consequences American Zoologist 37(6):621-632. doi: 10.1093/icb/37.6.

Sagarin, R.D., J.P. Barry, S.E. Gilman and C.H. Baxter. 1999. Climate-related change in an intertidal community over short and long term scales. Ecological Monographs,69(4):465-490.

Shaw, R. 2008. Draft, CEC PIER-EA Discussion Paper Ecology and Adaptation, California Energy Commission.

Sorte, C.J., W.T. Peterson, C.A. Morgan and R.L. Emmett. 2001. Larval dynamics of the sand crab, *Emerita analoga*, off the central Oregon coast during a strong El Niño period. Journal of Plankton Research 23:939-944.

Soto, C.G. 2002. The Potential Impacts of global climate change on marine protected areas. Reviews in Fish Biology and Fisheries 11:181-195.

Springer, Y.P., C.G. Hays, M.H. Carr and M.R. Mackey. 2010. Towards ecosystem-based management of marine macroalgae: the bull kelp, *Nereocystis luetkeana*. Oceanography and Marine Biology: An Annual Review 48:1-42.

Stachowicz, J.J., J.R. Terwin, R.B. Whitlatch, and R.W. Osman. 2002. Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. Proceedings of the National Academy of Science [USA] 99:15497-15500.

Sydeman, W.J., M.M. Hester, J.A. Thayer, F Gress, M. Paige, and J. Buffa. 2001. Climate change, reproductive performance and diet composition of marine birds in the southern California Current system, 1969–1997. Progress in Oceanography 49:309–329.

Topping, D.T., C.G. Lowe, and J.E. Caselle. 2006. Site fidelity and seasonal movement patterns of adult California sheephead *Semicossyphus pulcher* (Labridae): an acoustic monitoring study. Marine Ecology Progress Series 326:257–267.

Wolf, S.G., M.A. Snyder, W.J. Sydeman, D.F. Doak and D.A. Croll. 2010. Predicting population consequences of ocean climate change for an ecosystem sentinel, the seabird Cassin's auklet. Global Change Biology 16:1923-1935.

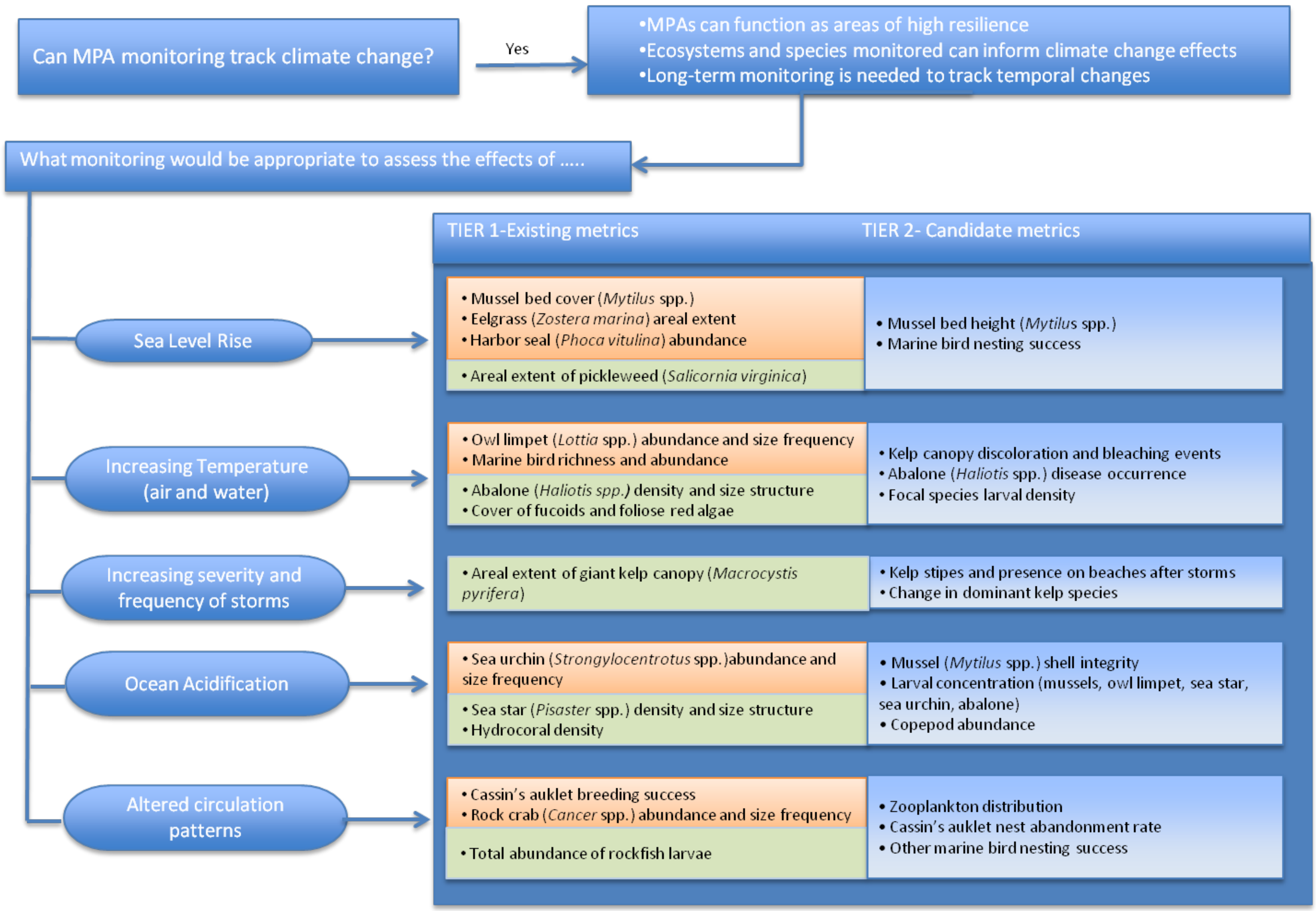
Zacherl, D., S.D. Gaines, and S.I. Lonhart. 2003. The limits to biogeographical distributions: insights from the northward range extension of the marine snail, *Kelletia kelletii* (Forbes, 1852). Journal of Biogeography 30:913–924.

APPENDIX 1

The following decision tree includes existing metrics[78] and additional metrics common to the North Central Coast and South Coast regions. It can be used to analyze existing MPA monitoring metrics (Tier 1) when considering climate changes within MPA monitoring plans. It can also be used to develop scientific priorities and inclusion of new climate change metrics and monitoring needs within MPA monitoring plans (Tier 2 and 3). This decision tree model uses sea level rise, increasing temperatures, increasing severity and frequency of storms, decreasing pH, and altered circulation patterns as parameters to consider when evaluating monitoring priorities. Local knowledge may dictate additional factors be considered in monitoring for the effects of climate change.

[78] Tier 1 metrics are divided into the MPA Monitoring Framework's two implementation options: Ecosystem Feature Checkup (orange) and Ecosystem Feature Assessment (green).

Climate Change and MPA Monitoring



APPENDIX 2

Schematic diagram of the MPA Monitoring Framework showing the two principal monitoring elements: 1) Assessing Ecosystem Condition & Trends; and 2) Evaluating MPA Design & Management Decisions. Ecosystem condition may be tracked using Ecosystem Feature Checkups, which employ monitoring metrics called vital signs, or through Ecosystem Feature Assessments, which employ key attributes and indicators/focal species as monitoring metrics. MPA design and management decisions are evaluated through answering targeted questions, including both short- and long-term questions.