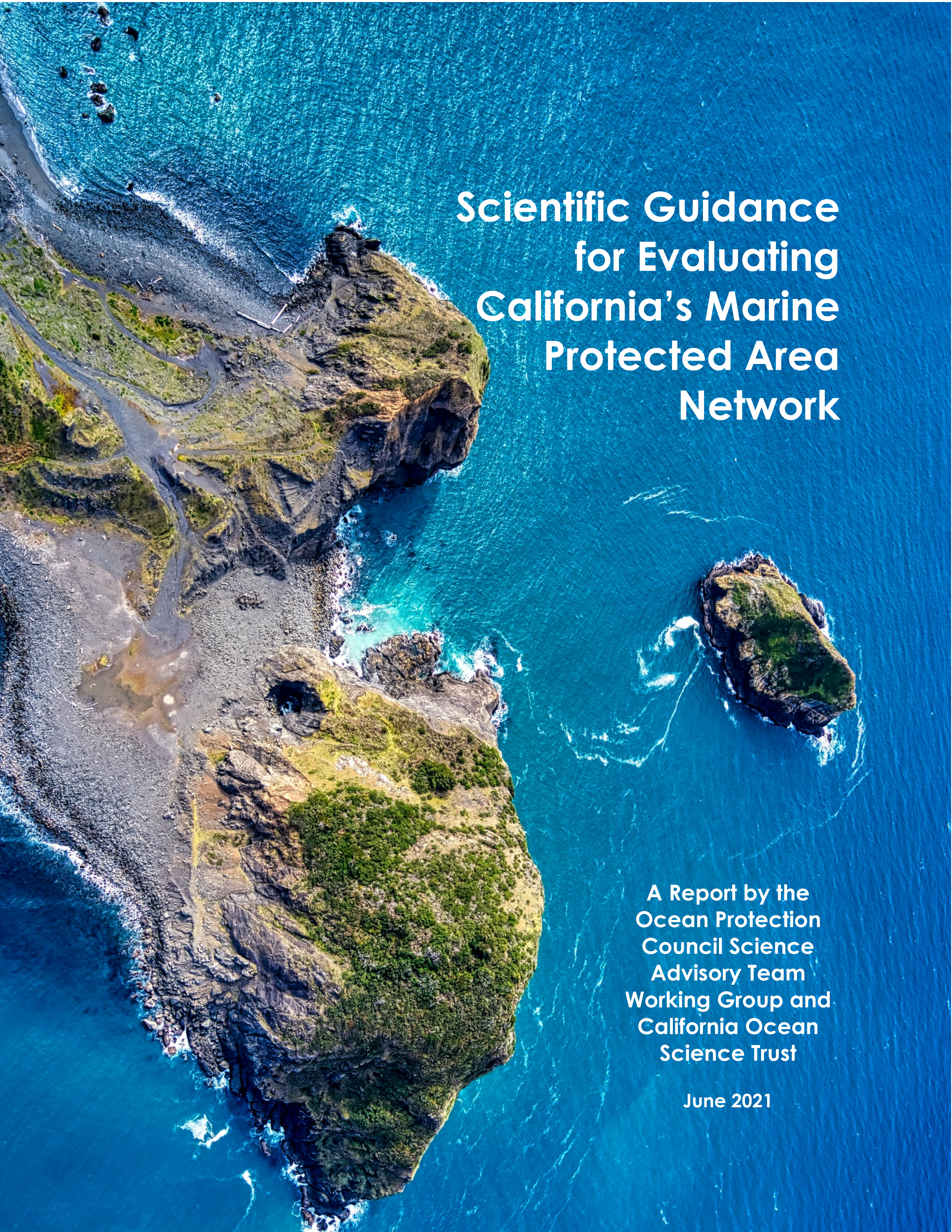

Scientific Guidance for Evaluating California's Marine Protected Area Network

A Report by the Ocean Protection Council Science Advisory Team Working Group and California Ocean Science Trust

June 2021

ABOUT THE REPORT

This report was produced by a working group of the Ocean Protection Council Science Advisory Team (OPC SAT) and Ocean Science Trust on behalf of the Ocean Protection Council (OPC), California Department of Fish and Wildlife (CDFW), and Fish and Game Commission (FGC). The report provides scientific guidance in support of decadal management reviews of California's Marine Protected Area (MPA) Network by the FGC. These decadal reviews will examine the effectiveness of the MPA Network and Adaptive Management Program at meeting the goals of the Marine Life Protection Act (MLPA) and inform the adaptive management process; the first such review is currently scheduled for December 2022. Ocean Science Trust served to convene and coordinate this MPA Decadal Review Working Group (Working Group) throughout the duration of its tenure, supporting collaboration and integration with the MPA Monitoring Program and other experts and working groups.

Building on the foundation set forth in California's MPA Monitoring Action Plan (Action Plan), working in close collaboration with researchers currently conducting long-term MPA monitoring, and drawing on outside expertise when necessary, the Working Group was tasked with translating the goals of the MLPA into scientifically tractable questions and associated analytical approaches, and taking a statewide, integrative approach. Specifically, the Working Group was charged to:

- **Provide a list of quantitative, tractable scientific questions that can reasonably be assessed at the 2022 management review and in future decadal evaluations, informed by Appendix B of the Action Plan.**
- **Provide scientific definitions of selected terms in the MLPA.**
- **Provide methods for integrating baseline MPA monitoring, long-term MPA monitoring, and other available data streams into informative analytical products.**
- **Provide appropriate approaches for answering network-wide evaluation questions.**
- **Identify significant gaps in our understanding of MPA performance in California and recommend monitoring approaches to fill those gaps.**

Working Group members were identified by soliciting nominations from the OPC SAT, OPC, CDFW, and Ocean Science Trust, and determined in consultation with the OPC SAT Executive Committee. Members have expertise in and cumulatively represent the following fields: marine protected area science, marine ecology, population and community ecology, ecological modeling, anthropology, marine resource management, fisheries science, oceanography, and climate science. The working group was convened from November 2019 - May 2021 and conducted their work via a series of remote meetings as well as an in-person workshop hosted by Ocean Science Trust in February 2020.

As expertise from the MPA long term monitoring projects was also essential in answering the charge of the Working Group, one Principal Investigator (PI) active in the MPA long-term-monitoring program served as a PI Liaison to the Working Group to ensure clear and effective communication and knowledge-sharing between the Working Group and the long-term monitoring PIs.

The development of this report took place during a time of uncertainty and turmoil with the effects of climate change becoming ever more present in the form of destructive wildfires, and the advent of the COVID-19 pandemic, which included major disruptions to almost all aspects of ocean and coastal research, natural resource management and university operations, as well as economic hardships for many Californians, including fishing communities and fleets. Moving forward during this tumultuous time, the Working Group acknowledges the increasing importance of managing for resilient ocean ecosystems and coastal communities to buffer against an uncertain world.

Contributors

OCEAN PROTECTION COUNCIL SCIENCE ADVISORY TEAM (OPC SAT)

The OPC SAT is a team of interdisciplinary scientists appointed by OPC to provide scientific advice on ocean and coastal issues. Working groups of the OPC SAT are composed of both SAT members and external experts and are formed to access, analyze, and synthesize scientific information on a particular topic or issue to inform policy, management, or investment decisions.

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CALIFORNIA OCEAN SCIENCE TRUST (OST)

California Ocean Science Trust is a non-profit organization dedicated to accelerating progress towards a healthy and productive ocean future for California. Created by state legislation, OST bridges the gap between cutting-edge scientific research and sound ocean management. To learn more, visit www.oceansciencetrust.org

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CALIFORNIA OCEAN PROTECTION COUNCIL (OPC)

The Ocean Protection Council is a cabinet-level state policy body nested within the California Natural Resources Agency. Created by the California Ocean Protection Act of 2004 (COPA), OPC advances the Governor's priorities for coastal and ocean policy and works broadly to ensure healthy coastal and ocean ecosystems for current and future generations by advancing innovative, science-based policy and management, making strategic investments, and catalyzing action through partnerships and collaboration. To learn more, visit http://www.opc.ca.gov/

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The California Department of Fish and Wildlife is the Department within the California Natural Resources Agency with designated authority to manage California's vast array of habitats and species. The Mission of the Department of Fish and Wildlife is to manage California's diverse fish, wildlife, and plant resources, and the habitats upon which they depend, for their ecological values and for their use and enjoyment by the public. To learn more, visit https://wildlife.ca.gov/

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ACKNOWLEDGEMENTS

Funding was provided by the California Ocean Protection Council. A Policy Advisory Committee, composed of leadership from the OPC (Mark Gold and Jenn Eckerle), CDFW (Becky Ota and Craig Shuman), and FGC (Susan Ashcraft and Melissa Miller-Henson), set the scope and charge for the Working Group and provided guidance to the Working Group throughout to ensure that the work product informs state policy and management needs and goals. Carrie Pomeroy, Marissa Baskett, and Jay Stachowicz provided review of this report at various points throughout the project as members of the OPC SAT to support sound scientific guidance for the state.

SUGGESTED CITATION

Hall-Arber, M.*, Murray, S.*, Aylesworth, L., Carr, M., Field, J., Grorud-Colvert, K., Martone, R., Nickols, K., Saarman, E., Wertz, S. Scientific Guidance for California's MPA Decadal Reviews: A Report by the Ocean Protection Council Science Advisory Team Working Group and California Ocean Science Trust, June 2021

(*Working Group co-chairs, other authors in alphabetical order)

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Front Cover Photo: Cameron Venti

EXECUTIVE SUMMARY

THE DECADAL EVALUATION WORKING GROUP

The Decadal Evaluation Working Group (Working Group) was convened to provide scientific guidance for monitoring and evaluation of California's MPA Network in advance of the state's first decadal management review in 2022. The Working Group worked within the context of the MLPA goals and the MPA Network evaluation questions from Appendix B of the MPA Monitoring Action Plan (Action Plan: CDFW and CA OPC 2018) to define key terms, refine questions, suggest analytical and integrative approaches, and identify data gaps. This report is intended to provide a conceptual framework, common language, and suggested approaches to support the California Department of Fish and Wildlife (CDFW) in evaluating and adaptively managing the MPA Network in 2022 and beyond.

RECOMMENDATIONS FOR FILLING KEY INFORMATION GAPS

A principal contribution of the Working Group was to identify data needs and information gaps for performing a robust evaluation of California's MPA Network. The Working Group developed a total of 20 recommendations including timeframe and priorities distributed across key topic areas. The greatest number of these recommendations are aimed at improving monitoring and evaluation of the human domain (5) and identifying the role of influencing factors including climate and fisheries (5), followed by filling information gaps in data integration (3), network performance (3), and addressing governance components (3). Each of these recommendations includes one or more action items, providing 50 actionable approaches.

KEY FINDINGS

The science of MPAs and MPA evaluation are rapidly evolving fields in California and beyond. Consistent with the wisdom of Indigenous societies worldwide, it is now well established in the scientific literature that most successful MPAs are designed and managed with human as well as ecological considerations, with benefits for both. Therefore, the Working Group adopted a **social-ecological systems (SES) framework** (Figure 1) to describe key components and interconnections of the Network, placing monitoring questions and evaluation efforts in a social-ecological context. The SES framework identifies ecological, human, and governance components of the Network (referred to as domains), functions, services, and outcomes that flow from these domains, and factors that influence aspects of MPA and network performance (influencing factors). The six key findings made in the context of this SES framework are included.

DEVELOPING TRACTABLE SCIENTIFIC QUESTIONS FOR EVALUATING CALIFORNIA'S MPA NETWORK

The questions from Appendix B of the Action Plan serve as a starting point for evaluating the performance of individual MPAs and the Network. The Working Group examined these questions in the context of the SES framework and clarified more tractable sub questions to better identify response variables and focus study hypotheses. In addition, the Working Group supplemented these questions where necessary to fill information gaps and guide a more complete evaluation of the MPA Network (see Appendices 1-3). Detailed considerations and approaches were provided for each question to assist in development of study designs and data analyses. Consideration should be given to incorporating the updated set of evaluation questions into the Action Plan to present a roadmap for CDFW to use in assessing the performance of California's MPA Network in 2022 and to formulate plans for future evaluations.

THE SOCIO-ECOLOGICAL SYSTEM (SES) FRAMEWORK

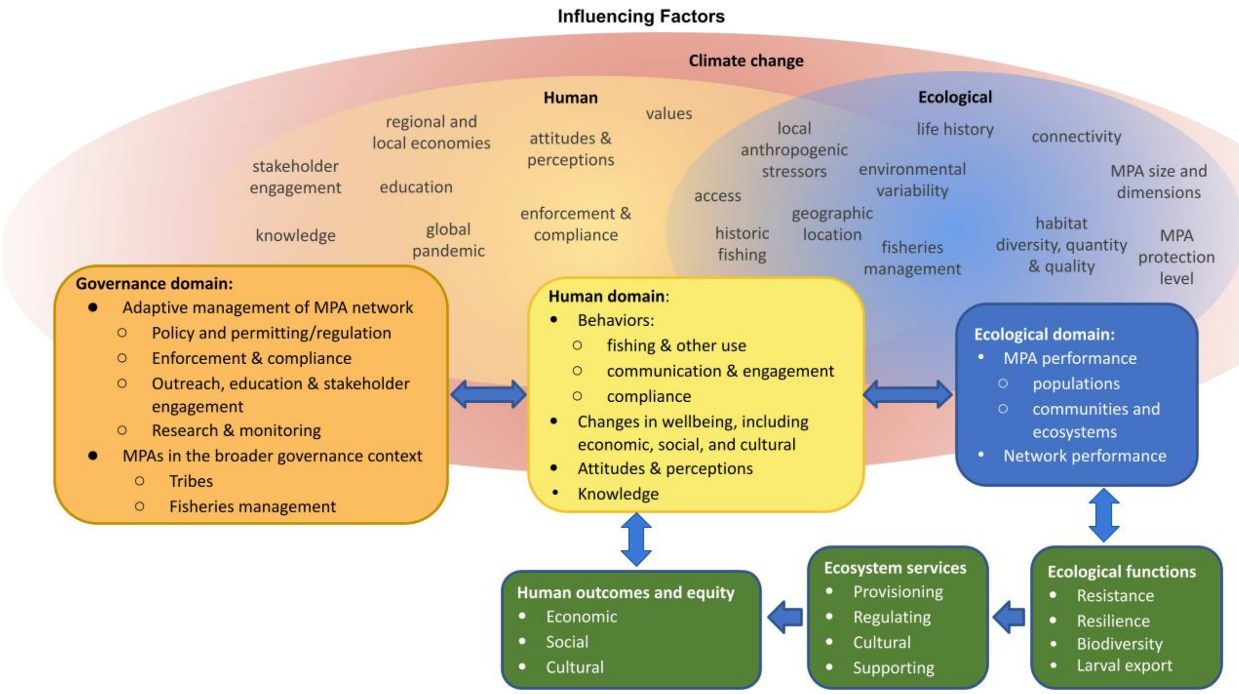


Figure 1. *A social-ecological system (SES) framework for understanding and evaluating California's MPA network. This framework identifies the three overarching domains of response to MPA implementation: governance, human, and ecological domains and the elements that respond within each (shown in orange, yellow and blue boxes, respectively). Numerous external factors influence multiple elements in the ecological, human and governance domains and how they respond to MPAs and can complicate MPA evaluations; these are represented as influencing factors (shown in clouds behind the domains). Climate change is represented as a ubiquitous influencing factor with impacts on all aspects of the SES. The components within the ecological domain support a suite of ecological functions and ecosystem services with a variety of human outcomes (shown in green boxes).*

KEY FINDINGS

1

Collectively, the MPA Network, ecological monitoring datasets, and resulting ecological performance evaluation, are unique, and can make an outsized contribution to global understanding of MPA networks as tools for marine conservation.

The Network's broad scale, biogeographic and cultural setting, and global rarity as an ecological connectivity network make it well-positioned to inform the role of MPAs in assessment and management of marine ecosystems in the face of climate change. Furthermore, California's investments in long-term monitoring and evaluation of the Network not only address many of the goals and priorities described in the Ocean Protection Council's Strategic Plan but also inform conservation and management west-coast wide. Thus, California's MPA Monitoring Program provides value well beyond MPAs, informing fisheries management, improving understanding of the consequences of climate change, the spread of invasive species, and the ecological mechanisms of ecosystem resistance and resilience.

2

Influencing factors emerge as important considerations in monitoring design, data analysis, and interpretation of monitoring results.

Differences in influencing factors among MPAs, including specific MPA attributes (size, location, population connectivity, spatial configuration, level of protection) can cause differences in the direction and rate of ecological responses among MPAs. Collecting information on influencing factors at MPA-relevant scales and pairing this information with monitoring data are key to interpreting and contextualizing MPA evaluations.

Climate change is the foremost influencing factor, potentially impacting all aspects of the MPA system, but climate-induced extreme events and changes in ocean conditions were not explicitly considered during MPA planning. Indeed, climate change must receive primary attention in efforts to monitor and understand ecological, human, and governance changes and to evaluate whether California's MPA Network is achieving its goals.

Because **fishing** can strongly influence ecological and human socio-economic responses to MPAs, both current and historical fishing data must be obtained and analyzed at MPA-relevant spatial scales to support MPA evaluations.

3

A plan to address critical knowledge gaps in the human domain must be developed, funded, and implemented.

Many of these knowledge gaps were identified by representatives of California's Native American Tribes during MPA planning, but efforts to obtain information have not received sufficient attention in the Action Plan, MPA research, monitoring, and evaluation efforts to date. In addition to specifying the relevant stakeholders, including rights holders, communities of interest and communities of place, consideration should be given to understanding aspects of the human system that are important for adaptive management of the MPA Network, such as: a) human behavior, including fishing and other use, communication and engagement, and compliance; b) economic, social, and cultural wellbeing outcomes and equity; c) stakeholder attitudes and perceptions; and, d) changes in stakeholder knowledge. The Working Group presents a concise set of new monitoring questions, to be further developed by a human dimensions advisory team, that will guide deeper understanding of the human aspects of MPAs and how they are intertwined with each other and linked to the overall social-ecological system.

4

Effective governance is key to the success of California s MPA Network and includes coordination across multiple managing agencies and jurisdictions, as well as adaptive management of the MPAs themselves.

Much of the complexity of cross-jurisdictional coordination is beyond the scope of this report, but three governance issues are especially significant and require continued attention. First, California's Native American Tribes have sovereign status and a long history of interaction with, and management of the marine environment, and as such CDFW should continue to improve engagement with Tribes in marine resource management, including MPAs. Second, fisheries and MPA management are inextricably linked, therefore, understanding the relationship between MPA and fisheries regulations, resource monitoring, and assessment is important in considering efficiencies in both monitoring and evaluating MPA performance. Third, adaptive management of the MPA Network will be based on outcomes of current and future evaluations, is strongly dependent on the quality of the evaluation information available, including monitoring data and evaluation questions, and requires understanding what constitutes meaningful change to different aspects of the MPA Network social-ecological system and the subsequent setting of achievement targets. Making these decisions in a robust framework that is informed by the ecological, human, and governance dimensions of MPAs to allow evaluation of tradeoffs and distribution of costs and benefits among stakeholders will be key to the long-term success of the Network.

5

Evaluating network function is the next frontier of California MPA research.

The Network is unparalleled in its ability to advance network science given the extensive science-based process to plan the MPAs as an ecologically connected network. CDFW should continue to support and invest in network studies to understand: a) if the Network generates benefits that exceed the sum provided by its individual MPAs, b) how these benefits are affected by connectivity between populations inside and outside MPAs, and c) how the Network affects human behavior and management as compared to a collection of individual MPAs. Because MPA connectivity can be very difficult to detect, modelling approaches provide the best means for evaluating network functioning, but these should be paired with focused empirical research for maximum impact.

6

Data integration is critical to fully evaluate the MPA Network and should be pursued within and across the interconnected ecological, human, and governance domains, as represented in the SES framework.

For example, within-domain integration includes understanding the roles of influencing factors across multiple MPAs, ecosystems and regions to draw more generalizable conclusions about MPA responses. Integration is also needed across domains to: a) link MPA protection with human attitudes, perceptions, and activities; b) follow fishing-related impacts from ecological, to human, to governance domains; and, c) identify ecosystem services and the distribution of human outcomes associated with the Network.


Photo: Pacheco

KEY RECOMMENDATIONS AND APPROACHES FOR MPA MONITORING AND EVALUATION

This table provides a list of key recommendations and suggested actionable approaches for developing a robust evaluation of California's MPAs and MPA Network. The timeframes and priorities for each approach are also presented based on the best professional judgment of the working group. Approaches are characterized as either meriting consideration for the 2022 ***decadal review,*** *or representing a* ***long-term*** *need where implementation will most likely generate results applicable to future MPA evaluations. Recommended priorities (critical, high, medium) for addressing each approach are also included. Approaches categorized as* ***Decadal review/Critical*** *should be viewed as essential for a robust MPA evaluation and should be addressed in the decadal review if possible. Those categorized as* ***Long-term/Critical*** *should be initiated as soon as practical so that results will be available to fill important data gaps in future evaluations.* ***High*** *priority approaches (both decadal review and long-term) should be addressed, but not at the expense of approaches identified as critical.* ***Medium*** *priority approaches should be addressed if time and resources allow.*

RECOMMENDATION	SUGGESTED APPROACH	TIMEFRAME	PRIORITY
INFLUENCING FACTORS			
1. Integrate influencing factors into evaluation efforts	1a. Continue to incorporate influencing factors including climate change parameters into ecological and human study designs, data analyses, and interpretations of MPA performance (e.g., develop shared datasets of environmental, design-specific, and anthropogenic conditions at MPAs and reference sites throughout the Network to inform evaluation analyses).	Decadal Review	Critical
2. Monitor climate and environmental parameters at scales that are useful for MPA management	2a. Continue to sustain and expand California's current array of coastal observing stations and data handling capacities to collect critical data on spatial and temporal variation in natural ocean parameters at MPA-relevant scales, including those ocean parameters influenced by climate change.	Long-Term	High
3. Improve estimates of fishing effort and other anthropogenic influences such as visitation, pollution, and infrastructure at MPA scales	3a. Continue to incorporate into ecological and human study designs, data analyses, and interpretations of MPA performance the best available data to estimate fishing effort and frequency in MPAs and reference sites pre- and post-MPA implementation.	Decadal Review	Critical
	3b. Continue work to identify where existing data are inadequate and focus efforts to improve fishing data in those areas (also see recommendations 13 and 19).	Long-Term	Critical

	3c. Use the best available data and continue to incorporate the frequency and intensity of local anthropogenic influences (e.g., pollution, sedimentation, trampling) into ecological and human study designs, data analyses, and interpretations of MPA performance.	Decadal Review & Long-Term	High
	3d. Improve the ability to characterize the frequency and intensity of local anthropogenic pressures at a subset of MPAs and reference sites that are likely to be influenced by these factors using in situ sensors, cameras, and remote sensing technologies to provide long-term monitoring and inform ecological forecasting or predictive modeling (e.g., predicting the probability of effects from land-based activities).	Long-Term	High
4. Use evaluations as an opportunity to learn more about the effectiveness of MPA design guidelines and different MPA designs	4a. Continue to use updated habitat maps to reassess regional habitat availability and habitat captured within MPAs and within the Network, including how stressors may have altered habitat quality since MPA implementation.	Decadal Review	Critical
	4b. Continue to determine differences in ecological responses (e.g., size and abundance of fished species) among MPAs that provide different levels of protection to marine life through allowed take.	Decadal Review	High
	4c. Use recent home range movement data and improved models of relationships between MPA size and protective capacity along with empirical data on the distribution, abundances, and size profiles of focal mobile species to assess the efficacy of the science size guidelines used during MPA implementation.	Long-Term	High
5. Improve understanding of the factors that influence human responses to MPAs	5a. Use the best available data and support new research to assess the influence of social factors (e.g., value orientations, levels and types of knowledge) on people's responses to MPAs.	Decadal Review & Long-Term	Critical
	5b. Use the best available data and support new research to assess the influence of socio-economic and fisheries factors (e.g., the diversity of alternative fishery targets or non-fishing employment opportunities in a coastal community) on people's responses to MPAs.	Decadal Review & Long-Term	High
	5c. Use the best available data and support new research to assess the direct and indirect effects of environmental factors, including climate change, on human uses, attitudes, perceptions and aspects of wellbeing related to	Decadal Review & Long-Term	Medium

	MPAs.		
ECOLOGICAL DOMAIN – MPA PERFORMANCE			
6. Continue to invest in understanding the ecological dimensions of MPAs	6a. Continue to use the evaluation questions from the Action Plan as clarified and extended in Appendix 1 to guide MPA evaluation efforts.	Decadal Review	Critical
	6b. Continue to maintain communication between CDFW and long-term monitoring investigators to ensure that the evaluation questions presented in this report are appropriately addressed as part of evaluation efforts.	Decadal Review	Critical
	6c. Continue to improve and extend evaluation questions and invest in long term monitoring of the ecological domain to advance understanding of the ecological aspects of MPA performance and linkages between these and influencing factors, including climate change.	Decadal Review	Critical
HUMAN DOMAIN			
7. Address human dimension questions and invest in improving understanding the human dimensions of MPAs.	7a. Continue to evaluate existing human dimensions research against the evaluation questions in this report (Appendix 2) to determine what the best available data can and cannot inform.	Decadal Review	Critical
	7b. Convene a human dimensions advisory team of trained natural resource social scientists across multiple disciplines including sociologists, social psychologists, economists, anthropologists, geographers, political scientists, and legal scholars to update the Action Plan to include a more comprehensive approach to human dimensions research and monitoring, considering the recommendations made in this report.	Long-Term	Critical
	7c. Determine a process to identify, prioritize, and fund specific research projects that will accomplish human dimensions research goals and generate the necessary data for future MPA monitoring and evaluation.	Long-Term	High
8. Identify the best approaches to consider the diversity of humans with an interest in MPAs and MPA management.	8a. Consult with a human dimensions advisory team (7b) to determine the best way to identify a broad spectrum of stakeholders and communities to engage in monitoring and research as it relates to adaptive management of MPAs and the MPA Network.	Long-Term	Critical

9. Improve understanding of changes in human behavior related to MPAs	9a. Use the best available data and support new monitoring efforts to examine a diversity of human behaviors related to the MPA Network including uses of MPAs and reference sites, compliance with MPA regulations, and engagement and communication with CDFW's management program.	Decadal Review & Long-Term	Critical
10. Improve understanding of how human wellbeing is affected by MPAs, including economic, social, and cultural wellbeing.	10a. Continue to use the best available socio-economic data to assess the impacts of MPAs on fishing and engage fishing communities in validating these assessments and improving data collection, metrics, and analyses (also see recommendation 13).	Decadal Review	Critical
	10b. Continue to use the best available data to conduct economic assessments of the impacts of MPAs that go beyond the proximal impacts to the fishing community and include broader assessments of the economic health of coastal communities.	Decadal Review	High
	10c. Continue to use a fully participatory process to identify relevant dimensions of social and cultural wellbeing and a set of valid indicators/metrics that capture the outcomes of the MPA Network for stakeholders and communities.	Decadal Review	High
	10d. Using appropriate frameworks, develop approaches for collecting data and evaluating changes across multiple dimensions of human wellbeing with input from social science experts.	Long-Term	High
11. Improve understanding of changes in attitudes, perceptions, and knowledge related to MPAs and how these factors influence one another	11a. Continue to use the best available data and support new research to determine the attitudes toward and perceptions of MPAs by different stakeholder groups, and how and why they change over time.	Decadal Review	High
	11b. Continue to use the best available data and support new research to determine knowledge of MPAs, expectations of MPA performance, and how these factors influence behaviors, attitudes, and perceptions by different stakeholder groups, and how and why these change over time.	Decadal Review	High
GOVERNANCE DOMAIN			
12. Continue to identify opportunities for meaningful engagement and collaboration between Tribes and the	12a. Use the best available data and support additional collaborative research to understand the impacts of MPAs on Tribal use of the coast and ocean (including by assessing the effectiveness of current Tribal take	Decadal Review & Long-Term	Critical

state on MPA monitoring, evaluation, and adaptive management. The Tribes should be considered true partners with the state in these efforts.	exemptions) as well as the cultural and ecological benefits of Tribal stewardship, and use these results in MPA evaluation efforts.		
	12b. Conduct listening sessions and other outreach as appropriate to identify Tribal priorities for MPAs. Develop pathways for ensuring that these priorities are elevated in MPA monitoring, evaluation, and adaptive management.	Long-Term	High
	12c. Continue the Tribal Marine Stewards Network pilot project and increase efforts by including additional coastal Tribes throughout the state.	Decadal Review & Long-Term	Critical
	12d. Explore ways in which Indigenous Traditional Knowledge (ITK) can be captured and shared in a respectful, appropriate manner in collaboration with the Tribe, community, or culturally knowledgeable people providing ITK.	Long-Term	High
13. Advance integration of MPAs and fisheries management	13a. Use the best available qualitative and quantitative data and support new research to examine changes in the distribution and magnitude of fishing effort and yield inside and outside of MPAs.	Decadal Review & Long-Term	Critical
	13b. Use the best available data and support new research to examine the associated impacts of changes in fishing effort and yield inside and outside MPAs on behavior and wellbeing for fishermen, fishing families, and fishing communities.	Decadal Review & Long-Term	High
	13c. Form a working group that includes fishermen and fisheries managers focused on identifying ecological, social, and economic data integration methods for data from fisheries management and MPAs (also see recommendation 19).	Long-Term	High
	13d. Where practicable, support MPA monitoring programs that can inform MPA performance and evaluation as well as traditional fisheries management for managed resources.	Long-Term	High
14. Work to establish a framework for adaptive management decision-	14a. Identify targets, trajectories, or reference points that indicate achievement (or not) of MPA goals across domains	Long-Term	Critical

making that incorporates information from the ecological, human, and governance domains	14b. Develop a framework based in decision-science that facilitates evaluation of tradeoffs among domains and distribution of wellbeing outcomes (i.e., costs and benefits) among stakeholders.	Long-Term	High
NETWORK PERFORMANCE			
15. Use and improve network models to understand the role of connectivity in MPA and network performance	15a. Continue to use modelling studies to evaluate the location and spacing of MPAs in the Network and the degree to which propagule export from MPAs can potentially connect MPAs and seed populations outside MPA boundaries. Incorporate the best available data into MPA evaluations.	Decadal Review	Critical
	15b. Use the best available data to evaluate how connectivity influences the structure, persistence, and resilience of communities within MPAs across the Network. Examine whether monitoring studies are designed to generate information that informs network models and that network models leverage information generated by monitoring studies.	Decadal Review	High
	15c. Use network models to evaluate whether sufficient protected area exists within the California MPA Network to protect against severe disturbance events and provide the resilience needed to facilitate climate change adaptation and deliver projected MPA-related conservation and fishery benefits into the future.	Decadal Review	High
	15d. Continue to refine models by incorporating improved (e.g., higher resolution) ocean circulation information and including parameters such as larval mortality and behavior, juvenile and adult demography, and spatial patterns of fishing mortality.	Long-Term	High
	15e. Support empirical studies designed to validate connectivity model predictions concentrating on ‘umbrella’, keystone, and foundation species and species of commercial and recreational importance.	Long-Term	Medium
16. Improve understanding of the ecological functions associated with the MPA Network	16a. Continue to support monitoring studies to explore the diversity of ways that individual MPAs and the Network can protect and enhance the functioning of populations, communities and ecosystems.	Decadal Review	Medium
17. Advance understanding of human dimensions and governance aspects of MPAs to determine if social and	17a. Support studies to identify synergistic human and governance effects that accrue from an ecological functional network and differentiate these from effects resulting from a collection of individual MPAs.	Long-Term	Medium

governance benefits are greater than the sum of benefits attained from individual MPAs.			
INTEGRATION			
18. Support within-domain integration of evaluation questions	18a. Compare answers to evaluation questions across multiple ecosystems to evaluate the generalizability of results and the conclusions based on those results.	Decadal Review	Critical
	18b. Extend analyses across ecosystems for focal species dependent on more than one ecosystem to determine the integrated effects of MPA protection.	Decadal Review	High
	18c. Compare answers to many of the evaluation questions across multiple human responses and stakeholders, such as communities of interest or place, to evaluate the generalizability of results and the conclusions based on those results.	Decadal Review	High
19. Improve opportunities for integration of fishing and ecological data	19a. Invest in new programs (e.g., mobile digital data collection for fisheries, spatially-explicit online surveys) to collect high spatial resolution data on fishing effort appropriate for MPA evaluation.	Long-Term	Critical
20. Manage California's MPA Network as an integrated system consisting of ecological, human, and governance domains and recognize interconnections between these domains in evaluation and adaptive management actions.	20a. Incorporate analyses into the decadal review that integrate ecological, human, and governance domains of the MPA Network.	Decadal Review	Critical
	20b. Support coordination and integration of monitoring efforts within and across domains, including feasibility of long-term monitoring costs	Long-Term	Critical
	20c. Improve communication, engagement, and reporting among researchers, stakeholders and governing bodies to increase efficiencies and inform adaptive management decision-making.	Long-Term	High

TABLE OF CONTENTS

LIST OF SIDEBARS

LIST OF APPENDICES

INTRODUCTION

California's Marine Life Protection Act (MLPA) became law in 1999 and was implemented regionally from 2004 to 2012 through an inclusive public-private partnership that involved stakeholders, science advisors, natural resource managers, and policy-makers (Gleason et al. 2013). The MLPA called for a scientifically designed network of MPAs, which when fully implemented in 2012, included approximately 16% of state waters in 124 marine protected areas (MPAs), 59 of which are fully protected no-take MPAs (~10% of state waters), distributed along California's more than 1,100-mile scientific studies that expand our understanding of MPAs and MPA network functions and continue to push the science of MPAs and MPA management forward.

The six goals articulated in the MLPA (Table 1, CA Fish and Game Code §2853(b)) guided MPA design during the planning process and continue to serve as a foundation for monitoring and evaluation efforts. Indeed, the MLPA explicitly addresses the importance of MPA monitoring and evaluation to facilitate adaptive management (CA Fish and Game Code §§2853(c), 2856(a)). During the planning process, the goals were translated by science advisors into simple and tangible guidelines for MPA design including minimum and preferred MPA size, MPA shape, inclusion of habitats, and spacing between patches of similar protected habitat (Saarman et al. 2013). Regional stakeholder groups used these guidelines to propose specific MPA configurations, while striving to minimize short term impacts on human users and communities (Fox et al. 2013b). Through an iterative process, the final MPAs in the Network were chosen from among these stakeholder-designed MPA configurations.

Photo: Adam Obaza

Table 1. Goals of the Marine Life Protection Act

To improve the design and management of that system, the commission, pursuant to Section 2859, shall adopt a Marine Life Protection Program, which shall have all of the following goals:
1. To protect the natural diversity and abundance of marine life, and the structure, function, and integrity of marine ecosystems. 2. To help sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted. 3. To improve recreational, educational, and study opportunities provided by marine ecosystems that are subject to minimal human disturbance, and to manage these uses in a manner consistent with protecting biodiversity. 4. To protect marine natural heritage, including protection of representative and unique marine life habitats in California waters for their intrinsic value. 5. To ensure that California's MPAs have clearly defined objectives, effective management measures, and adequate enforcement, and are based on sound scientific guidelines. 6. To ensure that the state's MPAs are designed and managed, to the extent possible, as a network.

Although stakeholders considered some tradeoffs between MPAs and fishing in MPA planning, these and other human use considerations, such as traditional, cultural, and subsistence uses by Tribes, were not explicitly articulated in the MLPA goals (Gleason et al. 2013). Consequently, as the goals were translated into scientific questions about MPA performance, the human dimensions of the Network received less attention than the ecological dimensions. As the numbers of MPAs have increased globally, research suggests that the most ecologically successful MPAs are often those that are socially successful, because they are designed and managed with consideration of human dimensions (Christie et al. 2003, Pomeroy et al. 2004, Laffoley et al. 2008, Bennett and Dearden 2014, Krueck et al. 2019). Thus, monitoring and evaluation that includes a focus on the human elements of MPAs should be an increasingly high priority for MPA managers.

California's current MPA Network encompasses tremendous physical, ecological, and human diversity, extending from the U.S-Mexico border to the Oregon state line and from the mean high tide line to three nautical miles offshore (including offshore islands but excluding San Francisco Bay). California's coastal waters are characterized by the natural complexity of ocean conditions, which have strong regional as well as more localized effects on its diverse biota. For example, the cold, southward flowing waters of the California Current have strong effects on ocean climate, facilitating the upwelling of nutrient-rich water along the northern and central coast. At Point Conception the California coastline changes orientation, and the Southern California Bight is characterized by warmer waters and reduced upwelling as the California Current lies farther offshore. The California Current is a major natural driver of biogeographic differences with a more southerly, warmer-water biota characterizing coastal habitats south of Point Conception, which transitions into a more northerly, colder-water biota towards the north (Caselle et al. 2015, Claisse et al. 2018, Pondella et al. 2019). As a consequence of these distinctive oceanographic conditions and species compositions, California's coastline has been divided into three "ecoregions". These ecoregions include a southern California region from the U.S.-Mexico border to Point Conception, a central California region from Point Conception to the mouth of San Francisco Bay, and a northern California region from the mouth of San Francisco Bay, including the Farallon Islands, to the Oregon border. In addition to these regional patterns, California waters also are exposed to natural, temporal cycles in ocean conditions including El Niño events (e.g., Tegner and Dayton 1987, Chavez et al. 2002) and longer-term oceanographic processes driven by the Pacific

Decadal Oscillation (Newman et al. 2016) and the North Pacific Gyre Oscillation (Parnell et al. 2010, Bell et al. 2020); these produce variable changes in regional ocean temperature and nutrient concentrations over scales of years to decades with cascading effects on phytoplankton, seaweeds, invertebrates, birds, and fish.

Beyond regional differences in oceanographic conditions and biota, the three ecoregions are also differentiated by their coastal human communities: the southern California region is characterized by expansive urbanized areas (e.g., San Diego, Orange, Los Angeles Counties), central California by fewer and much smaller cities (e.g., Morro Bay, Monterey, Santa Cruz), and northern California by even fewer and smaller coastal communities, with the exception of the San Francisco Bay area. As such, these ecoregions differ markedly not only in their ecological communities but also in the ways and extent to which humans interact with the coastal ocean and MPA Network, including coastal fisheries and their cultural, social, and economic importance. In addition, all three ecoregions are experiencing various manifestations of climate change, including gradual increases in ocean temperatures and sea level, as well as episodic events such as the warm-water "blob" of 2014-15 and El Niño of 2015-16 that collectively caused a marine heatwave (MHW) with substantial impacts to northern California ecosystems. These environmental changes are having strong influences on how marine species and humans interact with the coastal ocean and the MPA Network. The naturally occurring oceanographic patterns and effects of climate change on ocean conditions are fully described and discussed in the "Climate Resilience and California's Marine Protected Area Network" report and its Appendix A (Hofmann et al. 2021).

Given the complexity of the setting for California's MPA Network, effective monitoring is especially critical for understanding the ecological and human dimensions of the system, and how they are changing in the face of climate change. To inform the monitoring process CDFW generated the MPA Monitoring Action Plan (CDFW and CA OPC 2018) in partnership with California's Ocean Protection Council (OPC). The Action Plan was intended to be a living document to guide MPA monitoring and evaluation and includes as Appendix B a series of measurable questions and long-term monitoring indicators to guide cost-effective management and evaluation of the Network. This report builds upon the Action Plan and associated questions and complements a companion report on climate resilience and California's MPA Network (Hofmann et al. 2021). Here, we address the charge given our Working Group by using existing scientific knowledge about MPAs and current best practices in MPA monitoring to 1) clarify and supplement the measurable questions in the Action Plan, 2) define key terms in the MLPA, 3) suggest methods and approaches for integrating data into analytical products, 4) discuss approaches for answering network-wide evaluation questions, and 5) identify significant gaps in the data needed to evaluate MPA and network performance. We accomplish these tasks by refining and updating Appendix B questions based on the best available science and the data legacy of the MPA monitoring program. We contextualize this report around a social-ecological system (SES) framework, which identifies three major domains (ecological, human, and governance) for monitoring and managing California's MPA Network, emphasizes their interactions, and indicates the relevance and importance of climate change and other factors that influence MPA performance and evaluation. In addition, we make recommendations and offer approaches for undertaking current and future evaluations of the MPA Network while stressing the importance of integrating data within and across domains, and integrative thinking.

THE APPROACH

To approach our charge as laid out in the front matter of this report, we (the Working Group) began by examining the MLPA goals and the existing MPA evaluation questions from Appendix B of the Action Plan (CDFW and CA OPC 2018).

To assess the MPA Network's performance, we must share a common understanding of the six MLPA goals (Table 1). Toward that end, we identified terms in the MLPA goals that required clarification, and developed definitions based on consideration of scientific literature, the Action Plan, and other work by CDFW on the topic. To ensure common understanding, a list of these terms and their definitions are included in the Glossary at the end of this report along with terms from the Appendix B evaluation questions and this report.

To complete our charge to provide tractable scientific questions, approaches, and integration methods and contribute to the 2022 decadal review, we reviewed Appendix B of the Action Plan in the context of the SES framework and supplement the evaluation questions in the following ways: 1) we identify which questions are already being answered by ongoing monitoring programs, and which are not; 2) we suggest tractable sub questions that elucidate assessment approaches and shared this work with current monitoring principal investigators (PIs); and 3) we suggest potential data sources, new monitoring tools, and approaches for analyses and integration for any unaddressed questions. This process of question review revealed gaps in the existing questions, which were filled with additional scientific questions to better inform evaluation of the MPA Network. Refinements and extensions of the evaluation questions are provided in Appendices 1-3 of this report with the goal of clarifying response variables, hypotheses, and approaches for long-term monitoring PIs and others pursuing answers to these questions. In addition, we offer suggestions for filling important information gaps in the context of the SES framework to achieve a more holistic and integrated picture of MPA and network performance. Lastly, we provide recommendations and associated actionable approaches for future California MPA monitoring and evaluation efforts, prioritized by the timeframe within which they can be implemented.

APPROACHING CALIFORNIA'S MPA NETWORK EVALUATION USING A SOCIO-ECOLOGICAL SYSTEMS FRAMEWORK

Because most ecologically successful MPAs are also socially successful having been designed and managed with human as well as ecological considerations (Laffoley et al. 2008, Ban et al. 2013, Bennett and Dearden 2014, Christie et al. 2017, Krueck et al. 2019), we have framed this report in the context of an integrated social-ecological system. The SES framework (Figure 1) describes and highlights key system components, including their linkages, and facilitates discussion of the data needs for evaluating, understanding, and managing California's MPA Network. In addition, the framework acknowledges the need to consider a suite of 'influencing factors' expected to affect MPA and network performance that require attention during the design of monitoring programs as well as the analysis and interpretation of monitoring data.
The SES framework identifies three domains that comprise the MPA Network: ecological, human, and governance. These domains represent interconnected components of the system and support and deliver ecological functions, ecosystem services, and outcomes for humans (positive, negative, or neutral) as consequences of the MPA Network. Linkages exist among these components and their elements, within the same domain and across domains, as well as with external factors that influence their responses. These influencing factors (Table 2) can alter the ecological, social, and economic variables used to evaluate MPA performance, including how and when MPAs respond following establishment, and can help explain why responses might differ among MPAs.

As represented in the SES framework, climate change has a particularly strong influence on California's coastal waters and is affecting patterns and processes in all three domains; understanding the influence of climate change on the ecological, human, and governance domains is critical to interpreting the results of monitoring studies and evaluating progress of California's MPAs towards achieving their goals.

Additional influencing factors are placed in the framework based on their primary domain of influence. For example, habitat factors will primarily influence MPA performance within the ecological domain, while knowledge is likely to influence attitudes, perceptions, and behaviors within the human domain as well as compliance within the governance domain. Fishing, both past and present, is likely to influence responses and outcomes in both the human and ecological domains. In addition, not all influencing factors are separate from the system or domain. For example, outreach and education influence knowledge which in turn influences attitudes and perceptions. Therefore, some factors are both response variables and influencing factors.

The SES framework has played an important role in structuring the thinking behind this report. By considering how the goals of the MLPA and the existing questions from Action Plan Appendix B fit into the SES framework, data gaps and the need for additional questions became apparent. For example, existing human-centric Appendix B questions focus mostly on behavior for a small subset of stakeholders with no questions about the role of knowledge or other factors that influence behavior. Appendix B questions within the ecological domain were more targeted and comprehensive, but gaps in the area of ecological functions, especially drivers of population and community change and persistence and larval production and export were revealed, and the importance of influencing factors in assessing MPA network performance highlighted. The SES also emphasizes the importance of linkages between domains and integrative thinking to inform management by improving understanding of the socio-ecological functioning of the MPA Network.

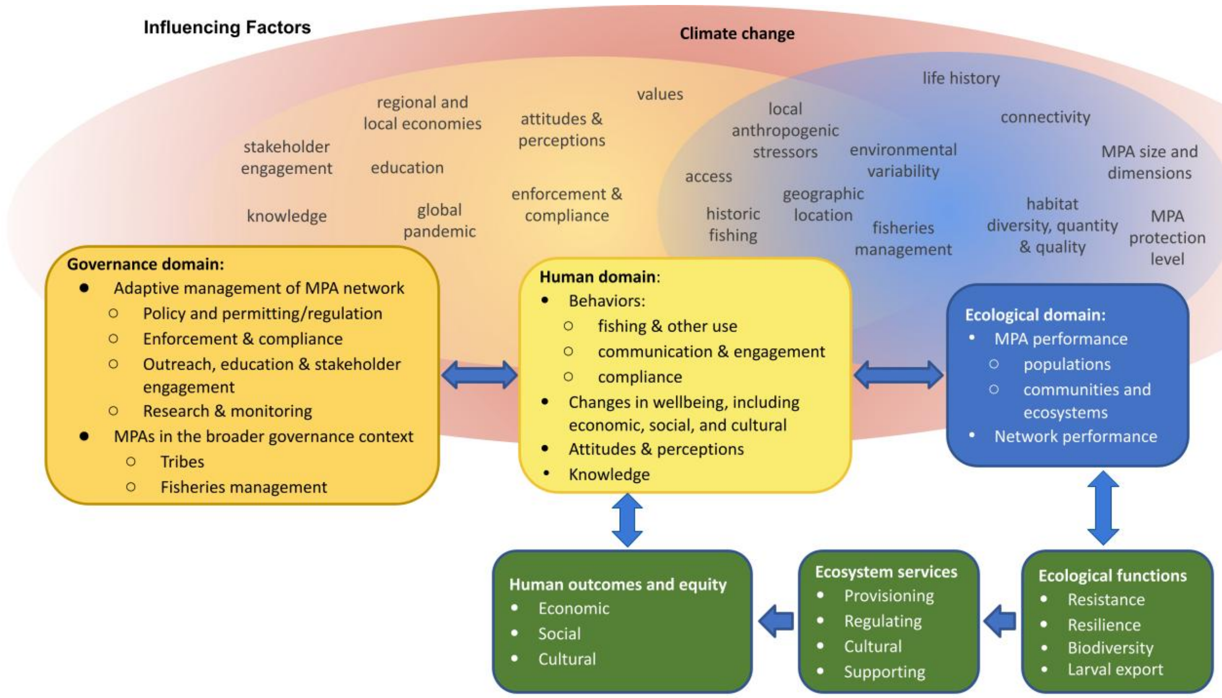


Figure 1. *A social-ecological system (SES) framework for understanding and evaluating California's MPA Network. This framework identifies the three overarching domains of response to MPA implementation: governance, human, and ecological domains and the elements that respond within each (shown in orange, yellow and blue boxes, respectively). Numerous external factors influence multiple elements in the ecological, human and governance domains and how they respond to MPAs and can complicate MPA evaluations; these are represented as influencing factors (shown in clouds behind the domains). Climate change is represented as a ubiquitous influencing factor with impacts on all aspects of the SES. The components within the ecological domain support a suite of ecological functions and ecosystem services with a variety of human outcomes (shown in green boxes).*

INFLUENCING FACTORS

Multiple factors affect California's coastal environments and, therefore, are expected to influence responses within ecological, human and governance domains described in the SES framework (Figure 1). A working list of these factors is provided in Table 2 with short explanations of their importance in understanding MPA performance.

CLIMATE CHANGE

Foremost among these factors is climate change. Ocean conditions have changed and continue to change over large spatial and temporally variable scales along the California coast since the implementation of the California MPA Network. Although natural variations in environmental conditions and the ability to accommodate localized major disturbances received consideration during the design phase, attention was not given to large-scale, anthropogenically-driven changes in ocean conditions. The effects of changing climate on California's coastal oceans, and its biota are more fully addressed in (Hofmann et al. 2021; see Box 1).

Climate change affects all aspects of the social-ecological system and is likely to increase in prominence in the coming decades. For example, as species' ranges shift with ocean warming, there will be consequences for commercial and recreational fisheries and how those stakeholders interact with MPAs. Climate change can also influence human relationships with MPAs directly. For example, sea level rise may alter access points leading to changes in patterns of human use surrounding MPAs. In addition, terrestrial consequences of climate change, such as water shortages and extreme wildfires, may alter human population distributions with consequences for coastal communities. Climate change may also engender anxiety among stakeholders and thus influence attitudes toward MPAs and other conservation strategies if they are perceived as mitigation tools (O'Connor et al. 1999, Roberts et al. 2017, Peterson St-Laurent et al. 2018) and lead to or exacerbate negative attitudes if MPAs are perceived as limiting adaptive capacity for stakeholders or communities dependent on resource extraction.

OTHER INFLUENCING FACTORS

THE ECOLOGICAL DOMAIN

California's MPAs are not a homogeneous group; they differ widely in factors known to affect their ecological performance (Table 2). Such factors include historical and on-going anthropogenic activities, MPA configuration, and regulatory features that mostly act at the MPA scale. Of particular importance is fishing because the main management action of the MLPA was to protect key habitats from direct and indirect effects of fishing in spatially-explicit areas of the California coast (see Box 2). Multiple studies have identified additional ecological impacts from consumptive (besides fishing, e.g., souvenir collecting) and non-consumptive (e.g., trampling of intertidal organisms) anthropogenic activities, point and nonpoint source discharges, ocean-located infrastructure, and other forms of human influence (Micheli et al. 2016, Mach et al. 2017). Geographic location, MPA size and dimensions, habitat quantity and quality (including depth range), connections with sources of larvae/propagules, and the level of protection provided are also factors known to affect MPA ecological expectations and outcomes.

THE HUMAN DOMAIN

Besides factors that influence the effects of MPAs on ecological resources, the SES framework (Figure 1) also identifies some of the most prominent factors that are likely to influence human responses to MPAs; however, this list is not exhaustive and in many cases the same factor (e.g., geographic location) influences both ecological and human domains. Besides climate change, influencing factors that affect the human dimension include:

1) *Social factors such as knowledge, attitudes, and stakeholder engagement*:

   Remote and proximate factors that include economic, governance, cultural, and social aspects must be considered to understand human responses and their interacting effects, and to inform adaptive management. Many of these social factors are measurable human responses to the implementation of MPAs and act as influencing factors on other responses. For example, a stakeholder's knowledge of MPAs as a marine conservation tool may be a direct result of outreach efforts by CDFW, and thus a human response to MPA governance. Furthermore, the level of knowledge of MPAs as a marine conservation tool, however obtained, may affect attitudes, perceptions, and/or behaviors, thus acting as an influencing factor. These influencing factors are also highly interrelated and must be disentangled to fully understand how humans are responding to MPAs. Values, for example, can affect attitudes and perceptions of MPAs and can even affect a stakeholder's openness to new knowledge (De Jong et al. 2006). Aligning MPA goals with social and cultural values, along with transparency in identifying outcomes can also influence perspectives on MPAs (Chaigneau and Brown 2016). Stakeholder engagement with management processes requires some initial knowledge, usually results in enhanced knowledge of MPAs, and has been shown in some cases to be correlated with more positive attitudes toward and greater acceptance of MPAs (Lucrezi et al. 2019, Mason et al. 2020). We define engagement as a meaningful dialogue between stakeholders and MPA managers, whereas communication is simply delivery of information, and can be accomplished through passive or unidirectional formats (e.g., signage, press releases, videos).

2) *Socio-economic and fisheries-related factors*:
Historic patterns of fishing can influence the impact of MPA placement with ramifications for both stakeholder attitudes and populations of fished species and ecological communities. This is an important consideration as we evaluate changes over time for both responses. Similarly, the interactions between current fisheries management and MPAs can affect both human and ecological responses such as stakeholder attitudes, and the ecological outcomes of MPAs. Additional factors, including public shoreline access, may influence human behaviors and perceptions, while also influencing the ecological system through take, trampling, and congestion. Enforcement activities (ranging from the presence of wildlife officers, to educational contact, to citations and penalties) are likely to influence human behaviors and compliance with MPA regulations, which can, in turn influence the ability of MPAs to protect ecological communities (Cinner et al. 2018).

THE GOVERNANCE DOMAIN

Like the ecological and human domains, elements of the governance domain also are subject to influencing factors and some factors that affect the ecological and human domains also affect the governance domain. For example, the context of institutions, specific laws, history, culture, access to resources or power, and climate change may all affect governance. The MPA Network's success and failures may also be affected by such aspects of governance as leadership and enforcement of fisheries regulations (Walmsley and White 2003, Christie et al. 2009, Cinner et al. 2016).

The influence of conflict and compromise are reflected in the governance of valued places. For example, governance of marine space within the West Coast's Exclusive Economic Zone is affected by the often uncoordinated policies and regulations set by myriad agencies from local to federal. In addition, traditional Indigenous governance and management has yet to be fully explored and incorporated. The demand for use of California's marine space is ever growing. Governance is complicated by the state and country's appetite for natural resources, including energy (e.g., wind farms), sand and gravel, fish and shellfish (wild and farm-raised), and recreation. Governance is also influenced by the values of those designing policy, who are influenced by their own culture and that of their leaders and followers, as well as economic and other interests. Gruby et al. (2016) note the influence of groups "(e.g., NGOs, philanthropic organizations, the private sector, foreign states, national governments, political elites, local people)" as well as "underlying interests (e.g., conservation, fisheries, geopolitics, sovereignty)" on the creation and governance of MPAs.

ROLE OF INFLUENCING FACTORS IN STUDY DESIGNS, ANALYSES, AND INTERPRETATIONS

Because of their importance in determining ecological and human responses, evaluations of MPAs and answers to Appendix B questions may depend on these influencing factors. Therefore, understanding their effects is important for designing monitoring studies and interpreting monitoring results. For example, differences in MPA attributes (size, location, population connectivity, spatial configuration, level of protection) can cause differences in the direction and

rate of ecological responses among MPAs. Geographic differences in species composition and their life history traits will likely influence rates and magnitudes of ecological responses. Similarly, fishing levels at MPA sites prior to their establishment and outside of MPAs after their establishment can determine the magnitude, rate, and type of ecological and socio-economic responses. Therefore, these influencing factors must be taken into account and treated as treatment levels (e.g., levels of protection, geographic regions) or covariates (e.g., historic and ongoing fishing pressure, MPA size) in undertaking analyses of performance of MPAs and the MPA Network.
Climate change, including events such as the 2014 to 2016 marine heat wave (MHW) had extraordinary ecological impacts and severely damaged many of the ecological attributes targeted for protection in several MPAs. For example, the MHW-associated loss of bull kelp (*Nereocystis luetkeana*) along the north coast has essentially eliminated many of the kelp forest communities designated for MPA protection (Rogers-Bennett and Catton 2019, Beas-Luna et al. 2020, McPherson et al. 2021). So, despite the ability to control for ocean climate change by constructing study designs that match environmental conditions in MPAs and unprotected reference sites, climate change can significantly impact the ability of MPAs to achieve specific protection goals. Recognition of these impacts is crucial to the interpretation of evaluation studies and subsequent management actions.

In contrast, influencing factors that operate more on a local scale can not only generate variability among metrics collected from MPA and unprotected site replicates but confound analyses when these factors differ inside and outside of MPA boundaries. The following Action Plan Appendix B question can be used to exemplify this study and analytical issue: "Do focal and or protected species inside of MPAs differ in size, numbers, and biomass relative to reference sites?" As indicated, the trajectories of these ecological response variables as well as social response variables in MPAs and reference sites can be affected by geography, MPA size and configuration, habitat features, degree of connectivity, past (and, if applicable, current) fishing pressure, level of protection, and other factors.

Clearly, given the diversity of MPA characteristics, simple answers to Appendix B questions will be difficult to obtain. Study designs and analytical approaches must lead to careful interpretations and appropriately account for influencing factors in detecting the effects of protection—an essential first step for evaluating whether or not MPAs have achieved their goals. In addition, important influencing factors should be assessed and their effects on MPA outcomes determined. Understanding changes in ecological and human dimensions will depend on knowledge of climate driven changes in ocean conditions, so it will be critically important to monitor ocean parameters (e.g., sea temperature, pH, oxygen content) influenced by climate change at MPA-relevant scales. It will also be essential to continue the monitoring of ecological and human populations and communities to link changes with climate-driven changes in ocean conditions. The key biological constituents of vulnerable ecosystems also will need to be studied to determine changes in species distributions and abundances and impacts of sea level rise on important functional processes such as predator-prey interactions and productivity. In cases where severe and large-scale changes in ocean conditions resulting from climate change have occurred, MPA goals and management actions might need to be reconsidered because such changes cannot be controlled by state MPA managers.

Photo: Shreve Garrott

Recommendations and Approaches:

1. Integrate influencing factors into evaluation efforts

1a. *Continue to incorporate influencing factors including climate change parameters into ecological and human study designs, data analyses, and interpretations of MPA performance (e.g., develop shared datasets of environmental, design-specific, and anthropogenic conditions at MPAs and reference sites throughout the Network to inform evaluation analyses).*

2. Monitor climate and environmental parameters at scales that are useful for MPA management

2a. *Continue to sustain and expand California's current array of coastal observing stations and data handling capacities to collect critical data on spatial and temporal variation in natural ocean parameters at MPA-relevant scales, including those ocean parameters influenced by climate change.*

3. Improve estimates of fishing effort and other anthropogenic influences such as visitation, pollution, and infrastructure at MPA scales

3a. *Continue to incorporate into ecological and human study designs, data analyses, and interpretations of MPA performance the best available data to estimate fishing effort and frequency at MPAs and reference sites pre- and post-MPA implementation.*

3b. *Continue work to identify where existing data are inadequate and focus efforts to improve fishing data in those areas (also see recommendations 13 and 19).*

3c. *Use the best available data and continue to incorporate the frequency and intensity of local anthropogenic influences (e.g., pollution, sedimentation, trampling) into ecological and human study designs, data analyses, and interpretations of MPA performance.*

3d. *Improve the ability to characterize the frequency and intensity of local anthropogenic pressures at a subset of MPAs and reference sites that are likely to be influenced by these factors using in situ sensors, cameras, and remote sensing technologies to provide long-term monitoring data and inform ecological* *forecasting or predictive modeling (e.g., predicting the probability of effects from land-based activities).*

4. Use evaluations as an opportunity to learn more about the effectiveness of MPA design guidelines and different MPA designs

4a. *Continue to use updated habitat maps to reassess regional habitat availability and habitat captured within MPAs and within the Network including how stressors may have altered habitat quality since MPA implementation.*

4b. *Continue to determine differences in ecological responses (e.g., size and abundance of fished species) among MPAs that provide different levels of protection to marine life through allowed take.*

4c. *Use recent home range movement data and improved models of relationships between MPA size and protective capacity along with empirical data on the distribution, abundances, and size profiles of focal mobile species to assess the efficacy of the science size guidelines used during MPA implementation.*

5. Improve understanding of the factors that influence human responses to MPAs

5a. *Use the best available data and support new research to assess the influence of social factors (e.g., value orientations, levels and types of knowledge) on people's responses to MPAs.*

5b. *Use the best available data and support new research to assess the influence of socio-economic and fisheries factors (e.g., the diversity of alternative fishery targets or non-fishing employment opportunities in a coastal community) on people's responses to MPAs.*

5c. *Use the best available data and support new research to assess the direct and indirect effects of environmental factors, including climate change, on human uses, attitudes, perceptions, and aspects of wellbeing related to MPAs.*

Photo: Sandra Fogg

Sidebar 1. Climate change

As changing ocean conditions along the California Current can have extraordinary impacts and affect many of the ecological attributes targeted for protection in several MPAs, below we briefly discuss a few key climate stressors. The effects of changing climate on California's coastal oceans, specifically as they relate to MPAs in California, is more fully addressed in (Hofmann et al. 2021)

Ocean warming and Marine Heat Waves

California's ocean temperatures are increasing. Records taken at the Scripps Institution of Oceanography show 0.12 °C warming per decade in southern California waters from 1917 to 2017 (Fumo et al. 2020). In addition, severe warming events, referred to as marine heat waves *sensu* Hobday et al. (2016), have increased in duration and frequency (Oliver et al. 2018) and are projected to continue to increase as a result of anthropogenic climate change (Laufkötter et al. 2020). The ecological effects of MHWs can be especially far-reaching (e.g., Wernberg et al. 2016), particularly if they impact foundational or keystone species that have a profound impact on the structure of ecological communities such as the bull kelp (*Nereocystis luetkeana)* in Northern California (Rogers-Bennett and Catton 2019). Additionally, warming ocean temperatures have been implicated in increasing frequencies of harmful algal blooms (HABS) (Griffith and Gobler 2020), poleward migration of species distributions (Helmuth et al. 2006, Sanford et al. 2019), increases in the successful invasion of non-native species (Sorte et al. 2010), and may potentially increase incidences of marine diseases (Raimondi et al. 2002, Eisenlord et al. 2016, Miner et al. 2018, Harvell et al. 2019, Lonhart et al. 2019, Gravem et al. 2020).

Ocean Acidification and Hypoxia

California's coastal waters also are experiencing climate-related increases in ocean acidification and decreases in dissolved oxygen. Changes in dissolved oxygen are being driven by a complex interplay between physical and biological drivers and are affecting coastal marine ecosystems (Keller et al. 2010, 2015, Somero et al. 2016), by, for example, causing mortality of animals that cannot move into more oxygenated waters (Grantham et al. 2004, Chan et al. 2008). Increasing atmospheric carbon dioxide concentration is causing changes in ocean chemistry and is of concern because the U.S. west coast is naturally characterized by some of the most acidic coastal waters in the world which, therefore, are vulnerable to additional anthropogenically-driven acidification (Gruber et al. 2012, Chan et al. 2017, 2019). Changes in carbonate chemistry resulting from ocean acidification can impact shell-producing species including their early life stages (Byrne et al. 2011), affect larval fish mortality, metabolism and behavior, possibly alter predator-prey interactions (Munday et al. 2009, 2010, Cripps et al. 2011, Kroeker et al. 2013, Watson et al. 2017) and significantly affect the populations and communities that MPAs are designed to protect (Klinger et al. 2017).

Sea Level Rise

Sea level along the California coast south of Cape Mendocino has risen 10 to 20 cm during the 20th century and is accelerating under all working greenhouse gas emission scenarios with predicted increases of at least 30 cm by 2050 (Sievanen et al. 2018). Sea level rise will impact coastal ecosystems, for example habitats bounded landward by cliffs or anthropogenic structures (Schaefer et al. 2020), by limiting the space available to intertidal organisms, a phenomenon known as 'coastal squeeze' (Pontee 2013). Besides rocky intertidal and sandy beach ecosystems, declines are predicted in salt marsh areas and the ecosystem services they provide (Park et al. 1993, Craft et al. 2009).

Sidebar 2. MPA Fishing Pressure and Impacts of Species' Life Histories

Theoretical modeling studies (White et al. 2011, 2013b) and studies based on monitoring data (Nickols et al. 2019, Jaco and Steele 2020) illustrate that the amount of fishing an MPA experienced prior to MPA implementation determines the magnitude and timescale of the response of targeted species to MPA implementation. If an area was not historically fished, there will likely not be an increase in the size or abundance of targeted species after MPA implementation. Thus, the evaluation question should not be simply, "is there a response to MPA implementation?" but "*should* there be a response to MPA implementation?" and if so, "how large and fast of a change is expected (Kaplan et al. 2019)?" Some CDFW data (i.e., fish ticket, block summary data, trawl logbooks and Commercial Passenger Fishing Vessel logbook data) on fishing effort are available and have been used to evaluate spatial-temporal development of selected California fisheries (Miller et al. 2014, 2017) and to assess fishing pressure prior to MPA implementation for select MPAs (Jaco and Steele 2020). However, these data are not available for all species of interest, and on a spatial scale appropriate for evaluating the magnitude of historical fishing pressure in individual MPAs. Modeling frameworks show promise for estimating pre-MPA fishing effort (White et al. 2016, Nickols et al. 2019), but are limited to species with a robust amount of monitoring data. However, a combination of knowledge of access to MPA areas, monitoring data, and available CDFW data could provide a reasonable estimate of pre-MPA fishing mortality rates.

Fishing effort post-MPA implementation can also influence the ecosystem responses to MPAs. When fishing ceases, effort is often spatially redistributed and increased effort can occur outside MPA boundaries, for example at reference sites (Murawski et al. 2005). However, many factors are involved in fisher decisions and not all users respond the same way (Cabral et al. 2017). Changes in fishing regulations outside of MPAs could also change fishing pressure. In addition, it is possible that poaching occurs within MPAs and that MPA implementation does not effectively remove fishing pressure (Paddack and Estes 2000). Recently, the COVID-19 pandemic has led to changing patterns of take, including increased take in intertidal areas. Regardless of the cause, changes in fishing effort post-MPA implementation can impact responses of fished species both outside and inside MPAs. As with historical fishing impacts, necessary data to analyze fishing effort post-MPA implementation are mostly lacking (but see Guenther et al. 2015). Modeling efforts using size-structure monitoring data have been used to detect poaching in the Channel Islands MPAs (White et al. 2020) and show promise for some species.

It is well established that species with different life history traits will respond differently to MPA implementation. Not only does fishing reduce overall population abundance, but also truncates the size and age structure of fished populations. When fishing pressure is removed, the size/age structure is expected to recover to that of an unfished population. The magnitude and timing of recovery will depend on reproductive rates. Long-lived, slow growing, late maturing species will take longer to recover than species that grow and reproduce faster (Starr et al. 2015). In addition, dispersal strategies and home range size are important life history factors to consider when evaluating responses of species to MPA implementation. Species with low dispersal rates and small home range sizes are expected to show a larger response to MPA implementation than species with higher dispersal rates and large home range sizes (White et al. 2011).

Table 2. Selected factors that influence ecological, human, and governance responses to MPAs.

FACTOR	BRIEF DESCRIPTION	SELECTED REFERENCES
Climate Change	Climate change, driven by greenhouse gas emissions, is changing ocean conditions. MPA ecological resources and the human interactions related to MPAs will be impacted by changes in ocean temperature (both mean and extreme events such as MHWs), ocean chemistry (leading to ocean acidification), hypoxia and sea level. Climate change will also impact the behaviors, knowledge, attitudes and perceptions of stakeholders with respect to natural resources (see Box 1). Besides its ecological effects, climate change also affects all aspects of the human and governance domains, and its effects are likely to increase in prominence in the coming decades. There are multiple ways in which climate change will affect human interactions with California's MPA Network; some may be related to MPA protection (e.g., mitigation of climate change effects through resistance and resilience).	Hofmann et al. 2021; *Ocean Warming:* Cornwall 2019, Rogers-Bennett and Catton 2019, Laufkötter et al. 2020; *Ocean Acidification and Hypoxia:* Byrne et al. 2011, Gruber et al. 2012, Kroeker et al. 2013, Somero et al. 2016, Klinger et al. 2017, Chan et al. 2017, 2019; *Sea Level Rise:* Griggs et al. 2017, Sievanen et al. 2018.
Pre- and Post MPA Fishing Pressure and Impacts of Species' Life Histories	The amount of fishing an MPA experienced pre-MPA implementation dictates the magnitude and timescale of the response. Historic fishing also influences stakeholder attitudes during MPA design, and may continue to influence stakeholder behaviors, attitudes and perceptions of MPAs now and into the future. Fishing effort post-MPA implementation can also influence the responses of ecosystems to MPA implementation. When fishing effort ceases, effort is often spatially redistributed and increased effort can occur outside MPA boundaries, for example at reference sites. Post-MPA implementation, poaching within MPAs, and changes to fishing pressure outside MPAs can impact species responses and human behaviors, attitudes, perceptions, and engagement. When fishing pressure is removed via MPA implementation, the size/age structure of previously fished species is expected to recover to that of unfished population. The magnitude and timing of recovery will depend on reproductive rates for some species, and recruitment rates for others. For species with limited dispersal of young, long-lived, slow growing, late maturing species will take longer to recover than species that grow and reproduce faster. For species with long distance dispersal of young, rates of population response are tied to the recruitment of young produced elsewhere. In addition, species with low dispersal rates and small home range sizes are expected to show a larger response to MPA implementation than species with higher dispersal rates and large home range sizes (see Box 2).	*Pre-MPA Impacts:* White et al. 2011, 2013a, 2016, Kaplan et al. 2019, Nickols et al. 2019, Jaco and Steele 2020; *Post-MPA Impacts:* Paddack and Estes 2000, Murawski et al. 2005, Cabral et al. 2017, White et al. 2020; *Life history effects:* White et al. 2011, Starr et al. 2015, Kaplan et al. 2019.

Geographic Location	Regional and local differences in environmental conditions influence both ecological and human responses in the Network. MPAs are located in three ecoregions characterized by their oceanographic conditions. In addition, other environmental factors (e.g., wave exposure regimes, localized upwelling frequency and intensity, shore circulation patterns, geomorphology, and proximity to freshwater inputs) differ spatially. Conditions also vary over time with changes due to the El Niño Southern Oscillation, Pacific Decadal Oscillation, and North Pacific Gyre Oscillation. There are also numerous environmental and anthropogenic factors that operate at more local spatial scales. Some sites are easily accessible, whereas others are located in remote, difficult-to-access areas. These MPA features have ecological effects and affect human activities and use patterns. For example, the southern California ecoregion supports a dense human population, and its coastal habitats are strongly influenced by anthropogenic factors compared with the northern California region, which is characterized by smaller population densities and significantly less urbanization. Rough ocean conditions and few ports, boat ramps, and other entry points in northern California have dramatic impacts on how stakeholders interact with MPA ecological resources. Many of these MPAs are difficult or even dangerous to access many days of the year and activities such as diving, kayaking, and surfing can be challenging. In contrast, the relatively tranquil ocean conditions and multiple access points in southern California lend themselves to a variety of ocean-based activities and make most MPAs comparatively accessible.	*Regional and Local Variation:* Blanchette et al. 2008, Caselle et al. 2015, Claisse et al. 2018, Pondella et al. 2019; *El Nino, Pacific Decadal Oscillation, and North Pacific Gyre Oscillation:* Tegner and Dayton 1987, Chavez et al. 2002, Parnell et al. 2010, Newman et al. 2016, Bell et al. 2020; *Anthropogenic Impacts:* Raffaelli and Hawkins 1999, Micheli et al. 2016, Mach et al. 2017.
Connectivity	Population persistence within an MPA and the level of larval/propagule connectivity with other MPAs and unprotected areas will influence both ecological and human responses and affect ecosystem services and human outcomes. Persistence is affected by local recruitment and connections to other areas that supply reproductive propagules. For many species, persistence will require inputs of propagules from other MPAs, and also unprotected sources. Connectivity depends on the life history of different species, their biomass, and patterns of ocean circulation. During MLPA planning, science guidelines provided recommendations on minimal and optimal distances between patches of like habitat protected in MPAs to create a network. These guidelines were largely based on a literature survey of genetic information, observations of distances traveled by propagules, and the geographic spread of invasive species. New models and empirical methods are under development that should greatly increase the ability to not only determine whether MPA connectivity exists in the California Network but also identify which areas might serve as recruitment sources or sinks.	Kinlan and Gaines 2003, Hastings and Botsford 2006, Jones et al. 2007, Gaines et al. 2007, 2010, Moffitt et al. 2011, White et al. 2021.

MPA Size and Dimensions	The size and dimensions of an MPA influences its ability to deliver conservation and fishery benefits. The total amount of habitat within an MPA will vary with its size and configuration, which also affects spillover of adults and juveniles into nearby fished areas (in smaller MPAs with a greater perimeter to area ratio) vs. retention and protection of adults and juveniles throughout their lifetime (in larger MPAs with smaller perimeter to area ratios). The size and configuration of an MPA will influence human and ecological responses and affect ecosystem services and human outcomes. During the planning process, scientific guidelines on minimum and optimal MPA sizes were provided based on the home range movements of the largely residential mobile species most likely to benefit from MPA protection. Since the Network was created, more research has been done on the home range movements of mobile species and better models of the relationships between MPA size and protective capacity, and spillover potential are now available.	Halpern 2003, Claudet et al. 2008, McLeod et al. 2009, Gaines et al. 2010, Moffitt et al. 2011.
Habitat Diversity, Quantity, and Quality	MPAs that contain a wide range of habitat types and depths will protect a greater variety of species and facilitate ecological connectivity among habitats. The quantity and quality of a habitat type will affect the abundances, diversity, and ability of species to sustain their populations in the event of a major disturbance. During MLPA implementation, the diversity and quantity of habitats contained within each proposed MPA were quantified using the best available technology and habitat maps were made available to the stakeholder groups developing plans for the MPA Network; however, much of the shallower water habitat (< 10m depth) remained unmapped due to technological issues. Recently, a statewide effort has been undertaken to compile the best available mapping data and use it to estimate habitat areas in the unmapped nearshore zone through interpolation. Updated and expanded habitat maps resulting from this effort are now available to CDFW and monitoring PIs to inform MPA evaluations.	Carr et al. 2017, Alsterberg et al. 2017, Lacharité and Brown 2019, Hopkins et al. 2020.
MPA Protection Level	MPAs in the California Network should differ in their ecological and human responses, ecosystem services, and human outcomes depending on the level of protection they provide to marine life within their boundaries. The Network was created as a combination of fully protected no-take MPAs and partially protected areas that allow some form of extraction. Partially protected areas are thought to balance conservation with socio-economic benefits, whereas in no-take MPAs the attainment of conservation goals is generally thought to conflict with fishery benefits. Literature syntheses have revealed that although highly variable, the conservation outcomes of partially protected areas are generally greater than areas open to extraction but significantly less than achieved by no-take MPAs.	Lester and Halpern 2008, Salomon et al. 2011, Sciberras et al. 2013, 2015, Giakoumi et al. 2017, Sala and Giakoumi 2018, Zupan et al. 2018.

Social Factors	Education, knowledge, attitudes and perceptions, values, and stakeholder engagement are social factors that influence human responses to MPAs. Many of these human responses act as influencing factors on other responses. For example, a stakeholder's knowledge of MPAs may be formed externally or internally (e.g., result of MPA outreach activities and thus a human response to the MPAs). Values can affect attitudes and perceptions of MPAs and openness to new knowledge. Aligning MPA goals with social and cultural values, and transparency in identifying outcomes can also affect human responses to MPAs.	David 2002, Christie et al. 2003, Pomeroy et al. 2004, Symes and Phillipson 2009, Charles and Wilson 2009, Voyer et al. 2012, McNeill et al. 2018, Gollan and Barclay 2020.
Socio-economic and Fisheries Factors	The context of regional and local economies, historic patterns of fishing and other uses, access to MPAs and fishing grounds, fisheries management, and enforcement of MPA regulations are also factors that influence human responses to MPAs. In areas with robust and diverse economies, fisheries may better adapt to the changes in fishing patterns associated with MPAs or changes in fisheries management and thus result in more positive perceptions of MPAs. Availability of tourism infrastructure and the distribution of financial, human, physical, and social capital also affects human responses to MPAs, as well as the distribution of benefits and costs related to MPAs. In many cases, both human and ecological responses to MPAs are influenced by the same factor. For example, historic patterns of fishing can influence the impact of MPA placement and ecological responses with ramifications for stakeholder attitudes and fished species as well as interactions between fisheries.	Bunce et al. 2000, Salz and Loomis 2004, 2005, Liu et al. 2012, Arias et al. 2015, Davis et al. 2019, Schadeberg et al. 2021.
Global Pandemic	The COVID-19 pandemic has been an unexpected influencing factor, changing human behavior related to the MPA Network. Notably, patterns of fishing have changed with increases in the number and diversity of participants in intertidal shellfish collection, and changed markets for commercial fish because of diminished demand by restaurants and increased demand for direct-sales to consumers by community supported fisheries or other direct marketing. COVID-19 has also negatively impacted the level of monitoring conducted to evaluate MPA performance. Future global pandemics are likely to have similarly dramatic and unexpected impacts on human behavior.	Liu et al. 2012, Hathaway 2020, Hill 2020, Sahagun 2020, Stoll et al. 2020.
Governance Factors	MPA governance is affected by the entire suite of factors that influence ecological and human responses to MPAs because governance actions take into account these responses. The context of institutions, specific laws and regulations, traditional rights holders, history, and culture, are all factors that influence governance.	Jentoft et al. 2007, Mascia et al. 2010, Cormier-Salem and Mainguy 2014, Di Franco et al. 2020, Gollan and Barclay 2020.

THE ECOLOGICAL DOMAIN

The ecological domain has been a dominant focus of the MLPA since its inception, which is reflected in the language of the MLPA goals (Table 1), four of which include ecological objectives (1, 2, 4, and 6) that involve organismal, population, community, and ecosystem responses to MPA establishment. This emphasis on the ecological domain is reflected in the science guidelines from the MPA planning phase, the funded long-term monitoring programs, and the focus of many of the evaluation questions from Appendix B of the Action Plan. This ongoing investment in ecological monitoring and evaluation in combination with the Network's geographic scale and the range of human and environmental conditions it spans, poise California to make an outsized contribution to global understanding of MPAs and MPA networks as tools for marine conservation. Beyond contributions to MPA science, the Network and its studies provide added value by addressing many of the goals and priorities described in CDFW's Master Plan for MPAs and OPC's Strategic Plan while informing conservation and management policies west coast-wide (see Box 3).

Ecological monitoring and evaluation of the Network can make important contributions to MPA science by 1) documenting the responses of organisms and populations to individual MPAs and adding these findings to the growing body of global MPA literature; 2) evaluating the more complex and less well understood community and ecosystem consequences of MPAs; 3) advancing knowledge of how MPA responses are mediated by influencing factors, especially climate change; 4) identifying how populations and communities respond to an ecologically connected MPA network; and 5) providing an opportunity to understand the interdependence of MPAs and fisheries management and the need to integrate data and develop synergistic management procedures. Of these contributions, the first two are addressed within this ecological domain section, but the latter three are addressed in the influencing factors, network, and governance sections, respectively.

The evaluation questions in Appendix B of the Action Plan were organized by their relationship to the MLPA goals and related performance objectives. Whereas this linkage of evaluation questions to goals is valuable, these questions can also be viewed through the SES framework, which helps to reveal commonalities, emergent questions, and gaps. We therefore structure our examination of the ecologically-based questions in the context of the SES framework, by separating the performance of individual MPAs from network performance (discussed in the network section) and considering population responses, separately from the responses of ecosystems and the communities associated with them.

Our approach to addressing these questions is threefold: (i) We first considered whether each question provides sufficient specificity to formulate hypotheses testable with monitoring data and, if questions would benefit by greater clarification and specificity, we suggest potential refinements and identified tractable subquestions. Importantly, this process involved direct collaboration with investigators currently conducting monitoring to simultaneously facilitate their thinking and development of data analysis procedures. (ii) We considered whether the evaluation would benefit from supplemental questions, which often function as extensions of existing questions. (iii) Upon examination, it becomes clear that many of these questions will benefit greatly by integrating their evaluation across ecosystems. We identify such questions and also address the importance of integration in the summary section of this report titled "The importance of integrative thinking". Ultimately, each of these three objectives as well as the interpretation of the results of the monitoring studies will benefit further from and require the species and ecosystem level expertise of the PI's conducting these studies.

Refinement of Action Plan Appendix B questions frequently required two objectives: greater specificity of the response variable being evaluated, and greater specificity of the predicted response. Below, we present three examples of both forms of refinement for population, community, and ecosystem-level MPA performance. We also use these examples to illustrate additional questions, which often extend the existing questions, and when questions would benefit by integrating the answers across the ecosystems evaluated. Note that we do not add questions that take into account the many influencing factors identified in the "Influencing factors" section. As for these examples, analyses that account for these influencing factors, such as conducting separate analyses for each of the geographic regions or for MPAs of similar level of protection, apply to the majority of Appendix B questions. For the full set of additional questions that the Working Group identified for these examples and the other Appendix B questions, see Appendix 1 of this report.

MPA PERFORMANCE

MPA performance in the ecological domain is evaluated by examining the ecological response to MPA implementation. Within the ecological domain, these responses can be divided into two groups, those that occur at the individual MPA level, and those responses that are dependent on a connected network of MPAs. MPA and network performance are inextricably linked because network responses are dependent on the functioning of the individual MPAs that make up that Network, but considering MPA and network performance separately provides some clarity. Here we focus on questions that evaluate the performance of individual MPAs to build a firm foundation for addressing network performance in subsequent sections of the report.

POPULATION RESPONSES

MPAs, and particularly no-take reserves, have been shown globally to increase the size, density, and biomass of fished species within their boundaries as compared to reference sites (Lester et al. 2009). These basic expectations of MPA performance were considered during MPA planning and are amply reflected in the evaluation questions from Appendix B of the Action Plan, including Questions 1, 4, 6(i), 7, 9(i), 11(i) 20, 23, and 32 where (i) indicates questions that require integration across domains. Here, we use Question 1 to provide an in-depth example and rationale for the clarification of a question into tractable sub questions and associated emergent questions:

1. *[Original] Do focal and/or protected species inside of MPAs differ in size, numbers, and biomass relative to reference sites?*

The inside-outside comparative approach is a well-established design used in MPA performance studies, but it requires that such comparisons be made over time to determine how MPAs and reference sites change relative to one another. Moreover, it should be clear that the predicted response of populations to MPA protection is that differences in size, number, and overall biomass of individuals between MPAs and reference areas are predicted to increase. However, the magnitude and time scale of response to MPA implementation depends on both the amount of fishing that occurred prior to MPA implementation and levels of fishing outside MPAs after establishment (White et al. 2013a, Nickols et al. 2019, Jaco and Steele 2020). It needs to be recognized that if fishing intensity increases outside MPA boundaries, the likelihood for differences in population metrics increases with exclusively inside-outside comparisons of fished species (see Caselle et al. 2015).

We also consider the necessity to make the response variable associated with this question more explicit. First, it is important to note that because of sampling differences, each of these metrics (size, number, biomass) must be addressed as separate questions and hypotheses, and require further refinement. For example, "size" pertains to the body size of individuals in a population (e.g., mean, median, or size distribution). Similarly, the more relevant measure of the number of individuals is their density (number of individuals per unit area) or in cases such as most macroalgae and colonial invertebrates where the number of individuals cannot be quantified, the percent cover of occupied substratum. Biomass is an important metric that combines both density and size but is more destructive and costly to obtain. Further refinement also leads to more explicit questions such as, "Does the difference in density (or cover, size, or biomass) of a focal and/or protected species between MPAs and reference areas increase over time?" It is also important to clarify that "focal" and "protected" species are explicitly identified in the Action Plan as priorities for the state, but that investigators funded to conduct these analyses should identify additional focal species relevant to each ecosystem.

Question 1 also provides an example of several emergent questions. For example, an overall objective of an MPA is for protected populations to increase larval production that can replenish populations inside and outside the MPA, including other MPAs. For many species, individual size, number, and biomass can be used in conjunction with size-fecundity relationships to estimate the larval production of a population. Thus, an emergent question is "Does the difference between MPAs and reference areas in larval production of a focal and/or protected species increase over time?" Another perceived benefit of MPAs for populations is an increase in genetic diversity, by reducing the potential impacts of fishing mortality on selected members of the population (Fernández-Chacón et al. 2020). Thus, another emergent question is "Does the difference between MPAs and reference areas in genetic diversity of a focal and/or protected species increase over time?" In addition to increases in individual size, age is a very important population metric, necessitating the question "Does the difference between MPAs and reference areas in the age structure of populations of a focal and/or protected species increase over time?" Like our example with density, the size and age of individuals in a population can be characterized in multiple ways (e.g., mean, median, size, or age distribution), with the chosen metric leading to different specific hypotheses. In addition, some metrics such as biomass can be compared not only for an individual population but also for an aggregation of species, "Does the difference between MPAs and reference areas in overall biomass of focal and/or protected species increase over time?" Because we would predict that this response would be greater for fished versus unfished species, we could also ask "Does the difference between MPAs and reference areas in overall biomass of fished species increase over time relative to species that are not fished?" Thus, refinements and extensions of Question 1 include:

1. *[Original] Do focal and/or protected species inside of MPAs differ in size, numbers, and biomass relative to reference sites?*
    - 1a. *Does the difference between MPAs and reference sites in the size of individuals of a focal and/or protected species increase over time?*
    - 1b. *Does the difference between MPAs and reference sites in density (or proportionate cover) of a focal and/or protected species increase over time?*
    - 1c. *Does the difference between MPAs and reference sites in biomass of a focal and/or protected species increase over time?*
    - 1d. *[Extension] Does the difference between MPAs and reference sites in larval production of a focal and/or protected species increase over time?*
    - 1e. *[Extension] Does the difference between MPAs and reference sites in genetic diversity of a focal and/or protected species increase over time?*
    - 1f. *[Extension] Does the difference between MPAs and reference sites in the size and age structure of populations of a focal and/or protected species increase over time?*
    - 1g. *[Extension] Does the difference between MPAs and reference sites in overall biomass of focal and/or protected species increase over time?*

1h. *[Extension] Does the difference between MPAs and reference sites in overall biomass of fished species increase over time relative to species that are not fished?*

In addition, most of these questions provide greater insight into how populations and species are responding to MPAs if they are addressed across multiple ecosystems. For example, Question 4 asks "Do the abundance, size/age structure, and/or diversity of predator and prey species differ inside MPAs or outside areas of comparable habitat?" This question focuses either on the response of both focal and non-focal predators to changes in the abundance of focal (i.e., fished) prey species, or the response of both focal and non-focal prey species to changes in the abundance of focal (i.e., fished) predators. The importance of this question is not specific to any particular ecosystem, but instead is relevant to all ecosystems in which predator or prey species are subject to fishing mortality. A more insightful and robust answer requires integrating the answer to this question across all ecosystems. With integration across ecosystems, we can evaluate how common observed responses are and for what types of predators and prey species (e.g., what trophic levels) the predicted responses are detected.

COMMUNITY AND ECOSYSTEM RESPONSES

The more complex responses of communities and ecosystems to MPAs are globally less well documented than population responses, but expectations are that by protecting the elements of the ecosystems, MPAs will support greater biodiversity than reference sites (Lester et al. 2009), larger species populations with larger individuals (Baskett and Barnett 2015) and by extension increase resistance and resilience to disturbances, species invasions, and other perturbations (Hamilton and Caselle 2015, and others cited in Carr et al. 2017, Caselle et al. 2018, Eisaguirre et al. 2020). Several questions in Appendix B (Questions 2, 3, 5, 21, 22, and 24) focus on community and ecosystem-level responses to the establishment of an MPA. Some of these questions also need more specificity for developing testable hypotheses and informing the design and metrics used in assessment. Here, we use Question 2 as an example to provide a rationale for the refinement of a question and the development of associated emergent questions. Question 2 asks "Does functional diversity differ in MPAs relative to reference sites?" Addressing this question requires clarification of what is meant by "functional diversity", which involves at least two distinct levels of response, both within and among functional groups. A species' function(s) characterizes how it influences other species, and in doing so, how it influences the structure and functioning of communities and ecosystems. Species that share similar functions are categorized in the same functional group. The criteria for defining a functional group is variable, but for invertebrates, fishes and other animals the most common are based on diet, feeding method, and mobility (e.g., mobile detritivores). In contrast, macrophyte (macroalgae and sea grasses) functional groups have historically been categorized on the basis of form-function relationships. This is because macrophytes of different forms (e.g., expansive and finely dissected blades, filaments, crusts) demonstrate different productivities and susceptibility to herbivory (Littler and Littler 1980, Steneck and Dethier 1994) and also harbor different assemblages of invertebrates. Importantly, increased diversity both within and among functional groups is thought to enhance the resilience of communities and ecosystems and their functioning (e.g., overall primary and secondary productivity). By reducing the size of fished populations, fishing might either increase or decrease species diversity within a functional group or the relative abundances or diversity of functional groups depending on the ecological role of the fished species. Hence, the general prediction of MPA performance is that the difference between MPAs and reference areas in species diversity within a functional group or the relative abundances or diversity of functional groups will increase over time, but how these parameters change will be specific to the abundance and ecological role of the fished species.

2. *[Original] Does functional diversity differ in MPAs relative to reference sites?*
   - *2a. Does the difference between MPAs and reference sites in species diversity within any given functional group increase over time?*
   - *2b. Does the difference between MPAs and reference sites in the diversity of functional groups increase over time?*

As with most of the ecological questions, the answer to this question is more robust and insightful when compared across ecosystems. Such comparisons can determine whether functional groups exhibit similar differences between MPAs and reference areas over time and, if so, which functional groups and metrics are best used to describe and interpret such MPA-related changes. Question 3 provides another example of question refinement; "Do MPAs that include multiple habitat types harbor higher species abundance or more diverse communities than those that encompass a single habitat type or less diverse habitat?" This question includes the confusing term "species abundance", which could be interpreted as either the abundance of any given species, or as the number (abundance) of species, which is more commonly thought of as species richness. To clarify the intent of the question, the Working Group reached out to CDFW staff involved in drafting the original question for insight. This revealed that the intent with the term "species abundance" was to ask about the abundance of any given species, with a focus on species that might benefit from an ecotone or interface between two habitats. This led to the clarification, "Is there a positive relationship between the density (cover or biomass) of any given focal species and habitat diversity across MPAs of similar protection levels?"

The second part of the question, which revolves around "diverse communities" can also benefit from clarification, since there are two distinct scales for this ecological response and its assessment. The first involves recognition that particular species inhabit particular habitats, and an increase in the number of habitats within an MPA should increase the number of protected species. The protection of biodiversity is a central goal of the MLPA and why the Network incorporated habitat representation as a key design criterion. To answer this question and test the hypothesis that species diversity increases with habitat diversity within an MPA involves testing for a positive relationship between species diversity and habitat diversity across MPAs of similar protection levels. The second important role of habitat diversity recognizes that species can use multiple habitats over their lifetime and benefit in many ways from the presence of multiple habitat types they can access. Here the question pertains to how species diversity within a particular habitat (e.g., deep rocky reef, kelp forest) is related to the diversity of habitats within an MPA. Testing this hypothesis involves sampling across MPAs of similar protection level to determine if the species diversity within a particular habitat increases with the number of habitats in those MPAs. Thus, Question 3 can be further clarified and posed as three testable hypotheses as follows.

3. *[Original] Do MPAs that include multiple habitat types harbor higher species abundance or more diverse communities than those that encompass a single habitat type or less diverse habitat types?*
   - *3a. Is there a positive relationship between the density (cover or biomass) of any given focal species and habitat diversity across MPAs of similar protection levels?*
   - *3b. Is there a positive relationship between species diversity and habitat diversity across MPAs of similar protection levels?*
   - *3b. Is there a positive relationship between species diversity within a habitat/ecosystem and habitat diversity across MPAs of similar protection levels?*

Like many of the ecological questions, a more robust and insightful answer will involve comparisons across multiple ecosystems (i.e., sandy beach, rocky intertidal, kelp forest, etc.) to determine their general applicability to MPA protection.

Recommendations and Approaches:

6. **Continue to invest in understanding the ecological dimensions of MPAs.**

6a. *Continue to use the evaluation questions from the Action Plan as clarified and extended in Appendix 1 of this report to guide MPA evaluation efforts.*

6b. *Maintain communication between CDFW and long-term monitoring investigators to ensure that the evaluation questions presented in this report are appropriately addressed as part of evaluation efforts.*

6c. *Continue to improve and extend evaluation questions and invest in long term monitoring of the ecological domain to advance understanding of the ecological aspects of MPA performance and linkages between these and influencing factors, including climate change.*

Sidebar 3: MPAs and Performance Evaluation Studies Provide Added Values
California's investment in both the MLPA Network and its monitoring and evaluation program is also being realized by their contributions to informing management and conservation policies beyond evaluating MPA performance. Examples include:

Climate Change - MPA monitoring studies in the rocky intertidal and kelp forest ecosystems have quantified ecological responses to both gradual trends in ocean warming and the 2014-2016 marine heatwave. The broad geographic scope of these surveys has revealed latitudinal shifts in species ranges and community composition, and how these responses vary along the entire state (e.g., Beas-Luna et al. 2020). Monitoring in the rocky intertidal, on sandy beaches, and in estuaries have identified ecosystem responses to sea level rise.

Invasive Species - MPA monitoring studies have identified the patterns and rates of spread of invasive species (e.g., invasive algae) in the rocky intertidal and kelp forest ecosystems along the California coast.

Status of Species of Concern - MPA monitoring in the rocky intertidal has contributed to tracking the status of black abalone, *Haliotis cracherodii*, populations along the state. Monitoring in both the rocky intertidal and kelp forests has quantified the continued loss of *Pycnopodia,* informing the recent proposal to list this species with the IUCN. Monitoring on sandy beaches has quantified the distribution and abundance of the Western Snowy Plover.

Photo: Sandra Fogg

Sidebar 3 (Continued)

Disease - MPA monitoring throughout the state identified the pattern and rate of spread of the Sea Star Wasting Disease in both the rocky intertidal and kelp forest ecosystems. The community characterizations by these surveys documented the community-level impacts of the loss of the ochre star, *Pisaster ochraceus*, in the rocky intertidal and the giant sunstar, *Pycnopodia helianthoides*, in kelp forests.

Fisheries - MPA monitoring in the surf zone, kelp forests, on deeper rocky reefs and through collaborative fisheries research have informed fisheries management in a variety of ways. They have contributed to the stock assessments of a number of finfish and invertebrates (e.g., the red abalone recreational fishery), produced life history data to inform fisheries models, and deeper rocky reef surveys identify the impacts of fishing gear. Monitoring data have also informed CDFW's Enhanced Status Reports of commercial and recreational species.

Human Dimensions - Focus groups with commercial fishermen are revealing how challenging MPAs can be for the industry, but also suggest the importance of outreach and education targeting fishermen to update them on what benefits are being derived from the MPA Network. They also offer ideas about the importance of fishing to coastal communities and how local and state governments can better support fishermen.

Ecological Processes - Through time, surveys of rocky intertidal and kelp forest ecosystems that differ in their community structure inside and outside of MPAs have revealed the ecological mechanisms that facilitate ecological resilience (e.g., rates of larval recruitment and replenishment, diversity of important functional groups).

Informing Other Regulatory Agencies - MPA monitoring provides data that inform management decisions by other state and federal management agencies, including the evaluation of Areas of Biological Significance; oil spill and coastal erosion impact evaluation in the rocky intertidal and sandy beaches; the success of environmental mitigation programs; monitoring in estuaries has assisted California State Parks in establishing their Estuary Management Initiative and informed the California Coastal Commission of bar-built estuary mouth breaching impacts and guidance. Monitoring data also provide information addressing ocean-related goals and priorities described in OPC's Strategic Plan.

Photo: Charlotte Stevenson

THE HUMAN DOMAIN

While a few aspects of the human domain are addressed in the MLPA goals and MPA Monitoring Action Plan, there has been comparatively little focus on the human domain in MPA monitoring and evaluation to date. Two of the MLPA goals (Goal 2 and 3) point towards understanding information about consumptive and non-consumptive human use. The Action Plan does identify a number of key performance measures and metrics to understand aspects of the human domain and inform network evaluation, some of which are included in baseline and long-term monitoring projects (e.g., MPA Watch, which uses volunteers to monitor both consumptive and non-consumptive human use of coastal resources in MPAs; EcoTrust studies of commercial fishermen behaviors and attitudes), and Appendix D of the Action Plan discusses some approaches for monitoring human dimensions. However, while this is a good start, there are many ways that humans affect and are affected by MPAs, and a more rigorous, evidence-based approach informed by an SES framework will improve monitoring for MPA Network evaluation over the long-term.

Reviewing the Appendix B questions in the context of the SES framework reveals the limitations of the existing questions to elucidate the breadth and depth of the human relationship with California's MPA Network. While human ecology and related social science has long been a subject of research, its application to analyses of MPA has evolved relatively recently. The field of SES research began to generate substantial publications in the mid 2000s (Colding and Barthel 2019), and the importance of viewing MPA effectiveness and management through an SES lens began appearing in the literature after the implementation of California's MPA Network (Ban et al. 2013, Picone et al. 2020). However, Indigenous worldviews have incorporated a more holistic social-ecological perspective into managing ecosystems for millennia (Berkes 2008, 2012, Simpson 2014, Tiakiwai et al. 2017, Diggon et al. 2020), providing further emphasis on the importance of incorporating Tribes into aspects of governance and monitoring for MPA Network evaluation. Viewing the human dimensions of California's MPAs through an updated SES framework generates numerous new questions, which can be addressed by a more integrated research and monitoring program, informed by multiple ways of knowing and "two-eyed seeing" (Alexander et al. 2019, Reid et al. 2021).

The MLPA goals most explicitly address ecological responses to MPAs, although several of the goals involve some human dimensions (e.g., fisheries, recreation, education, and research). During the MPA planning process, input on aspects of the human dimensions of MPAs was elicited through public participation, especially through the creation of regional stakeholder groups (RSGs), that played an important role in MPA planning. As distinct from the more generic term stakeholder used elsewhere in this report to refer to anyone with an interest in MPAs, RSGs engaged in MPA planning were made up of individuals officially appointed by the MLPA Initiative and carefully chosen to represent a variety of consumptive (e.g., commercial and recreational fishers) and non-consumptive interests (e.g., whale watchers, birders, conservation NGOs), as well as governance representatives (e.g., California Native American Tribes, state and federal management agencies). Indeed, the MLPA planning process was one of the most stakeholder-involved processes in the history of California's environmental policy implementation, and yet it fell short of expectations by some for inclusivity, consultation with Tribes, and consideration of human outcomes. From 2004 to 2012, the RSGs used science-based MPA design guidelines derived from the MLPA's ecological goals to propose specific MPA configurations, while striving to minimize negative impacts on human users and communities (Fox et al. 2013b). Through an iterative and transparent public process, the final MPAs in the Network were adopted from among these stakeholder-designed MPAs by the California Fish and Game Commission. It is important to note, however, that while the public participation process is important, it does not substitute for human dimensions research.

The RSGs explicitly considered tradeoffs among stakeholders' objectives (e.g., consumptive vs non-consumptive use) in MPA design, but these considerations are not articulated in the MLPA goals (Gleason et al. 2013) and only the fisheries-related economic trade offs were formally evaluated (White et al. 2013b). Consequently, much of the human dimensions knowledge amassed during MPA planning has not been carried into the present evaluation phase. Furthermore, studies of public hearings elsewhere suggest that, "Extensive involvement is not synonymous with meaningful public input" (Gregory 2000).

The human dimensions literature suggests that public hearings and processed-based stakeholder engagement should be supplemented with research that is focused on diverse stakeholders and combines qualitative and quantitative methods to effectively evaluate the human dimensions of MPAs (Barclay et al. 2017). In many instances, human dimensions data hold critical information to explain *why* particular changes are occurring. Cinner et al. (2009) highlight the critical importance of human dimensions for both the design and performance of MPAs, and other studies show compliance with MPA regulations appears to be related to complex social interactions rather than simply enforcement (Pollnac et al. 2010). This in turn has critical implications for how monitoring and evaluation programs are designed to inform the adaptive management of MPAs. Christie, et al. (2003) offer a succinct essay on the complexity and importance of measuring MPA success by considering both biological (e.g., biodiversity) and social success (e.g., equity and wellbeing). Evaluating whether MPAs are meeting social goals needs specific metrics and associated targets to be defined and operationalized in context of the social-ecological framework presented here, requiring a rigorous social science research and monitoring program.

Recommendations and Approaches:

7. **Address human dimension questions and invest in improving understanding the human dimensions of MPAs.**

7a. *Continue to evaluate existing human dimensions research against the evaluation questions in this report (Appendix 2) to determine what the best available data can and cannot inform.*

7b. *Convene a human dimensions advisory team of trained natural resource social scientists across multiple disciplines including sociologists, social psychologists, economists, anthropologists, geographers, political scientists, and legal scholars to update the Action Plan to include a more comprehensive approach to human dimensions research and monitoring, considering the recommendations made in this report.*

7c. *Determine a process to identify, prioritize, and fund specific research projects that will accomplish human dimensions research goals and generate the necessary data for future MPA monitoring and evaluation.*

THE HUMAN DIMENSIONS OF MPA PERFORMANCE

Our integrated socio-economic approach to evaluating the human dimensions of MPA and MPA Network performance has three components: 1) the relevant human stakeholders including rights holders, communities of interest and communities of place that act within the system; 2) the responses of these stakeholders to MPA management actions and the marine environment; and 3) the factors that influence human responses vis a vis MPAs. Human responses include changes in behavior such as fishing and other use, communication, engagement (i.e., dialogue between stakeholders and managers) and compliance with MPA regulations. Additional responses that are important to consider are changes in wellbeing, including economic, social, and cultural aspects, perceptions, attitudes, and knowledge. They are tightly linked to both the governance and ecological domains as well as ecosystem services and the distribution of outcomes and equity (Figure 1). With respect to influencing factors, the actions and interactions of the MPA social-ecological system occur in the context of factors that influence aspects of the three domains. These outside factors, including aspects of the larger social, cultural, and economic contexts that arise at local, regional, and global scales, such as local and regional economies or educational opportunities, are important to consider when evaluating the responses in the human domain. We describe and provide input on each of these dimensions in the following sections.

Specifying stakeholders, communities of interest, and communities of place: One key step in evaluation and adaptive management of the MPA Network is to clearly specify the relevant stakeholders, including rights holders, communities of interest and communities of place that affect or are affected by MPAs. While the MLPA planning process engaged a suite of stakeholders in the design and initial implementation of the Network of MPAs in California (Klein et al. 2008, Gleason et al. 2010, Fox et al. 2013a, Sayce et al. 2013), the diverse set of actors was not comprehensive, and their charge was to design the MPA Network, not to inform ongoing evaluation of MPA effectiveness. Thus, in considering the list of humans that are relevant to MPA performance in a social-ecological context, we must look beyond those stakeholders that engaged in MPA planning and develop programs to assess the interactions between humans and MPAs more broadly. Throughout this section, we will use the term *stakeholders* for consistency with the literature, but define it to refer broadly to anyone with any interest in MPAs, which, since MPAs are a public trust resource, includes any member of the public within the state of California.

A major challenge in specifying stakeholder groups is that stakeholders are not homogeneous, even within particular categories or geographic locations. For example, the commercial fishing industry is characterized by diverse people, vessel sizes, gear types, species sought, fishing methods and practices, and ownership. In addition, there are significant differences in management across fisheries and locales. Similarly, California's coastal communities are economically and socially diverse, and individuals within them vary in their perceptions, attitudes, knowledge and values. All of these factors affect behaviors, engagement, and regulatory compliance within California's MPA Network.

One group that is often overlooked regardless of whether or not they are engaged in fishing are the Tribes. In many areas they are keepers of Indigenous traditional knowledge (ITK) and have values and practices that must be considered. Further, Tribes are rights holders and should be engaged as such (Gray et al. 2017). Although Tribes fit within our definition of stakeholders as Tribal people, individuals and groups, they have relationships with the coast, ocean and MPAs and are clearly important to the evaluation and adaptive management of the MPAs and the MPA Network, they also have a unique and separate governmental status and consequently a different relationship with CDFW than any other group. Consistent with CDFW's policy of government-to-government consultation with Tribes, we reserve the majority of our discussion of the Tribes for the governance domain section of this report, while acknowledging that Tribal people are an important component of the human domain with behaviors, attitudes, knowledge, and wellbeing that influence and are influenced by the interconnected social-ecological system. As an initial exercise the Working Group identified a list of stakeholders that provide an example of ways to be more inclusive and more clearly define the relevant communities of interest and place for evaluation and adaptive management of the MPA Network. This list is not intended to be exhaustive, but should identify broad categories of stakeholders that are networked in communities of interest, and communities of place. These, with descriptive examples, could serve as starting points for future human dimensions research.

Examples of stakeholders or communities of interest:

- Local Institutions: community leaders; museums, aquaria, educational research institutions, ocean-based NGOs; scientists and researchers
- Governance bodies: Tribal governments; state agencies and associated policy-makers; local governments; federal agencies; elected officials
- Non-consumptive users and supporting ocean-dependent businesses: coastal residents including retirees; public recreators including pleasure boaters, kayakers, wildlife watchers, surfers, divers, beachgoers and others; commercial tourism operators including wildlife watching operations, kayak guides and others; coastal businesses supporting non-consumptive activities and tourism including dive shops, surf shops, restaurants, souvenir shops, and others
- Ocean-dependent industry: seafood processing; aquaculture; alternative energy; desalination
- Consumptive users and supporting ocean-dependent businesses: commercial fishermen; recreational fishermen; shoreside businesses supporting consumptive users including bait & tackle shops, gear manufacturers, fuel docks, and others

Examples of communities of place:

- Coastal residents & non-coastal residents
- Cities and towns with and without fishing ports
- Counties: coastal v. non-coastal counties
- Region (geographical area): north coast, north central coast, SF Bay area, central coast, south coast
- Proximity to MPA(s): towns or cities that are close (far) from MPA sites

Many of the questions developed by CDFW to inform evaluation of the MPA Network (Appendix B) identify stakeholders based on a subset of behavior, such as a consumptive or non-consumptive user of the marine space, but neither clearly define nor consider other stakeholders that may affect and be affected by policy decisions. In addition to the examples of stakeholders categorized above, there are others that cross categories. For example, ports and fuel depots are important to both consumptive and non-consumptive users. The questions in Appendix B are mostly geared towards commercial and recreational fishers and non-consumptive recreational users (that are not clearly defined). To some degree, the "general" public is considered but again not clearly defined; further understanding of how those members of the public define their relationship with the marine space and knowledge of what influences their understanding, perceptions, and access would better inform adaptive management. For example, there are questions about the economic effects of MPA placement, with a focus on commercial and recreational fishing, but these could be modified to include economic effects on coastal communities or non-consumptive users (e.g., eco-tourism operators, other ocean-dependent marine industries, or related support businesses) to determine who bears the costs or receives benefits associated with these areas. Furthermore, other communities of interest or communities of place are likely to have different values, knowledge, attitudes and perceptions that influence their compliance with MPA regulations as well as their communication and engagement with MPA adaptive management.

Recently, typologies of stakeholders have been developed for marine management (Elliott 2014, Newton and Elliott 2016) and may be useful for helping to refine the relevant groups of stakeholders in this ongoing adaptive management process. One way forward is to engage focus groups of stakeholders and community members, possibly drawing from the MPA Collaborative Network ("MPA Collaborative Network: Empowering Coastal Communities" 2018) to co-develop a typology that is more inclusive of the diverse suite of social actors that exist in California. Furthermore, since the inception of the MLPA process, aspects of equity, diversity, intersectionality, and inclusion have evolved to be more in the forefront of society in general and of scientific research and natural resource management more specifically (Christie et al. 2017). Indigenous people and people of color and/or of lower economic status are often marginalized and their access to marine resources and ocean spaces and associated wellbeing is often not considered by decision-making processes (Bennett et al. 2018, Malin et al. 2019). Though not exclusively MPA-related, this can lead to poverty traps and social issues within coastal communities and linked urban environments and undermine the desired management outcomes.

An opportunity exists to better consider and incorporate the concerns of the diversity of interested parties into MPA management and marine management more generally. Toward this goal, we pose two new monitoring questions under the subheading "Changes in Behavior" that begin to address the inclusiveness of the MPA Network. By more clearly defining and engaging diverse communities of interest and place, CDFW can more clearly and collaboratively define the key questions and identify influencing factors to create an evaluation framework that will better inform effective and inclusive policy development, outreach, education and engagement, science and research, and enforcement and compliance.

Photo: K. Lesyna

Recommendations and Approaches:

8. Identify the best approaches to expand consideration of the diversity of humans with an interest in MPAs and MPA management.

8a. *Consult with a human dimensions advisory team (7b) to determine the best way to identify a broad spectrum of stakeholders and communities to engage in monitoring and research as it relates to adaptive management of MPAs and the MPA Network.*

EVALUATING HUMAN RESPONSES TO MPA NETWORK IMPLEMENTATION

Humans are affected by and respond to marine management, changes in the marine environment, and other related social, economic, and cultural factors in a number of ways that can further influence the social-ecological system. It is important to clarify and define the different dimensions of the human response to MPA Network implementation to evaluate how well the Network is meeting both its ecological and social goals. We have characterized aspects of the human system that are important to consider for adaptive management of the MPA Network into four general categories: (a) changes in behavior, including fishing and other use, communication and engagement, and compliance; (b) changes in wellbeing, including economic, social, and cultural aspects; (c) changes in attitudes and perceptions; and, (d) changes in knowledge. We emphasize that these aspects are intertwined and will influence each other and the overall social-ecological system.

Because California's Network of MPAs is an innovative approach, there is relatively little literature that is directly applicable to issues associated with human dimensions of the Network. However, research on the human dimensions of large-scale MPAs offers important insights including: ignoring human dimensions initially can negatively affect long-term conservation especially in light of the complex web of relationships between stakeholder groups and individual/groups of MPAs; ongoing monitoring is essential; social impacts and perceptions vary across groups; transparency and participation is key (Gray et al. 2017, Christie et al. 2017). Also, critical points to consider are 1) the MPA Network encompasses marine space that is dynamic and variable, and 2) the connection and correspondence between the diverse stakeholders and individual MPAs/Network is multifaceted and complex.

CHANGES IN BEHAVIOR

Implementation and management of the MPA Network can lead to changes in human behavior by different stakeholders. Here we interpret behavior broadly to include fishing and other use, but also communication and engagement with management processes, as well as compliance with MPA regulations. To understand the social behavior related to the MPA Network, we must understand not only how stakeholders have changed their use of the marine environment in and around MPAs, but the level to which different stakeholder groups are engaged in a meaningful dialogue with managers about MPAs, how they communicate with other stakeholders, including researchers and managers, and the level of compliance with MPA regulations. All of these aspects of behavior can influence perceptions about the value of the Network, acceptance of regulations associated with MPAs and the MPA Network, wellbeing outcomes, as well as ecological outcomes within and outside MPA footprints (e.g., larval export, adult spillover).

The original questions in Appendix B address changes in use, not other types of behavior, and focus on only a subset of stakeholders (commercial and recreational fishers, researchers, educators, and non-consumptive recreational users) with little consistency in the types of questions asked for each group. In the original questions, there is a specific focus on the displacement and reduction of commercial and recreational fishing effort with the implementation of the MPA Network. But non-consumptive users also may shift their behavior and use of the marine environment with the implementation of MPAs (Sanchirico et al. 2002, Milazzo et al. 2002). For example, non-consumptive recreational users may increase their use of MPAs if they perceive that the MPAs are beneficial to their outdoor experience (Wahle 2014). Use of marine space is connected to many other factors within the human-ecological system. For example, members of the commercial fishing sector may be displaced to other locations and shift their effort (Mangi et al. 2011).

Alternatively, tourism may increase in the MPAs, or commercial passenger fishing vessel operators may diversify their business to include non-extractive activities, such as wildlife viewing tours. Furthermore, human dimensions research in Oregon reveals that certain stakeholders may be more (or less) likely to engage in collaborative research projects, provide comment in public meetings, or otherwise engage with MPA management because of how they perceive the MPAs and the process by which they were created (ODFW 2020). These changes in engagement may be due to several factors, such as perceptions of legitimacy of MPAs as conservation tools, perception of the socio-economic costs or benefits to different groups, or perceptions of fairness in the governance process (Bennett et al. 2019).

Using the SES framework as our guide, we sought to broaden the questions to ask about changes in a variety of behaviors, not only use, and to ask those questions across a diversity of stakeholders, communities of interest and communities of place. Here we articulate a short list of questions about behavior that should be assessed across as many stakeholder groups as possible. We address compliance in detail within the governance domain section, so although compliance is an element of behavior, we do not pose specific questions about compliance in this section. This list of questions represents new questions proposed by the Working Group (question numbers with the "N" prefix).

- *N1. Which stakeholder groups are accessing MPAs and adjacent non-MPA reference sites?*
- *N2. Has use of MPAs and reference sites changed over time, and why?*
- *N3. How do the demographics of those who use MPAs and reference sites compare to state demographics?*
- *N4. Are there groups that disproportionately access or don't access MPAs and reference sites, and why?*
- *N5. What stakeholders engage with CDFW and the MPA management program, how do they engage, and why?*
- *N6. How does CDFW communicate with stakeholders about MPAs, which stakeholders do they reach, and is the communication effective?*

These questions effectively contain all of the behavior-related questions within Appendix B, albeit with less specificity, and expand upon the existing questions to encompass more types of behavior and a more diverse array of stakeholders. For example, the original Question 14, "Are researchers accessing MPAs, and has research increased over time in MPAs?" is a specific version of Questions N1 and N2 above, focused on researchers. In Appendix 2 we list the newly conceived questions above, show how some of the original Appendix B questions fit within them, and articulate more specific examples of each broad question that could guide future monitoring and evaluation. We anticipate that any social science research group that may take on these questions in the future will further refine and specify them to guide their research.

Note that Questions N3 and N4 seek answers about how use of MPAs is distributed across the population, which could shed light on how equitably the outcomes of MPAs, including potential benefits, are distributed. Answers to these questions could highlight groups that currently do not access MPAs or their benefits and provide direction for future outreach and education efforts to engage a broader array of stakeholders with the MPA Network. Similarly, Questions N5 and N6 could help identify the stakeholders that do and don't engage with MPA management processes, evaluate the effectiveness of CDFW's communication with different stakeholder groups, and reveal effective avenues for outreach to underrepresented groups.

Recommendations and Approaches:

9. **Improve understanding of changes in human behavior related to MPAs**

9a. Use the best available data and support new monitoring efforts to examine a diversity of human behaviors related to the MPA Network including uses of MPAs and reference sites, compliance with MPA regulations, and engagement and communication with CDFW's management program.

CHANGES IN WELLBEING

The establishment of MPAs and MPA networks can lead to positive, negative or neutral changes in multiple aspects of human wellbeing, including economic, social, and cultural dimensions. Direct economic benefits or costs to fisheries and fishing-dependent businesses are the most commonly considered economic outcomes of MPAs, but we advocate broadening this view to consider both direct and indirect economic outcomes for a diversity of stakeholders and communities. We also suggest that economic outcomes are just one aspect of human wellbeing and that other social, cultural and spiritual outcomes that may not be reflected in economics should be considered among the consequences of MPAs, both for current and future generations. Finally, the ecosystem services provided by MPAs should be considered among the human outcomes of MPAs with consequences to wellbeing that can be assessed even if placing economic valuation on them is challenging.

Direct economic benefits and costs to commercial and recreational fisheries may be due to changes in fishing regulations, changes in revenue per unit of fishing effort, or in effort and cost per unit of fish caught. These economic costs may be a direct result of fishing regulations or MPA implementation, where benefits may be due to increased recruitment of juveniles, increased sizes and age of adults leading to significant increases in eggs and larvae, and movement of adults from MPAs (spillover) (Silva et al. 2015) and costs may be due, for example, to loss of known and productive fishing ground and searching for new areas, fishing longer/differently, higher fuel costs associated with fishing more distant areas or crowding. Other stakeholders may also see changes in direct economic outcomes from MPAs, related to increased (or decreased) visitation to MPAs (e.g., tourism operators or bait shops). Furthermore, there may be changes in indirect economic outcomes to various stakeholders, related to supply or demand for goods and services (e.g., changes in infrastructure use patterns (Pomeroy 2002) local real estate prices or availability of fresh, local seafood). With any of these economic outcomes, there remains the challenge of disentangling the effects of the MPAs from a number of other influencing factors, such as market conditions, fuel prices, technological changes, competition for space by other industries, among others.

While economic indicators of wellbeing, such as revenue and income, have been partially recognized and evaluated in relation to MPAs (Davis et al. 2019), there is increasing recognition of the importance of including a broader and more multi-faceted approach to evaluating human wellbeing when evaluating conservation interventions (Woodhouse et al. 2015, Hicks et al. 2016), including not only the present, but also future generations. Despite the nascent development of accepted definitions and frameworks, there is increasing agreement in the literature that wellbeing encompasses both objective and subjective elements and that there exist three general aspects to wellbeing: material wellbeing (e.g., housing, income, livelihoods), quality of life, and relational wellbeing (e.g., community networks, tangible and intangible connections to nature). These established, multidimensional elements have a number of indicators that can be drawn upon (Hicks et al. 2016, Breslow et al. 2016, 2017). In addition, there are such intangibles as an increased sense of danger when forced to fish farther from shore or an aversion to fishing close to others when MPAs cause compaction or crowding at the boundaries or other areas that remain open. While acknowledgement of the importance of considering these dimensions exists (Bennett et al. 2017), there has been limited empirical research on the influence of conservation on multiple aspects of human wellbeing and the complex set of interactions that take place, but there is a growing body of work that can be built upon.

Photo: Gerick Bergsma

Recommendations and Approaches:

10. **Improve understanding of how human wellbeing is affected by MPAs, including economic, social, and cultural wellbeing.**

10a. Continue to use the best available socio-economic data to assess the impacts of MPAs on fishing and engage fishing communities in validating these assessments and improving data collection, metrics, and analyses (also see recommendation 13).

10b. Continue to use the best available data to conduct economic assessments of the impacts of MPAs that go beyond the proximal impacts to the fishing community and include broader assessments of the economic health of coastal communities.

10c. Continue to use a fully participatory process to identify relevant dimensions of social and cultural wellbeing and a set of valid indicators/metrics that capture the outcomes of the MPA Network for stakeholders and communities.

10d. Using appropriate frameworks, develop approaches for collecting data and evaluating changes across multiple dimensions of human wellbeing with input from social science experts.

We propose the following questions to address changes to wellbeing:

- *N7.* *What are the direct and indirect economic consequences of MPAs for relevant stakeholders and coastal communities?*
- *N8.* *How have MPAs affected dimensions of social and cultural wellbeing for relevant stakeholders and coastal communities?*

These simplified questions encompass the questions originally posed in Appendix B that address economic and other aspects of wellbeing, including parts of Question 8, which addresses changes to fisheries, Question 12, which asks about the economic impacts of MPA placement, and parts of Question 17, which asks about the value of edge effects to recreational consumptive users. Because Questions 8 and 17 involve aspects of both the ecological and human response to MPAs, they are also integrative questions that are addressed as well in the integration section below. In Appendix 2 we list the newly conceived questions above, show how some of the original Appendix B questions fit within them, and articulate more specific examples of each broad question that could guide future monitoring and evaluation. We anticipate that any social science research group that may take on these questions in the future could further refine and specify them.

CHANGES IN ATTITUDES AND PERCEPTIONS

People's values, knowledge, and experiences shape their attitudes and perceptions. In turn values, attitudes, and perceptions can influence people's behavior and interactions with marine space (Schultz et al. 2005, Leiserowitz 2006, Milfont et al. 2006), and their support for the MPA Network and management actions (Charles and Wilson 2009, Chaigneau and Brown 2016, McNeill et al. 2018). Furthermore, individuals may value the Network but oppose certain management regulations, actions, or decisions. Efforts to define and evaluate attitudes and perceptions for all stakeholders should incorporate aspects of what drives those changes and how those changes in turn influence human behaviors and perceptions of wellbeing. Examples of the types of variables that can significantly influence perceptions of and attitudes towards establishment and management of MPAs include the following taken from McClanahan et al. (2005):

- The perceived costs and benefits that may accrue from MPA establishment,
- Awareness and knowledge of MPA objectives and rules that govern the use of marine and coastal resources,
- Participation in and perceived legitimacy of the process of establishment,
- Dependency on marine and coastal activities, and
- Demographic variables (e.g., wealth, education, age).

In addition, ongoing communication about the effects of MPAs based on the long-term monitoring projects and reports on compliance can affect attitudes and perceptions.
Appendix B already has a broad question about knowledge, attitudes, and perceptions (Question 18, "How are knowledge, attitudes, and perceptions regarding the MPAs changing over time?") We chose to separate the question about knowledge from that about attitudes and perceptions, as these may be influenced in different ways. We also considered that the perceived value of MPAs and desire to visit them is important *relative* to adjacent non-MPA areas and to assess how MPA designation may contribute to these perceptions. Thus, we have developed two questions to guide study of attitudes and perceptions:

- *18a.* *Have attitudes towards and perceptions of individual MPAs and the MPA Network as a whole by stakeholders changed over time and why?*

N9. *Is there a difference in the perceived value of, and desire to visit MPAs as compared to non-MPA reference sites?*

As before, we list the above questions in Appendix 2, show how the original Appendix B questions fit within them, and articulate more specific examples of each broad question that could guide future monitoring and evaluation. We anticipate that any social science research group that may take on these questions in the future could further refine and specify them.

CHANGES IN KNOWLEDGE

Knowledge of the MPA Network and the costs and benefits of MPAs can influence people's perceptions, attitudes, and behaviors, including compliance with regulations. Outreach and education activities are generally focused on increasing knowledge of MPAs with the goal of changing attitudes and ultimately behavior (Leisher et al. 2012). There are, however, a variety of outreach and education strategies, from signage, to on-site educators at common access points, to engagement of stakeholders in collaborative or citizen MPA monitoring. Knowing which strategies have the greatest impact on knowledge could be helpful for CDFW to prioritize resources in support of effective outreach and education efforts. A number of citizen science organizations (e.g., fisheries trusts, ReefCheck, California Cooperative Fisheries Research Program (CCFRP), Long-term Monitoring Program and Experiential Training for Students (LiMPETS), and others) gather data for ecological monitoring and raise awareness about the MPA Network. For example, recent work by CCFRP surveyed volunteer anglers and found that angler opinions toward MPAs were more positive after participating in the CCFRP and that the likelihood of that response was even higher for volunteers that participated for longer (Mason et al. 2020). Determining what people know, and how they obtain and process information can further inform approaches for outreach and education, a key aspect of adaptive management of the MPA Network. Here we propose two questions about stakeholder knowledge; we delve into greater detail about the adaptive management implications of knowledge in the governance domain where we discuss outreach, education, and stakeholder engagement in dialogue with management.

18b. Has knowledge of MPAs by stakeholders changed over time and why?
18c. How does stakeholder knowledge of MPAs influence attitudes toward and perceptions of MPAs?

Recommendations and Approaches:

11. Improve understanding of changes in attitudes, perceptions, and knowledge related to MPAs and how these factors influence one another

11a. Continue to use the best available data and support new research to determine the attitudes toward and perceptions of MPAs by different stakeholder groups, and how and why they change over time.

11b. Continue to use the best available data and support new research to determine knowledge of MPAs, expectations of MPA performance, and how these factors influence behaviors, attitudes, and perceptions by different stakeholder groups, and how and why these change over time.

DATA GAPS IN THE HUMAN SYSTEM AND PRIORITIZATION OF MONITORING EFFORTS

While human dimensions were considered in the original design and establishment of the MPA Network, on-going monitoring projects heavily favor ecological concerns. Only one long-term monitoring project focused on human dimensions is on-going (Ecotrust) and that is focused principally on commercial fishing stakeholders with some attention to commercial passenger fishing vessel operators. While the Action Plan included some limited human dimensions metrics, without more detailed information, refined questions, and priorities, it's difficult to successfully fund individual projects to generate the needed data for evaluation and monitoring of the California MPA Network. Additionally, volunteer groups or citizen science programs require guidance to ensure their efforts result in valuable data. For example, MPA Watch (mpawatch.org) is a coordinated network of citizen science programs around the state that train volunteers to collect data on different types of consumptive and non-consumptive use in MPAs, but the data are largely observational. Structured, scientifically sound interviews could be used to collect data to help address some of the social science questions listed above, though assistance in interpreting results with attention to validity and reliability would be needed. As yet no formal social science monitoring of the diverse stakeholders noted above has yet been undertaken. Furthermore, the evaluation and monitoring of individual MPAs and the Network is hampered by a lack of data about relevant stakeholders at a comparable scale.

Example from Oregon: There are many resources both within the state of California and elsewhere in the Pacific Northwest to guide California as it navigates the development of a human dimensions research agenda and monitoring program for the California MPA Network. Applied social science research and guidance are detailed in the Marine Life Management Act (MLMA) Socio-Economic Guidance and the Work Plan. Universities in California, Oregon, and Washington have social science departments that focus on topics such as natural resource economics, changes in behavior, and attitudes, perceptions and knowledge related to natural resource policy. Even within CDFW there may be an economist associated with another program that could provide valuable input from an agency perspective. Oregon has a state-led marine reserves program with a human dimensions monitoring program that has several lessons learned that may be of use for California.

The legislation that established the Oregon Department of Fish and Wildlife (ODFW) Marine Reserve program mandated and allocated resources for a human dimensions monitoring program to monitor Oregon's five marine reserve sites. Oregon's monitoring program began in 2010, and while smaller in scope than the California MPA Network, focuses on many of the same research questions (behaviors, aspects of wellbeing, knowledge, attitudes, perceptions) recommended in this report. The development of the human dimensions research agenda in Oregon was guided by an advisory team of social scientists from universities in Oregon; such an advisory team still provides guidance and advice to the human dimensions monitoring program to this day. ODFW invested in a formal position to lead and coordinate the human dimensions monitoring program. The diverse fields of research that contribute to a human dimensions research agenda and monitoring program are too much for one person to tackle alone without a full research team behind them. Therefore, ODFW relies on collaborative partners outside the agency to address such multifaceted research and monitoring.

There are many qualified social scientists in California's higher education system, and elsewhere, who could help develop a California MPA human dimensions research agenda and monitoring program (e.g., Recommendation 8). In particular for the primary step of forming an advisory group, several California universities have social science programs focusing on aspects of natural resources, and would have faculty and researchers that could provide valuable advice to CDFW.

The Pacific Southwest Research Station of the US Forest Service also has a strong program in natural resource social sciences and would provide valuable input to an advisory group that could potentially build upon land-sea connections in California.

The first task of the advisory group is to define the human dimensions research agenda and monitoring program as it relates to the California MPA Network, considering the mandate from the MLPA, supporting documents and recommendations from this report. Once this is accomplished the advisory group and/or someone delegated by CDFW can determine a way forward for selecting smaller research projects that will meet the goals of the research agenda while generating the necessary data in support of human dimensions monitoring and evaluation. Many of the recommendations in the human dimensions section of this report are broad in nature and further refinement and prioritization of research questions, stakeholder groups, and methods will be required as specific projects are identified to meet human dimensions goals of the California MPA Network. Identifying and prioritizing smaller projects to accomplish research agenda goals could take a variety of forms including a grant or request for proposals (RFP) process, a CDFW appointed science administrator, or the creation of a co-op agreement with a willing university.

Photo: Diane Castaneda (MPA Watch)

THE GOVERNANCE DOMAIN

Governance is a broad concept that refers to the exercise of economic, political and administrative authority and includes the processes and institutions through which "[individuals] and groups articulate their interests, exercise their legal rights and obligations, and mediate their differences. Natural resource governance is influenced by "formal and informal arrangements, institutions and mores" that guide the use of the resources and the environment (Juda 1999). Coastal and ocean governance in the US is complicated by the multiple layers of federal and state agencies with legal authority, Native American Tribal nations with reserved rights and/or jurisdiction over some ocean spaces and resources, as well as other interested parties and stakeholders (Center for American Progress 2017). Here we discuss the importance of viewing MPAs in the broader context of coastal governance and management then focus on the specifics related to adaptive management of California's MPA Network.

MPAS IN THE BROAD CONTEXT OF COASTAL GOVERNANCE

Because governance of coastal areas is complicated by multiple layers of interest and jurisdiction, effective governance of MPAs requires consideration of this governance context including coordination across governance or management entities. For example, "the MPA Master Plan acknowledges the separate, sovereign status of Indian Tribes as co-equal users, managers, and stewards of marine species." Also, "the Master Plan commits the California Department of Fish and Wildlife to "meaningful consultation" with Tribes and their governments" (Berkey and Williams 2019) on proposed projects that have the potential to impact Tribes. At times, Tribes may opt for informal meetings rather than official consultations. Cooperation and communication between Tribal and state decision-makers as well as consultation is encouraged by the state.

Neither the government-to-government relationship nor the reserved rights of the Tribes were initially recognized by the state during the establishment of California's Network of MPA. Due to the advocacy of Tribal nations, particularly the Kashia Pomo in the North Central Coast Region, this governmental relationship, consultation requirement, and recognition of the unique rights and uses by Tribes came to be recognized during the north coast MPA planning process (Berkey and Williams 2019). In some instances, exemptions to MPA take restrictions for Tribes are written into MPA regulations to allow Tribes to participate in traditional harvesting.

Fisheries management provides another example of a complex governance context with the potential to impact the functioning of MPAs; fished species are managed at different geographic scales by federal and state management entities with consequences for the populations of fished species. Also, at the federal level, shipping activities, mineral rights, and Department of Defense training operations, and protections afforded by National Marine Sanctuaries can impact the functioning and management of MPAs. At a regional scale, California water boards manage freshwater resources and runoff to marine waters that could impact MPAs. At the local scale, city and county governments make decisions about land use and development, regulation of tourism and supporting industries, and coastal access that can have profound impacts on MPAs. In fact, the need for a team to address some of the issues that arise from these overlapping layers of governance, was first identified in the Marine Managed Areas Improvement Act (MMAIA, CA Public Resources Code §§36600-36900). In 2014 the California Secretary of Natural Resources convened the MPA Statewide Leadership Team in 2014 (CA Public Resources Code §36800), with Tribal representation added in 2018. This team, which is composed of representatives from state and federal agencies, Tribes, philanthropic groups, and non-governmental organizations (NGOs), is tasked with ensuring communication, collaboration, and coordination among entities with an interest in MPA management. Understanding and managing these layers of overlapping and sometimes conflicting governance that influence MPAs is the subject of marine spatial planning

(MSP) efforts around the world and extends far beyond the scope of the MPA Statewide Leadership Team or this report. However, we call out two areas where we think managing MPAs in this broader context is essential: California Native American Tribes and Tribal communities, and fisheries management.

CALIFORNIA'S NATIVE AMERICAN TRIBES

Federally and state recognized Tribes have an official government-to-government relationship with the U.S. government and California state government (Brown 2011). According to Executive Order B-10-11, "the state of California recognizes and reaffirms the inherent right of these Tribes to exercise sovereign authority over their members and territory." The order goes on to state that "Agencies and departments shall permit elected officials and other representatives of Tribal governments to provide meaningful input into the development of legislation, regulations, rules, and policies on matters that may affect Tribal communities." That policy was reaffirmed with Executive Order N-15-19 (Newsome 2019).

Marine resources, including deep-sea and nearshore fisheries, marine mammals, shellfish, and seaweeds continue to support the lifeways of California's Tribes. Seasonal travel to camp on the coast, as well as trade and uses of marine resources extending far inland demonstrate the extensive inter-Tribal social networks connected to the ocean. While property ownership was not common, exclusive use rights to specific fishing grounds (as well as hunting and other food-collecting areas) existed in the past among some Tribes, and these traditions continue today.
The state of California did not have a formal process for consulting with Tribal governments when the MLPA was implemented. The lack of attention to the interests of California Tribes and Tribal communities finally drew statewide attention in 2010. Through strong advocacy, significant engagement, and pressure, Tribal leadership, community members, and representatives worked with CDFW and the Fish and Game Commission to find solutions other than litigation to address Tribal interests. Ultimately, the state demonstrated an acknowledgement of the unique considerations distinct to California Tribes, and created a regulatory provision that provided an exemption from MPA-specific area and take regulations for individual federally-recognized Tribes within their ancestral areas.

The state included traditional ecological knowledge (TEK) or Indigenous traditional knowledge (ITK) of important resources and habitats in the North Coast MPA Baseline Monitoring Program (Van Pelt et al. 2017). The acknowledgement of the importance of ITK was also included in the Action Plan and was a foundational consideration in the development of the Tribal Marine Stewards Network.

The Tribal Stewards Program, funded by the state, will help with gathering ITK and supporting Tribal community educational needs. Among the topics that may be illuminated are the Tribes' use and cultural value of marine resources in California, and how they have been affected by the MPA regulations, whether behavior has changed, whether traditional harvest has changed, what their perceptions are, whether MPAs have affected their wellbeing, and whether they are satisfied with the MPAs and the Tribal exemptions. Tribes may also note if they are seeing ecological improvements where MPAs are located. Equally important and previously overlooked are the Tribes' cultural or non-use values associated with their history, heritage, and identity to the ocean (Jobstvogt et al. 2014). Non-use values may include altruistic values (maintaining the site for others), bequest values for future generations, and/or existence values for other species (Balmford et al. 2008). The collaboration with Tribes will provide opportunities to explore these and other considerations.

It is critical that the state ensure the protection of unique Tribal uses, acknowledgement of their continued responsibility to care for ancestral areas, and recognition of the unceded aboriginal rights of Tribes to coastal and nearshore waters, all of which should be considered in the decadal evaluation of MPAs.

Recommendations and Approaches:

12. **Continue to identify opportunities for meaningful engagement and collaboration between Tribes and the state on MPA monitoring, evaluation, and adaptive management. The Tribes should be considered true partners with the state in these efforts.**

12a. Use the best available data and support additional collaborative research to understand the impacts of MPAs on Tribal use of the coast and ocean (including by assessing the effectiveness of current Tribal take exemptions) as well as the cultural and ecological benefits of Tribal stewardship, and use these results in MPA evaluation efforts.

12b. Conduct listening sessions and other outreach as appropriate to identify Tribal priorities for MPAs. Develop pathways for ensuring that these priorities are elevated in MPA monitoring, evaluation, and adaptive management.

12c. Continue the Tribal Marine Stewards Network pilot project and increase efforts by including additional coastal Tribes throughout the state.

12d. Explore ways in which Indigenous Traditional Knowledge (ITK) can be captured and shared in a respectful, appropriate manner in collaboration with the Tribe, community, or culturally knowledgeable people providing ITK.

INTEGRATION OF MPAS AND FISHERIES MANAGEMENT

Management falls under the rubric of governance and focuses on how the goals articulated by governance are to be met. In the case of California's MPAs, management is the responsibility of CDFW, but can be strongly influenced by the objectives, policies, and management decisions of other management entities. These influences can be observed in both the ecological and human domains, and it was recognition of the interconnections between protecting ecological communities and fisheries management efforts that led to the MLPA. By focusing on the protection of California's coastal habitats and biota, the MLPA complements the MLMA, which requires an ecosystem-based approach instead of concentrating management actions on individual species fisheries. However, in an effort to ensure that both the MLPA and MLMA could provide robust ecosystem protection on their own, the planning processes for the two acts deliberately excluded consideration of protections provided by the other. The resulting system of MPAs and fisheries management provides a rich opportunity to study the poorly understood synergy between MPAs and fisheries management. Furthermore, because MPAs are affected by fishing activities in and outside their boundaries, fisheries management regulations (both past and present) are among the key influencing factors to consider when evaluating the ecological performance of MPAs and the MPA Network. The Pacific Fishery Management Council, the National Marine Fisheries Service, CDFW and the California Fish and Game Commission, and the California legislature are the primary entities that share fisheries management and other regulatory responsibilities for the living marine resources in state and federal waters off California. The results of their resource monitoring and assessment efforts inform decisions regarding regulations such as allowable catches of fish populations, which in turn drive the level of fishing activities that take place throughout the coastal marine ecosystem. Thus, trends in fishing effort, fishing mortality and total catches outside of (and often adjacent to) MPAs are influenced by the MPAs themselves, but are driven to a considerably greater degree by the scientific analyses and management decisions of other management entities.

The goals and objectives of MPA networks and fisheries management overlap in their contributions to biodiversity conservation, ecosystem-based fisheries management, and the human dimensions associated with each. In social, economic, and ecological contexts, networks of MPAs and fisheries are inextricably linked and therefore are best managed as an integrated system. For example, the increased larval production generated across a network can enhance the resilience of fished populations, while sustainable fishing outside MPAs enhances the resilience of populations and communities within MPAs. However, there are substantial barriers to integrating MPA and fisheries management.

As noted by a National Research Council (NRC) panel on MPAs (NRC 2001) the complexity of jurisdictional responsibility for managing marine resources in general can create barriers to the development and implementation of coordinated policies for managing living marine resources. Such barriers are most readily apparent for fisheries management efforts, as federally-managed fisheries along the U.S. west coast do not explicitly take the California MPA Network into consideration with respect to management philosophy, practice and implementation, nor with respect to the science products that inform management decisions. Because California fishermen often participate in—and depend on—a mix of both federally- and state-managed fisheries to enable them to cope with variable resource availability, any lack of coordination between the two management regimes, particularly in response to climate volatility, may lead to additional management challenges (Thomson 2015, Richerson and Holland 2017, Holland and Leonard 2020). Understanding both the challenges and contributions of the statewide Network of MPAs to California's fisheries, and how these fisheries may respond to this Network, is necessary for improving fishery management strategies. MPAs are expected to result in various biological, ecological, and socioeconomic effects within and adjacent to their boundaries, with broad implications for the management of California's marine fisheries.

These implications can lead to some tensions among management approaches and objectives for fisheries resources. Most current fisheries management approaches, particularly for federally managed species, are largely based on constraining total allowable catches. These total allowable catches are in turn informed by stock assessment models—statistical models that estimate population abundance, demographic structure, and a sustainable level of yield. Spatial closures like MPAs complicate current approaches to stock assessments by increasing spatial heterogeneity in abundance and size or age structure of fished stocks. The more effective MPAs are at protecting populations within them, the more traditional assessment approaches will be biased or more uncertain as a result of this increased heterogeneity, particularly if such models lack data from within the MPAs themselves (Punt and Methot 2004, Field et al. 2006, Berger et al. 2017). As most of the stocks that are protected by MPAs are relatively data-poor nearshore species, more informative data are needed to parameterize more complex, spatially-explicit models.

In addition to the impacts on the science products that inform management, fisheries managers need to know the social and economic impacts of MPAs to fisheries participants and behavior.

No-take or restricted MPAs can displace or reduce fishing effort, increasing costs and travel time if, for example, fishermen have to travel a greater distance from port or their residences. For commercial fishermen, if economic (i.e., market) conditions are sufficiently favorable to compensate for increased costs (e.g., fuel), this may have little effect on their economic outcomes but could have social wellbeing consequences (e.g., if anxiety or danger increases with the effort to find new productive grounds; if they have to be away from home longer; or if they perceive that their ability to adapt to other influencing factors may be limited). Furthermore, small-scale fishermen could be disadvantaged if their vehicles or boats are not capable of traveling the longer distances. To date, these types of consequences of the Network have not received much attention and the direction (positive or negative) and magnitude of the Network on the social (including fishing behavior) and economic impacts (e.g., yield and quality of catch) will vary markedly across the regions and the diversity of California's fisheries.

Integrating (or at least reconciling) MPA and fisheries management is critical to maximizing human and ecological benefits from the MPAs, but this integration poses substantial challenges. A more detailed discussion of such integration is included in Appendix 4, including trade-offs and interactions among management systems and assumptions, identification of areas in which the MPA Network and the other fisheries management entities either complement or contradict each other with respect to the assumptions and the processes that support fisheries governance. One common thread that emerged from discussions of integrating MPA and fisheries management is the lack of spatially-explicit fisheries data—especially data appropriate for individual MPAs and reference sites—to address and answer evaluation questions. In addition, of the datasets that do exist, there has been relatively limited analysis conducted. There is clearly an opportunity and a need for the state to invest in the development of analyses using available data, rigorously evaluate the applicability of these datasets, and build upon them with new programs that collect and analyze higher-resolution spatially-explicit data.

Recommendations and Approaches:

13. Advance integration of MPAs and fisheries management

13a. Use the best available qualitative and quantitative data and support new research to examine changes in the distribution and magnitude of fishing effort and yield inside and outside of MPAs.

13b. Use the best available data and support new research to examine the associated impacts of changes in fishing effort and yield inside and outside MPAs on behavior and wellbeing for fishermen, fishing families and fishing communities.

13c. Form a working group that includes fishermen and fisheries managers focused on identifying ecological, social, and economic data integration methods for data from fisheries management and MPAs (also see recommendation 19).

13d. Where practicable, support MPA monitoring programs that can inform MPA performance and evaluation as well as traditional fisheries management for managed resources.

INFORMING ADAPTIVE MANAGEMENT

Key to effective governance of California's MPA Network is effective management of the MPAs themselves. The MLPA specifically mentions the importance of effective management and adequate enforcement in Goal 5; "To ensure that California's MPAs have clearly defined objectives, effective management measures, and adequate enforcement, and are based on sound scientific guidelines." The MLPA also specifies that the MPA Management Program shall include provisions for adaptive management, which is defined as "a management policy that seeks to improve management of biological resources, particularly in areas of scientific uncertainty, by viewing program actions as tools for learning. Actions shall be designed so that, even if they fail, they will provide useful information for future actions, and monitoring and evaluation shall be emphasized so that the interaction of different elements within marine systems may be better understood" (CA Fish and Game Code §2852(a)).

Recognizing the importance of strong oversight and a process to implement the MLPA, the MPA Management Program compartmentalized the core elements of successful MPA programs from around the world: policy and permitting; enforcement and compliance; outreach and education; and research and monitoring. The combination of these elements provides a robust process for adaptive management that seeks to improve management and enable learning and course-correction based on monitoring and evaluation, as well as lessons learned throughout ongoing management. In addition, these elements are a direct reflection of the six goals and requirements of the MLPA and were designed to ensure California's MPA Network is adaptively managed and informed by engaged partnerships (CDFW 2016).

We address these four core elements of adaptive management below, with special attention to those that should be informed by the decadal review.

POLICY PERMITTING AND REGULATION

The policy and permitting element of the MPA Management Program is guided by regulatory authority, management, and policy that interact to facilitate the design, implementation, and adaptive management of the MPA Network to achieve the goals of the MLPA. These components are led by the FGC, CDFW, and OPC, respectively (CDFW 2016). As such, this entire report is designed to inform the policy and permitting arm of the MPA Management Program.

ENFORCEMENT AND COMPLIANCE

Globally, achieving high levels of compliance with MPA regulations has proven to be a challenge. Lack of compliance can be classified as either *intentional* or *unintentional*. Intentional non-compliance, or poaching, is likely to be subject to penalties and possibly incentives, but may not be easily remedied with education and outreach. Community outreach programs, however, can effectively build trust and raise awareness and motivation. For example, in terrestrial protected areas when communities were given opportunities for action and control, social pressure against poaching increased (Steinmetz et al. 2014). A study from British Columbia, Canada showed that poaching, while damaging, makes up a small fraction of non-compliant behavior in MPAs (Lancaster et al. 2015). The majority of non-compliant behavior in this study was reported (by the users) as unintentional and stemming from a lack of knowledge of MPA boundaries, regulations, etc. This type of non-compliance is likely to be most amenable to correction through outreach, education, and stakeholder engagement in management processes.

Although there are clear distinctions between intentional and unintentional non-compliance, practically speaking, it can be very difficult to disentangle the two. Here we present a short list of questions that could help CDFW identify patterns of compliance, distinguish poaching from unintentional non-compliance, and identify potential management actions to increase compliance. This list of questions represents a mix of new questions proposed by the Working Group (question numbers with the "N" prefix) and questions that were already included in Appendix B.

- *N10. What is the level of compliance with MPA regulations by stakeholder groups?*
- *29a. How has compliance changed over time since MPA implementation?*
- *29b. What factors (e.g., penalties, wildlife enforcement, warden presence) influence differences in compliance within and among MPAs?*

OUTREACH, EDUCATION, AND STAKEHOLDER ENGAGEMENT

Outreach and education efforts can influence unintentional non-compliance as well as provide a means to communicate with stakeholders about MPAs and engage them in MPA management. These efforts can take a variety of forms, from signage to direct contact with the general public, to working with citizen science groups. CDFW conducts public outreach and education primarily through printed and digital information about MPAs, and through enforcement contacts or other CDFW representatives informing fishers of regulations and restrictions at boat ramps, docks, beaches, and other access points. Partner organizations coordinate and collaborate with CDFW to develop regulatory signage and interpretive panels at popular access points to inform visitors about MPAs. Many tourist destinations, such as parks, aquaria, and museums also provide information about local MPAs through signage and docents, so educating these docents about MPAs is valuable. Businesses that depend on consumptive and non-consumptive tourism (tackle shops, wildlife tour operators) may also share information about MPAs with their clients. Some citizen science and collaborative monitoring programs such as the CCFRP, Long-term Monitoring Program and Experiential Training for Students (LiMPETS), and ReefCheck California may also provide a valuable avenue for sharing information about MPAs and may engage stakeholders in MPA science and management in a meaningful long-term way. Given these various avenues of outreach and education and the expense associated with them, determining how these efforts influence compliance, as well as foster interest in stewardship and increase knowledge about California's ocean ecosystems could be valuable to CDFW going forward.

- *N11. How do outreach and education activities influence compliance with MPA regulations by stakeholders?*
- *N12. How do outreach and education activities influence knowledge, attitudes, and perceptions of MPAs by stakeholders?*

RESEARCH AND MONITORING

Research and monitoring are key ways that information about MPA performance is collected, assessed, and ultimately fed back into adaptive management actions. Consequently, it is critical that the MPA monitoring program is adequate to answer the questions necessary for adaptive management. Appendix B contains two questions that address the performance of the monitoring program and the MPA Monitoring Action Plan that directs that monitoring program (CDFW and CA OPC 2018).

- *25. [Refined] Are efforts to collect long-term monitoring data coordinated sufficiently to help evaluate MPA Network performance?*
- *26. [Refined] Does the MPA Monitoring Action Plan produce sufficient information to evaluate Network performance and inform adaptive management?*

Ultimately adaptive management will entail making decisions about whether or not individual MPAs and the Network as a whole are meeting their goals and identifying appropriate actions to improve goal achievement if necessary. This decision-making will likely occur based on the outcome of current and future evaluations, and thus is strongly dependent on the quality of the evaluation information available, including monitoring data and evaluation questions. Making assessments about goal achievement also requires understanding what constitutes meaningful change to different aspects of the MPA Network social-ecological system and evaluating tradeoffs and the distribution of costs and benefits among stakeholders (equity). To inform whether the MPA Network is meeting its goals requires evaluation of the goals and associated questions in relation to targets or trajectories of change across multiple elements within and across domains. This can be done in a variety of ways, including setting reference points based on ecological or social baselines, effect sizes, or thresholds (Samhouri et al. 2012), or asking people their tolerance, acceptance, or desire for conditions that may arise from the MPAs and MPA Network (Samhouri et al. 2011). To support this, research programs can help identify targets and reference points and evaluate the simultaneous responses of multiple aspects of the social-ecological system to MPA Network management actions, as suggested in the integration section below. Additionally, identifying influencing factors and their impacts is key to understanding why the MPA Network may or may not be meeting its goals or achieving its targets. Making adaptive management decisions in a robust framework that is informed by the ecological, human, and governance domain dimensions of MPAs will be key to the long-term success of the Network.

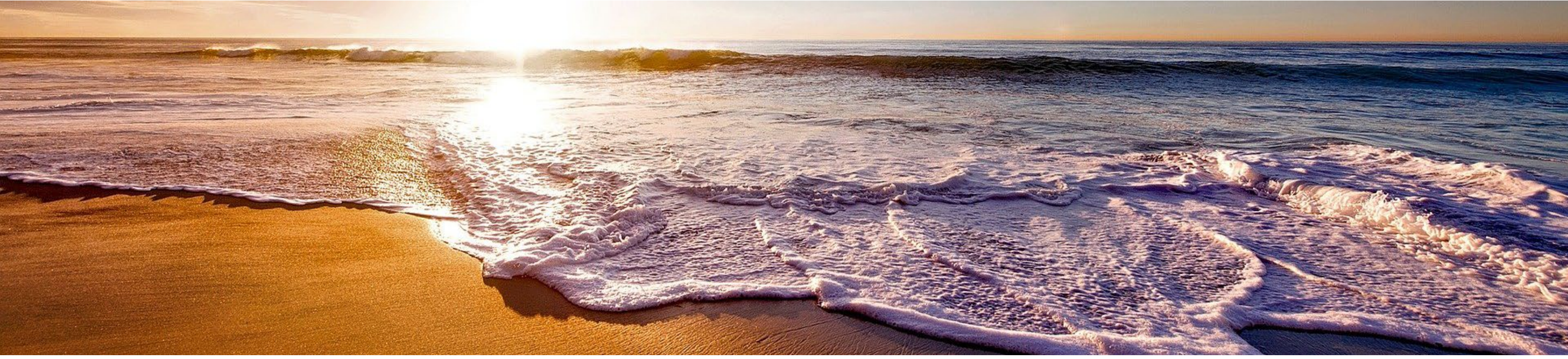

Photo: Brian Hawkins

Recommendations and Approaches:

14. Work to establish a framework for adaptive management decision-making that incorporates information from the ecological, human, and governance domains

14a. Identify targets, trajectories, or reference points that indicate achievement (or not) of MPA goals across domains

14b. Develop a framework based in decision-science that facilitates evaluation of tradeoffs among domains and distribution of wellbeing outcomes (i.e., costs and benefits) among stakeholders.



NETWORK PERFORMANCE

MPA establishment across the globe has increased considerably since the MLPA became law and there are now MPAs in most of the world's coastal oceans. Most of these MPAs have either been designed to achieve individual protection goals or to attain their goals and to be managed as a collection of individual MPAs; few MPA systems were planned to function as actual networks. Although MPA networks have been defined as consisting of an organized group of individual MPAs that operate in a cooperative and synergistic manner (Laffoley et al. 2008, Meehan et al. 2020), there are two primary ecological expectations for MPA networks: 1) they generate conservation and fishery benefits that exceed the sum of those provided by their constituent MPAs (Grorud-Colvert et al. 2014), and 2) these additional benefits accrue from the mutual replenishment of populations located in MPAs in the Network and to populations interspersed between them (Botsford et al. 2014, Green et al. 2014, Carr et al. 2017). Thus, individual MPAs are ecologically connected via the dispersal of reproductive propagules and in some cases the movements of juveniles or adults (e.g., Jones et al. 2007, Laffoley et al. 2008, Carr et al. 2017).

The design of the California MPA Network was based on scientific considerations known to affect MPA network performance (Gaines et al. 2010, Botsford et al. 2014) such as MPA size, spacing, and habitat representation with the goals of enhancing spatial protection of benthic and mobile populations, increasing the likelihood of ecological connectivity between MPA sites, and capturing the full diversity of resident species (Saarman et al. 2013). California's MPA Network stands as one of the largest scientifically designed MPA networks in the world and has received global recognition for its implementation process and its ongoing role in advancing our understanding of how MPAs can achieve desired conservation and fishery outcomes. As it exists, the California coastal MPA Network has been described as a 'connectivity network' (Grorud-Colvert et al. 2014), with goals of maximizing conservation benefits while minimizing areas excluded from fishing and other forms of take, including scientific research (Saarman et al. 2018). Evaluation of the performance of the California MPA Network must begin with determinations of whether the expectations derived from ecological connectivity are being met, i.e., greater benefits are being achieved compared with those generated by individual MPAs alone and population replenishment in and outside MPAs is occurring from the spread of reproductive propagules and juveniles produced by protected sources within MPA boundaries. The six MLPA goals (Table 1) focus on ecological expectations for the California MPA Network; however, as depicted in the SES framework (Figure 1) it is also important to consider MPA outcomes from the perspective of the human and governance domains and to develop integrated assessment tools that address social-ecological and management effectiveness (Picone et al. 2020). How are human activities, perceptions, and behavior being influenced by the large collection of MPAs that now provide protection for 16% of California's coastal waters? How is state management working to ensure that the MLPA goals are being met and the expected ecological benefits are being realized? And, are effects on the human and governance domains different in an ecologically-connected MPA network from those that would be realized by a collection of individual MPAs?

ECOLOGICAL DOMAIN

The ecological benefits of an MPA network depend on the development inside individual MPAs of more abundant species populations consisting of larger, older, and more fecund individuals, which export reproductive propagules (animal larvae and algal spores) that replenish populations in and outside MPA boundaries. These expectations for species populations scale-up to community level attributes, resulting for example in greater diversity of species, diversity of functional groups, and functional group redundancy, characteristics known to enhance community resistance and resilience. However, these population and community level outcomes of protection take time to develop, and for full network functionality need to occur in multiple MPAs distributed across the spatial scales required to achieve population-level connectivity. For example, for demographic responses to be realized across a network, populations first need to increase in number, age and size to increase larval production, then successful dispersal of young among MPAs is dependent on ephemeral environmental conditions conducive for larval survival and delivery to recipient populations. Therefore, the ability to quantify the ecological contributions of MPAs to the Network and to measure MPA network properties will slowly accrue over years as protected populations move towards expected demographic outcomes.

Unlike evaluation of the effects of individual MPAs for which there are numerous studies (e.g., Halpern 2003, Russ et al. 2004, Lester et al. 2009, Pelc et al. 2010, Kaiser et al. 2011, Baskett and Barnett 2015), assessments of the connectivity and connectivity-derived benefits of MPA networks, including resistance and resilience to major disturbance events (e.g., Wagner et al. 2007, Blowes and Connolly 2012, White et al. 2020), are more challenging. Evaluations of the degree to which an MPA network's ecological benefits are attained will largely be dependent on: 1) increases in the reproductive output of protected populations resulting from increases in species abundances, size, age, and fecundity; 2) persistence of these protected populations inside individual MPA boundaries; 3) the realized connectivity of populations between MPA sites and in unprotected areas through propagule (e.g., eggs, spores, larvae) dispersal; 4) the availability of suitable habitat in Network MPAs and unprotected areas receiving exported propagule inputs; and 5) the frequency, intensity, and extent of the disturbance regime. Therefore, evaluation of the degree to which California's MPAs are functioning as a network, must include assessments of these factors. The first two factors are being addressed by multiple on-going monitoring studies designed to identify ecological changes in MPAs and non-MPA reference sites, and relevant questions are included in the section titled "Population responses". These studies will provide information on the abundance, size, age, and fecundity of species in and outside MPAs and gain insight into their persistence. Assessments of recent habitat data will increase knowledge of how suitable habitat is distributed throughout the Network (Young and Carr 2015), and gathering information on the disturbance regime, connectivity, and MPA spacing will allow assessments of the buffering capacity of the Network against catastrophic events (Wagner et al. 2007, White et al. 2020) thereby examining the fourth and fifth factors. Determining the third factor, realized connectivity between MPA and non-MPA sites in the Network, is a critical prerequisite to evaluating ecological functioning of the Network and is poorly understood. Therefore, the ability to evaluate performance of California's MPA Network hinges upon improved understanding of the degree of connectivity between MPA and non-MPA sites throughout the Network based on a combination of empirical and modelled data on population and community characteristics.

Ecological responses to the MPA Network can be classified as either population or ecosystem responses. Population responses include demographic changes resulting from patterns of connectivity across the Network, whereas ecosystem responses refer to how ecological communities respond to connectivity across the Network. Community responses include the composition and relative abundance of species that occur as a consequence of differences in the relative rates of connectivity among species. For example, MPAs with higher connectivity (i.e., influx of propagules) of a greater number of species from other MPAs may support more diverse communities and recover faster after a catastrophic event. The combination of long-term ecological monitoring and the connectivity model in which the state has already invested will provide insights into both population and ecosystem responses to the MPA Network.

POPULATION RESPONSES TO THE NETWORK

The operational premise of California's MPA Network is that individual MPAs separated geographically have been sited to be connected by the movements of propagules exported from one MPA site to another. This export not only is predicted to provide an influx of recruits throughout MPAs making up the California Network but also to seed unprotected areas open to fishing. In fact, as pointed out by Goñi et al. (2010), most MPA Network benefits to fisheries are expected to come from the export of propagules, although benefits also can be realized from the dispersal of juveniles and adults that move from individual MPAs to surrounding areas where they become available to fisheries.

There are several questions in Action Plan Appendix B that address the network performance with respect to populations through movement of propagules (e.g., larvae), juveniles, and adults. For example, two questions that emerged from the original Question 1, 1d and 1e, ask about how population responses in MPAs translate to the ecological functions of larval export and biodiversity respectively.

- *1d. [Extension] Does the difference between MPAs and reference areas in larval production of a focal and/or protected species increase over time?*
- *1e. [Extension] Does the difference between MPAs and reference areas in genetic diversity of a focal and/or protected species increase over time?*

In addition, question 24 probes the resistance of communities within MPAs to the spread of invasive species.

24. [Original] Do MPAs limit the spread of invasive species?
- *24. [Refined] Is the rate of invasion (i.e., increase in population size) of invasive species lower in MPAs compared to reference areas?*

Question 10 asks about spillover of adults into fisheries, while Questions 34, 36, and 39 address larval connectivity and its consequences. These questions do not clarify the approach to evaluate network performance, although CDFW and OPC have funded connectivity modeling work to answer most network-related questions. Here we present two examples of questions from Appendix B that address population responses to the Network with rephrasing to more clearly articulate hypotheses and emergent questions.

10. [Original] What is the rate and distribution of adult spillover of targeted fishery species from MPAs into adjacent areas?
- *10a. Is adult abundance of targeted fishery species higher in areas adjacent to MPAs than areas farther from MPAs? (distribution of adult spillover)*
- *10b. How has adult abundance of targeted fishery species changed over time in relationship to distance from MPAs? (rate of adult spillover)*
- *10c. [Extension]: How does adult spillover vary with species density inside MPAs?*

By rephrasing question 10 we make clear the hypothesis that adults of targeted species will be more abundant closer to MPA boundaries if there is adult spillover. We also separate the questions about the distribution and rate of adult spillover. Finally, with question 10c, we get at *why* spillover may vary across species or MPAs by asking how spillover varies with species density inside MPAs.

These questions can be evaluated by spatially designed surveys or from fisheries catch data (e.g., Russ et al. 2004).

34. *[Original] What are the demographic effects of siting MPAs in larval source or sink locations, and how do demographic responses to MPAs contribute to larval production and connectivity?*
    - *34a. What are the metapopulation dynamic consequences of siting MPAs in locations associated with high larval export vs. high larval import?*
    - *34b. How does MPA siting affect the value or contribution (in terms of metapopulation growth rate or resilience) of that MPA to the MPA Network?*
    - *34c. How do demographic responses of populations within MPAs contribute to larval production?*
    - *34d. How do demographic responses of populations within MPAs contribute to larval connectivity?*

Question 34 focuses on the demographic consequences of connectivity and presents as a complex multi-part question. First, rather than using the terms "source" or "sink" locations, which can be misleading, we use the terms "high larval export" vs. "high larval import" and note that these are not mutually exclusive. Second, we clarify that there are two types of demographic effects of MPAs that are of interest in this question: first metapopulation dynamics across the Network may be influenced by MPA siting (Questions 34a-b) and second, demographic responses within individual MPAs may contribute to larval production and connectivity (Questions 34c-d).
Potential approaches for answering these network-level questions about California's MPA Network can be categorized into: a) theoretical studies that rely on models and simulations and b) empirical studies that quantify directly (larval production and transport numbers and realized or actual patterns of recruitment into resident populations) or indirectly through inference (gene flow and genetic differentiation or microchemical signatures). Ultimately, greatest progress towards answering these network-level ecological-connectivity questions will depend on iteratively integrating data collected from empirical studies with model outputs (Burgess et al. 2014). One such model continues to be developed with support of CDFW and OPC (Carr et al. 2020).

THEORETICAL MODELLING STUDIES

Because of the expectation of greater abundances, sizes, and fecundity of targeted species, MPAs should serve as significant exporters of propagules (Baskett and Barnett 2015, Marshall et al. 2019) but propagule dispersal from one MPA to another can be very difficult to directly detect (Goñi et al. 2010, Watson et al. 2010, Christie et al. 2010, Johnson et al. 2018, Baetscher et al. 2019). Consequently, theoretical modelling approaches have become tools of choice for evaluating population connectivity among MPAs (Watson et al. 2010). With knowledge of the status of populations inside MPAs, estimates can be made of the quantity of reproductive output produced, a parameter necessary to quantitatively model export. Such models commonly treat propagules as Lagrangian particles carried passively by ocean currents, for example by incorporating Regional Ocean Modeling System (ROMS) data and species-specific knowledge of pelagic duration of young life history stages. Such models can be empirically parameterized to account for spatial and temporal differences in ocean circulation patterns and the reproductive periodicities and spawning characteristics of modeled species. When combined with habitat data and MPA spacing, empirically informed connectivity models can provide estimates of the supply of propagules that can recruit to suitable habitat inside MPAs (where they serve to replenish protected populations) and outside MPAs (where they can contribute to fished populations). These models also can enable assessments of the degree to which the Network might provide buffering capacity against catastrophic disturbance events (Wagner et al. 2007, White et al. 2020).

Theoretical models, however, have their limitations. Larvae of many fishes and invertebrates, even those with lengthy pelagic durations, don't behave as passively carried particles and can be retained locally prior to settlement (Warner et al. 2000, Baetscher et al. 2019). In addition, adjustments must be made for largely unknown but spatially and temporally variable rates of larval mortality and advection from appropriate settlement habitat during their transport. Integrating empirical data that enable model parameterization to address larval behavior and spatial and temporal dynamics of larval mortality and advection will ultimately improve the ability to ecologically evaluate actual MPA network performance.

Modelling studies will continue to provide the best evidence of the degree to which MPAs are connected via propagule transport and the degree to which this connectivity can potentially replenish populations in MPAs constituting the Network given their size, location, and spacing. Moreover, modelling studies will be informed by improved information on population persistence and reproductive output and finer scale understanding of spatial and temporal variations in ocean circulation systems from on-going ecological and oceanographic monitoring work. Therefore, modelling studies present the best available means now and in the near future for evaluating: 1) whether the California MPA Network is likely producing benefits that exceed those representing the sum of its individual MPA parts, and 2) the degree to which MPA sites are potentially connected through propagule dispersal.

Clearly, modelling studies are and will be for some time critical tools for evaluating connectivity between MPAs. As knowledge becomes available, adjustments can be made in model parameters to improve resolution and predictability by including finer scale information on ocean circulation, and accommodating larval mortality, larval behavior, the demographics of juveniles and adults (including spatial patterns of fishing mortality), and the localized physical oceanographic processes that affect advection and retention. Because modelling studies shed light on connectivity among MPAs, they can also be used to evaluate the location and spacing of MPAs in the Network and the degree to which the MPA Network likely provides protection against catastrophic disturbances. Lastly, the results of modelling studies can provide insight into the degree to which propagule export (and adult spillover) from MPAs contribute to populations outside MPA boundaries and enhance opportunities for fishermen to extract targeted species.

EMPIRICAL STUDIES

An important next step will be to expand from a theoretical understanding of site connectivity within California's MPA Network towards one that incorporates more data from empirical studies and then to use these data to improve model performance. Studies of the quantity of recruits received by individual MPA sites in the Network can be performed and matched to model predictions. Such studies can be difficult to perform for many taxa and although important for model validation also leave open the question of the source of recruits. Genetic studies have been widely used to assess population connectivity in terrestrial and marine systems and can advance understanding of connectivity patterns beyond the modelling stage (Marti-Puig et al. 2013, Jenkins and Stevens 2018), but have only rarely been used to evaluate connectivity within MPA networks. Genetic studies can indirectly determine between-population connectivity by quantifying gene flow and genetic differentiation and be used to shed light on the origins of individuals recruiting into a population (Truelove et al. 2015, Jenkins and Stevens 2018).

Recent developments in detecting genetic relatedness of parental source populations and recruits can more directly estimate patterns of connectivity and retention across MPAs (e.g., Planes et al. 2009, Christie et al. 2010, Pujolar et al. 2013, Johnson et al. 2018, Baetscher et al. 2019). Coupled with ocean circulation models, these empirical studies can help explain patterns of connectivity, provide a broader framework for evaluating MPA connectivity, and a means for validating model predictions. Although much less applied compared with genetic-based investigations, microchemical studies, for example of fish otoliths and invertebrate statoliths, also can be used to assess origins and destinations of organisms based on trace element profiles (e.g., Zacherl 2005). However, a downside to these approaches is the expense of collecting, preparing, and processing samples and measuring genetic features and microchemical profiles.

Studies of recruitment of individuals into populations residing within MPA boundaries will contribute information needed to validate model predictions. Genetic studies probably hold the most promise because genetic studies can also provide information on the sources of newly recruited individuals. However, the costs of performing recruitment and genetic studies probably limit their ability to be widely employed today as monitoring tools. Therefore, recruitment and genetic studies should be selectively used to validate model predictions with prioritization for key species—particularly 'umbrella' (Jenkins and Stevens 2018), keystone, and foundation species known to be of greatest importance to the integrity of marine ecosystems—and species of commercial and recreational importance.

COMMUNITY AND ECOSYSTEM RESPONSES TO THE NETWORK

Three questions in Appendix B apply to how the MPA Network might benefit ecological communities within the ecosystems across the Network. The answers to these questions will require the integration of the ecosystem monitoring studies with the population and community connectivity model being developed for network evaluation. The network connectivity model will provide estimates of the levels of connectivity across the Network for focal species. Monitoring data will provide descriptions of community structures based on species composition and abundances, the persistence of these communities over time, and the magnitude, trajectories, and rates of recovery experienced by these communities following perturbations. These findings can then be compared with model estimates of connectivity to relate the connectivity of focal species to resistance and resilience of ecological communities across monitored ecosystems.

Two aspects of ecosystem-level responses include: 1) the structure of the community (species and relative abundances) within a recipient MPA resulting from the level of connectivity of multiple species from other areas, including other MPAs, and 2) the persistence of that community structure over time. Community structure within an MPA should reflect the relative rates of propagule influx of species from other MPAs and unprotected populations. Moreover, the structure of communities in MPAs characterized by higher rates of propagule influx should be more persistent and less variable compared with less connected MPA communities. Thus, Question 35 can be rephrased more explicitly as:

35. *[Original] How does the distance and larval contribution between a source MPA and sink MPA influence the ecosystem response inside the sink MPA?"*
    - *35a. How does the larval contribution between an origin and destination MPA influence the structure of ecological communities inside the destination MPA?*
    - *35b. How does the larval contribution between an origin and destination MPA influence the dynamics, including persistence, of ecological communities inside the destination MPA?*

Reproduction in many species, including commercially and recreationally important invertebrates (e.g., Levitan et al. 1992, Hobday et al. 2000) and fishes (e.g., Keith and Hutchings 2012, Saha et al. 2013) are strongly subjected to Allee effects—reduced breeding success at low population densities—and are particularly vulnerable to catastrophic events that reduce populations to numbers insufficient for successful breeding. MPAs can engender greater resistance in ecological communities by protecting larger, older individuals, which are less susceptible to disturbance events (Micheli et al. 2012). Because reproductive output scales hyperallometrically for many fish species (Marshall et al. 2019), MPAs can increase the rate and likely recovery (resilience) of disturbance impacted communities by exporting large numbers of propagules from undisturbed MPA sites that can replenish populations in disturbed areas. Recovery can be accelerated if the impacted MPA is positioned to receive propagules from adjacent protected but unimpacted habitat and this benefit can be extended to areas outside MPA boundaries (e.g., Micheli et al. 2012, Aalto et al. 2019). Hence, the degree of connectivity among individual MPAs will also influence resistance to and the rate of recovery after that community experiences a perturbation (e.g., climatic event or oil spill). How the combined levels of propagule influx of constituent species influence the resistance (i.e., the ability to resist change in community parameters) and the resilience (i.e., rate and likelihood of recovery after a perturbation) of a community within an MPA is captured in Questions 5 and 37. However, community resistance and resilience also may be driven by the degree of self-replenishment of species constituting that community, which raises an additional question. Modifications to Questions 5 and 37 have been made to now include consideration of both the nature and timing of recovery (resilience) as well as resistance.

5. *[Original] Does the nature or timing of recovery of natural communities from disturbance events differ in different types of MPAs relative to outside areas?*
    - *5a. Does the nature of recovery of natural communities from disturbance events differ in MPAs relative to outside reference sites?*
    - *5b. Does the timing of recovery of natural communities from disturbance events differ in MPAs relative to outside reference sites?*
    - *5c. Does the nature of recovery of natural communities from disturbance events differ in MPAs with different levels of protection?*
    - *5d. Does the timing of recovery of natural communities from disturbance events differ in MPAs with different levels of protection?*
    - *5e. [Extension] Do MPAs contribute to the recovery of impacted ecosystems?*

37. *[Original] Are MPAs with higher connectivity more resilient to sudden environmental disturbance as compared to more isolated MPAs with higher self-retention?*
    - *37a. Do high-connectivity populations and communities within MPAs have greater resilience to spatially discrete short-term disturbances than low-connectivity populations?*
    - *37b. Do populations and communities with greater self-recruitment in MPAs exhibit greater resilience to spatially discrete short-term disturbances than populations with less self-recruitment?*

Besides enhancing recovery from disturbance events, MPA networks also can mitigate the impacts of climate change (McLeod et al. 2009, 2012, Carr et al. 2017). Although much is known about designing MPAs to convey conservation and fishery benefits, much less attention has been given to addressing the threats and impacts of climate change (McLeod et al. 2009). And, as pointed out by Green et al. (2014) there are often conflicting outcomes in MPA network design concerning conservation goals, fisheries benefits, and climate change adaptation. To achieve an integrated network design that works to advance these three outcomes, Green et al. (2014) proposed that the following categories should be addressed: 1) habitat representation; 2) risk spreading; 3) protection of critical, special and unique areas; 4) incorporation of connectivity; 5) allowance of time for recovery; 6) adapting to changes in climate and ocean chemistry; and, 7) minimizing and avoiding local threats. It is also well known that a crucial response of species to a changing climate is to shift their geographic or depth distribution, thereby tracking environmental conditions.

In addition, by protecting the integrity of ecosystems with the spacing required for successful larval connectivity, including estuaries and other coastal nursery habitats, networks of MPAs distributed along latitudinal gradients can facilitate the redistribution of species in the face of climate change (Carr and Hazen 2019). With the exception of climate change, the design categories proposed by Green et al. (2014) were considered during the implementation of the California MPA Network. However, it is now recognized that changing ocean climate and chemistry represent an increasingly serious threat to California's coastal marine ecosystems and that adaptation to climate change should be built into MPA network designs.

An example of how the California MPA Network might address climate change is through the incorporation of ecological refugia with properties more resistant or resilient to ocean climate change. Such refugia might include areas (Green et al. 2014): 1) containing populations with a past history of withstanding environmental change; 2) with populations subject to historically variable ocean conditions; and, 3) where there is the availability of habitat for local range expansion driven by sea level rise. However, the scientific guidelines for the design of the California MPA Network did not directly take into account these or other such considerations.

Lastly, in response to threats posed by localized catastrophic disturbances, Allison et al. (2003) pointed out the need for additional reserve area to be built into MPA network design as an insurance factor, underscoring the principle that resilience (the likelihood and rate of recovery) will be a function of the distance of impacted sites from sources of propagules. The design of the California MPA Network included the replication of protected habitat among MPAs within a biogeographic region and the spacing of MPAs to likely achieve connectivity with the belief that these features will buffer MPAs from major disturbances. However, the scientific guidelines for implementing the California MPA Network did not include a multiplier for reserve area to serve as insurance against severe disturbance events as suggested by Allison et al. (2003).

Recommendations and Approaches:

15. Use and improve network models to understand the role of connectivity in MPA and Network performance

15a. Continue to use modelling studies to evaluate the location and spacing of MPAs in the Network and the degree to which propagule export from MPAs can potentially connect MPAs and seed populations outside MPA boundaries. Incorporate the best available data into MPA evaluations.

15b. Use the best available data to evaluate how connectivity influences the structure, persistence, and resilience of communities within MPAs across the Network. Examine whether monitoring studies are designed to generate information that informs network models and network models leverage information generated by monitoring studies.

15c. Use network models to evaluate whether sufficient protected area exists within the California MPA Network to protect against severe disturbance events and provide the resilience needed to facilitate climate change adaptation and deliver projected MPA-related conservation and fishery benefits into the future.

15d. Support empirical studies designed to validate connectivity model predictions concentrating on 'umbrella', keystone, and foundation species and species of commercial and recreational importance.

15e. Continue to refine models by incorporating improved (e.g., higher resolution) ocean circulation information and including parameters such as larval mortality and behavior, juvenile and adult demography, and spatial patterns of fishing mortality

16. Improve understanding of the ecological functions associated with the MPA Network

16a. Continue to support monitoring studies to explore the diversity of ways that individual MPAs and the Network can protect and enhance the functioning of populations, communities and ecosystems.

HUMAN AND GOVERNANCE DOMAINS

Although the literature on the ecological expectations and outcomes for MPAs is expansive, less attention has been given to understanding the human dimensions and best governance practices. Yet, research suggests that organizational and social not biological or physical factors are important determinants of MPA success (Kelleher and Recchia 1998, McClanahan 1999, Mascia 2003, Bennett et al. 2017, Krueck et al. 2019, Di Franco et al. 2020). And, in addition to limited understanding of the human dimensions of MPAs, governance shortcomings (insufficient participation, communication, and transparency) and capacity shortages (inadequate staff and budgets, enforcement, and ineffective management procevsses) also can impede MPAs from achieving their goals (Di Franco et al. 2016, 2020, Gill et al. 2017). Therefore, understanding of the human and governance dimensions of MPAs is limited, not only for individual MPAs but clearly for designed MPA networks. In contrast, ecologists have for some time been examining how networks might generate benefits beyond those expected of collections of individual MPAs (e.g., Murray et al. 1999). The synergistic human and governance effects that occur following implementation of a functional, ecological MPA network remain fertile grounds for study.

Effects of California's MPA Network on aspects of the human domain likely depend greatly on the ecological response resulting from the collection of MPAs functioning as a network. If the Network multiplies the ecological benefits of single MPAs (and these benefits are broadly and clearly communicated), stakeholders may experience mitigation of the perceived and actual costs attributable to individual MPAs. However, if there are no perceived ecological benefits of the Network, stakeholders may weigh the costs and respond negatively, and their responses might vary from area to area. Research has shown that local perspectives are highly important for understanding the social impacts of MPAs (Gollan and Barclay 2020) and engaging local people is crucial for obtaining support for MPAs and other conservation initiatives (Di Franco et al. 2020). Hence, given the oceanographic and ecological differences across California's bioregions, the attitudes, perceptions, and activities of local stakeholders towards MPAs are expected to vary regionally and need to be understood regionally.

The fact that the MPAs are part of a larger interconnected network also could change perceptions of their importance, permanence, and costs and benefits. In the context of the Network, the value of an individual MPA to a stakeholder may not be simply the ability of that MPA to generate spillover of adult fish or non-consumptive diving opportunities. The perceived value of the MPA may also be related to its network contribution, role in providing refugia from take-related impacts, and larval supply to MPA and non-MPA areas. In addition, the degree to which California's MPA Network confers resistance and resilience to disturbance events and climate change may be valued by stakeholders engaged in consumptive and non-consumptive uses of coastal and ocean resources.

Perhaps a unique feature engendered by the California MPA Network is the development of a statewide human network of stakeholders, communities of interest, and communities of place that was created following MLPA implementation. One example of this human network is the MPA Collaborative Network which includes 14 collaboratives that span the entire California coastline. The vision of these collaboratives is to "encourage civic engagement in local resource management to ensure the health and sustainability of our natural and social environments" ("MPA Collaborative Network: Empowering Coastal Communities" 2018). Each of these collaboratives has a member composition that reflects the regional differences across the state, and they are all working on projects to increase knowledge, engagement, and compliance with respect to MPAs. If lessons learned from one collaborative are shared with other collaboratives in the state, this human knowledge network may prove to be resources with value beyond the sum of its parts.


Photo: Surfrider Foundation

Recommendations and Approaches:

17. Advance understanding of human dimensions and governance aspects of MPAs to determine if social and governance benefits are greater than the sum of benefits attained from individual MPAs.

17a. Support studies to identify synergistic human and governance effects that accrue from an ecological functional network and differentiate these from effects resulting from a collection of individual MPAs.

THE IMPORTANCE OF INTEGRATIVE THINKING

As illustrated by the SES framework (Figure 1), integrative thinking is key to understanding the many ways in which humans and ecological communities will respond to MPAs, how to evaluate change in these dimensions, and how management can respond to changes effectively. Throughout the discussion of ecological, human, and governance domains, we have emphasized the importance of interconnections among domains, influencing factors, and integration of results across species, ecosystems, and human communities to develop a more holistic understanding of MPA performance. Within-domain integration, for example, asking the same question across multiple species, ecosystems or stakeholders has already been discussed in the domain-specific sections above, so discussion in this section is brief and focuses on far more challenging, and potentially more rewarding, cross-domain integration where answers to questions depend on information from multiple domains. Evaluation of the costs and benefits of the MPA Network will necessarily need to consider multiple ecological and human dimensions in a decision framework that can look at tradeoffs among valued components, including considerations of what is meaningful change to different stakeholders.

WITHIN-DOMAIN INTEGRATION

ECOLOGICAL DOMAIN

While analyzing monitoring data from individual MPAs and reference sites enables focused evaluation of the performance of an MPA of particular interest, the benefit of a monitoring program spanning the Network—across regions and ecosystems—is the ability to draw conclusions of broader inference. For example, integration across multiple MPAs of similar (i.e., replicates) or different design criteria (e.g., size, spacing, levels of protection) or environmental conditions (e.g., across geographic regions) provides managers with greater insight as to how these factors influence the ecological consequences of MPAs, leads to more robust conclusions about MPA performance, and can advance overall understanding of how MPAs achieve conservation goals. Integrating these and other influencing factors with performance assessments of multiple MPAs will provide much greater insight regarding their interaction with MPA performance.

Another aspect of integration in the ecological domain is the insight gained by integrating evaluation questions and answers across ecosystems. Ecologists strive to develop higher level understanding of patterns and processes in the structure and functioning of populations and communities, i.e., to identify generalities that extend beyond those revealed by a single ecosystem or area. Answers to almost all the evaluation questions that pertain to the ecological consequences of MPAs are more robust when evaluated across multiple ecosystems (i.e., monitoring programs). A key question is whether the identified ecological consequences of MPAs in one ecosystem are mirrored in others. For example, are the life history traits of species that respond more quickly to MPAs in the rocky intertidal shared across other ecosystems (e.g., Questions 7a-c)? Do the functional groups that exhibit stronger responses to MPAs in kelp forests do so in other ecosystems (e.g., Questions 2a-b)? Are there structural and functional responses to MPAs that are shared across all of the ecosystems monitored? And, can these common MPA outcomes lead to more advanced models of MPA expectations for the Network as a whole?

Another important element of integration is that of empirical monitoring studies with network evaluation models. This integration should ensure that monitoring studies are designed to inform models created to assess network performance, and that these network models incorporate information generated by monitoring studies. This integration pertains to network performance evaluation questions (e.g., Questions 34a-d, 35a-b, 37a-b, and 39).

Another form of integration within the ecological domain is assessing focal species data across ecosystems and regions (e.g., Questions 1a-h and 32a-b). The monitoring studies offer an opportunity to assess the degree to which focal species depend on different ecosystems to sustain their populations. For example, some species might spend their adult life in deeper rocky or pelagic habitats but require shallow coastal kelp forests or protected estuarine waters as nursery grounds during earlier life history stages.

Most of the ecological evaluation questions can benefit from these forms of integration, which are addressed within the ecological domain section and shown in Appendix 1. In some cases, such within-domain integration is suggested through refinement or logical extension of the original questions from Appendix B.

The richness of the monitoring data provides an unparalleled opportunity to advance MPA science and explore common responses to MPA implementation. Additional analyses that require integration across the Network include seeing how level of protection, MPA size, number of habitats within an MPA, and other attributes impact MPA performance.

HUMAN DOMAIN

Paralleling the importance of integrative thinking in the ecological domain, such comparative scrutiny of the outcomes of the various MPAs with human use in mind could result in insights that help explain MPA performance. Once established, a human dimensions monitoring program spanning the Network - across regions and stakeholders - also enhances the ability to draw conclusions of broader inference. For example, integration of human dimensions data across multiple MPAs of similar (i.e., replicates) or different (e.g., size, spacing, levels of protection) design criteria or environmental conditions (e.g., across geographic regions) provides managers with greater insight into how these factors influence human behaviors, people's relationships and perceptions of nature and support for various natural resource policies. Such integration leads to greater insight into how and why MPAs achieve conservation goals.

Social scientists strive to develop higher level understanding of patterns and processes in the structure and functioning of human populations and communities, i.e., to identify generalities that extend beyond those revealed by a single human response or stakeholder group. Insights gained from integration across human domain responses and or stakeholders will highlight the commonalities that link to MPA performance and conservation outcomes. A key question is whether the identified human consequences of MPAs in one stakeholder group such as a community of interest (e.g., commercial fishing) or community of place (e.g., North Coast) are mirrored in others. For example, integrating monitoring data about human behaviors, knowledge, attitudes and perceptions of MPAs across multiple groups in the North Coast may reveal why compliance or citizen-science research is high in certain MPAs but not others. These commonalities would provide a broader lens to explore the linkages to ecological and conservation outcomes across the Network.

GOVERNANCE DOMAIN

Understanding the effect of complex governance structures and processes associated with MPAs clearly requires integrative thinking since MPA management issues vary widely across California's MPA Network. Integration of fisheries and MPA management is one important example of governance integration that is discussed above (and in Appendix 4), but there are many other ways in which management integration could contribute to more effective MPAs. At the level of the evaluation questions, integration across groups of stakeholders or MPAs is also important to understanding the effectiveness of specific management measures. For example, Question N10, which asks about compliance with MPA regulations, should be assessed for a variety of relevant stakeholder groups and results should be integrated to find commonalities among the groups. This type of integrative thinking may point to more or less effective management strategies for achieving compliance with the MPA regulations.

Recommendations and Approaches:

18. Support within-domain integration of evaluation questions

18a. Compare answers to evaluation questions across multiple ecosystems to evaluate the generalizability of results and the conclusions based on those results.

18b. Extend analyses across ecosystems for focal species dependent on more than one ecosystem to determine the integrated effects of MPA protection.

18c. Compare answers to many of the evaluation questions across multiple human responses and stakeholders, such as communities of interest or place, to evaluate the generalizability of results and the conclusions based on those results.

CROSS-DOMAIN INTEGRATION

The original goals of the MLPA emphasize biological conservation benefits to be realized by a network of MPAs. However, during implementation of the MLPA and in the following years, it became clear that human dimensions must be strongly integrated with efforts to protect ecological communities if MPAs are to be successful. Moreover, understanding the interactions between human interests and the ecology of marine communities is the key to effective governance. Ecological changes drive changes in human interactions with California's coastal biota and environments. In addition, changes in the intensity and diversity of human activities impact the structure and functioning of ecological communities. Governing bodies must address feedback between these two domains to manage MPAs effectively. Therefore, as illustrated by the SES framework (Figure 1), there is a need to think collectively and integratively about the ecological, human, and governance domains to develop full and holistic understanding of the expectations and performances of MPAs. The interconnections between these three domains are emphasized in this report and underscore the importance of integrative thinking in evaluating the performance of California's MPA Network and Management Program. Integrating across systems is not an easy task. Scale mismatches can complicate integration, and there are challenges in integrating different data types (e.g., qualitative vs quantitative data). However, integration presents an opportunity to develop approaches for explicitly linking domains that will ultimately improve management.

There are a number of evaluation questions posed in Appendix B that require integration across governance, human, and ecological domains. These questions are presented in Appendix 3 and many of them relate to fisheries but may approach the issue from either a human or ecological perspective. There are also questions that require integration across governance and ecological domains to assess the effectiveness of management strategies. Finally, there is a question (broken out into three parts) about ecosystem services that approaches the potential benefits of MPAs to humans more broadly.

INTEGRATIVE QUESTIONS ON FISHERIES

Questions 6, 9, and 36 are examples of questions that examine the relationship between ecological performance of MPAs and fisheries from an ecological perspective. As such, these questions pose similar integration challenges in that they require information on fishing effort or mortality at scales that are relevant to individual MPAs and to the ecological responses within those MPAs. For example, Question 6 asks "*How does spatial variability in fishing effort and fishing mortality rates prior to and after MPA implementation affect the abundance and/or size/age structure of harvested species in MPAs?*" We refined this question to clarify that comparisons would be made between MPAs and to separate pre- and post-MPA fishing effort as well as changes in abundance from changes in size/age structure. However, these clarifications do little to address the most serious challenge associated with answering this type of integrative question; most of the fishing data that exist are at spatial scales too coarse for linkages to individual MPAs.

6. *[Original] How does spatial variability in fishing effort and fishing mortality rates prior to and after MPA implementation affect the abundance and/or size/age structure of harvested species in MPAs?*
   - *6a. Are differences in the magnitude of change in abundance of focal species in response to MPA establishment related to differences between MPAs in the level of pre-MPA fishing mortality (or effort)?*
   - *6b. Are differences in the magnitude of change in size/age structure of focal species in response to MPA establishment related to differences between MPAs in the level of pre-MPA fishing mortality (or effort)?*
   - *6c. Are differences in the magnitude of change in abundance of focal species in response to MPA establishment related to differences between MPAs in the level of MPA-adjacent fishing mortality (or effort)?*
   - *6d. Are differences in the magnitude of change in size/age structure of focal species in response to MPA establishment related to differences between MPAs in the level of MPA-adjacent fishing mortality (or effort)?*

When fisheries-related questions are approached from the human perspective, the challenges with data availability and scale mismatches are no less daunting. For example, Question 8, which asks about the relationship between MPAs and changes to the distribution and magnitude of nearshore fishing, is complicated by the coarse block scale at which much of the fisheries data are collected, which cannot readily reveal effort or yield changes due to specific MPAs. Furthermore, as described in the human domain section above, fisheries are complex and the non-MPA factors that influence human decisions about where, when, and how much to fish must be considered to understand what aspects of the changes to fisheries are actually a result of MPAs. Although Question 8 could be addressed completely within the human domain, we have classified it as an integrative question because it could be informed by ecological data in the absence of well-resolved spatial data on fisheries. Modeling approaches show promise for estimating pre-MPA fishing effort if informed by sufficient ecological data (White et al. 2016, Nickols et al. 2019). Our attempts to clarify and disentangle Question 8 are illustrated below.

8. *[Original] What is the relationship between MPAs and the displacement, compaction, and concentration of nearshore fishing efforts? Did overall fishing effort/mortality rates and yield change since MPA implementation?*
   - *8a. Did the distribution of fishing effort change following MPA implementation?*
   - *8b. Did overall fishing effort/mortality rates and yield change following MPA implementation?*
   - *8c. [Extension] What are the fisheries related economic changes that accompany changes in the distribution of fishing effort/mortality following MPA implementation?*

Recommendations and Approaches:

19. Improve opportunities for integration of fishing and ecological data

19a. Invest in new programs (e.g., mobile digital data collection for fisheries, spatially-explicit online surveys) to collect high spatial resolution data on fishing effort appropriate for MPA evaluation.

INTEGRATIVE QUESTIONS ON GOVERNANCE AND MANAGEMENT

There are two evaluation questions from Appendix B (questions 11 and 38) that require integration across ecological and governance domains, which pose many of the same challenges as integration across ecological and human domains. Question 11 asks about the relative effectiveness of MPAs and traditional fisheries management at maintaining sustainable fisheries. To refine this question, we articulated two comparisons that could be made: the sustainability of fisheries before and after MPA implementation, and the sustainability of fisheries more and less likely to be influenced by MPAs.

11. *[Original] Is the Implementation of MPAs as a habitat-based approach to marine fisheries management more or less effective in maintaining sustainable fisheries than traditional management strategies such as limiting harvest in a non-spatially explicit manner?*
    - *11a. Is catch more sustainable for a targeted fishery species before or after MPA implementation?*
    - *11b. Is catch more sustainable for fishery species deemed likely to benefit from California's MPAs than for species that are less likely to be influenced by the MPAs?*

While these question refinements may be clarifying, efforts to answer them must still contend with the challenges posed by mismatches in the spatial scales of fisheries data and MPAs.

CASE STUDY: INTEGRATING DATA TO EVALUATE GOAL 3: IMPROVING RECREATIONAL OPPORTUNITIES

A robust understanding of California MPA Network performance requires consideration of data and analyses across the domains of the SES Framework. Goal 3 of the MLPA provides a useful example to explore this concept in a concrete way. For example, Goal 3 of the MLPA states "To improve recreational, educational and study opportunities provided by marine ecosystems that are subject to minimal human disturbance". For this case study, we will focus on the objective, to "improve recreational opportunities," with the implication that similar thinking could be applied to understanding changes to educational and study opportunities. The definition of "improvement" is necessarily dependent on the perspective of the stakeholder (Table 3). The factors that lead to that perception of improvement could lie in the ecological, human or governance domains. Furthermore, consideration of evidence across SES domains could also be used to evaluate the objective(s) of Goal 3 at a broader, more comprehensive level. For example, from pre- to post-MPA establishment do ecological data show improvements in the condition of habitats in MPAs and do diver perceptions of habitat conditions pre- to post- MPA establishment also support the same conclusions?

There are several evaluation questions (from Appendix B) that address some aspects of how recreational opportunities may be changing, within and near MPAs (Questions 15, 16, 17, and 19, Appendix 2), but the format of individual questions does not lend itself to a more holistic picture of what constitutes an improved recreational experience for each community of interest, what might influence that experience, and how a researcher would determine if the experience had improved due to MPAs.

To fully evaluate the performance of California MPAs in relation to Goal 3 requires not only a comprehensive investigation of the responses/performance measures but also consideration of the possible reasons for improvement (or lack thereof). These influencing factors may stem from all three domains and illustrate the links of the SES Framework showing the relationships among domains.

Table 3: Case study on evaluating improvement in recreational opportunities with some examples of communities of interest, their **potential definitions of improvement** indicating what would entail an improved recreational opportunity associated with the CA MPA Network, possible metrics to provide evidence of such an improvement; and influencing factors that may affect outcomes and interpretation of data related to metrics.

Goal 3: To improve recreational opportunities provided by marine ecosystems that are subject to minimal human disturbance			
Community of Interest	**Potential definitions of improvement**	**Indicators of improvement**	**Influencing factors**
Recreational Non-consumptive Divers	Improved habitat condition; More diverse marine species; Perception of improved habitat condition or more diverse species Increased access to MPAs for diving Reduced activity of other marine users perceived to affect experience	**Ecological:** □ Changes in habitat from ecological surveys □ More diverse species observations **Human:** □ Changes in perception of species diversity within MPAs □ Changes in perception of habitat condition in MPAs □ Increases in diving in MPAs □ Perceptions of stable or improved enjoyment of recreational activity	**Ecological:** □ Connectivity □ Trophic interactions □ Oceanographic conditions **Human:** □ Increased knowledge of MPAs □ Personal or cultural values **Governance:** □ Outreach & education efforts □ Improved monitoring □ Improved enforcement
Recreational Fisherman	Stable or improved catch; Better conditions for next generation	**Ecological:** □ More fish; bigger fish □ Recreationally targeted stocks stable/improving/rebuilt	**Ecological:** □ Historical fishing pressure □ Environmental conditions **Human:** □ Increased knowledge of MPAs □ Conservation value orientation

		Human: □ Increasing CPUE □ Perceptions of stable or improved enjoyment of recreational activity □ Changes in perception of ecosystem services & human benefits for future generations	**Governance:** □ Outreach and education efforts □ Improved enforcement □ Change in fishing regulations
Coastal Resident	Fewer tourism impacts; Protection or maintenance of local ocean viewscape	**Ecological:** □ Changes in habitat condition from ecol. surveys; □ Changes in density; age/size structure/biomass of fish species **Human:** □ Changes in tourist behavior (visitation) □ Perception of ocean viewscape	**Human:** □ Change in community demographics □ Change in perception or value or ecosystem services & human benefits □ Attitudes towards tourism **Governance:** □ Change in regulations that restrict access or development
Government Agency	Improved stock status for recreationally targeted species Increased recreational fishing license sales Increased revenue	**Ecological:** □ Stable or increase in abundance estimates for recreationally targeted species □ Stable or increase in abundance with fishery independent monitoring efforts **Human:** □ Increase recreational boats/users in MPAs or at access points	**Ecological:** □ Historical fishing pressure on recreational species □ Environmental conditions **Human:** □ Perceived benefits of MPAs □ Economic conditions in state/region **Governance:** □ Changes in recreational fishing regulations that influencer access & opportunity □ Improved monitoring □ Enforcement efforts □ Increased communication & outreach

<table>
<tr><td></td><td></td><td>Governance:
Change in number of licenses permitted;
Changes in revenue from license sales</td><td></td></tr>
<tr><td>Tourism Operator (e.g., Kayak Business)</td><td>Increased participation by tourists

Increased revenue</td><td>Human:
Increases in number of tourists renting kayaks/participating;
Increases in revenue to sector;
Reduced use by marine activities that influence access or enjoyment
Perceptions of stable or improved business conditions related to MPAs</td><td>Ecological:
Changes in species abundance and diversity;
Environmental conditions;
Historical and current human pressures;
Human:
Perceived benefits of MPAs
Economic conditions in state/region</td></tr>
<tr><td>Marine Supply Store</td><td>Increased revenue

Increased opportunities to diversify</td><td>Human:
Changes in demand for recreational fishing or other recreational supplies
Perceptions of stable or improved business conditions related to MPAs</td><td>Ecological:
Changes in species abundance or diversity
Human:
Perceived benefits of MPAs by recreational sector;
Conservation value orientation;
Economic conditions in state/region
Governance:
Changes in fishing or boating regulations</td></tr>
</table>

This example also demonstrates the need to consider multiple aspects of the human and ecological domains when evaluating a specific goal and associated questions. This approach should also be applied to multiple goals to evaluate tradeoffs among objectives and perspectives using multiple lines of evidence across domains to evaluate the MPA Network in a more holistic manner. Undoubtedly, MPA network evaluation will reveal tradeoffs among stakeholders in the delivery of costs and benefits, and across goals and objectives. Adaptive management will need to contend with these tradeoffs using deliberate, legitimate stakeholder processes and decision science tools.

INTEGRATION OF RESEARCH AND MONITORING

An area of integration that has not yet been discussed is the integration of monitoring efforts. The state continues to invest in ensuring communication and coordination across ecological monitoring programs, but this type of integration is less well developed across the human dimensions monitoring efforts, and integration across ecological, physical, and human monitoring programs poses an ongoing challenge. The MPA Watch program provides an example of where future integration across monitoring efforts could improve our ability to evaluate the MPA Network. MPA Watch is a coordinated network of citizen science programs that use volunteers to collect data on human activities in MPAs. This dataset represents a potentially valuable, but largely underutilized resource. However, the program should be reviewed in relation to key questions developed here, determine whether the data are robust, and whether it is being implemented to address key influencing factors to ensure its relevance for MPA evaluation. For example, are data being collected to allow for comparison of MPAs with reference sites with similar features (e.g., access, biophysical features)? If the observational power of the MPA Watch program were integrated within a more comprehensive social science research program, it could have a larger impact on our understanding of the human dimensions of MPAs. Furthermore, improved coordination and integration between human and ecological monitoring could help to answer pressing questions about why MPAs may differ in their ecological response, for example, identifying whether low compliance with MPA regulations is occurring and to what degree. Integration between biological and physical monitoring is also important and is largely discussed within the section on ecological influencing factors. Although links between the physical properties of the ocean (e.g., temperature, pH, etc.) and ecosystem responses are well accepted, the challenge of obtaining these physical data at the scale relevant to ecological monitoring of MPAs should not be underestimated. We discuss approaches for integrating information across domains and dealing with the challenges posed by mismatches in scale in multiple sections of the report, but it bears mentioning here that these efforts to integrate could be eased with improved coordination between monitoring programs within and across domains throughout the monitoring period.

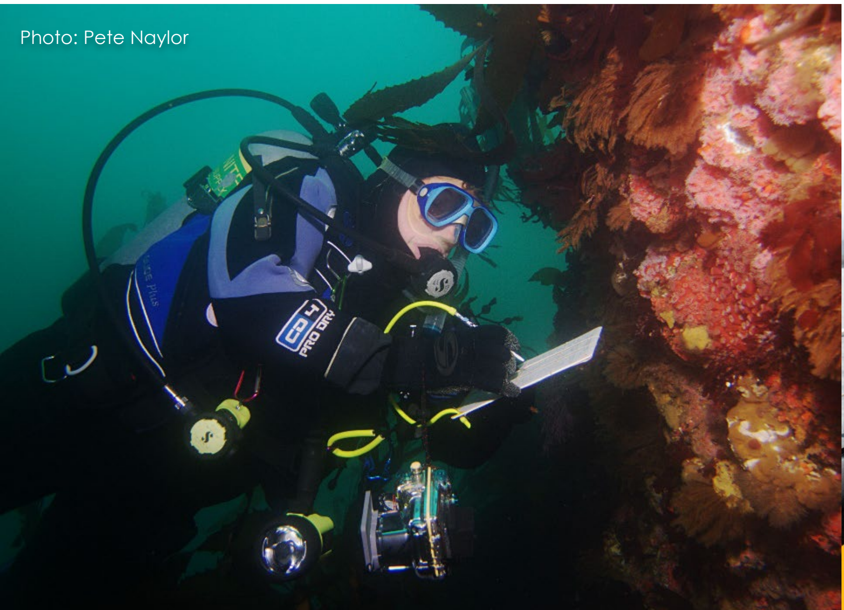


Photo: Pete Naylor


Photo: Rick Starr

Recommendations and Approaches:

20. Manage California's MPA Network as an integrated system consisting of ecological, human, and governance domains and recognize interconnections between these domains in evaluation and adaptive management actions.

20a. Incorporate analyses into the decadal review that integrate ecological, human, and governance domains of the MPA Network.

20b. Support coordination and integration of monitoring efforts within and across domains, including feasibility of long-term monitoring costs.

20c. Improve communication, engagement, and reporting among researchers, stakeholders and governing bodies to increase efficiencies and inform adaptive management decision-making.

ECOSYSTEM SERVICES

Ecosystem services by definition must be assessed with cross-domain integration. Ecosystem services are the benefits people derive from nature (Corvalán et al. 2005) and support human wellbeing through direct and indirect processes (Leenhardt et al. 2015). They represent the relationship between nature and humans. The flow of ecosystem services arises from ecosystem functions that arise from biophysical structures and processes (Liquete et al. 2013). The delivery of ecosystem services leads to individual and societal outcomes, both tangible and intangible, across multiple aspects of human wellbeing. MPAs are a management tool used to support and potentially enhance the delivery of marine ecosystem services (Fletcher et al. 2011, Leenhardt et al. 2015, Pascal et al. 2018), including provisioning, regulating, cultural and supporting services (Corvalán et al. 2005). Assessing the changes in delivery of ecosystem services from conservation interventions including MPAs can be challenging. One approach is cost benefit analysis that uses valuation methods (Balmford et al. 2008, UNEP 2010, Pascal et al. 2018, Gregr et al. 2020). This approach is useful particularly for provisioning services and some regulating services that can be accounted for using monetary valuation. Other data and approaches are needed for evaluating the delivery of other ecosystem services, particularly regulating, supporting, and other non-monetary provisioning services such as subsistence fishing and most cultural services. For example, social media data can be used to evaluate cultural ecosystem services in coastal areas (Ruiz-Frau et al. 2020). The original evaluation questions posed in Appendix B contained a single question about ecosystem services (Question 13). In refining the question, we break it down into steps: first considering the ecosystem services, independent of their value; then addressing any changes to those services that could be resulting from MPAs; and finally assigning both economic and socio-cultural values to those services.

13. *[Original] What is the value of the ecosystem services provided by California MPAs?*
    - 13a. *What are the ecosystem services provided by ecosystems represented in the MPA Network?*
    - 13b. *How has the flow of these ecosystem services changed following MPA implementation?*

13c. What are the short- and long-term economic values of these services?
13d. What are the short- and long-term social and cultural values of these services?

Assessing and valuing ecosystem services is a complex undertaking, and one that extends far beyond the scope of this report, and the realm of the existing monitoring and evaluation programs associated with California's MPA Network. Although a full evaluation of the ecosystem services arising from MPAs may be challenging, a key step forward is the acquisition of ecological and social data needed for this evaluation. Therefore, we recommend integration of monitoring, evaluation, and management efforts to facilitate the collection of data that can be used for such an integrated assessment.

HUMAN OUTCOMES AND EQUITY

As noted above, assessment and valuation of ecosystem services is complicated. Nevertheless, in the SES framework (Figure 1) we illustrate the human outcomes of MPAs as flowing from ecosystem services and directly from the interactions of humans with MPAs in the human domain. Those outcomes include commonly considered economic costs or benefits, but also less recognized social and cultural outcomes. How equitably (or not) the outcomes of MPAs are distributed among individuals, stakeholders, and communities of place is likely to influence people's perceptions of MPAs as well as their engagement with management processes. The distribution of costs and benefits can influence the perceived legitimacy of the MPA Network and support for management efforts (Di Franco et al. 2016, Dehens and Fanning 2018, Pita et al. 2020). Therefore, it is important to evaluate the distribution of the benefits and costs of MPAs, including multiple aspects of economic, social, and cultural equity. As a small step toward this end, we propose two questions within the human domain: N3. *How do the demographics of those who use MPAs and reference sites compare to state demographics?* and N4. *Are there groups that disproportionately access or don't access MPAs and reference sites, and why?* The demographic questions should help identify potential areas of inequity by revealing diversity in the fishing industry (commercial and recreational) and coastal communities. The "why" portion of the question should elicit differences in social impacts and perceptions, cultural values and knowledge. For example, what is considered equitable vis a vis social impact for small-scale, day fishermen may be radically different for large trip boats and vice versa. Similarly, the diversity identified may affect economic analyses, and this should be reflected in the answers to the questions about economic and other aspects of wellbeing; N7. *What are the direct and indirect economic consequences of MPAs for relevant stakeholders and coastal communities?* and N8. *How have MPAs affected dimensions of social and cultural wellbeing for relevant stakeholders and coastal communities?* Opportunity costs considering the immediate and the long-term changes in options (or reduction in the possibility of flexibility) due to MPAs will likely differ according to a wide-range of characteristics of the fishing and/or coastal communities.
Typically, it is the less powerful (e.g., vessel crew or employees and small business owners) who suffer negative impacts or inequitable distribution of (or access to) benefits flowing from ecosystem services (e.g., Gustavsson et al. 2014). The consequences can lead to fractures within human communities and/or between neighboring communities. If the structures of communities change, relationships among people change and dominant values may also shift. In order to track cost and/or benefit to humans, it is important to understand the trade-offs among stakeholders' objectives. Cultural values, perceptions and attitudes, as well as knowledge, play a role in wellbeing that is associated with individuals, families, groups, and communities. Ultimately, MPA network evaluation should measure outcomes of the MPAs and the Network, determining whether and what benefits are being achieved by whom and whether and what costs are borne and by whom. What values should be supported, what the future of communities should be, and who should decide are essential questions for adaptive management of California's MPAs and MPA Network.

LITERATURE CITED

Aalto, E. A., F. Micheli, C. A. Boch, J. A. Espinoza Montes, C. B. Woodson, and G. A. De Leo. 2019. Catastrophic mortality, Allee effects, and marine protected areas. The American Naturalist 193:391–408. DOI:10.1086/701781.

Alexander, S. M., J. F. Provencher, D. A. Henri, J. J. Taylor, J. I. Lloren, L. Nanayakkara, J. T. Johnson, and S. J. Cooke. 2019. Bridging Indigenous and science-based knowledge in coastal and marine research, monitoring, and management in Canada. Environmental Evidence 8:36. DOI:10.1186/s13750-019-0181-3.

Allison, G. W., S. D. Gaines, J. Lubchenco, and H. P. Possingham. 2003. Ensuring persistence of marine reserves: catastrophes require adopting an insurance factor. Ecological Applications 13:8–24. DOI:10.1890/1051-0761(2003)013[0008:EPOMRC]2.0.CO;2.

Alsterberg, C., F. Roger, K. Sundbäck, J. Juhanson, S. Hulth, S. Hallin, and L. Gamfeldt. 2017. Habitat diversity and ecosystem multifunctionality—The importance of direct and indirect effects. Science Advances 3:e1601475. DOI:10.1126/sciadv.1601475.

Arias, A., J. E. Cinner, R. E. Jones, and R. L. Pressey. 2015. Levels and drivers of fishers compliance with marine protected areas. Ecology and Society 20:art19. DOI:10.5751/ES-07999-200419.

Baetscher, D. S., E. C. Anderson, E. A. Gilbert-Horvath, D. P. Malone, E. T. Saarman, M. H. Carr, and J. C. Garza. 2019. Dispersal of a nearshore marine fish connects marine reserves and adjacent fished areas along an open coast. Molecular Ecology 28:1611–1623. DOI:10.1111/mec.15044.

Balmford, A., A. S. L. Rodrigues, M. Walpole, P. Brink, M. Kettunen, L. Braat, and R. Groot. 2008. The Economics of biodiversity and ecosystems: scoping the science. European Commission, Cambridge, UK. https://edepot.wur.nl/8959.

Ban, N. C., M. Mills, J. Tam, C. C. Hicks, S. Klain, N. Stoeckl, M. C. Bottrill, J. Levine, R. L. Pressey, T. Satterfield, and K. M. Chan. 2013. A social–ecological approach to conservation planning: embedding social considerations. Frontiers in Ecology and the Environment 11:194–202. DOI:10.1890/110205.

Barclay, K., M. Voyer, N. Mazur, A. M. Payne, S. Mauli, J. Kinch, M. Fabinyi, and G. Smith. 2017. The importance of qualitative social research for effective fisheries management. Fisheries Research 186:426. DOI:10.1016/j.fishres.2016.08.007.

Baskett, M. L., and L. A. K. Barnett. 2015. The ecological and evolutionary consequences of marine reserves. Annual Review of Ecology, Evolution, and Systematics 46:49–73. DOI:10.1146/annurev-ecolsys-112414-054424.

Beas-Luna, R., F. Micheli, C. B. Woodson, M. Carr, D. Malone, J. Torre, C. Boch, J. E. Caselle, M. Edwards, J. Freiwald, S. L. Hamilton, A. Hernandez, B. Konar, K. J. Kroeker, J. Lorda, G. Montaño-Moctezuma, and G. Torres-Moye. 2020. Geographic variation in responses of kelp forest communities of the California Current to recent climatic changes. Global Change Biology 26:6457–6473. DOI:10.1111/gcb.15273.

Bell, T. W., J. G. Allen, K. C. Cavanaugh, and D. A. Siegel. 2020. Three decades of variability in California's giant kelp forests from the Landsat satellites. Remote Sensing of Environment 238:110811. DOI:10.1016/j.rse.2018.06.039.

Bennett, N. J., and P. Dearden. 2014. From measuring outcomes to providing inputs: Governance, management, and local development for more effective marine protected areas. Marine Policy 50:96–110. DOI:10.1016/j.marpol.2014.05.005.

Bennett, N. J., A. Di Franco, A. Calò, E. Nethery, F. Niccolini, M. Milazzo, and P. Guidetti. 2019. Local support for conservation is associated with perceptions of good governance, social impacts, and ecological effectiveness. Conservation Letters 12. DOI:10.1111/conl.12640.

Bennett, N. J., E. Pinkerton, A. M. Goodfellow, J. Couture, S. Eger, and M. Kaplan-Hallam. 2018. Coastal and Indigenous community access to marine resources and the ocean. Marine Policy. DOI:10.1016/j.marpol.2017.10.023.
Bennett, N. J., R. Roth, S. C. Klain, K. Chan, P. Christie, D. A. Clark, G. Cullman, D. Curran, T. J. Durbin, G. Epstein, A. Greenberg, M. P. Nelson, J. Sandlos, R. Stedman, T. L. Teel, R. Thomas, D. Veríssimo, and C. Wyborn. 2017. Conservation social science: Understanding and integrating human dimensions to improve conservation. Biological Conservation 205:93–108. DOI:10.1016/j.biocon.2016.10.006.
Berger, A. M., D. R. Goethel, P. D. Lynch, T. Quinn, S. Mormede, J. McKenzie, and A. Dunn. 2017. Space oddity: The mission for spatial integration. Canadian Journal of Fisheries and Aquatic Sciences 74:1698–1716. DOI:10.1139/cjfas-2017-0150.
Berkes, F. 2008. Sacred ecology. 2nd ed. Routledge, New York. ISBN:978-0-415-95827-1.
Berkes, F. 2012. Implementing ecosystem-based management: evolution or revolution? Fish and Fisheries 13:465–476. DOI:10.1111/j.1467-2979.2011.00452.x.
Berkey, C., and S. Williams. 2019. California Indian tribes and the Marine Life Protection Act: The seeds of a partnership to preserve natural resources. American Indian Law Review 43:307. ISSN:1930-7918.
Blanchette, C. A., C. M. Miner, P. T. Raimondi, D. Lohse, K. E. K. 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. DOI:10.1111/j.1365-2699.2008.01913.x.
Blowes, S. A., and S. R. Connolly. 2012. Risk spreading, connectivity, and optimal reserve spacing. Ecological Applications 22:311–321. DOI:10.1890/11-0952.1.
Botsford, L. W., J. W. White, M. H. Carr, and J. E. Caselle. 2014. Chapter six - marine protected area networks in California, USA. Pages 205–251 *in* M. L. Johnson and J. Sandell, editors. Advances in Marine Biology. Academic Press. DOI:10.1016/B978-0-12-800214-8.00006-2.
Breslow, S. J., M. Allen, D. Holstein, B. Sojka, R. Barnea, X. Basurto, C. Carothers, S. Charnley, S. Coulthard, N. Dolšak, J. Donatuto, C. García-Quijano, C. C. Hicks, A. Levine, M. B. Mascia, K. Norman, M. Poe, T. Satterfield, K. S. Martin, and P. S. Levin. 2017. Evaluating indicators of human well-being for ecosystem-based management. Ecosystem Health and Sustainability 3:1–18. DOI:10.1080/20964129.2017.1411767.
Breslow, S. J., B. Sojka, R. Barnea, X. Basurto, C. Carothers, S. Charnley, S. Coulthard, N. Dolšak, J. Donatuto, C. García-Quijano, C. C. Hicks, A. Levine, M. B. Mascia, K. Norman, M. Poe, T. Satterfield, K. St. Martin, and P. S. Levin. 2016. Conceptualizing and operationalizing human wellbeing for ecosystem assessment and management. Environmental Science & Policy 66:250–259. DOI:10.1016/j.envsci.2016.06.023.
Brown, E. G. 2011. Executive Order B-10-11. https://www.ca.gov/archive/gov39/2011/09/19/news17223/index.html.
Bunce, L., P. Townsley, R. S. Pomeroy, and R. B. Pollnac. 2000. Socioeconomic manual for coral reef management. IUCN. https://www.iucn.org/content/socioeconomic-manual-coral-reef-management.
Burgess, S. C., K. J. Nickols, C. D. Griesemer, L. A. K. Barnett, A. G. Dedrick, E. V. Satterthwaite, L. Yamane, S. G. Morgan, J. W. White, and L. W. Botsford. 2014. Beyond connectivity: how empirical methods can quantify population persistence to improve marine protected-area design. Ecological Applications 24:257–270. DOI:10.1890/13-0710.1.
Byrne, M., M. Ho, E. Wong, N. A. Soars, P. Selvakumaraswamy, H. Shepard-Brennand, S. A. Dworjanyn, and A. R. Davis. 2011. Unshelled abalone and corrupted urchins: development of marine calcifiers in a changing ocean. Proceedings of the Royal Society B: Biological Sciences 278:2376–2383. DOI:10.1098/rspb.2010.2404.
CA Fish and Game Code. (n.d.). California Fish and Game Code. Page California Fish and Game Code. https://law.justia.com/codes/california/2018/code-fgc/division-

3/chapter-10.5/.
CA Public Resources Code. (n.d.). California Public Resources Code. http://www.search-california-law.com/research/titletoc/ca/PRC/index.html.
Cabral, R. B., S. D. Gaines, B. A. Johnson, T. W. Bell, and C. White. 2017. Drivers of redistribution of fishing and non-fishing effort after the implementation of a marine protected area network. Ecological Applications 27:416–428. DOI:10.1002/eap.1446.
Carr, M. H., and E. L. Hazen. 2019. Chapter 9: Ecological connectivity in the ocean. Pages 216–237 Corridor Ecology: Linking Landscapes for Biodiversity Conservation and Climate Adaptation. Second Edition. Island Press. ISBN:978-1-61091-951-7.
Carr, M. H., P. T. Raimondi, and E. T. Saarman. 2020. Further development of the California connectivity population model (CCPM). CDFW.
Carr, M. H., S. P. Robinson, C. Wahle, G. Davis, S. Kroll, S. Murray, E. J. Schumacker, and M. Williams. 2017. The central importance of ecological spatial connectivity to effective coastal marine protected areas and to meeting the challenges of climate change in the marine environment. Aquatic Conservation: Marine and Freshwater Ecosystems 27:6–29. DOI:10.1002/aqc.2800.
Caselle, J. E., K. Davis, and L. M. Marks. 2018. Marine management affects the invasion success of a non-native species in a temperate reef system in California, USA. Ecology Letters 21:43–53. DOI:10.1111/ele.12869.
Caselle, J. E., A. Rassweiler, S. L. Hamilton, and R. R. Warner. 2015. Recovery trajectories of kelp forest animals are rapid yet spatially variable across a network of temperate marine protected areas. Scientific Reports 5:14102. DOI:10.1038/srep14102.
CDFW. 2016. California Marine Life Protection Act Master Plan for Marine Protected Areas. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=133535&inline.
CDFW and CA OPC. 2018. Marine Protected Area Monitoring Action Plan. California, USA. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=161748&inline.
Center for American Progress. 2017. Briefing for the participants of Blue Future 2017 - Appendix 1, Overview of U.S. Ocean Governance. Center for American Progress. https://cdn.americanprogress.org/content/uploads/2018/05/18120800/BlueFuture-Appendix1-8.pdf?_ga=2.200757678.1058839027.1620830793-52662210.1620830793.
Chaigneau, T., and K. Brown. 2016. Challenging the win-win discourse on conservation and development: analyzing support for marine protected areas. Ecology and Society 21. DOI:10.5751/ES-08204-210136.
Chan, F., J. A. Barth, C. A. Blanchette, R. H. Byrne, F. Chavez, O. Cheriton, R. A. Feely, G. Friederich, B. Gaylord, T. Gouhier, S. Hacker, T. Hill, G. Hofmann, M. A. McManus, B. A. Menge, K. J. Nielsen, A. Russell, E. Sanford, J. Sevadjian, and L. Washburn. 2017. Persistent spatial structuring of coastal ocean acidification in the California Current System. Scientific Reports 7:2526. DOI:10.1038/s41598-017-02777-y.
Chan, F., J. A. Barth, J. Lubchenco, A. Kirincich, H. Weeks, W. T. Peterson, and B. A. Menge. 2008. Emergence of Anoxia in the California Current Large Marine Ecosystem. Science 319:920–920. DOI:10.1126/science.1149016.
Chan, F., J. Barth, K. Kroeker, J. Lubchenco, and B. Menge. 2019. The dynamics and impact of ocean acidification and hypoxia: Insights from sustained investigations in the northern California Current large marine ecosystem. Oceanography 32:62–71. DOI:10.5670/oceanog.2019.312.
Charles, A., and L. Wilson. 2009. Human dimensions of marine protected areas. ICES Journal of Marine Science 66:6–15. DOI:10.1093/icesjms/fsn182.
Chavez, F. P., J. T. Pennington, C. G. Castro, J. P. Ryan, R. P. Michisaki, B. Schlining, P. Walz, K. R. Buck, A. McFadyen, and C. A. Collins. 2002. Biological and chemical consequences of the 1997-1998 El Nino in central California waters. Progress in Oceanography 54:205–232. DOI:10.1016/S0079-6611(02)00050-2.

Christie, M. R., B. N. Tissot, M. A. Albins, J. P. Beets, Y. Jia, D. M. Ortiz, S. E. Thompson, and M. A. Hixon. 2010. Larval connectivity in an effective network of marine protected areas. PLOS ONE 5:e15715. DOI:10.1371/journal.pone.0015715.

Christie, P., N. J. Bennett, N. J. Gray, T. ʻAulani Wilhelm, N. Lewis, J. Parks, N. C. Ban, R. L. Gruby, L. Gordon, J. Day, S. Taei, and A. M. Friedlander. 2017. Why people matter in ocean governance: Incorporating human dimensions into large-scale marine protected areas. Marine Policy 84:273–284. DOI:10.1016/j.marpol.2017.08.002.

Christie, P., B. J. McCay, M. L. Miller, C. Lowe, A. T. White, R. Stoffle, D. L. Fluharty, L. T. McManus, R. Chuenpagdee, C. Pomeroy, D. O. Suman, B. G. Blount, D. Huppert, R. L. V. Eisma, E. Oracion, K. Lowry, and R. B. P. C. 2003. Toward developing a complete understanding: A social science research agenda for marine protected areas. Fisheries 28:22–26. ISSN:0363-2415.

Christie, P., R. B. Pollnac, E. G. Oracion, A. Sabonsolin, R. Diaz, and D. Pietri. 2009. Back to basics: An empirical study demonstrating the importance of local-level dynamics for the success of tropical marine ecosystem-based management. Coastal Management 37:349–373. DOI:10.1080/08920750902851740.

Cinner, J. E., C. Huchery, M. A. MacNeil, N. A. J. Graham, T. R. McClanahan, J. Maina, E. Maire, J. N. Kittinger, C. C. Hicks, C. Mora, E. H. Allison, S. D'Agata, A. Hoey, D. A. Feary, L. Crowder, I. D. Williams, M. Kulbicki, L. Vigliola, L. Wantiez, G. Edgar, R. D. Stuart-Smith, S. A. Sandin, A. L. Green, M. J. Hardt, M. Beger, A. Friedlander, S. J. Campbell, K. E. Holmes, S. K. Wilson, E. Brokovich, A. J. Brooks, J. J. Cruz-Motta, D. J. Booth, P. Chabanet, C. Gough, M. Tupper, S. C. A. Ferse, U. R. Sumaila, and D. Mouillot. 2016. Bright spots among the world's coral reefs. Nature 535:416–419. DOI:10.1038/nature18607.

Cinner, J. E., E. Maire, C. Huchery, M. A. MacNeil, N. A. J. Graham, C. Mora, T. R. McClanahan, M. L. Barnes, J. N. Kittinger, C. C. Hicks, S. D'Agata, A. S. Hoey, G. G. Gurney, D. A. Feary, I. D. Williams, M. Kulbicki, L. Vigliola, L. Wantiez, G. J. Edgar, R. D. Stuart-Smith, S. A. Sandin, A. Green, M. J. Hardt, M. Beger, A. M. Friedlander, S. K. Wilson, E. Brokovich, A. J. Brooks, J. J. Cruz-Motta, D. J. Booth, P. Chabanet, C. Gough, M. Tupper, S. C. A. Ferse, U. R. Sumaila, S. Pardede, and D. Mouillot. 2018. Gravity of human impacts mediates coral reef conservation gains. Proceedings of the National Academy of Sciences 115:E6116–E6125. DOI:10.1073/pnas.1708001115.

Cinner, J., M. M. P. B. Fuentes, and H. Randriamahazo. 2009. Exploring social resilience in Madagascar's marine protected areas. Ecology and Society 14. DOI:10.5751/ES-02881-140141.

Claisse, J. T., C. A. Blanchette, J. E. Dugan, J. P. Williams, J. Freiwald, D. J. Pondella, N. K. Schooler, D. M. Hubbard, K. Davis, L. A. Zahn, C. M. Williams, and J. E. Caselle. 2018. Biogeographic patterns of communities across diverse marine ecosystems in southern California. Marine Ecology 39:e12453. DOI:10.1111/maec.12453.

Claudet, J., C. W. Osenberg, L. Benedetti-Cecchi, P. Domenici, J.-A. García-Charton, Á. Pérez-Ruzafa, F. Badalamenti, J. Bayle-Sempere, A. Brito, F. Bulleri, J.-M. Culioli, M. Dimech, J. M. Falcón, I. Guala, M. Milazzo, J. Sánchez-Meca, P. J. Somerfield, B. Stobart, F. Vandeperre, C. Valle, and S. Planes. 2008. Marine reserves: size and age do matter. Ecology Letters 11:481–489. DOI:10.1111/j.1461-0248.2008.01166.x.

Colding, J., and S. Barthel. 2019. Exploring the social-ecological systems discourse 20 years later. Ecology and Society 24:2. DOI:10.5751/ES-10598-240102.

Cormier-Salem, M.-C., and G. Mainguy. 2014. Participatory governance of Marine Protected Areas: a political challenge, an ethical imperative, different trajectories. SAPIENS 7. http://journals.openedition.org/sapiens/1560.

Cornwall, W. 2019. A new 'Blob' menaces Pacific ecosystems. Science 365:1233–1233. DOI:10.1126/science.365.6459.1233.

Corvalán, C., S. Hales, A. J. McMichael, Millennium Ecosystem Assessment (Program), and World

Health Organization, editors. 2005. Ecosystems and human well-being: health synthesis. World Health Organization, Geneva, Switzerland. ISBN:978-92-4-156309-3.
Craft, C., J. Clough, J. Ehman, S. Joye, R. Park, S. Pennings, H. Guo, and M. Machmuller. 2009. Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. Frontiers in Ecology and the Environment 7:73–78. DOI:10.1890/070219.
Cripps, I. L., P. L. Munday, and M. I. McCormick. 2011. Ocean acidification affects prey detection by a predatory reef fish. PLOS ONE 6:e22736. DOI:10.1371/journal.pone.0022736.
David, J. B. 2002. Human dimensions of MPAs: Facing the challenges of social science and its implementation. MPA News 4:1–4. https://mpanews.openchannels.org/news/mpa-news/human-dimensions-mpas-facing-challenges-social-science-and-its-implementation.
Davis, K. J., G. M. S. Vianna, J. J. Meeuwig, M. G. Meekan, and D. J. Pannell. 2019. Estimating the economic benefits and costs of highly-protected marine protected areas. Ecosphere 10:e02879. DOI:10.1002/ecs2.2879.
De Jong, E., R. Smeets, and J. Smits. 2006. Culture and openness. Social Indicators Research 78:111–136. ISSN:03038300.
Dehens, L. A., and L. M. Fanning. 2018. What counts in making marine protected areas (MPAs) count? The role of legitimacy in MPA success in Canada. Ecological Indicators 86:45–57. DOI:10.1016/j.ecolind.2017.12.026.
Di Franco, A., K. E. Hogg, A. Calò, N. J. Bennett, M.-A. Sévin-Allouet, O. Esparza Alaminos, M. Lang, D. Koutsoubas, M. Prvan, L. Santarossa, F. Niccolini, M. Milazzo, and P. Guidetti. 2020. Improving marine protected area governance through collaboration and co-production. Journal of Environmental Management 269:110757. DOI:10.1016/j.jenvman.2020.110757.
Di Franco, A., P. Thiriet, G. Di Carlo, C. Dimitriadis, P. Francour, N. L. Gutiérrez, A. Jeudy de Grissac, D. Koutsoubas, M. Milazzo, M. del M. Otero, C. Piante, J. Plass-Johnson, S. Sainz-Trapaga, L. Santarossa, S. Tudela, and P. Guidetti. 2016. Five key attributes can increase marine protected areas performance for small-scale fisheries management. Scientific Reports 6:38135. DOI:10.1038/srep38135.
Diggon, S., J. Bones, C. J. Short, J. L. Smith, M. Dickinson, K. Wozniak, K. Topelko, and K. A. Pawluk. 2020. The Marine Plan Partnership for the North Pacific Coast – MaPP: A collaborative and co-led marine planning process in British Columbia. Marine Policy:104065. DOI:10.1016/j.marpol.2020.104065.
Eisaguirre, J. H., J. M. Eisaguirre, K. Davis, P. M. Carlson, S. D. Gaines, and J. E. Caselle. 2020. Trophic redundancy and predator size class structure drive differences in kelp forest ecosystem dynamics. Ecology 101:e02993. DOI:10.1002/ecy.2993.
Eisenlord, M. E., M. L. Groner, R. M. Yoshioka, J. Elliott, J. Maynard, S. Fradkin, M. Turner, K. Pyne, N. Rivlin, R. van Hooidonk, and C. D. Harvell. 2016. Ochre star mortality during the 2014 wasting disease epizootic: role of population size structure and temperature. Philosophical Transactions of the Royal Society B: Biological Sciences 371:20150212. DOI:10.1098/rstb.2015.0212.
Elliott, M. 2014. Integrated marine science and management: Wading through the morass. Marine Pollution Bulletin 86:1–4. DOI:10.1016/j.marpolbul.2014.07.026.
Fernández-Chacón, A., D. Villegas-Ríos, E. Moland, M. L. Baskett, E. M. Olsen, and S. M. Carlson. 2020. Protected areas buffer against harvest selection and rebuild phenotypic complexity. Ecological Applications 30. DOI:10.1002/eap.2108.
Field, J. C., A. E. Punt, R. D. Methot, and C. J. Thomson. 2006. Does MPA mean "Major Problem for Assessments"? Considering the consequences of place-based management systems. Fish and Fisheries 7:284–302. DOI:10.1111/j.1467-2979.2006.00226.x.
Fletcher, S., J. Saunders, and R. J. H. Herbert. 2011. A review of the ecosystem services provided

by broad-scale marine habitats in England's MPA network. Journal of Coastal Research:378–383. ISSN:0749-0208.
Fox, E., S. Hastings, M. Miller-Henson, D. Monie, J. Ugoretz, A. Frimodig, C. Shuman, B. Owens, R. Garwood, D. Connor, P. Serpa, and M. Gleason. 2013a. Addressing policy issues in a stakeholder-based and science-driven marine protected area network planning process. Ocean & Coastal Management 74:34–44. DOI:10.1016/j.ocecoaman.2012.07.007.
Fox, E., E. Poncelet, D. Connor, J. Vasques, J. Ugoretz, S. McCreary, D. Monié, M. Harty, and M. Gleason. 2013b. Adapting stakeholder processes to region-specific challenges in marine protected area network planning. Ocean & Coastal Management 74:24–33. DOI:10.1016/j.ocecoaman.2012.07.008.
Fumo, J. T., M. L. Carter, R. E. Flick, L. L. Rasmussen, D. L. Rudnick, and S. F. Iacobellis. 2020. Contextualizing marine heatwaves in the Southern California Bight under anthropogenic climate change. Journal of Geophysical Research: Oceans 125:e2019JC015674. DOI:10.1029/2019JC015674.
Gaines, S. D., C. White, M. H. Carr, and S. R. Palumbi. 2010. Designing marine reserve networks for both conservation and fisheries management. Proceedings of the National Academy of Sciences 107:18286–18293. DOI:10.1073/pnas.0906473107.
Gaines, S., B. Gaylord, L. Gerber, A. Hastings, and B. Kinlan. 2007. Connecting Places: The Ecological Consequences of Dispersal in the Sea. Oceanography 20:90–99. DOI:10.5670/oceanog.2007.32.
Giakoumi, S., C. Scianna, J. Plass-Johnson, F. Micheli, K. Grorud-Colvert, P. Thiriet, J. Claudet, G. Di Carlo, A. Di Franco, S. D. Gaines, J. A. García-Charton, J. Lubchenco, J. Reimer, E. Sala, and P. Guidetti. 2017. Ecological effects of full and partial protection in the crowded Mediterranean Sea: a regional meta-analysis. Scientific Reports 7:8940. DOI:10.1038/s41598-017-08850-w.
Gill, D. A., M. B. Mascia, G. N. Ahmadia, L. Glew, S. E. Lester, M. Barnes, I. Craigie, E. S. Darling, C. M. Free, J. Geldmann, S. Holst, O. P. Jensen, A. T. White, X. Basurto, L. Coad, R. D. Gates, G. Guannel, P. J. Mumby, H. Thomas, S. Whitmee, S. Woodley, and H. E. Fox. 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature 543:665–669. DOI:10.1038/nature21708.
Gleason, M., E. Fox, S. Ashcraft, J. Vasques, E. Whiteman, P. Serpa, E. Saarman, M. Caldwell, A. Frimodig, M. Miller-Henson, J. Kirlin, B. Ota, E. Pope, M. Weber, and K. Wiseman. 2013. Designing a network of marine protected areas in California: Achievements, costs, lessons learned, and challenges ahead. Ocean & Coastal Management 74:90–101. DOI:10.1016/j.ocecoaman.2012.08.013.
Gleason, M., S. Mccreary, M. Miller-Henson, J. Ugoretz, E. Fox, M. Merrifield, W. Mcclintock, P. Serpa, and K. Coombes. 2010. Science-based and stakeholder-driven marine protected area network planning: A successful case study from north central California. Ocean & Coastal Management 53:52–68. DOI:10.1016/j.ocecoaman.2009.12.001.
Gollan, N., and K. Barclay. 2020. "It's not just about fish": Assessing the social impacts of marine protected areas on the wellbeing of coastal communities in New South Wales. PLOS ONE 15:e0244605. DOI:10.1371/journal.pone.0244605.
Goñi, R., R. Hilborn, D. Díaz, S. Mallol, and S. Adlerstein. 2010. Net contribution of spillover from a marine reserve to fishery catches. Marine Ecology Progress Series 400:233–243. DOI:10.3354/meps08419.
Grantham, B. A., F. Chan, K. J. Nielsen, D. S. Fox, J. A. Barth, A. Huyer, J. Lubchenco, and B. A. Menge. 2004. Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific. Nature 429:749–754. DOI:10.1038/nature02605.
Gravem, S., S. Hamilton, W. Heady, V. Saccomanno, K. Alvstad, A. Gehman, and T. Frierson.

2020, August 26. IUCN Red List of Threatened Species: Pycnopodia helianthoides. https://www.iucnredlist.org/en. https://www.iucnredlist.org/en.
Gray, S., R. Jordan, A. Crall, G. Newman, C. Hmelo-Silver, J. Huang, W. Novak, D. Mellor, T. Frensley, M. Prysby, and A. Singer. 2017. Combining participatory modelling and citizen science to support volunteer conservation action. Biological Conservation 208:76–86. DOI:10.1016/j.biocon.2016.07.037.
Green, A. L., L. Fernandes, G. Almany, R. Abesamis, E. McLeod, P. M. Aliño, A. T. White, R. Salm, J. Tanzer, and R. L. Pressey. 2014. Designing marine reserves for fisheries management, biodiversity conservation, and climate change adaptation. Coastal Management 42:143–159. DOI:10.1080/08920753.2014.877763.
Gregory, R. 2000. Using stakeholder values to make smarter environmental decisions. Environment: Science and Policy for Sustainable Development 42:34–44. DOI:10.1080/00139150009604888.
Gregr, E. J., V. Christensen, L. Nichol, R. G. Martone, R. W. Markel, J. C. Watson, C. D. G. Harley, E. A. Pakhomov, J. B. Shurin, and K. M. A. Chan. 2020. Cascading social-ecological costs and benefits triggered by a recovering keystone predator. Science 368:1243–1247. DOI:10.1126/science.aay5342.
Griffith, A. W., and C. J. Gobler. 2020. Harmful algal blooms: A climate change co-stressor in marine and freshwater ecosystems. Harmful Algae 91:101590. DOI:10.1016/j.hal.2019.03.008.
Griggs, G., J. Arvai, D. Cayan, R. DeConto, J. Fox, H. A. Fricker, R. Kopp, C. Tebaldi, and E. Whiteman. 2017. Rising seas in California: An update on sea-level rise science. California Ocean Science Trust. DOI: 10.1142/9789811213960_0016.
Grorud-Colvert, K., J. Claudet, B. N. Tissot, J. E. Caselle, M. H. Carr, J. C. Day, A. M. Friedlander, S. E. Lester, T. L. de Loma, D. Malone, and W. J. Walsh. 2014. Marine protected area networks: Assessing whether the whole is greater than the sum of its parts. PLOS ONE 9:e102298. DOI:10.1371/journal.pone.0102298.
Gruber, N., C. Hauri, Z. Lachkar, D. Loher, T. L. Frölicher, and G.-K. Plattner. 2012. Rapid progression of ocean acidification in the California Current system. Science 337:220. DOI:10.1126/science.1216773.
Gruby, R. L., N. J. Gray, L. M. Campbell, and L. Acton. 2016. Toward a social science research agenda for large marine protected areas: Social science and large MPAs. Conservation Letters 9:153–163. DOI:10.1111/conl.12194.
Guenther, C., D. López-Carr, and H. S. Lenihan. 2015. Differences in lobster fishing effort before and after MPA establishment. Applied Geography 59:78–87. DOI:10.1016/j.apgeog.2014.12.016.
Gustavsson, M., L. Lindström, N. S. Jiddawi, and M. de la Torre-Castro. 2014. Procedural and distributive justice in a community-based managed Marine Protected Area in Zanzibar, Tanzania. Marine Policy 46:91–100. DOI:10.1016/j.marpol.2014.01.005.
Halpern, B. S. 2003. The impact of marine reserves: Do reserves work and does reserve size matter? Ecological Applications 13:117–137. DOI:10.1890/1051-0761(2003)013[0117:TIOMRD]2.0.CO;2.
Hamilton, S. L., and J. E. Caselle. 2015. Exploitation and recovery of a sea urchin predator has implications for the resilience of southern California kelp forests. Proceedings of the Royal Society B: Biological Sciences 282:20141817. DOI:10.1098/rspb.2014.1817.
Harvell, C. D., D. Montecino-Latorre, J. M. Caldwell, J. M. Burt, K. Bosley, A. Keller, S. F. Heron, A. K. Salomon, L. Lee, O. Pontier, C. Pattengill-Semmens, and J. K. Gaydos. 2019. Disease epidemic and a marine heat wave are associated with the continental-scale collapse of a pivotal predator (Pycnopodia helianthoides). Science Advances 5:eaau7042. DOI:10.1126/sciadv.aau7042.
Hastings, A., and L. W. Botsford. 2006. Persistence of spatial populations depends on returning

home. Proceedings of the National Academy of Sciences 103:6067–6072. DOI:10.1073/pnas.0506651103.
Hathaway, J. 2020. Catch it live: Direct marketing, ocean to plate. National Fisherman. https://www.nationalfisherman.com/catch-it-live-direct-marketing-ocean-to-plate.
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. DOI:10.1146/annurev.ecolsys.37.091305.110149.
Hicks, C. C., A. Levine, A. Agrawal, X. Basurto, S. J. Breslow, C. Carothers, S. Charnley, S. Coulthard, N. Dolsak, J. Donatuto, C. Garcia-Quijano, M. B. Mascia, K. Norman, M. R. Poe, T. Satterfield, K. S. Martin, and P. S. Levin. 2016. Engage key social concepts for sustainability. Science 352:38–40. DOI:10.1126/science.aad4977.
Hill, S. 2020. Community-supported fisheries rush to pivot models as coronavirus cuts off restaurant clients. National Fisherman. https://www.nationalfisherman.com/northeast/community-supported-fisheries-rush-to-pivot-models-as-coronavirus-cuts-off-restaurant-clients.
Hobday, A. J., L. V. Alexander, S. E. Perkins, D. A. Smale, S. C. Straub, E. C. J. Oliver, J. A. Benthuysen, M. T. Burrows, M. G. Donat, M. Feng, N. J. Holbrook, P. J. Moore, H. A. Scannell, A. Sen Gupta, and T. Wernberg. 2016. A hierarchical approach to defining marine heatwaves. Progress in Oceanography 141:227–238. DOI:10.1016/j.pocean.2015.12.014.
Hobday, A. J., M. J. Tegner, and P. L. Haaker. 2000. Over-exploitation of a broadcast spawning marine invertebrate: Decline of the white abalone. Reviews in Fish Biology and Fisheries 10:493–514. DOI:10.1023/A:1012274101311.
Hofmann, G., E. Hazen, D. Aseltine-Nielsen, J. Caselle, F. Chan, A. Levine, F. Micheli, J. Sunday, and W. White. 2021. Climate resilience and California's Marine Protected Area Network: A report by the Ocean Protection Council Science Advisory Team Working Group and California Ocean Science Trust.
Holland, D. S., and J. Leonard. 2020. Is a delay a disaster? Economic impacts of the delay of the California dungeness crab fishery due to a harmful algal bloom. Harmful Algae 98:101904. DOI:10.1016/j.hal.2020.101904.
Hopkins, C. R., N. M. Burns, E. Brooker, S. Dolman, E. Devenport, C. Duncan, and D. M. Bailey. 2020. Evaluating whether MPA management measures meet ecological principles for effective biodiversity protection. Acta Oecologica 108:103625. DOI:10.1016/j.actao.2020.103625.
Jaco, E. M., and M. A. Steele. 2020. Pre-closure fishing pressure predicts effects of marine protected areas. Journal of Applied Ecology 57:229–240. DOI:10.1111/1365-2664.13541.
Jenkins, T. L., and J. R. Stevens. 2018. Assessing connectivity between MPAs: Selecting taxa and translating genetic data to inform policy. Marine Policy 94:165–173. DOI:10.1016/j.marpol.2018.04.022.
Jentoft, S., T. C. van Son, and M. Bjørkan. 2007. Marine protected areas: A governance system analysis. Human Ecology 35:611–622. DOI:10.1007/s10745-007-9125-6.
Jobstvogt, N., V. Watson, and J. O. Kenter. 2014. Looking below the surface: The cultural ecosystem service values of UK marine protected areas (MPAs). Ecosystem Services 10:97–110. DOI:10.1016/j.ecoser.2014.09.006.
Johnson, D. W., M. R. Christie, T. J. Pusack, C. D. Stallings, and M. A. Hixon. 2018. Integrating larval connectivity with local demography reveals regional dynamics of a marine metapopulation. Ecology 99:1419–1429. DOI:10.1002/ecy.2343.
Jones, G. P., M. Srinivasan, and G. R. Almany. 2007. Population connectivity and conservation of marine biodiversity. Oceanography 20:100–111. ISSN:1042-8275.
Juda, L. 1999. Considerations in developing a functional approach to the governance of large

marine ecosystems. Ocean Development & International Law 30:89–125. DOI:10.1080/009083299276203.

Kaiser, M. J., R. E. Blyth-Skyrme, P. J. Hart, G. Edwards-Jones, and D. Palmer. 2011. Evidence for greater reproductive output per unit area in areas protected from fishing. Canadian Journal of Fisheries and Aquatic Sciences. DOI:10.1139/f07-090.

Kaplan, K. A., L. Yamane, L. W. Botsford, M. L. Baskett, A. Hastings, S. Worden, and J. W. White. 2019. Setting expected timelines of fished population recovery for the adaptive management of a marine protected area network. Ecological Applications 29:e01949. DOI:10.1002/eap.1949.

Keith, D. M., and J. A. Hutchings. 2012. Population dynamics of marine fishes at low abundance. Canadian Journal of Fisheries and Aquatic Sciences. DOI:10.1139/f2012-055.

Kelleher, G., and C. Recchia. 1998. Lessons from marine protected areas around the world. Parks 8:1–4. https://www.iucn.org/sites/dev/files/import/downloads/parks_jun98.pdf#page=4.

Keller, A. A., L. Ciannelli, W. W. Wakefield, V. Simon, J. A. Barth, and S. D. Pierce. 2015. Occurrence of demersal fishes in relation to near-bottom oxygen levels within the California Current large marine ecosystem. Fisheries Oceanography 24:162–176. DOI:10.1111/fog.12100.

Keller, A. A., V. Simon, F. Chan, W. W. Wakefield, M. E. Clarke, J. A. Barth, D. Kamikawa, and E. L. Fruh. 2010. Demersal fish and invertebrate biomass in relation to an offshore hypoxic zone along the US West Coast. Fisheries Oceanography 19:76–87. DOI:https://doi.org/10.1111/j.1365-2419.2009.00529.x.

Kinlan, B. P., and S. D. Gaines. 2003. Propagule dispersal in marine and terrestrial environments: A community perspective. Ecology 84:2007–2020. DOI:10.1890/01-0622.

Klein, C. J., A. Chan, L. Kircher, A. J. Cundiff, N. Gardner, Y. Hrovat, A. Scholz, B. E. Kendall, and S. Airamé. 2008. Striking a balance between biodiversity conservation and socioeconomic viability in the design of marine protected areas. Conservation Biology: The Journal of the Society for Conservation Biology 22:691–700. DOI:10.1111/j.1523-1739.2008.00896.x.

Klinger, T., E. A. Chornesky, E. A. Whiteman, F. Chan, J. L. Largier, and W. W. Wakefield. 2017. Using integrated, ecosystem-level management to address intensifying ocean acidification and hypoxia in the California Current large marine ecosystem. Elementa: Science of the Anthropocene 5. DOI:10.1525/elementa.198.

Kroeker, K. J., R. L. Kordas, R. Crim, I. E. Hendriks, L. Ramajo, G. S. Singh, C. M. Duarte, and J.-P. Gattuso. 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology 19:1884–1896. DOI:10.1111/gcb.12179.

Krueck, N. C., A. Y. Abdurrahim, D. S. Adhuri, P. J. Mumby, and H. Ross. 2019. Quantitative decision support tools facilitate social-ecological alignment in community-based marine protected area design. Ecology and Society 24:6. DOI:10.5751/ES-11209-240406.

Lacharité, M., and C. J. Brown. 2019. Utilizing benthic habitat maps to inform biodiversity monitoring in marine protected areas. Aquatic Conservation: Marine and Freshwater Ecosystems 29:938–951. DOI:10.1002/aqc.3074.

Laffoley, D. D., IUCN World Commission on Protected Areas, United States, National Oceanic and Atmospheric Administration, and Nature Conservancy (U.S.). 2008. Establishing resilient marine protected area networks--making it happen. IUCN-WCPA : National Oceanic and Atmospheric Association : The Nature Conservancy, Washington, D.C. ISBN:978-2-8317-1090-7.

Lancaster, D., P. Dearden, and N. C. Ban. 2015. Drivers of recreational fisher compliance in temperate marine conservation areas: A study of Rockfish Conservation Areas in British Columbia, Canada. Global Ecology and Conservation 4:645–657.

DOI:10.1016/j.gecco.2015.11.004.
Laufkötter, C., J. Zscheischler, and T. L. Frölicher. 2020. High-impact marine heatwaves attributable to human-induced global warming. Science 369:1621–1625. DOI:10.1126/science.aba0690.
Leenhardt, P., N. Low, N. Pascal, F. Micheli, and J. Claudet. 2015. Chapter 9 - The role of marine protected areas in providing ecosystem services. Pages 211–239 *in* A. Belgrano, G. Woodward, and U. Jacob, editors. Aquatic Functional Biodiversity. Academic Press, San Diego. DOI:10.1016/B978-0-12-417015-5.00009-8.
Leiserowitz, A. 2006. Climate change risk perception and policy preferences: The role of affect, imagery, and values. Climatic Change 77:45–72. DOI:10.1007/s10584-006-9059-9.
Leisher, C., S. Mangubhai, S. Hess, H. Widodo, T. Soekirman, S. Tjoe, S. Wawiyai, S. Neil Larsen, L. Rumetna, A. Halim, and M. Sanjayan. 2012. Measuring the benefits and costs of community education and outreach in marine protected areas. Marine Policy 36:1005–1011. DOI:10.1016/j.marpol.2012.02.022.
Lester, S. E., and B. S. Halpern. 2008. Biological responses in marine no-take reserves versus partially protected areas. Marine Ecology Progress Series 367:49–56. DOI:10.3354/meps07599.
Lester, S. E., B. S. Halpern, K. Grorud-Colvert, J. Lubchenco, B. I. Ruttenberg, S. D. Gaines, S. Airamé, and R. R. Warner. 2009. Biological effects within no-take marine reserves: a global synthesis. Marine Ecology Progress Series 384:33–46. DOI:10.3354/meps08029.
Levitan, D. R., M. A. Sewell, and F.-S. Chia. 1992. How distribution and abundance influence fertilization success in the sea urchin Strongylocentrotus franciscanus. Ecology 73:248–254. DOI:10.2307/1938736.
Liquete, C., C. Piroddi, E. G. Drakou, L. Gurney, S. Katsanevakis, A. Charef, and B. Egoh. 2013. Current status and future prospects for the assessment of marine and coastal ecosystem services: A systematic review. PLOS ONE 8:e67737. DOI:10.1371/journal.pone.0067737.
Littler, M. M., and D. S. Littler. 1980. The evolution of thallus form and survival strategies in benthic marine macroalgae: Field and laboratory tests of a functional form model. The American Naturalist 116:25–44. DOI:10.1086/283610.
Liu, W., C. A. Vogt, J. Luo, G. He, K. A. Frank, and J. Liu. 2012. Drivers and socioeconomic impacts of tourism participation in protected areas. PLOS ONE 7:e35420. DOI:10.1371/journal.pone.0035420.
Lonhart, S. I., R. Jeppesen, R. Beas-Luna, J. A. Crooks, and J. Lorda. 2019. Shifts in the distribution and abundance of coastal marine species along the eastern Pacific Ocean during marine heatwaves from 2013 to 2018. Marine Biodiversity Records 12:13. DOI:10.1186/s41200-019-0171-8.
Lucrezi, S., M. H. Esfehani, E. Ferretti, and C. Cerrano. 2019. The effects of stakeholder education and capacity building in marine protected areas: A case study from southern Mozambique. Marine Policy 108:103645. DOI:10.1016/j.marpol.2019.103645.
Mach, M. E., L. M. Wedding, S. M. Reiter, F. Micheli, R. M. Fujita, and R. G. Martone. 2017. Assessment and management of cumulative impacts in California's network of marine protected areas. Ocean & Coastal Management 137:1–11. DOI:10.1016/j.ocecoaman.2016.11.028.
Malin, S. A., S. Ryder, and M. G. Lyra. 2019. Environmental justice and natural resource extraction: intersections of power, equity and access. Environmental Sociology 5:109–116. DOI:10.1080/23251042.2019.1608420.
Mangi, S. C., L. D. Rodwell, and C. Hattam. 2011. Assessing the impacts of establishing MPAs on fishermen and fish merchants: The case of Lyme Bay, UK. AMBIO 40:457–468. DOI:10.1007/s13280-011-0154-4.
Marshall, D. J., S. Gaines, R. Warner, D. R. Barneche, and M. Bode. 2019. Underestimating the benefits of marine protected areas for the replenishment of fished populations. Frontiers

in Ecology and the Environment 17:407–413. DOI:10.1002/fee.2075.
Marti-Puig, P., F. Costantini, L. Rugiu, M. Ponti, and M. Abbiati. 2013. Patterns of genetic connectivity in invertebrates of temperate MPA networks. Advances in Oceanography and Limnology 4:138–149. DOI:10.1080/19475721.2013.850445.
Mascia, M. B. 2003. The human dimension of coral reef marine protected areas: recent social science research and its policy implications. Conservation Biology 17:630–632. DOI:10.1046/j.1523-1739.2003.01454.x.
Mascia, M. B., C. A. Claus, and R. Naidoo. 2010. Impacts of marine protected areas on fishing communities: MPA social impacts. Conservation Biology 24:1424–1429. DOI:10.1111/j.1523-1739.2010.01523.x.
Mason, E. T., A. N. Kellum, J. A. Chiu, G. T. Waltz, S. Murray, D. E. Wendt, R. M. Starr, and B. X. Semmens. 2020. Long-term participation in collaborative fisheries research improves angler opinions on marine protected areas. PeerJ 8:e10146. DOI:10.7717/peerj.10146.
McClanahan, T. 1999. Is there a future for coral reef parks in poor tropical countries? Coral Reefs 18:321–325. https://link.springer.com/content/pdf/10.1007/s003380050205.pdf.
McClanahan, T., J. Davies, and J. Maina. 2005. Factors influencing resource users and managers' perceptions towards marine protected area management in Kenya. Environmental Conservation 32:42–49. DOI:10.1017/S0376892904001791.
McLeod, E., A. Green, E. Game, K. Anthony, J. Cinner, S. F. Heron, J. Kleypas, C. E. Lovelock, J. M. Pandolfi, R. L. Pressey, R. Salm, S. Schill, and C. Woodroffe. 2012. Integrating climate and ocean change vulnerability into conservation planning. Coastal Management 40:651–672. DOI:10.1080/08920753.2012.728123.
McLeod, E., R. Salm, A. Green, and J. Almany. 2009. Designing marine protected area networks to address the impacts of climate change. Frontiers in Ecology and the Environment 7:362–370. DOI:10.1890/070211.
McNeill, A., J. Clifton, and E. S. Harvey. 2018. Attitudes to a marine protected area are associated with perceived social impacts. Marine Policy 94:106–118. DOI:10.1016/j.marpol.2018.04.020.
McPherson, M. L., D. J. I. Finger, H. F. Houskeeper, T. W. Bell, M. H. Carr, L. Rogers-Bennett, and R. M. Kudela. 2021. Large-scale shift in the structure of a kelp forest ecosystem co-occurs with an epizootic and marine heatwave. Communications Biology 4:298. DOI:10.1038/s42003-021-01827-6.
Meehan, M. C., N. C. Ban, R. Devillers, G. G. Singh, and J. Claudet. 2020. How far have we come? A review of MPA network performance indicators in reaching qualitative elements of Aichi Target 11. Conservation Letters 13:e12746. DOI:10.1111/conl.12746.
Micheli, F., K. W. Heiman, C. V. Kappel, R. G. Martone, S. A. Sethi, G. C. Osio, S. Fraschetti, A. O. Shelton, and J. M. Tanner. 2016. Combined impacts of natural and human disturbances on rocky shore communities. Ocean & Coastal Management 126:42–50. DOI:10.1016/j.ocecoaman.2016.03.014.
Micheli, F., A. Saenz-Arroyo, A. Greenley, L. Vazquez, J. A. E. Montes, M. Rossetto, and G. A. D. Leo. 2012. Evidence that marine reserves enhance resilience to climatic impacts. PLOS ONE 7:e40832. DOI:10.1371/journal.pone.0040832.
Milazzo, M., R. Chemello, F. Badalamenti, R. Camarda, and S. Riggio. 2002. The impact of human recreational activities in marine protected areas: What lessons should be learnt in the Mediterranean Sea? Marine Ecology 23:280–290. DOI:10.1111/j.1439-0485.2002.tb00026.x.
Milfont, T. L., J. Duckitt, and L. D. Cameron. 2006. A cross-cultural study of environmental motive concerns and their implications for proenvironmental behavior. Environment and Behavior 38:745–767. DOI:10.1177/0013916505285933.
Miller, R., J. Field, J. Santora, M. Monk, R. Kosaka, and C. Thomson. 2017. Spatial valuation of California marine fisheries as an ecosystem service. Canadian Journal of Fisheries and

Aquatic Sciences 74. DOI:10.1139/cjfas-2016-0228.
Miller, R. R., J. C. Field, J. A. Santora, I. D. Schroeder, D. D. Huff, M. Key, D. E. Pearson, and A. D. MacCall. 2014. A spatially distinct history of the development of California groundfish fisheries. PLOS ONE 9:e99758. DOI:10.1371/journal.pone.0099758.
Miner, C. M., J. L. Burnaford, R. F. Ambrose, L. Antrim, H. Bohlmann, C. A. Blanchette, J. M. Engle, S. C. Fradkin, R. Gaddam, C. D. G. Harley, B. G. Miner, S. N. Murray, J. R. Smith, S. G. Whitaker, and P. T. Raimondi. 2018. Large-scale impacts of sea star wasting disease (SSWD) on intertidal sea stars and implications for recovery. PLOS ONE 13:e0192870. DOI:10.1371/journal.pone.0192870.
Moffitt, E. A., J. Wilson White, and L. W. Botsford. 2011. The utility and limitations of size and spacing guidelines for designing marine protected area (MPA) networks. Biological Conservation 144:306–318. DOI:10.1016/j.biocon.2010.09.008.
MPA Collaborative Network: Empowering Coastal Communities. 2018. https://www.mpacollaborative.org/
Munday, P. L., D. L. Dixson, J. M. Donelson, G. P. Jones, M. S. Pratchett, G. V. Devitsina, and K. B. Døving. 2009. Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. Proceedings of the National Academy of Sciences 106:1848–1852. DOI:10.1073/pnas.0809996106.
Munday, P. L., D. L. Dixson, M. I. McCormick, M. Meekan, M. C. O. Ferrari, and D. P. Chivers. 2010. Replenishment of fish populations is threatened by ocean acidification. Proceedings of the National Academy of Sciences 107:12930–12934. DOI:10.1073/pnas.1004519107.
Murawski, S. A., S. E. Wigley, M. J. Fogarty, P. J. Rago, and D. G. Mountain. 2005. Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science 62:1150–1167. DOI:10.1016/j.icesjms.2005.04.005.
Murray, S. N., R. F. Ambrose, J. A. Bohnsack, L. W. Botsford, M. H. Carr, G. E. Davis, P. K. Dayton, D. Gotshall, D. R. Gunderson, M. A. Hixon, J. Lubchenco, M. Mangel, A. MacCall, D. A. McArdle, J. C. Ogden, J. Roughgarden, R. M. Starr, M. J. Tegner, and M. M. Yoklavich. 1999. No-take Reserve Networks: Sustaining Fishery Populations and Marine Ecosystems. Fisheries 24:11–25. DOI:10.1577/1548-8446(1999)024<0011:NRN>2.0.CO;2.
Newman, M., M. A. Alexander, T. R. Ault, K. M. Cobb, C. Deser, E. Di Lorenzo, N. J. Mantua, A. J. Miller, S. Minobe, H. Nakamura, N. Schneider, D. J. Vimont, A. S. Phillips, J. D. Scott, and C. A. Smith. 2016. The Pacific decadal oscillation, revisited. Journal of Climate 29:4399–4427. DOI:10.1175/JCLI-D-15-0508.1.
Newsome, G. 2019. Executive Order N 15-19. https://www.courts.ca.gov/documents/BTB25-PreConTrauma-02.pdf.
Newton, A., and M. Elliott. 2016. A typology of stakeholders and guidelines for engagement in transdisciplinary, participatory processes. Frontiers in Marine Science 3. DOI:10.3389/fmars.2016.00230.
Nickols, K. J., J. W. White, D. Malone, M. H. Carr, R. M. Starr, M. L. Baskett, A. Hastings, and L. W. Botsford. 2019. Setting ecological expectations for adaptive management of marine protected areas. Journal of Applied Ecology 56:2376–2385. DOI:10.1111/1365-2664.13463.
NRC. 2001. Marine Protected Areas: Tools for Sustaining Ocean Ecosystem. Page 9994. National Academies Press, Washington, D.C. DOI:10.17226/9994.
O'Connor, R. E., R. J. Bard, and A. Fisher. 1999. Risk perceptions, general environmental beliefs, and willingness to address climate change. Risk Analysis 19:461–471. DOI:10.1111/j.1539-6924.1999.tb00421.x.
ODFW. 2020. What do fishermen think about marine reserves? https://oregonmarinereserves.com/content/uploads/2020/04/FishingCommunities_infographic.pdf.

Oliver, E. C. J., M. G. Donat, M. T. Burrows, P. J. Moore, D. A. Smale, L. V. Alexander, J. A. Benthuysen, M. Feng, A. Sen Gupta, A. J. Hobday, N. J. Holbrook, S. E. Perkins-Kirkpatrick, H. A. Scannell, S. C. Straub, and T. Wernberg. 2018. Longer and more frequent marine heatwaves over the past century. Nature Communications 9:1324. DOI:10.1038/s41467-018-03732-9.

Paddack, M. J., and J. A. Estes. 2000. Kelp forest fish populations in marine reserves and adjacent exploited areas of Central California. Ecological Applications 10:855–870. DOI:10.1890/1051-0761(2000)010[0855:KFFPIM]2.0.CO;2.

Park, R. A., J. K. Lee, and D. J. Canning. 1993. Potential effects of sea-level rise on Puget Sound wetlands. Geocarto International 8:99–110. DOI:10.1080/10106049309354433.

Parnell, P. E., E. F. Miller, C. E. L. Cody, P. K. Dayton, M. L. Carter, and T. D. Stebbinsd. 2010. The response of giant kelp (*Macrocystis pyrifera*) in southern California to low-frequency climate forcing. Limnology and Oceanography 55:2686–2702. DOI:10.4319/lo.2010.55.6.2686.

Pascal, N., A. Brathwaite, L. Brander, A. Seidl, M. Philip, and E. Clua. 2018. Evidence of economic benefits for public investment in MPAs. Ecosystem Services 30:3–13. DOI:10.1016/j.ecoser.2017.10.017.

Pelc, R. A., R. R. Warner, S. D. Gaines, and C. B. Paris. 2010. Detecting larval export from marine reserves. Proceedings of the National Academy of Sciences 107:18266–18271. DOI:10.1073/pnas.0907368107.

Peterson St-Laurent, G., S. Hagerman, R. Kozak, and G. Hoberg. 2018. Public perceptions about climate change mitigation in British Columbia’s forest sector. PLOS ONE 13:e0195999. DOI:10.1371/journal.pone.0195999.

Picone, F., E. Buonocore, J. Claudet, R. Chemello, G. F. Russo, and P. P. Franzese. 2020. Marine protected areas overall success evaluation (MOSE): A novel integrated framework for assessing management performance and social-ecological benefits of MPAs. Ocean & Coastal Management 198:105370. DOI:10.1016/j.ocecoaman.2020.105370.

Pita, C., B. Horta e Costa, G. Franco, R. Coelho, I. Sousa, E. J. Gonçalves, J. M. S. Gonçalves, and K. Erzini. 2020. Fisher’s perceptions about a marine protected area over time. Aquaculture and Fisheries 5:273–281. DOI:10.1016/j.aaf.2020.01.005.

Planes, S., G. P. Jones, and S. R. Thorrold. 2009. Larval dispersal connects fish populations in a network of marine protected areas. Proceedings of the National Academy of Sciences 106:5693–5697. DOI:10.1073/pnas.0808007106.

Pollnac, R., P. Christie, J. E. Cinner, T. Dalton, T. M. Daw, G. E. Forrester, N. A. J. Graham, and T. R. McClanahan. 2010. Marine reserves as linked social-ecological systems. Proceedings of the National Academy of Sciences 107:18262–18265. DOI:10.1073/pnas.0908266107.

Pomeroy, C. 2002. Chapter 6: Effectiveness of marine reserves: socio-economic considerations. Page 128. Monterey Bay National Marine Sanctuaries, Moss Landing, CA. https://labs.eemb.ucsb.edu/caselle/jennifer/sites/labs.eemb.ucsb.edu.caselle.jennifer/files/pubs/starr_et_al_part_1.pdf.

Pomeroy, R. S., J. E. Parks, and L. M. Watson. 2004. How is your MPA doing? A guidebook of natural and social indicators for evaluating marine protected areas management effectiveness. IUCN. DOI:10.2305/IUCN.CH.2004.PAPS.1.en.

Pondella, D. I., S. Piacenza, J. Claisse, C. Williams, J. Williams, A. Zellmer, and J. Caselle. 2019. Assessing drivers of rocky reef fish biomass density from the Southern California Bight. Marine Ecology Progress Series 628:125–140. DOI:10.3354/meps13103.

Pontee, N. 2013. Defining coastal squeeze: A discussion. Ocean & Coastal Management 84:204–207. DOI:10.1016/j.ocecoaman.2013.07.010.

Pujolar, J. M., M. Schiavina, A. D. Franco, P. Melià, P. Guidetti, M. Gatto, G. A. D. Leo, and L. Zane. 2013. Understanding the effectiveness of marine protected areas using genetic connectivity patterns and Lagrangian simulations. Diversity and Distributions 19:1531–

1542. DOI:10.1111/ddi.12114.
Punt, A. E., and R. D. Methot. 2004. Effects of marine protected areas on the assessment of marine fisheries. Pages 133–154 Aquatic protected areas as fisheries management tools. American Fisheries Society, Quebec, Canada.
Raffaelli, D., and S. Hawkins. 1999. Human impact on the shore. Pages 214–254 Intertidal Ecology. Springer Netherlands, Dordrecht. DOI:10.1007/978-94-009-1489-6_7.
Raimondi, P. T., C. M. Wilson, R. F. Ambrose, J. M. Engle, and T. E. Minchinton. 2002. Continued declines of black abalone along the coast of California: are mass mortalities related to El Niño events? Marine Ecology Progress Series 242:143–152. DOI:10.3354/meps242143.
Reid, A. J., L. E. Eckert, J. Lane, N. Young, S. G. Hinch, C. T. Darimont, S. J. Cooke, N. C. Ban, and A. Marshall. 2021. "Two-Eyed Seeing": An Indigenous framework to transform fisheries research and management. Fish and Fisheries 22:243–261. DOI:10.1111/faf.12516.
Richerson, K., and D. S. Holland. 2017. Quantifying and predicting responses to a US West Coast salmon fishery closure. ICES Journal of Marine Science 74:2364–2378. DOI:10.1093/icesjms/fsx093.
Roberts, C. M., B. C. O'Leary, D. J. McCauley, P. M. Cury, C. M. Duarte, J. Lubchenco, D. Pauly, A. Sáenz-Arroyo, U. R. Sumaila, R. W. Wilson, B. Worm, and J. C. Castilla. 2017. Marine reserves can mitigate and promote adaptation to climate change. Proceedings of the National Academy of Sciences 114:6167–6175. DOI:10.1073/pnas.1701262114.
Rogers-Bennett, L., and C. A. Catton. 2019. Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. Scientific Reports 9:15050. DOI:10.1038/s41598-019-51114-y.
Ruiz-Frau, A., A. Ospina-Alvarez, S. Villasante, P. Pita, I. Maya-Jariego, and S. de Juan. 2020. Using graph theory and social media data to assess cultural ecosystem services in coastal areas: Method development and application. Ecosystem Services 45:101176. DOI:10.1016/j.ecoser.2020.101176.
Russ, G. R., A. C. Alcala, A. P. Maypa, H. P. Calumpong, and A. T. White. 2004. Marine reserve benefits local fisheries. Ecological Applications 14:597–606. DOI:10.1890/03-5076.
Saarman, E., M. Gleason, J. Ugoretz, S. Airamé, M. Carr, E. Fox, A. Frimodig, T. Mason, and J. Vasques. 2013. The role of science in supporting marine protected area network planning and design in California. Ocean & Coastal Management 74:45–56. DOI:10.1016/j.ocecoaman.2012.08.021.
Saarman, E. T., B. Owens, S. N. Murray, S. B. Weisberg, R. F. Ambrose, J. C. Field, K. J. Nielsen, and M. H. Carr. 2018. An ecological framework for informing permitting decisions on scientific activities in protected areas. PLOS ONE 13:e0199126. DOI:10.1371/journal.pone.0199126.
Saha, B., A. R. Bhowmick, J. Chattopadhyay, and S. Bhattacharya. 2013. On the evidence of an Allee effect in herring populations and consequences for population survival: A model-based study. Ecological Modelling 250:72–80. DOI:10.1016/j.ecolmodel.2012.10.021.
Sahagun, L. 2020, July 17. Crowds removing sea creatures from San Pedro tide pools put delicate ecosystem at risk. Los Angeles Times.
Sala, E., and S. Giakoumi. 2018. No-take marine reserves are the most effective protected areas in the ocean. ICES Journal of Marine Science 75:1166–1168. DOI:10.1093/icesjms/fsx059.
Salomon, A. K., S. K. Gaichas, O. P. Jensen, V. N. Agostini, N. Sloan, J. Rice, T. R. McClanahan, M. H. Ruckelshaus, P. S. Levin, N. K. Dulvy, and E. A. Babcock. 2011. Bridging the divide between fisheries and marine conservation science. Bulletin of Marine Science 87:251–274. DOI:10.5343/bms.2010.1089.
Salz, R. J., and D. K. Loomis. 2004. Saltwater anglers' attitudes towards marine protected areas. Fisheries 29:10–17. DOI:10.1577/1548-8446(2004)29[10:SAATMP]2.0.CO;2.
Salz, R. J., and D. K. Loomis. 2005. Recreation specialization and anglers' attitudes towards restricted fishing areas. Human Dimensions of Wildlife 10:187–199.

DOI:10.1080/10871200591003436.
Samhouri, J. F., S. E. Lester, E. R. Selig, B. S. Halpern, M. J. Fogarty, C. Longo, and K. L. McLeod. 2012. Sea sick? Setting targets to assess ocean health and ecosystem services. Ecosphere 3:art41. DOI:10.1890/ES11-00366.1.
Samhouri, J. F., P. S. Levin, C. Andrew James, J. Kershner, and G. Williams. 2011. Using existing scientific capacity to set targets for ecosystem-based management: A Puget Sound case study. Marine Policy 35:508–518. DOI:10.1016/j.marpol.2010.12.002.
Sanchirico, J., K. Cochran, and P. Emerson. 2002. Marine protected areas: economic and social implications. Discussion Paper, Resources for the Future, Washington, D.C. https://www.cbd.int/doc/case-studies/inc/cs-inc-rf-04-en.pdf.
Sanford, E., J. L. Sones, M. García-Reyes, J. H. R. Goddard, and J. L. Largier. 2019. Widespread shifts in the coastal biota of northern California during the 2014–2016 marine heatwaves. Scientific Reports 9:4216. DOI:10.1038/s41598-019-40784-3.
Sayce, K., C. Shuman, D. Connor, A. Reisewitz, E. Pope, M. Miller-Henson, E. Poncelet, D. Monié, and B. Owens. 2013. Beyond traditional stakeholder engagement: Public participation roles in California's statewide marine protected area planning process. Ocean & Coastal Management 74:57–66. DOI:10.1016/j.ocecoaman.2012.06.012.
Schadeberg, A., M. Kraan, and K. G. Hamon. 2021. Beyond métiers: social factors influence fisher behaviour. ICES Journal of Marine Science:fsab050. DOI:10.1093/icesjms/fsab050.
Schaefer, N., M. Mayer-Pinto, K. J. Griffin, E. L. Johnston, W. Glamore, and K. A. Dafforn. 2020. Predicting the impact of sea-level rise on intertidal rocky shores with remote sensing. Journal of Environmental Management 261:1–9. DOI:10.1016/j.jenvman.2020.110203.
Schultz, P. W., V. V. Gouveia, L. D. Cameron, G. Tankha, P. Schmuck, and M. Franěk. 2005. Values and their relationship to environmental concern and conservation behavior. Journal of Cross-Cultural Psychology 36:457–475. DOI:10.1177/0022022105275962.
Sciberras, M., S. R. Jenkins, M. J. Kaiser, S. J. Hawkins, and A. S. Pullin. 2013. Evaluating the biological effectiveness of fully and partially protected marine areas. Environmental Evidence 2:4. DOI:10.1186/2047-2382-2-4.
Sciberras, M., S. R. Jenkins, R. Mant, M. J. Kaiser, S. J. Hawkins, and A. S. Pullin. 2015. Evaluating the relative conservation value of fully and partially protected marine areas. Fish and Fisheries 16:58–77. DOI:10.1111/faf.12044.
Sievanen, L., J. Phillips, C. Colgan, G. Griggs, J. Finzi Hart, E. Hartge, T. Hill, R. Kudela, N. Mantua, K. Nielsen, and L. Whiteman. 2018. California's coast and ocean summary report. California's Fourth Climate Change Assessment. https://www.middlebury.edu/institute/sites/www.middlebury.edu.institute/files/2018-08/8.27.18-OceanCoastSummary-CharlesColgan-coLead-CenterForTheBlueEconomy.pdf.
Silva, I. M. da, N. Hill, H. Shimadzu, A. M. V. M. Soares, and M. Dornelas. 2015. Spillover effects of a community-managed marine reserve. PLOS ONE 10:e0111774. DOI:10.1371/journal.pone.0111774.
Simpson, A. 2014. Mohawk interruptus: Political life across the borders of settler states. Duke University Press. DOI: 10.1215/9780822376781.
Somero, G. N., J. M. Beers, F. Chan, T. M. Hill, T. Klinger, and S. Y. Litvin. 2016. What changes in the carbonate system, oxygen, and temperature portend for the Northeastern Pacific Ocean: A physiological perspective. BioScience 66:14–26. DOI:10.1093/biosci/biv162.
Sorte, C. J. B., S. L. Williams, and R. A. Zerebecki. 2010. Ocean warming increases threat of invasive species in a marine fouling community. Ecology 91:2198–2204. DOI:10.1890/10-0238.1.
Starr, R. M., D. E. Wendt, C. L. Barnes, C. I. Marks, D. Malone, G. Waltz, K. T. Schmidt, J. Chiu, A. L. Launer, N. C. Hall, and N. Yochum. 2015. Variation in responses of fishes across multiple reserves within a network of marine protected areas in temperate waters. PLOS ONE

10:e0118502. DOI:10.1371/journal.pone.0118502.
Steinmetz, R., S. Srirattanaporn, J. Mor-Tip, and N. Seuaturien. 2014. Can community outreach alleviate poaching pressure and recover wildlife in South-East Asian protected areas? Journal of Applied Ecology 51:1469–1478. DOI:https://doi.org/10.1111/1365-2664.12239.
Steneck, R. S., and M. N. Dethier. 1994. A functional group approach to the structure of algal-dominated communities. Oikos 69:476–498. DOI:10.2307/3545860.
Stoll, J. S., H. L. Harrison, E. De Sousa, D. Callaway, M. Collier, K. Harrell, B. Jones, J. Kastlunger, E. Kramer, S. Kurian, A. Lovewell, S. Strobel, T. Sylvester, B. Tolley, A. Tomlinson, E. R. White, T. Young, and P. A. Loring. 2020. Alternative seafood networks during COVID-19: Implications for resilience and sustainability. preprint, EcoEvoRxiv. DOI:10.32942/osf.io/kuzwq.
Symes, D., and J. Phillipson. 2009. Whatever became of social objectives in fisheries policy? Fisheries Research 95:1–5. DOI:10.1016/j.fishres.2008.08.001.
Tegner, M. J., and P. Dayton K. 1987. El Niño effects on Southern California kelp forest communities. Advances in Ecological Research 17:243–279. DOI:10.1016/S0065-2504(08)60247-0.
Thomson, C. J. 2015. California's commercial fisheries: 1981-2012. Marine Fisheries Review 77:48–72. DOI:10.7755/MFR.77.3.5.
Tiakiwai, S.-J., J. T. Kilgour, and A. Whetu. 2017. Indigenous perspectives of ecosystem-based management and co-governance in the Pacific Northwest: lessons for Aotearoa. AlterNative: An International Journal of Indigenous Peoples 13:69–79. DOI:10.1177/1177180117701692.
Truelove, N. K., S. Griffiths, K. Ley-Cooper, J. Azueta, I. Majil, S. J. Box, D. C. Behringer, M. J. Butler, and R. F. Preziosi. 2015. Genetic evidence from the spiny lobster fishery supports international cooperation among Central American marine protected areas. Conservation Genetics 16:347–358. DOI:10.1007/s10592-014-0662-4.
UNEP, editor. 2010. Mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of teeb. UNEP, Geneva. ISBN:978-3-9813410-3-4.
Van Pelt, M., H. Rosales, R. Sundberg, T. Torma, C. Chen, J. Steinruck, R. Laucci, J. Rohde, J. Ben, S. Comet, T. Hernandez, and D. Seminara. 2017. Informing the north coast MPA baseline: traditional ecological knowledge of keystone marine species and ecosystems. North Coast MPA Baseline.
Voyer, M., W. Gladstone, and H. Goodall. 2012. Methods of social assessment in Marine Protected Area planning: Is public participation enough? Marine Policy 36:432–439. DOI:10.1016/j.marpol.2011.08.002.
Wagner, L. D., J. V. Ross, and H. P. Possingham. 2007. Catastrophe management and inter-reserve distance for marine reserve networks. Ecological Modelling 201:82–88. DOI:10.1016/j.ecolmodel.2006.07.030.
Wahle, C. 2014, March 25. MPAs and recreation: being a special place can be a double-edged sword. National Marine Protected Area Center. https://marineprotectedareas.noaa.gov/aboutmpas/perspectives/mpas-and-recreation.html.
Walmsley, S. F., and A. T. White. 2003. Influence of social, management and enforcement factors on the long-term ecological effects of marine sanctuaries. Environmental Conservation 30:388–407. DOI:10.1017/S0376892903000407.
Warner, R. R., S. E. Swearer, and J. E. Caselle. 2000. Larval accumulation and retention: implications for the design of marine reserves and essential habitat. Bulletin of Marine Science 66:821–830. https://www.ingentaconnect.com/content/umrsmas/bullmar/2000/00000066/00000003/art00022.
Watson, J. R., S. Mitarai, D. A. Siegel, J. E. Caselle, C. Dong, and J. C. McWilliams. 2010. Realized

and potential larval connectivity in the Southern California Bight. Marine Ecology Progress Series 401:31–48. DOI:10.3354/meps08376.

Watson, S.-A., J. B. Fields, and P. L. Munday. 2017. Ocean acidification alters predator behaviour and reduces predation rate. Biology Letters 13:20160797. DOI:10.1098/rsbl.2016.0797.

Wernberg, T., S. Bennett, R. C. Babcock, T. de Bettignies, K. Cure, M. Depczynski, F. Dufois, J. Fromont, C. J. Fulton, R. K. Hovey, E. S. Harvey, T. H. Holmes, G. A. Kendrick, B. Radford, J. Santana-Garcon, B. J. Saunders, D. A. Smale, M. S. Thomsen, C. A. Tuckett, F. Tuya, M. A. Vanderklift, and S. Wilson. 2016. Climate-driven regime shift of a temperate marine ecosystem. Science 353:169–172. DOI:10.1126/science.aad8745.

White, E. R., M. L. Baskett, and A. Hastings. 2021. Catastrophes, connectivity and Allee effects in the design of marine reserve networks. Oikos 130:366–376. DOI:10.1111/oik.07770.

White, J. W., L. W. Botsford, M. L. Baskett, L. A. Barnett, R. J. Barr, and A. Hastings. 2011. Linking models with monitoring data for assessing performance of no-take marine reserves. Frontiers in Ecology and the Environment 9:390–399. DOI:10.1890/100138.

White, J. W., L. W. Botsford, A. Hastings, M. L. Baskett, D. M. Kaplan, and L. A. K. Barnett. 2013a. Transient responses of fished populations to marine reserve establishment. Conservation Letters 6:180–191. DOI:10.1111/j.1755-263X.2012.00295.x.

White, J. W., K. J. Nickols, D. Malone, M. H. Carr, R. M. Starr, F. Cordoleani, M. L. Baskett, A. Hastings, and L. W. Botsford. 2016. Fitting state-space integral projection models to size-structured time series data to estimate unknown parameters. Ecological applications : a publication of the Ecological Society of America 26:2675–2692. DOI:10.1002/eap.1398.

White, J. W., A. J. Scholz, A. Rassweiler, C. Steinback, L. W. Botsford, S. Kruse, C. Costello, S. Mitarai, D. A. Siegel, P. T. Drake, and C. A. Edwards. 2013b. A comparison of approaches used for economic analysis in marine protected area network planning in California. Ocean & Coastal Management 74:77–89. DOI:10.1016/j.ocecoaman.2012.06.006.

White, J. W., M. T. Yamane, K. J. Nickols, and J. E. Caselle. 2020. Analysis of fish population size distributions confirms cessation of fishing in marine protected areas. Conservation Letters. DOI:10.1111/conl.12775.

Woodhouse, E., K. M. Homewood, E. Beauchamp, T. Clements, J. T. McCabe, D. Wilkie, and E. J. Milner-Gulland. 2015. Guiding principles for evaluating the impacts of conservation interventions on human well-being. Philosophical Transactions of the Royal Society B: Biological Sciences 370:20150103. DOI:10.1098/rstb.2015.0103.

Young, M., and M. Carr. 2015. Assessment of habitat representation across a network of marine protected areas with implications for the spatial design of monitoring. PLOS ONE 10:e0116200. DOI:10.1371/journal.pone.0116200.

Zacherl, D. C. 2005. Spatial and temporal variation in statolith and protoconch trace elements as natural tags to track larval dispersal. Marine Ecology Progress Series 290:145–163. DOI:10.3354/meps290145.

Zupan, M., E. Fragkopoulou, J. Claudet, K. Erzini, B. Horta e Costa, and E. J. Gonçalves. 2018. Marine partially protected areas: drivers of ecological effectiveness. Frontiers in Ecology and the Environment 16:381–387. DOI:10.1002/fee.1934.

APPENDIX 1: TABLE OF QUESTIONS FROM THE ECOLOGICAL DOMAIN

Questions from Appendix B of the Action Plan that fall within the ecological domain are presented here with proposed wording changes that either refine the questions to more clearly specify response variables and predicted responses, or extend the questions to additional topics of interest for MPA evaluation. Rationale for these question changes are presented, along with potential considerations to be taken into account during analyses. The final column indicates those questions that have been proposed to be addressed by ongoing monitoring programs, and which programs proposed to address them.

MLPA Goal	Question #	Original Question	Question Refinement or Extension	Rationale for Question Changes	Considerations	Proposed to be Addressed by Ongoing Monitoring Programs
MPA PERFORMANCE- POPULATIONS						
G1	1a	[Original] Do focal and/or protected species inside of MPAs differ in size, numbers, and biomass relative to reference sites?	[Refined] Does the difference between MPAs and reference sites in the size of individuals of a focal and/or protected species increase over time?	Clarify, rephrase, and focus the question. Focus question on trajectories in the size of individuals of focal and/or protected species.	Inside-outside response ratio trajectories over time. Multiple ways to measure size can be explored: mean, median, distribution, upper quartile, proportion above minimum fished size, etc. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	1b		[Refined] Does the difference between MPAs and reference sites in density (or proportionate cover) of a focal and/or protected	Focus question on trajectories in the abundances (density or cover) of focal and/or	Inside-outside response ratio trajectories over time. Might look not just at total density, but density of mature individuals or those greater than the minimum fished size. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)

			species increase over time?	protected species.	establishment fishing data for MPAs and adjacent reference sites.	
G1	**1c**		[Refined] Does the difference between MPAs and reference sites in biomass of a focal and/or protected species increase over time?	Focus question on trajectories in the biomass of focal and/or protected species.	Inside-outside response ratio trajectories over time. Requires species-specific size-biomass relationships. Might look not just at total biomass, but biomass of mature individuals or those greater than the minimum fished size. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	**1d**		[Extended] Does the difference between MPAs and reference sites in larval production of a focal and/or protected species increase over time?	Extend question to include the ecological function of larval export.	Inside-outside response ratio trajectories over time. Requires species-specific size-fecundity relationships or biomass of mature individuals for relative larval production. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	**1e**		[Extended] Does the difference between MPAs and reference sites in genetic diversity of a focal and/or	Extend to include the ecological function of genetic biodiversity.	Inside-outside response ratio trajectories over time. Requires a measure of genetic diversity. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)

			protected species increase over time?		establishment fishing data for MPAs and adjacent reference sites.	
G1	**1f**		[Extended] Does the difference between MPAs and reference sites in the size and age structure of populations of a focal and/or protected species increase over time?	Extend original size question to consideration of population demographics.	Inside-outside response ratio trajectories over time. Similar to 1a except looking at populations of individual species and groups of species. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	**1g**		[Extended] Does the difference between MPAs and reference sites in overall biomass of focal and/or protected species increase over time?	Extend original biomass question to an aggregation of all focal and/or protected species.	Inside-outside response ratio trajectories over time. Similar to 1c except looking at overall biomass of focal or protected species. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	**1h**		[Extended] Does the difference between MPAs and reference sites in overall biomass of fished species increase over time relative to species that are not fished?	Extend original biomass question to aggregations of all fished and unfished species.	Inside-outside response ratio trajectories over time. Similar to 1c except looking at overall biomass of fished vs. unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)

G1	**4a**	[Original] Do the abundance, size/age structure, and/or diversity of predator and prey species differ inside MPAs, or outside areas of comparable habitat?	[Refined] Does the difference between MPAs and reference sites in the density of predators whose prey are fished increase over time?	Clarify that the focus of this question is the relationship between predators and their specific prey and how MPAs can alter this relationship by reducing fishing mortality. Focus question on the density of predators whose prey are fished.	Inside-outside response ratio trajectories over time. Might look at individual species or aggregate by fished/unfished predator species whose prey are fished. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	**4b**		[Refined] Does the difference between MPAs and reference areas in the density of prey whose predators are fished increase over time?	Focus question on the density of prey whose predators are fished.	Inside-outside response ratio trajectories over time. Might look at individual species or aggregate by fished/unfished prey species whose predators are fished. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)

G1	4c		[Refined] Does the difference between MPAs and reference sites in the size/age structure of predators whose prey are fished increase over time?	Extend original predator/prey density question to include size/age structure.	Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	4d		[Refined] Does the difference between MPAs and reference sites in the size/age structure of prey whose predators are fished increase over time?	Extend original predator/prey density question to include size/age structure.	Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	4e		[Refined] Does the difference between MPAs and reference sites in the diversity of predators whose prey are fished increase over time?	Extend original predator/prey density question to include diversity considerations.	Inside-outside response ratio trajectories over time. Calculation of predator diversity and prey diversity (possibly species richness, evenness, and diversity indices). Use biomass or density of each species to calculate taxonomic diversity of either predators or prey. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)

G1	**4f**		[Refined] Does the difference between MPAs and reference sites in the diversity of prey whose predators are fished increase over time?	Extend original predator/prey density question to include diversity considerations.	Inside-outside response ratio trajectories over time. Calculation of predator diversity and prey diversity (possibly species richness, evenness, and diversity indices). Use biomass or density of each species to calculate taxonomic diversity of either predators or prey. Might look at individual species or aggregate by fished/unfished species. Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G2	**7a**	[Original] How do species differ in their rate of response to MPA implementation?	[Refined] How does the mean rate of response in abundance and size/age structure differ among species?	Clarify the analytical design of MPA-reference site comparisons over time to include specific response variables.	Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Would benefit from abundance and size/age structure data for targeted species pre-MPA establishment where available. Might look at individual species or aggregate by fished/unfished species. Would benefit greatly from pre- MPA establishment fishing data for MPAs and adjacent reference sites. Would benefit from fundamental life history information associated with population growth rates, including home range size and rates of propagule recruitment, to explain differences in species response rates.	Yes (InterT, KF, ROV, Beach, CCFRP & IOOS)

G2	7b		[Extended] How do changes in abundance and size/age structure differ among species? (assess within an MPA)	Extend question to include consideratio n of absolute changes in abundance and size/age structure among examined species.	Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Might look at individual species or breakout by fished/unfished species. Would greatly benefit from pre- MPA establishment fishing data for MPAs and adjacent reference sites. Would benefit from fundamental life history information associated with population growth rates, including home range size and rates of propagule recruitment, to explain differences in species response rates.	Yes (InterT, KF, ROV, Beach, CCFRP & IOOS)
G2	7c		[Extended]: Are differences in rate of species responses to MPA establishment related to life history (longevity, homerange, dispersal distances) or demographic variables?	Extend question to include consideratio n of life history differences and demographi c variables among examined species.	Inside-outside response ratio trajectories over time. Might look at individual species or breakout by fished/unfished species. Would benefit greatly from pre- MPA establishment fishing data for MPAs and adjacent reference sites. Would benefit from fundamental life history information associated with population growth rates, including home range size and rates of propagule recruitment, to explain differences in species response rates.	Yes (InterT, KF, ROV, Beach, CCFRP & IOOS)
G3	20a	[Original] Are the size/age structure of recreation ally valued species increasing in MPAs over time?	[Refined] Has the difference between MPAs and reference areas in the size/age structure of recreationally fished species increased over time?	Clarify the analytical design to include specific response variables. Focus question on size and age	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Might look at individual species or breakout by fished/unfished species. [This question is the same as Question 1a but applied to particular species.]	Yes (InterT, KF, ROV, Beach, CCFRP, IOOS & Estuaries)

				structure of recreationally fished species.		
G3	20b		[Refined] Has the difference between MPAs and reference areas in the mean size of recreationally fished species increased over time?	Focus question on mean size of recreationally fished species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Might look at individual species or breakout by fished/unfished species. [This question is the same as Question 1a but applied to particular species.]	Yes (InterT, KF, ROV, Beach, CCFRP, IOOS & Estuaries)
G3	20c		[Extended] Has the difference between MPAs and reference areas in the size/age structure of culturally valued species increased over time? (non-consumptive species)	Extend question to focus on size and age structure of unfished culturally valued species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Might look at individual species or breakout by fished/unfished species. [This question is the same as Question 1a but applied to particular species.]	Yes (InterT, KF, ROV, Beach, CCFRP, IOOS & Estuaries)

G3	20d		[Extended] Has the difference between MPAs and reference areas in the mean size of culturally valued species increased over time? (non-consumptive species)	Extend question to focus on mean size of unfished culturally valued species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Might look at individual species or breakout by fished/unfished species. [This question is the same as Question 1a but applied to particular species.]	Yes (InterT, KF, ROV, Beach, CCFRP, IOOS & Estuaries)
G4	23a	[Original] Have endangered species and/or culturally significant species benefited from the presence of California's MPAs? (See list of endangered and culturally significant species in column D of notes tab)	[Refined] Has the difference between MPAs and reference areas in the abundance of endangered species increased over time?	Clarify the analytical design to include specific response variables. Focus question on abundance of endangered species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Likely evaluate by individual species. [This question is the same as Question 1b but applied to particular species.]	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G4	23b		[Refined] Has the difference between MPAs and reference areas in the abundance of culturally significant species increased over time? (e.g. species used by the Tribes)	Focus question on abundance of culturally significant species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Likely evaluate by individual species. [This question is the same as Question 1b but applied to particular species.]	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)

G4	**23c**		[Refined] Has the difference between MPAs and reference areas in the size/age structure of endangered species increased over time?	Focus question on size/age structure of endangered species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Likely evaluate by individual species. [This question is the same as Question 1a but applied to particular species.]	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G4	**23d**		[Refined] Has the difference between MPAs and reference areas in the size/age structure of culturally significant species increased over time? (e.g. species used by the Tribes)	Focus question on size/age structure of culturally significant species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Likely evaluate by individual species. [This question is the same as Question 1a but applied to particular species.]	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G5	**32a**	[Original] Do State Marine Reserve (SMR)/State Marine Conservation Area(SMCA) clusters provide greater protection than stand-alone SMRs?	[Refined] Is there an increase over time in the difference between MPAs and reference sites in abundance (density, cover, biomass) of focal species and if so is the difference in combined SMR/SMCA clusters greater than in stand-alone MPAs of similar size and protection?	Clarify the analytical design to include specific response variables. Focus question on abundance of focal species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Test for differences in responses between stand-alone MPAs and clusters. Might look at individual species or aggregate by fished/unfished species.	Yes (InterT, KF, ROV, Beach, CCFRP & Rec CPUE)

	32b		[Refined] Is there an increase over time in the difference between MPAs and reference sites in size/age structure of focal species and if so is the difference in combined SMR/SMCA clusters greater than in stand-alone MPAs of similar size and protection?	Focus question on size/age structure of focal species.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Might look at individual species or aggregate by fished/unfished species.	Yes (InterT, KF, ROV, Beach, CCFRP & Rec CPUE)
	32c		[Refined] Is there an increase over time in the difference between MPAs and reference sites in abundance (density, cover, biomass) of focal species and if so are there differences between SMR and SMCAs of similar size?	Extend question to consider differences in abundances of focal species between SMRs and SMCAs.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Might look at individual species or breakout by fished/unfished species. Consider using "level of protection" for SMCAs.	Yes (InterT, KF, ROV, Beach, CCFRP & Rec CPUE)

	32d		[Refined] Is there an increase over time in the difference between MPAs and reference sites in size/age structure of focal species and if so and if so are there differences between SMR and SMCAs of similar size?	Extend question to consider differences in size/age structure of focal species between SMRs and SMCAs.	Would benefit from pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Multiple ways to consider size/age structure. Might look at individual species or breakout by fished/unfished species. Consider using "level of protection" for SMCAs.	Yes (InterT, KF, ROV, Beach, CCFRP & Rec CPUE)
MPA PERFORMANCE – COMMUNITIES & ECOSYSTEMS						
G1	2a	[Original] Does functional diversity differ in MPAs relative to reference sites?	[Refined] Does the difference between MPAs and reference sites in species diversity within any given functional group increase over time?	Clarify the analytical design to include specific response variables. Focus question on diversity within functional groups.	Would benefit from pre- and post-MPA establishment diversity and fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Multiple ways to calculate diversity (species richness, evenness, or diversity indices). Multiple ways to consider functional group categorization. Might look at fished/unfished species where appropriate.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)
G1	2b		[Refined] Does the difference between MPAs and reference sites in the diversity of functional groups increase over time?	Focus question on the diversity of functional groups.	Would benefit from pre- and post-MPA establishment diversity and fishing data for MPAs and adjacent reference sites. Inside-outside response ratio trajectories over time. Multiple ways to calculate diversity (species richness, evenness, or diversity indices). Multiple ways to consider functional group categorization.	Yes (InterT, KF, ROV, Beach, CCFRP & Estuaries)

					Might look at fished/unfished species where appropriate.	
G1	**3a**	[Original] Do MPAs that include multiple habitat types harbor higher species abundance or more diverse communities than those that encompass a single habitat type or less diverse habitat types?	[Refined] Is there a positive relationship between the density (cover or biomass) of any given focal species and habitat diversity across MPAs of similar protection levels?	Clarify the analytical design to include specific response variables. Focus question on density (cover or biomass) of focal species.	Inside-outside response ratio trajectories over time. Requires data on habitat diversity of appropriate scale. Might look at fished/unfished species where appropriate. Multiple ways to calculate habitat diversity (richness or diversity). Could benefit from pre- and post-MPA establishment density data for MPAs and adjacent reference sites. Test for relationship (regression) between species abundance and richness or diversity of habitats across MPAs.	Yes (InterT, KF, ROV, Beach & CCFRP)
G1	**3b**		[Refined] Is there a positive relationship between species diversity and habitat diversity across MPAs of similar protection levels?	Focus question on species diversity.	Inside-outside response ratio trajectories over time. Requires data on habitat diversity of appropriate scale. Might look at fished/unfished species where appropriate. Multiple ways to calculate species and habitat diversity (richness or diversity). Could benefit from pre- and post-MPA establishment diversity data for MPAs and adjacent reference sites. Test for relationship (regression) between species richness or diversity and diversity of habitats across MPAs.	Yes (InterT, KF, ROV, Beach & CCFRP)

G1	3c		[Refined] Is there a positive relationship between species diversity within a habitat/ecosystem and habitat diversity across MPAs of similar protection levels?	Focus question on species and habitat diversity.	Inside-outside response ratio trajectories over time. Requires data on habitat diversity of appropriate scale. Might look at fished/unfished species where appropriate. Multiple ways to calculate species and habitat diversity. Could benefit from pre- and post-MPA establishment diversity data for MPAs and adjacent reference sites.	Yes (InterT, KF, ROV, Beach & CCFRP)
G1	5a	Does the nature or timing of recovery of natural communities from disturbance events differ in different types of MPAs relative to outside areas?	[Refined] Does the nature of recovery of natural communities from disturbance events differ in MPAs relative to outside reference sites?	Clarify the analytical design to include specific response variables. Focus question on the nature of community recovery.	Inside-outside response ratio trajectories over time. Might look at fished/unfished species and their community roles where appropriate. Would benefit from pre- disturbance community level data for MPAs and adjacent reference sites. Consider definition and metrics of recovery.	Yes (InterT, KF, ROV, CCFRP, IOOS & Estuaries)
G1	5b		[Refined] Does the timing of recovery of natural communities from disturbance events differ in MPAs relative to outside reference sites?	Focus question on the rate of community recovery.	Inside-outside response ratio trajectories over time. Might look at fished/unfished species and their community roles where appropriate. Would benefit from pre- disturbance community level data for MPAs and adjacent reference sites. Consider definition and metrics of recovery.	Yes (InterT, KF, ROV, CCFRP, IOOS & Estuaries)

G1	**5c**		[Refined] Does the nature of recovery of natural communities from disturbance events differ in MPAs with different levels of protection?	Focus question on the nature of community recovery and level of protection of MPAs.	Inside-outside response ratio trajectories over time. Might look at fished/unfished species and their community roles where appropriate. Would benefit from pre- disturbance community level data for MPAs and adjacent reference sites. Consider definition and metrics of recovery.	Yes (InterT, KF, ROV, CCFRP, IOOS & Estuaries)
G1	**5d**		[Refined] Does the timing of recovery of natural communities from disturbance events differ in MPAs with different levels of protection?	Focus question on the rate of community recovery and level of protection of MPAs.	Inside-outside response ratio trajectories over time. Might look at fished/unfished species and their community roles where appropriate. Would benefit from pre- disturbance community level data for MPAs and adjacent reference sites. Consider definition and metrics of recovery.	Yes (InterT, KF, ROV, CCFRP, IOOS & Estuaries)
G1	**5e**		[Extended] Do MPAs contribute to the recovery of impacted ecosystems?	Focus question on the community recovery in impacted ecosystems.	Inside-outside response ratio trajectories over time. Might look at fished/unfished species and their community roles where appropriate. Would benefit from pre- disturbance community level data for MPAs and adjacent reference sites. Consider the nature of impacted ecosystem and definition of recovery.	Yes (InterT, KF, ROV, CCFRP, IOOS & Estuaries)
G4	**21**	[Original] Have unique habitats been adequately represented and protected by the current distribution and designation of MPAs?		No changes	Consider definition of unique habitats. Requires spatial data on distribution of unique habitats.	Yes (ROV, IOOS, Estuaries & Connectivity)

G4	**22**	[Original] Does the abundance or quality of habitat (geologic, oceanographic, biogenic) increase or remain the same within an MPA?	[Refined] How has the abundance or quality of habitat (geologic, oceanographic, biogenic) changed within MPAs?	Clarify and rephrase the question for greater specificity.	Consider definition of habitat quality. Requires spatial data on distribution of geologic, oceanographic and biogenic habitats.	Yes (InterT, KF, ROV, Beach, Estuaries & Connectivity)
G4	**24**	[Original] Do MPAs limit the spread of invasive species?	[Refined] Is the rate of invasion (i.e. increase in population size) of invasive species lower in MPAs compared to reference areas?	Clarify and rephrase the question for greater specificity.	Requires identification of invasive species and their abundances in and outside of MPAs. Inside-outside response ratio trajectories over time. Might look at fished/unfished species and their community roles where appropriate. Would benefit from historical data on species abundances for MPAs and adjacent reference sites.	Yes (KF, ROV, Beach & Estuaries)
NETWORK PERFORMANCE - POPULATIONS						
G2	**10a**	[Original] What is the rate and distribution of adult spillover of targeted fishery species from MPAs	[Refined] Is adult abundance of targeted fishery species higher in areas adjacent to MPAs than areas farther from MPAs? (distribution of adult spillover)	Clarify, focus, and rephrase the question. Focus question on spatial differences in spillover with reference to MPAs.	Requires data on targeted fishery species across a spatial gradient representing distance from MPAs. Could look at mean rate of movement of tagged animals both directions across MPA boundaries to test for net directional movement, or cohort analysis of untagged animals. Might look at fished/unfished species	Yes (CCFRP)

G2	**10b**	into adjacent areas?	[Refined] How has adult abundance of targeted fishery species changed over time in relationship to distance from MPAs? (rate of adult spillover)	Focus question on abundances of fishery species (spillover) over time in relation to distance from MPAs.	Requires time series data on targeted fishery species across a spatial gradient representing distance from MPAs. Might look at aggregate fished and unfished species.	Yes (CCFRP)
G2	**10c**		[Extended]: How does adult spillover vary with species density inside MPAs?	Focus question on variations in spillover of fishery species as a function of density inside MPAs.	Requires density data on targeted fishery species inside MPAs and also across a spatial gradient representing distance from MPAs. Might look at aggregate fished and unfished species.	Yes (CCFRP)
G6	**34a**	[Original] What are the demographic effects of siting MPAs in larval source or sink locations,	[Refined] What are the metapopulation dynamic consequences of siting MPAs in locations associated with high larval export vs. high larval import?	Clarify, focus, and rephrase the question. Focus question on areas of high larval export and low larval import.	Requires data on the demographics of species. Requires data on degree of larval export and import. Multiple ways to collect and analyze demographic data. Consider the number of populations to be analyzed and efficacy of larval production and range of larval distribution. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (InterT, IOOS & Connectivity)

G6	**34b**	and how do demographic responses to MPAs contribute to larval production and connectivity?	[Refined] How does MPA siting affect the value or contribution (in terms of metapopulation growth rate or resilience) of that MPA to the MPA network?	Focus question on contributions of specific MPAs to the network based on connectivity expectations.	Requires time series data the demographics of species in order to calculate growth rate. Requires data on degree of larval export and import. Multiple ways to collect and analyze demographic data. Consider the number of populations to be analyzed and efficacy of larval production and range of larval distribution. Data from multiple MPAs required to estimate the value of an individual MPA. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (InterT, IOOS & Connectivity)
G6	**34c**		[Refined] How do demographic responses of populations within MPAs contribute to larval production?	Focus question on how population demographics affect larval export in specific MPAs.	Requires data on the demographics of species and how these demographics change in relation to MPA protection. Consider inside and outside MPA responses. Requires data on degree of larval production as a function of population demography. Multiple ways to collect and analyze demographic data. Consider the number of populations to be analyzed. Data from multiple MPAs required to estimate the value of an individual MPA.	Yes (InterT, IOOS & Connectivity)

G6	**34d**		[Refined] How do demographic responses of populations within MPAs contribute to larval connectivity?	Focus question on how population demographics in specific MPAs affect larval connectivity in the network.	Requires data on the demographics of species. Consider inside and outside MPA responses. Requires data on degree of larval production as a function of population demography. Requires data on connectivity among assessed MPAs. Multiple ways to collect and analyze demographic data. Consider the number of populations to be analyzed. Data from multiple MPAs required to estimate the value of an individual MPA. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (InterT, IOOS & Connectivity)
G6	**39**	[Original] Do MPAs with higher connectivity have lower variability in population trends compared to more isolated MPAs?	[Refined] Do high-connectivity populations within MPAs have lower temporal variability compared to low-connectivity populations within MPAs?	Clarify, focus, and rephrase the question.	Requires time series data on species populations (abundance, demographics) and related data on the magnitude of connectivity for these populations within an MPA. Consider inside and outside MPA responses. Requires data on degree of larval import to population within an MPA. Multiple ways to collect and analyze demographic data. Consider the number of populations to be analyzed. Data from multiple reference sites and MPAs required to estimate the role of connectivity and larval supply in structuring populations within an individual MPA. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (InterT, IOOS, Estuaries & Connectivity)

NETWORK PERFORMANCE - ECOSYSTEMS						
G6	35a	[Original] How does the distance and larval contribution between a source MPA and sink MPA influence the ecosystem response inside the sink MPA?	[Refined] How does the larval contribution between an origin and destination MPA influence the structure of ecological communities inside the destination MPA?	Clarify, focus, and rephrase the question. Focus question on structural attributes of ecological communities inside an MPA.	Requires data on the structure of ecological communities and related data on the magnitude of connectivity of populations in these communities from one MPA to another. Consider inside and outside MPA responses. Requires data on degree of larval export from one MPA and degree of larval import to a destination MPA. Consider the number of populations within the community to be sampled. Data from multiple MPA pairs required to estimate the role of connectivity and larval supply in structuring communities within a destination MPA. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (InterT, IOOS & Connectivity)
G6	35b		[Refined] How does the larval contribution between an origin and destination MPA influence the dynamics, including resilience, of ecological communities inside the destination MPA?	Clarify, focus, and rephrase the question. Focus question on the dynamics of ecological communities, including their resilience, inside an MPA.	Requires data on the structure of ecological communities and related data on the magnitude of connectivity of populations in these communities from one MPA to another. Consider inside and outside MPA responses. Requires data on degree of larval export from one MPA and degree of larval import to a destination MPA. Consider the number of populations within the community to be sampled. Consider method of measuring and expressing resilience. Data from multiple MPA pairs required to estimate the role of connectivity and larval supply in structuring communities within a destination MPA. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (InterT, IOOS & Connectivity)

G6	**37a**	[Original] Are MPAs with higher connectivity more resilient to sudden environmental disturbance as compared to more isolated MPAs with higher self-retention?	[Refined] Do high-connectivity populations within MPAs have greater resilience to spatially discrete short-term disturbances than low-connectivity populations?	Clarify, focus, and rephrase the question. Focus question on the resilience of ecological communities in response to short term spatially discrete disturbances.	Requires data on the populations and related data on the magnitude of connectivity of populations from one MPA to another. Consider inside and outside MPA responses. Consider obtaining demographic data on populations of interest. Requires data on degree of larval export from one MPA and degree of larval import to a destination MPA. Consider the number of populations to be sampled. Consider method of measuring and expressing resilience. Data from multiple MPA pairs required to estimate the role of connectivity and larval supply in structuring populations within a destination MPA. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (InterT, KF, ROV, CCFRP, IOOS, Estuaries & Connectivity)

G6	**37b**		[Refined] Do populations with greater self-recruitment in MPAs exhibit greater resilience to spatially discrete short-term disturbances than populations with less self-recruitment?	Focus question on the role of self-recruitment in MPAs and resilience in response to short term spatially discrete distrubances.	Requires data on the populations and related data on the magnitude of connectivity of populations and the proportion of recruitment within an MPA (self-recruitment) and from one MPA to another. Consider Inside and outside MPA responses. Consider obtaining demographic data on populations of interest. Requires data on degree of larval export from one MPA and degree of larval import to a destination MPA and amount of self-recruitment within an MPA. Consider the number of populations to be sampled. Consider method of measuring and expressing resilience. Data from multiple MPA pairs required to estimate the role of connectivity and larval supply in structuring populations within a destination MPA. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (InterT, KF, ROV, CCFRP, IOOS, Estuaries & Connectivity)

APPENDIX 2: TABLE OF QUESTIONS FROM THE HUMAN AND GOVERNANCE DOMAINS

Questions posed in this report that fall within the human and governance domains are presented here. Some questions are newly proposed (indicated as [New]), while others originate in Appendix B of the Action Plan with some wording refinements or extensions. Rationale for these question changes are presented, along with potential considerations to be taken into account during analyses. As many of the human and governance questions from Appendix B of the Action Plan were narrowly focused on specific stakeholder groups, these are indicated as "Example subquestions". The final column indicates those questions that have been proposed to be addressed by ongoing monitoring programs, and which programs proposed to address them.

Question #	Proposed Human and Governance Questions	Rationale for Question Changes	Considerations	Subquestion #	Example Subquestions from Action Plan Appendix B and Beyond	Proposed to be Addressed by Ongoing Monitoring Programs
HUMAN DOMAIN						
CHANGES IN BEHAVIOR AND USE						
N1	[New] Which stakeholder groups are accessing MPAs and adjacent non-MPA reference sites?	MPA and coastal access is of interest across a diversity of stakeholder groups, and this broadens the scope to	Potential data sources will depend on the stakeholder group in question: - MPA watch data could provide information about some user groups and will be especially useful if there is adequate data from non-MPA reference sites. - Scientific collecting permit data (from CDFW) should reveal information about research inside and outside MPAs, but	14	[Original] Are researchers accessing MPAs, and has research increased over time in MPAs?	No
				14a	[Refined] Are researchers accessing MPAs?	No

		include that diversity.	there may be spatial mismatches, and only consumptive research that results in take of organisms will be reflected in these data. - Surveys could also prove useful here. - There is likely a need for new data collection efforts to answer this question.	N1a	[New] Are coastal residents (and non-coastal residents) accessing MPAs? For what types of activities?	No
N2	[New] Has use of MPAs and reference sites changed over time, and why?	Changes in use of MPAs and reference is of interest across a diversity of stakeholder groups; this unites a number of similar questions from Appendix B to ask broadly about changes in use.	Assessing changes in use over time is especially challenging due to differences in the quantity and quality of use data available from different time periods. Metrics of use should be carefully considered, will depend on characteristic of the source data, and should consider influencing factors (e.g., ease of access, weather, etc.); this is especially true with respect to changes over time. Unless the "why" is analyzed, there is no way to determine what caused changes over time. Potential data sources will depend on the stakeholder group in question: - MPA Watch could provide information about some user groups. - "Big data" techniques should be considered including using social media to quantify tourism and recreation uses in MPAs and other areas (e.g., Wood et al. 2013). - Scientific collecting permit data (from CDFW) should reveal information about	14b	[Refined] How has MPA use by researchers changed over time?	No
				15	[Original] Has the magnitude and variety of recreational/educational use increased over time in MPAs?	Yes (CDFW non-consumptive)
				15a	[Refined] Has the magnitude and variety of recreational use in MPAs changed over time? Why?	
				15b	[Refined] Has the magnitude and variety of educational use in MPAs changed over time? Why?	Yes (CDFW non-consumptive)
				16	[Original] How has non-consumptive use and enjoyment of marine ecosystems changed since MPA implementation? Has the public's perceived value or desire to visit the areas where the MPAs have	Yes (CDFW non-consumptive)

			research inside and outside MPAs, but there may be spatial mismatches, and only consumptive research that results in take of organisms will be reflected in these data. - Surveys could also prove useful here. - There is likely a need for new data collection efforts to answer this question.		been implemented changed due to their presence?	
				16a	[Refined] How has non-consumptive use of marine ecosystems (in MPAs) changed since MPA implementation?	Yes (CDFW non-consumptive)
N3	[New] How do the demographics of those who use MPAs and reference sites compare to state demographics?	This focuses on how equitably (or not) use of MPAs is distributed across California's citizens.	Existing census data are already collected at various spatial scales to summarize state demographics, and this could be compared to demographic data gathered from those who use MPAs.			No
N4	[New] Are there groups that disproportionately access or don't access MPAs and reference sites, and why?	This focuses on why MPA use may not be equitably distributed.	Comparison of state demographics and demographics of MPA users will be key to answering this question. The "why" question is essential for evaluation and to know what action to take to encourage more equitable MPA use.			No
N5	[New] What stakeholders engage with CDFW and the MPA management	This focuses on engagement as a conversation between	Focused qualitative research is needed. CDFW may have records from public meetings that could be mined for information about stakeholder participation/engagement and might	N5a	[New] What recreational non-consumptive users enage with CDFW and the MPA management program, how do they engage, and why?	Possibly (CDFW)

	program, how do they engage, and why?	stakeholders and managers and seeks to identify factors that are correlated with stakeholder engagement	provide insight into the some of the concerns about how stakeholder engagement did or did not work and provide a foundation for future research. In the Ecotrust monitoring project, reponses in the focus groups summaries offer some information, but do not fully answer these questions. Advisory groups could be surveyed to learn whether they are representative of other users and stakeholders.	N5b	[New] What stakeholders on the North coast engage with CDFW and the MPA management program, how do they engage, and why?	Possibly (CDFW)
N6	[New] How does CDFW communicate with stakeholders about MPAs, which stakeholders do they reach, and is the communication effective?	This focuses on communication as a one-way transmission from CDFW to stakeholders and seeks to identify the effectiveness of different strategies for different stakeholder groups.	CDFW almost certainly has records of public outreach and communication strategies, including investments in those strategies. To understand effectiveness, those data must be connected to stakeholder responses. This could be an interesting project for a graduate student in policy and/or communication.	N5a	[New] How does CDFW communicate with the conservation community about MPAs, and is the communication effective?	Possibly (CDFW)
				N5b	[New] How does CDFW communicate with coastal residents about MPAs and is the communication effective?	Possibly (CDFW)
CHANGES IN WELLBEING						
N7	[New] What are the direct and indirect economic consequences of MPAs for	Economic consequences of MPAs are of interest across a diversity of	Socio-economic focused research is needed, which could include both gathering new data or using existing secondary data sources. Broadening the current focus from fishing stakeholders to the broader coastal	12	[Original] What are economic effects of MPA placement; specifically, distance from ports and location relative to fishing grounds?	Yes (CCFRP, Ecotrust & Rec CPUE)

	relevant stakeholders and coastal communities?	stakeholder groups, and this broadens the scope to include that diversity.	community and other communities of interest is needed. Existing monitoring programs may allow assessment of (mostly) direct economic consequences of MPAs, but additional research is likely needed to assess indirect consequences.	12a	[Refined] What are the economic costs and benefits of MPA placement for relevant user groups? (examples distance from ports and locations relative to fishing grounds, diversity of livelihoods in the community)	
N8	[New] How have MPAs affected dimensions of social and cultural wellbeing for relevant stakeholders and coastal communities?	Wellbeing consequences of MPAs are of interest across a diversity of stakeholder groups, and this broadens the scope to include social and cultural (non-economic) wellbeing and a diversity of stakeholders.	Wellbeing is a fairly recent consideration. NOAA social scientists have taken the lead in research on this topic and likely have information of use for California.	8d	[Extended] What are the fisheries-related changes to dimensions of social and cultural wellbeing?	Possibly (Rec CPUE)
				12b	[Extended] How has MPA placement affected dimensions of social and cultural wellbeing for relevant user groups?	No
CHANGES IN ATTITUDES AND PERCEPTIONS						
18a	[Refined] Have attitudes towards and perceptions of individual MPAs and the MPA	This focuses on changing attitudes towards and perceptions of MPAs	While the existing monitoring projects do elicit some changing attitudes and perceptions toward MPAs, they are focused on a small subset of stakeholders, and this focus should be broadened. Understanding changing	18	[Original] How are knowledge, attitudes, and perceptions regarding the MPAs changing overtime?	Yes (CCFRP, Ecotrust & CDFW non-consumptive)

	network as a whole by stakeholders changed over time and why?	across a diversity of stakeholders, thus uniting several questions from Appendix B.	attitudes and perceptions will require a project or two specifically focused on recreational and/or non-consumptive users.	19	[Original] Are non-consumptive recreational experiences in areas subject to reduced fishing improving? What are the attitudes and perceptions of users and their recreational experience and how has that changed over time?	Yes (CDFW non-consumptive)
				19a	[Refined] Are non-consumptive recreational experiences in MPAs improving?	
				19b	[Refined] How have the attitudes of non-consumptive users towards MPAs changed over time?	Yes (CDFW non-consumptive)
				19c	[Refined] How have the perceptions of the recreational experience in MPAs among non-consumptive users changed over time?	Yes (CDFW non-consumptive)
N9	[New] Is there a difference in the perceived value of, and desire to visit MPAs as compared to non-MPA reference sites?	This focuses on whether perceptions of MPAs drive changes in behavior, including MPA access and use.	Answering these questions will probably require a focused qualitative research project. Selection of appropriate non-MPA reference sites relative to human visitation will be key to answering this question.	16b	[Refined] How has enjoyment of marine ecosystems (in MPAs) by non-consumptive users changed since MPA implementation?	Yes (CDFW non-consumptive)
				16c	[Refined] Has the perceived value of, and desire to visit MPA areas changed over time? (evaluate by user group)	Yes (CDFW non-consumptive)

				19d	[Extended] How do non-consumptive recreational experiences in MPAs compare to experiences in adjacent non-MPA areas?	Possibly (CDFW non-consumptive)
18b	[Refined] Has knowledge of MPAs by stakeholders changed over time and why?	This refinement of question 18 focuses on changing knowledge of MPAs across a diversity of stakeholders.	As with all the questions pertaining to change vis a vis human use, the lack of "pre-MPA" knowledge makes comparison reliant on stakeholder's memories. Qualitative analysis can help reveal knowledge, attitudes, and perceptions.			Yes (CCFRP, Ecotrust & CDFW non-consumptive)
18c	[Extended] How does stakeholder knowledge of MPAs influence attitudes toward and perceptions of MPAs?	This refinement of question 18 focuses on how knowledge of MPAs influences attitudes and perceptions.	Answering this question will probably require a focused qualitative research project.			Possibly (CCFRP, Ecotrust & CDFW non-consumptive)
MANAGEMENT DOMAIN						
N10	[New] What is the level of compliance with MPA regulations by stakeholder groups?	Broadens question to ask about MPA compliance across a diversity of stakeholders.	Analysis of non-compliant use data (e.g., from MPA Watch or similar) and enforcement actions supplemented with qualitative research among different stakeholder groups may reveal differing levels of compliance by stakeholder group.	27	[Original] Is monitoring of human activity and enforcement adequate for preventing illegal take in MPAs?	No
				27	[Refined] Is current wildlife enforcement capacity adequate for preventing illegal take in MPAs?	No

29a	[Refined] How has compliance changed over time since MPA implementation ?	Refinement of question 29 focuses on changes in compliance.	Analysis of non-compliant use data (e.g., from MPA Watch or similar) and enforcement actions may reveal changes in the levels of compliance over time. Changing enforcement policies (e.g., warnings vs. citations) could complicate analyses. This could be an interesting project for a graduate student in law/ criminal justice.	29	[Original] How has the level of compliance changed over time since the MPAs were first implemented and what factors influence variation in compliance within and among MPAs?	No
29b	[Refined] What factors (e.g. penalties, wildlife enforcement, warden presence) influence differences in compliance within and among MPAs?	Refinement of question 29 focuses on the factors that influence compliance. This unites several questions from Appendix B in a simple and informative way.	Analysis of non-compliant use data (e.g., from MPA Watch or similar) and enforcement actions supplemented with qualitative research among different stakeholder groups may reveal differing levels of compliance in MPAs across the Network. Considering the influencing factors that correlate with those differences may help inform CDFW about what incentives or enforcement actions have the largest influence on compliance.	28	[Original] Do penalties for non-compliance deter users from violating regulations?	No
				28a	[Refined] How do penalties influence compliance with MPA regulations?	No
				28b	[Extended] What types of penalties have the largest influence on compliance?	No
				28c	[Extended] What management actions are most likely to increase compliance?	No
				30	[Original] Does locating a boat ramp or other access point affect the level of enforcement and compliance with MPA regulations?	Possibly (Rec CPUE)
				30	[Refined] How does the accessibility of an MPA (nearby boat ramp or other access point) relate	Possibly (Rec CPUE)

					to warden presence and compliance?	
				31	[Original] Are there incentives that can help reduce noncompliant behavior inside MPAs?	No
				31	[Refined] Do incentives influence compliance with MPA regulations?	No
				33a	[Original] Does the level of compliance differ between SMRs and SMCAs?	No
				33b	[Extended] Does compliance differ for MPAs with different levels of protection?	No
N11	[New] How do outreach and education activities influence compliance with MPA regulations by stakeholders?	This focuses on the influence of outreach and education activities on compliance with MPA regulations.	Research to answer this question would likely need to connect specific outreach and education activities (e.g., signage, information kiosks, wildlife enforcement officer contact, park docent activities) with user compliance data, both spatially and temporally.	29e	[Extended] How is knowledge of MPA regulations related to compliance?	No
N12	[New] How do outreach and education activities influence knowledge, attitudes, and perceptions of	This focuses on the influence of outreach and education activities on knowledge of MPAs.	A focused survey could shed light on this (possibly integrate some questions into IPCC survey). This work should build on CDFW's ongoing efforts to evaluate communication tools to different groups and any research efforts should be connected to answering question N6.			No

	MPAs by stakeholders?					
25	[Refined] Are efforts to collect long-term monitoring data coordinated sufficiently to fully evaluate MPA Network performance?	Minor wording changes for clarity.	Comprehensive answers to these related questions would likely require a review of the MPA Management Program. Recommendations and approaches provided in this report indicate areas of opportunity to improve the effectiveness of MPA and Network evaluation and better inform adaptive management.	25	[Original] Are efforts to collect long-term monitoring data coordinated sufficiently such that cohesive conclusions can be formed about MPA Network performance?	Yes (InterT, KF, ROV, Beach, CCFRP, Ecotrust & Estuaries)
26	[Refined] Does the MPA Monitoring Action Plan produce sufficient information to evaluate Network performance and inform adaptive management?	Minor wording changes for clarity.		26	[Original] Does the MPA Monitoring Action Plan produce sufficient information that enables the evaluation of Network performance and informs adaptive management?	Yes (InterT, KF, ROV, CCFRP, IOOS & Estuaries)

APPENDIX 3: TABLE OF INTEGRATIVE

Questions from Appendix B of the Action Plan that integrate across domains are presented here with proposed wording changes that either refine the questions to more clearly specify response variables and predicted responses, or extend the questions to additional topics of interest for MPA evaluation. Rationale for these question changes are presented, along with potential considerations to be taken into account during analyses. The final column indicates those questions that have been proposed to be addressed by ongoing monitoring programs, and which programs proposed to address them.

MLPA Goal	Question #	Original Question	Question Refinement or Extension	Rationale for Question Changes	Considerations	Proposed to be Addressed by Ongoing Monitoring Programs
FISHERIES INTEGRATION - ECOLOGICAL PERSPECTIVE						
G2	**6a**	[Original] How does spatial variability in fishing effort and fishing mortality rates prior to and after MPA implementation affect the abundance and/or size/age structure of harvested species in MPAs?	[Refined] Are differences in the magnitude of change in abundance of focal species in response to MPA establishment related to differences between MPAs in the level of pre-MPA fishing mortality (or effort)?	Clarify that the focus of this question is on changes resulting from fishing effort and fishing mortality rates. Focus question on changes in abundance due to fishing effort and fishing mortality prior to MPA establishment.	Requires fishing effort or take data inside of MPAs and at reference sites both pre- and post-MPA establishment. Would benefit from abundance data pre-MPA establishment where available. Test for relationship (regression) between spatial variability in pre-MPA fishing effort or fishing mortality rates versus abundance of harvested species. IPM can enable use of ecological timeseries Might look at individual species or aggregate by fished/unfished species.	Yes (CCFRP & Rec CPUE)

G2	6b		[Refined] Are differences in the magnitude of change in size/age structure of focal species in response to MPA establishment related to differences between MPAs in the level of pre-MPA fishing mortality (or effort)?	Focus question on changes in size/age structure due to fishing effort and fishing mortality prior to MPA establishment.	Requires fishing effort or take data inside of MPAs and at reference sites both pre- and post-MPA establishment. Would benefit from size/age structure data pre-MPA establishment where available. Might look at individual species or aggregate by fished/unfished species. Multiple ways to consider size/age structure.	Yes (CCFRP & Rec CPUE)
G2	6c		[Refined] Are differences in the magnitude of change in abundance of focal species in response to MPA establishment related to differences between MPAs in the level of MPA-adjacent fishing mortality (or effort)?	Extend original question to examine effects of level of MPA-adjacent fishing effort and fishing mortality on abundance changes following MPA establishment.	Requires fishing effort or take data inside of MPAs and at reference sites both pre- and post-MPA establishment. Would benefit from abundance of targeted species data pre-MPA establishment where available. Might look at individual species or aggregate by fished/unfished species.	Yes (CCFRP & Rec CPUE)
G2	6d		[Refined] Are differences in the magnitude of change in size/age structure of focal species in response to MPA establishment	Extend original question to examine effects of level of MPA-adjacent fishing effort and fishing mortality on size/age	Requires fishing effort or take data inside of MPAs and at reference sites both pre- and post-MPA establishment. Might look at individual species or aggregate by fished/unfished species. Multiple ways to consider size/age structure.	Yes (CCFRP & Rec CPUE)

			related to differences between MPAs in the level of MPA-adjacent fishing mortality (or effort)?	structure changes following MPA establishment.		
G2	**9a**	[Original] Do differences in fishing distribution, magnitude, and mortality rates prior to MPA implementation affect changes in the abundance and/or size/age structure of populations of focal species within MPAs relative to reference sites over time?	[Refined] Is there a relationship between the relative change in abundance of focal species inside and outside of MPAs and the level of fishing mortality (or effort) prior to MPA establishment?	Clarify the analytical design of MPA-reference site comparisons over time to include specific response variables. Focus question on abundance changes of focal species and fishing mortality and/or effort.	Requires pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites and inside-outside response ratio trajectories over time. Test for relationship (regression) between abundance of focal species and the rate of pre-MPA fishing effort or mortality. Might look at individual species or aggregate by fished/unfished species.	Yes (ROV, CCFRP, IOOS & Rec CPUE)
G2	**9b**		[Refined] Is there a relationship between the relative change in size/age structure of focal species inside and outside of MPAs and the level of fishing mortality (or effort) prior to MPA establishment?	Focus question on size/age structure changes of focal species and fishing mortality and/or effort.	Requires pre- and post-MPA establishment fishing data for MPAs and adjacent reference sites and inside-outside response ratio trajectories over time. Test for relationship (regression) between size/age structure of focal species and the rate of pre-MPA fishing effort or mortality. Multiple ways to consider size/age structure. Might look at individual species or breakout by fished/unfished species.	Yes (ROV, CCFRP, IOOS & Rec CPUE)

G6	**36a**	[Original] How does the level of connectivity and larval supply from an MPA to areas outside of MPAs affect fisheries?	[Refined] Does the degree of connectivity and magnitude of larval supply from an MPA to a fished (non-MPA) site support additional potential fisheries yield at the fished site?	Clarify, focus, and rephrase the question. Focus question on role of an MPA in contributing larvae to an unfished reference sites and increasing fisheries yield.	Requires data on species demographics and related larval production inside an MPA. Consider inside and outside MPA responses. Requires data on connectivity between MPA and adjacent assessed MPAs. Multiple ways to collect and analyze demographic data. Consider the number of populations to be analyzed. Data from multiple MPAs required to estimate the value of an individual MPA. Iterative integration of empirical and modeling studies is recommended when possible.	Yes (IOOS, Estuaries, Connectivity)
G6	**36b**		[Extended] Does the degree of connectivity and magnitude of larval supply from fished (non-MPA) sites to an MPA influence the structure and dynamics of populations within an MPA?	Extends question to focus on role of a fished areas in contributing larvae to an MPA and influencing its population demographics and dynamics.	Requires data on species demographics and related larval production outside an MPA. Consider inside and outside MPA responses. Requires data on connectivity between adjacent unprotected reference site and MPA. Multiple ways to collect and analyze demographic data. Consider the number of populations to be analyzed. Data from multiple reference sites and MPAs required to estimate the value of an unprotected site to an individual MPA. Iterative integration of emipiral and	Yes (IOOS, Estuaries, Connectivity)

					modeling studies is recommended when possible.	
FISHERIES INTEGRATION - HUMAN PERSPECTIVE						
G2	**8a**	[Original] What is the relationship between MPAs and the displacement, compaction, and concentration of nearshore fishing efforts? Did overall fishing effort/mortality rates and yield change since MPA implementation?	[Refined] Did the distribution of fishing effort change following MPA implementation?	Separate, clarify, and rephrase the question. Focus question on changes in the distribution of fishing since MPA implementation.	Requires pre-MPA and post-MPA fishing distributional data for areas adjacent to MPAs expressed as fishing effort. Focus can be on individual MPAs or groups of MPAs.	Possibly (Rec CPUE)
G2	**8b**		[Refined] Did overall fishing effort/mortality rates and yield change following MPA implementation?	Focus question on changes in fishing effort and mortality rates since the MPA implementation.	Requires pre-MPA and post-MPA fishing data for areas adjacent to MPAs, including fishing effort, and catch (mortality) data. Could look at individual species to compare effort/mortality rates. Focus can be on individual MPAs or groups of MPAs.	Possibly (Rec CPUE)

G2	**8c**		[Extended] What are the fisheries-related economic changes that accompany changes in the distribution of fishing effort/mortality following MPA implementation?	Extend question to address the fisheries-related economic changes related to changes in fishing distribution and fishing effort/mortality since MPA implementation.	Requires pre-MPA and post-MPA fishing data for areas adjacent to MPAs, including fishing effort, and catch (mortality) data. Requires data that translate catch into economic metrics, including changes in costs related to fishing (e.g., travel time, vehicle or vessel operation, fishing effort, etc.), value of catch to fishermen (e.g., market prices, handling costs, etc.). Could look at individual species to compare translation of catch into economic metrics. Focus can be on individual MPAs or groups of MPAs.	Possibly (Rec CPUE)
G3	**17a**	[Original] Are recreational consumptive users able to mitigate short-term costs of displacement from MPAs by conducting activities along the edge of MPAs? Will there be long-term benefits from the edge effect?	[Refined] Are recreational consumptive users fishing the edges of MPAs?	Separate, clarify, focus, and rephrase the question. Focus question on the amount and distribution of recreational consumptive use (effort/take) in areas immediately adjacent to MPAs following MPA implementation.	Requires post-MPA data on patterns of recreational consumptive use for areas adjacent to MPAs, including fishing distribution, effort, and catch (mortality) data. Would benefit from similar pre-MPA data to determine changes resulting from MPA implementation. Could look at changes in recreational consumptive users for individual species. Focus can be on individual MPAs or groups of MPAs.	Possibly (Rec CPUE)

G3	**17b**		[Refined] Is recreational take from MPA edges similar to historical take from the MPAs?	Focus question on changes in recreational consumptive use (effort/take) in areas immediately adjacent to MPAs following MPA implementation.	Requires pre- and post-MPA data on patterns of recreational consumptive use for areas adjacent to MPAs, including fishing distribution, effort, and catch (mortality) data. Also requires effort/catch data for MPA prior to establishment to determine changes resulting from MPA implementation. Requires ability to categorize and measure forms of consumptive recreational use. Could look at changes in recreational consumptive users for individual species. Focus can be on individual MPAs or groups of MPAs.	Possibly (Rec CPUE)
G3	**17c**		[Refined] Based on current patterns, are edge effects likely to provide long term benefits to consumptive recreational users?	Focus question on identifying benefits (economic, social) to consumptive recreational users from changes in use (effort/take) in areas immediately adjacent to MPAs following MPA implementation, including the time course for	Requires time series post-MPA data on patterns of recreational consumptive use for areas adjacent to MPAs, including fishing distribution, effort, and catch (mortality) data. Requires definition of 'beneifts' (e.g., well-being, economics, etc.) and time course attributed to 'long-term'. Requires ability to categorize and measure forms of consumptive recreational use. Would benefit from similar pre-MPA data to determine changes resulting from MPA implementation. Could look at changes in recreational consumptive users for individual species. Focus can be on individual MPAs or groups of MPAs.	Possibly (Rec CPUE)

				obtaining these benefits.		
G3	17d		[Extended] Do recreational consumptive users percieve benefits from MPA edge effects?	Extend the question to focus on whether consumptive recreational users identify benefits (economic, fishing success, well being) from changes in use (effort/take) in areas immediately adjacent to MPAs following MPA implementation.	Requires post-MPA data on perceptions of benefits obtained by recreational consumptive use for areas adjacent to MPAs. Requires definition of 'beneifts' (e.g., well-being, economics, etc.). Requires ability to categorize and measure forms of consumptive recreational use. Would benefit from time series data and from pre-MPA data to determine changes resulting from MPA implementation. Could look at changes in recreational consumptive users for individual species. Focus can be on individual MPAs or groups of MPAs.	Possibly (Rec CPUE)
G3	17e		[Extended] How does recreational consumptive use of MPAs that prohibit commercial use differ from MPAs that don't make this distinction?	Extend the question to focus on determining whether differences exist as a function of level of protection in the activities (effort/take) and benefits (economic, fishing success,	Requires post-MPA data on patterns of recreational consumptive use for areas within and adjacent to MPAs, including fishing distribution, effort, and catch (mortality) data for MPAs that do and do not allow commercial take. Requires ability to categorize and measure forms of consumptive recreational use. Would benefit from time series data and from pre-MPA data to determine changes resulting from MPA	Possibly (Rec CPUE)

				wellbeing) of consumptive recreational users in areas within and immediately adjacent to MPAs. Question focuses on MPAs that do and do not allow commercial use.	implementation. Could look at changes in recreational consumptive use for individual species. Focus can be on individual MPAs or groups of MPAs. Would benefit from comparisons that include no-take MPAs as well as MPAs that allow recreational but not commercial use.	
GOVERNANCE AND MANAGEMENT INTEGRATION						
G2	**11a**	[Original] Is the Implementation of MPAs as a habitat-based approach to marine fisheries management more or less effective in maintaining sustainable fisheries than traditional management strategies such as limiting harvest in a non-spatially explicit manner?	[Refined] Is catch more sustainable for a targeted fishery species before or after MPA implementation?	Clarify, focus, and rephrase the question. Focus question on the whether catch is more sustainable for a targeted fishery following MPA implementation.	Requires pre- and post-MPA data on fishing distribution, effort, and catch (mortality) data for targeted fishery species for MPAs and reference sites. Inside-outside response ratios over time. Requires setting of time to answer sustainability question. This also means having time series of historical fishing data for targeted species before and after MPA establishment. Requires ability to identify targeted species and treat these individually and collectively. Could look at fished and unfished species. Focus can be on individual MPAs or groups of MPAs.	No

G2	**11b**		[Refined] Is catch more sustainable for fishery species deemed likely to benefit from California's MPAs than for species that are less likely to be influenced by the MPAs?	Focus question on the whether catch is more sustainable for fished species likely to benefit from MPA protection following MPA implementation.	Requires pre- and post-MPA data on fishing distribution, effort, and catch (mortality) data for species likely to benefit from MPA protection for MPAs and reference sites. Inside-outside response ratios over time. Requires setting of time to answer sustainability question. This also means having time series of historical fishing data for species likely to benefit before and after MPA establishment. Requires ability to identify species likely to benefit and treat these individually and collectively. Could look at fished and unfished species. Focus can be on individual MPAs or groups of MPAs.	No
G6	**38**	[Original] How do other stressors impact the management of MPAs over time?	[Refined] How do non-fishing stressors impact the management of MPAs over time?	Clarify, focus, and rephrase the question.	Requires identification and measurement of non-fishing stressors and link the distribution and magnitude of these stressors with management considerations/actions. Would benefit from pre- and post-MPA metrics for non-fishing stressors for MPAs and reference sites. Inside-outside response ratios over time. Requires identification of what constitutes management actions. Might want to treat non fishing stressors collectively as well as individually. Focus can be on individual MPAs or groups of MPAs.	Yes (InterT, KF, ROV, Beach, CCFRP, IOOS, & Estuaries)

ECOSYSTEM SERVICES						
G2	**13a**	[Original] What is the value of the ecosystem services provided by California MPAs?	[Refined] What are the ecosystem services provided by ecosystems represented in the MPA network?	Clarify, focus, and rephrase the question. Focus question on identifying and quantifying (or some qualitative metric) of the ecosystem services provided by MPAs in the MPA network.	Requires identification and quantification (or some qualitative metric) of ecosystem services as a function of each ecosystem for MPAs in the MPA network. Requires ability to categorize and measure (quantitatively or qualitatively) forms of ecosystem services. Would benefit from time series data and from pre-MPA and post-MPA data to determine changes in ecosystem services resulting from MPA implementation. Would benefit from comparable data for ecosystems outside MPA boundaries. Focus can be on individual MPAs or groups of MPAs. Would benefit from comparisons that include no-take MPAs as well as MPAs that allow some form of take. To fully answer question, requires multiple lines of data collection and	Yes (CCFRP, Estuaries)

					translation of data into 'ecosystem service' metrics.	
G2	**13b**		[Refined] How has the flow of these ecosystem services changed following MPA implementation?	Focus question on how the identified ecosystem services provided by MPAs in the MPA network have changed (quantitatively or qualitatively) since MPA implementation.	Requires identification and quantification (or some qualitative metric) of ecosystem services as a function of ecosystem for MPAs in the MPA network. Requires ability to categorize and measure (quantitatively or qualitatively) forms of ecosystem services. Requires time series data from pre-MPA and post-MPA establishment to determine changes in ecosystem services resulting from MPA implementation. Would benefit from comparable data for ecosystems outside MPA boundaries. Focus can be on individual MPAs or groups of MPAs. Would benefit from comparisons that include no-take MPAs as well as MPAs that allow some form of take. To fully answer question, requires models parameterized by multiple lines of data collection and translation of data into 'ecosystem service' metrics.	Yes (CCFRP, Estuaries)

G2	**13c**		[Refined] What are the short- and long-term economic values of these services?	Focus question on determining the short and long-term economic values of the ecosystem services provided by MPAs in the MPA network following MPA implementation.	Requires identification and quantification (or some qualitative metric) of ecosystem services as a function of ecosystem for MPAs in the MPA network. Requires ability to categorize and measure (quantitatively or qualitatively) forms of ecosystem services and to translate these services into economic metrics. Requires definition of 'short-term' and 'long-term'. Would benefit from time series data from pre-MPA and post-MPA establishment to determine changes in ecosystem services resulting from MPA implementation. Would benefit from comparable data for ecosystems outside MPA boundaries. Focus can be on individual MPAs or groups of MPAs. Would benefit from comparisons that include no-take MPAs as well as MPAs that allow some form of take. To fully answer question, requires models parameterized by multiple lines of data collection and translation of data first into 'ecosystem service' and then into economic metrics.	Yes (CCFRP, Estuaries)

	13d		[Refined] What are the short and long term social and cultural values of these services?	Focus question on determining the short and long-term socio-cultural values of the ecosystem services provided by MPAs in the MPA network following MPA implementation.	Requires identification and quantification (or some qualitative metric) of ecosystem services as a function of ecosystem for MPAs in the MPA network. Requires ability to categorize and measure (quantitatively or qualitatively) forms of ecosystem services and to relate these services to socio-cultural (attitude, behavior, perception, etc.) values. Requires definition of 'short-term' and 'long-term'. Would benefit from time series data from pre-MPA and post-MPA establishment to determine changes in socio-cultural values related to ecosystem services resulting from MPA implementation. Would benefit from analyses of comparable socio-cultural and ecosystem services data for ecosystems outside MPA boundaries. Focus can be on individual MPAs or groups of MPAs. Would benefit from comparisons that include no-take MPAs as well as MPAs that allow some form of take. To fully answer question, requires models parameterized by multiple lines of data collection and translation of data first into 'ecosystem service' and then the relationship of these services to socio-cultural values.	Yes (CCFRP, Estuaries)

APPENDIX 4: MANAGING AN MPA NETWORK AND FISHERIES AS AN INTEGRATED SYSTEM

Networks of marine protected areas (MPAs) are uniquely embedded across a landscape of commercial, recreational, and artisanal fisheries. This spatial integration provides MPA and fisheries managers with unique opportunities to leverage the conservation and sustainability goals of each to the benefit of the other. Although the management goals and objectives of MPA networks and fisheries appear distinct, there is extensive overlap in their contributions to biodiversity conservation, ecosystem-based management, and the ways that humans interact with the ocean environment. In social, economic, and ecological contexts, networks of MPAs and fisheries are inextricably linked and, therefore, are best managed as an integrated system.

The Marine Life Management Act (MLMA) of 1998 is California's primary framework for managing the State's commercial and recreational fisheries using an adaptive management approach. Although the framework includes ecosystem-based considerations to achieve the primary goal of resource sustainability, it recognizes that fishery conservation and management measures alone were inadequate to address broad ecosystem protection. Hence, the Marine Life Protection Act (MLPA) was adopted one year later mandating an improved system of MPAs managed as a statewide network to protect marine life, habitats, and ecosystems (Wertz et al. 2011).

Understanding both the challenges and contributions of the MPA network to California's fisheries, and how these fisheries might respond to MPA protection, is necessary for the development of effective fishery management strategies. While only a few of the MPAs within this network have specific fishery resource objectives, the MPAs are expected to result in various ecological and socioeconomic effects within and adjacent to their boundaries. As such, the California MPA network is likely to have broad implications for the management of California's marine fisheries. As a consequence, many commercial and recreational fishermen have raised concerns about the expected effects of the MPA network on fish populations and have called for the need to adaptively manage fisheries in response to MPA effects on fishery yields. Therefore, MPA monitoring must be designed to not only determine the conservation benefits of the MPA network but also to specifically address MPA-fishery questions for managers to optimally balance ecosystem protections and their impacts on fisheries (Wertz et al. 2011).
How do MPA and fisheries management interact?

Defining the management nexus between the MLMA and MLPA is not straightforward because their management objectives are not fully in alignment, which can lead to conflicts between management approaches. Most current fisheries management approaches, particularly for species co-managed by federal and state agencies (such as groundfish, salmon and coastal pelagic species), are largely based on constraining total allowable catches.These total allowable catches are in turn informed by stock assessment models, i.e. statistical models that approximate population abundance and demographic structure and a yield level that should be sustainable based on estimates (or proxy estimates) of the compensatory responses of stocks to projected levels of fishing. For fisheries that are federally managed, states can implement more restrictive management, but not less restrictive management measures. Given existing federal law and the coastwide nature of fishery management plans and stock assessments, it is not feasible at this time to replace the current fisheries management approach (annual catch limits based on stock assessment) for one exclusively based on MPA restrictions on fishing.

However, there have been a few limited examples where MPA monitoring has informed stock assessment, such as the inclusion of CCFRP relative abundance, length and age data in the most recent PFMC assessment of the gopher/black and yellow rockfish complex. However, the patchy temporal and spatial resolution of these data limit their utility (most years only central California data were available, an unacceptable situation for assessing a stock with a broader geographic distribution). In addition, a few attempts have been made to develop conceptual models that use catch rate or relative abundance data from inside and outside MPAs as an alternative to traditional stock assessments, particularly for data limited species such as nearshore groundfish (McGilliard et al. 2011, Babcock and MacCall 2011). While approaches that incorporate MPA collected data remain largely conceptual, some of the time series currently being collected to inform MPA evaluations could be appropriate cornerstones for building such approaches. Clearly, in the foreseeable future data collected from MPAs will become a valuable asset to stock assessment efforts and fishery managers, and fisheries management would benefit from a more integrated approach that leverages the conservation attributes of MPAs.

Besides protecting fished species, spatial closures (e.g., no-take marine reserves) also affect quota-based fisheries management by complicating stock assessments. This is because spatial closures generally increase the spatial heterogeneity in abundance and size or age structure of fished stocks. Therefore, the more effective MPAs are at protecting populations within them, the greater the likelihood that traditional stock assessment approaches will be biased or made more uncertain (Punt and Methot 2004, Field et al. 2006, Berger et al. 2017), particularly if such models lack abundance time series and demographic data collected within MPAs. While there has been some research to better understand how spatial closures (and other spatially explicit processes that reduce fishing) can bias traditional stock assessment models, the best solutions are generally more data-intensive, spatially explicit models (McGilliard et al. 2015, Berger et al. 2017, Punt 2019). However, many California fish stocks protected by MPAs are data poor, thereby constraining the ability to parameterize the needed more complex and spatially explicit models.

Separate from impacts to fish stocks and their assessments, fisheries managers need to understand the social and economic impacts of MPAs on commercial and recreational fisheries. Therefore, fisheries managers benefit from information on how fishermen are responding to both the actual and the perceived impacts of the MPA network, and how their observations or perceptions alter how they make decisions about where, and whether, to fish. For example, no-take or restricted MPAs can displace fishing effort, increasing costs and travel time if fishermen have to travel a greater distance from their home port or residence to fish. If economic (i.e., market) conditions are favorable for commercial fishermen, this may not affect their economic benefits; however, displaced fishing effort can have social wellbeing consequences (e.g., if they have to be away from home longer or experience greater hazards to fish) for both commercial and recreational fishermen. Furthermore, small-scale fishermen, including artisanal fishers, could be disadvantaged by MPAs if their boats and vehicles are not capable of safely or economically traveling longer distances. Also, it may be that fishing the line on an MPA may be more appealing than motoring around the MPA to get to open habitat on the other side even if there is no indication that catch rates are any (or much) better. In dynamic spatial closures to protect juvenile anchoveta off the coast of Peru, it was demonstrated (albeit unpublished) that some closures can have the counterintuitive effect of increasing juvenile anchoveta catch, because vessels fishing areas with low anchoveta densities moved to closed areas to "fish the line" (and often increase catch rates, but also increase catch rates of juveniles).

To date, these consequences of California's MPA network have not received much attention, yet the direction (positive or negative) and magnitude of the social (e.g., fishermen wellbeing and behavior) and economic (e.g., yield and quality of catch) impacts of the MPA network will vary markedly across the diversity of California's fisheries. Three of the few studies to evaluate how California MPAs have influenced fishery yield and distribution is of the lobster fishery of the Northern Channel Islands. The earliest study (Kay et al. 2012) concluded that lobster abundance and size responded positively within MPAs, but that these responses were insufficient to enhance yield or concentration of fishing effort in MPA-adjacent areas. In fact, fishing effort declined in close proximity to MPAs relative to trends in areas farther removed (Guenther et al. 2015). However, a more recent study (Lenihan et al. 2021) found greater build-up of lobsters within MPAs relative to unprotected areas, and greater increases in fishing effort and total lobster catch, but not CPUE, in fishing zones containing two MPAs versus those without MPAs. The authors concluded that a 35% reduction in fishing area resulting from MPA designation was compensated for by a 225% increase in total catch after 6-years at that local spatial scale. Such studies of other MPAs and fisheries are critical to understanding the various consequences of MPAs, and how MPA impacts vary among fisheries and across geographic regions. However, datasets with the appropriate resolution to robustly evaluate shifts in the spatial distribution of fishing effort and catch rates are rare throughout most California waters and for most California fisheries.

> **Recommendation:** Support studies that evaluate the social and economic influences of MPAs on coastal commercial, recreational, and artisanal fisheries likely to be most influenced by MPAs. These studies should be designed to identify the mechanisms underpinning the responses of these fisheries and how and why they vary geographically.

How MPA management, monitoring, and evaluation inform fisheries management

The most critical need for both spatial management and traditional fisheries management is robust data on the relative abundance and size structure of species populations. If data are not available within MPAs, this can impact the ability to monitor and model populations; the best modelling arises when there are robust fishery independent data obtained throughout the range of a given stock's distribution (both within and outside of MPAs and areas closed to fishing). Monitoring studies generate estimates of the density and size structure of fished species inside and outside of MPAs and, therefore, provide information not only on MPA performance but also to support fisheries management by supplementing status estimates in fishery stock assessments. There is also the ability to use information from inside MPAs to directly establish rules for harvest limits, but there is mixed evidence from theoretical studies for the potential success of such approaches (McGilliard et al. 2011, Babcock and MacCall 2011). Some state-managed shellfish fisheries, like Dungeness crab, are managed using a "3S" approach to limit take of individuals based on sex, size, and season. By collecting data on unfished populations, MPA monitoring can help index fishing-induced changes in these and other demographic parameters for these largely unassessed but highly valuable stocks.

> **Recommendation**: Monitoring studies should generate estimates of the density and size structure of fished species inside and outside of MPAs to supplement estimates of stock status in fishery stock assessments and to inform CDFW's Enhanced Status Reports of commercial and recreational species.

Similar to demographic data, MPA monitoring studies can also generate life history data that can inform fisheries management. For example, abundance estimates of different life stages can describe the ecosystems or habitats species recruit to, occur in, and move among during their life spans, including the temporal patterns in these dynamics. These data identify a species' habitat requirements and improve understanding of its "essential fish habitat". The collection of age data from within MPAs can also provide key demographic information and may provide the opportunity to more robustly estimate key life history parameters such as reproductive output, growth, and natural mortality (Garrison et al. 2011).

> **Recommendation**: Monitoring studies should record the timing and occurrence of life stages of fishery species, among other life history information, that identifies their association with different habitats and ecosystems. These data should be made available to fisheries managers, including CDFW's Enhanced Status Reports of commercial and recreational species.

MPA surveys can identify ecological responses to changing environmental conditions, including changes in ecosystem productivity and a changing global climate, by annually monitoring the condition of individual organisms and the dynamics of populations, communities, and ecosystems. This information can reveal the exposure, sensitivity, and adaptability of organisms, populations, and ecosystems that can potentially inform management harvest decisions and climate vulnerability assessments. These observations and relationships are most robust when environmental data are collected consistently and concurrently (i.e., annually) and at the same locations where ecological data are collected. By estimating or providing information about ecosystem-wide changes in productivity and population responses to such changes, MPA monitoring can help characterize and track population carrying capacity. A research frontier in stock assessment, not yet widely adopted into current fisheries management in the U.S., focuses on the concept of dynamic unfished biomass (dynamic B_0; Sibert et al. 2006, Berger 2019). In short, this is the idea that the carrying capacity of a population is not static, but rather varies with fluctuations in abiotic (e.g., temperature, oxygen; habitat quality) and biotic (e.g., abundance of competitors, predators) factors. Evaluation of trends in the biomass of target species within MPAs can be related to variations in these factors, potentially allowing stock assessments to provide improved estimates of dynamic B_0 over time. However, the value of MPA-based indices in stock assessments will depend in part on spatial variability in recruitment, as well as movement and dispersal patterns of assessed populations, within and outside of MPAs.

> **Recommendation**: Monitoring studies should include observations of organismal condition and population, community, and ecosystem dynamics as they relate to changing environmental conditions, to potentially inform stock assessments for fisheries management, improve decision-making on harvest adjustments, and inform climate vulnerability evaluations.

Comparisons of fished populations (abundance, size structure, life history characteristics, genetic diversity, etc.) and the state and condition of communities and ecosystems exposed to different levels of fishing morality and types of fishing (i.e. no-take SMRs and limited-take SMCAs) can reveal the effects of the level of spatial protection on populations and communities. Moreover, these data can be used to estimate larval production and generate spatial and temporal recruitment signals for fished species that can inform demographic connectivity models. Such connectivity models can not only be used to evaluate the performance of the MPA network but also can provide estimates of regional stock dynamics. By incorporating realistic estimates of the spatial and temporal patterns of fishing mortality, these models can estimate spatial patterns of stock dynamics across the MPA network and adjacent fished areas.

Recommendation: Monitoring studies should be designed to leverage the opportunity to compare population and ecosystem responses to different levels and types of fishing mortality across the different types of MPAs (i.e., SMRs and SMCAs).

Recommendation: Monitoring studies should include estimates of annual rates of larval production and recruitment of fished species, which can inform demographic connectivity models that provide fisheries managers with estimates of the regional contributions of MPAs and the MPA network to replenishment of fished stocks. These demographic connectivity models should be shared with fisheries biologists to evaluate contributions of MPAs and the MPA network to estimates of regional stock dynamics.

Monitoring studies should also be designed to collect information on biotic and abiotic habitat features important to species subjected to commercial, recreational, and artisanal fishing. Visual surveys that identify crucial habitat and the impacts of fishing on abiotic (e.g., disruption of soft-bottom, destruction of hard-bottom) and biotic (e.g., loss of habitat-forming, foundational species) attributes of deep rock and soft-bottom habitats inside and outside of MPAs can identify the impacts of fishing gear and inform management actions to prevent such impacts. Such surveys can also identify crucial habitat for populations of interest, including recruitment sites and habitats that serve as nursery grounds.

Recommendation: Ecosystem surveys should include observations and records of important abiotic and biotic features inside and outside of MPAs to determine whether nursery and other critical habitats are being protected and to identify the potential impacts of fishing gear.

In addition to larval connectivity, key data gaps for informing both MPA and fisheries management models are data on species' dispersal and movement. Monitoring studies that estimate annual rates of juvenile and adult emigration from MPAs, and the spatial extent of home range movements near MPA boundaries (so-called "spillover") will inform fisheries managers of the level of localized enhancement in the abundance and size of fished species in the vicinity of an MPA. Because where spillover adjacent to MPA boundaries is high, there will likely be more intense fishing, leading to a need for enhanced enforcement and efforts to obtain compliance with fishing regulations.

Recommendation: Studies should be undertaken to estimate annual rates of juvenile and adult emigration from MPAs, and home range movements near MPA boundaries. These studies should be designed to test for the contribution via spillover of individual MPAs as well as the MPA network to fish stocks sought after by commercial, recreational, and artisanal fishermen.

Monitoring studies can evaluate how the structure and functioning of communities and ecosystems respond to changes in species populations protected from fishing mortality. Comparison of species abundance and ecosystem attributes between MPAs and reference sites outside MPAs can help inform ecosystem-based fisheries management (EBFM), a new federal policy in the U.S., by identifying how fishing mortality of one or more species affects wider community and ecosystem responses. The EBFM specifically calls for enhanced understanding of trade-offs within an ecosystem and maintenance of resilient ecosystems. MPAs provide insight into ecological tradeoffs (e.g., if predators are not fished, how large a prey population can be sustained?). They also provide for resilience under the EBFM Policy definition, by maintaining "core ecosystem structure, biodiversity, production, energy flow, and functioning." (Denit 2016). However, similar to using MPA data on unfished populations to inform fishery stock assessments, such comparisons are complicated by larval inputs from fished areas on the state of communities and ecosystems within MPAs.

> **Recommendation**: Monitoring studies should be designed to identify both the population responses of fished species to protection by MPAs and the community and ecosystem-wide responses within MPAs to the protection of these species.

HOW FISHERIES INFLUENCE AND ENHANCE MPA MANAGEMENT

Effective fisheries management is a prerequisite for MPAs to meet their conservation goals. Populations within MPAs are largely replenished by larvae produced by the much larger fished populations occupying areas outside MPA boundaries. Therefore, both the magnitude and the spatial patterns of fishing will influence the replenishment of populations within MPAs. Fishing gear and practices that damage fish habitat also reduce the potential contribution of these larger fished stocks to the replenishment of populations within MPAs. Rates of fishing mortality in close proximity to MPAs can also influence the conservation value of MPAs and the contribution made by these MPAs to fisheries. For example, heavy fishing along the boundary of an MPA can increase density-dependent emigration rates of older life stages from MPAs, drawing down populations within MPAs, thereby simultaneously reducing their conservation value while increasing MPA contributions to localized fishery yields.

HOW FISHERIES INFORM ECOLOGICAL EVALUATIONS OF MPA PERFORMANCE

Fisheries management actions and the information generated by fisheries management practices are fundamentally important to the evaluation of MPA effectiveness. At the broadest spatial scale, knowledge of fisheries management actions and rates of fishing mortality greatly influence expectations of the condition (size and size structure) for fished populations inside and outside MPAs. For example, groundfish fisheries were highly constrained during the 2002-2010 period, particularly for shelf rockfish, so predicted differences in the condition of groundfish stocks inside and outside MPAs should be much different from those before and after that period. Similarly, knowledge of the geographic status of stocks informs predictions of the potential contributions of MPAs and the MPA network to the replenishment of fished stocks.

> **Recommendation:** Studies should be undertaken to downscale stock assessment results and stock status estimates (e.g., fully exploited, rebuilding, etc.) in order to characterize the expected contributions of fished areas and MPAs to larval replenishment of populations in the MPA network.

At smaller spatial scales, the design of ecological performance studies often involve comparisons of ecological metrics (e.g., species density and size structure, biomass, taxonomic and functional group diversity) inside MPAs compared with "reference" sites outside MPAs over time (e.g., Caselle et al. 2015). An implicit assumption of this design is that the "reference" areas outside MPAs are representative of the level of fishing mortality experienced by populations and communities in the area surrounding that MPA or multiple MPAs. Knowledge of fishing effort or mortality in reference areas and the areas they represent is critical to both testing that assumption and interpreting the data generated from these comparison-based analyses (Moffitt et al. 2013).

Similarly, knowledge of take immediately outside an MPA's boundary (fishing the line) can provide MPA managers with estimates of species emigration or spillover rates from MPAs. These rates can be considered when estimating population responses to MPAs and in estimating their contributions to local fishery yield.

Rates of fishing mortality or effort at individual MPAs prior to their establishment greatly influence the time course and magnitude of the response of populations and, by extension, communities and ecosystems to the establishment of an MPA (Jaco and Steele 2020). In combination with demographic models (White et al. 2016, Kaplan et al. 2019, Nickols et al. 2019), these predicted responses inform reasonable expectations of the ecological consequences of MPAs; they provide context and constraints on the expected responses in ecological metrics of populations, communities, and ecosystems to MPA establishment. These fishing data also are needed for comparisons inside and outside MPAs to evaluate MPA performance. Fishing effort and mortality data are most useful if collected at the lowest level of taxonomic resolution and at an MPA-scale of spatial resolution. Such information will also inform the spatial distribution of fishing effort in a coast-wide demographic connectivity model for assessing MPA network performance. However, most traditional fisheries programs do not collect data at the appropriate spatial resolution to inform MPA management questions. Nevertheless, in select cases available data are likely to provide insights into fishing effort and mortality, particularly resulting from recreational fishing where onboard observer data are being collected for CPFV fisheries. A careful comparison of research and data needs for both the assessment universe and the MPA management/evaluation universe will reveal broad overlap- and as the data improve, the ability to model spatially will improve as well - and this will inform both fishery and MPA management efforts.

Recommendation: Fisheries management should provide estimates of fishing effort and mortality at MPA sites prior to and after their establishment, including within MPAs that allow fishing, and at monitoring ("reference") sites outside of MPAs. Strong fisheries management programs generate highly valuable demographic data and life history information for fished species. This information is also critical for understanding interpreting differences in species responses to MPAs (Kaplan et al. 2019).

Recommendation: Fisheries management should generate and disseminate life history data (age, size, maturity, length-weight, length-fecundity, etc.) that can inform demographic connectivity models used to evaluate MPA network performance. These data are also useful in estimating biomass and larval production from length-based visual surveys (divers and ROVs).

LITERATURE CITED

Babcock, E. A., and A. D. MacCall. 2011. How useful is the ratio of fish density outside versus inside no-take marine reserves as a metric for fishery management control rules? Canadian Journal of Fisheries and Aquatic Sciences 68:343–359. DOI:10.1139/F10-146.

Berger, A. M. 2019. Character of temporal variability in stock productivity influences the utility of dynamic reference points. Fisheries Research 217:185–197. DOI:10.1016/j.fishres.2018.11.028.

Berger, A. M., D. R. Goethel, P. D. Lynch, T. Quinn, S. Mormede, J. McKenzie, and A. Dunn. 2017. Space oddity: The mission for spatial integration. Canadian Journal of Fisheries and Aquatic Sciences 74:1698–1716. DOI:10.1139/cjfas-2017-0150.

Caselle, J. E., A. Rassweiler, S. L. Hamilton, and R. R. Warner. 2015. Recovery trajectories of kelp forest animals are rapid yet spatially variable across a network of temperate marine protected areas. Scientific Reports 5:14102. DOI:10.1038/srep14102.

Denit, K. 2016. Ecosystem-Based Fisheries Management Policy of the National Marine Fisheries Service. NOAA NMFS. https://media.fisheries.noaa.gov/2020-09/01-120.pdf.

Field, J. C., A. E. Punt, R. D. Methot, and C. J. Thomson. 2006. Does MPA mean "Major Problem for Assessments"? Considering the consequences of place-based management systems. Fish and Fisheries 7:284–302. DOI:10.1111/j.1467-2979.2006.00226.x.

Garrison, T. M., O. S. Hamel, and A. E. Punt. 2011. Can data collected from marine protected areas improve estimates of life-history parameters? Canadian Journal of Fisheries and Aquatic Sciences 68:1761–1777. DOI:10.1139/f2011-073.

Guenther, C., D. López-Carr, and H. S. Lenihan. 2015. Differences in lobster fishing effort before and after MPA establishment. Applied Geography 59:78–87. DOI:10.1016/j.apgeog.2014.12.016.

Jaco, E. M., and M. A. Steele. 2020. Pre-closure fishing pressure predicts effects of marine protected areas. Journal of Applied Ecology 57:229–240. DOI:10.1111/1365-2664.13541.

Kaplan, K. A., L. Yamane, L. W. Botsford, M. L. Baskett, A. Hastings, S. Worden, and J. W. White. 2019. Setting expected timelines of fished population recovery for the adaptive management of a marine protected area network. Ecological Applications 29:e01949. DOI:10.1002/eap.1949.

Kay, M. C., H. S. Lenihan, C. M. Guenther, J. R. Wilson, C. J. Miller, and S. W. Shrout. 2012. Collaborative assessment of California spiny lobster population and fishery responses to a marine reserve network. Ecological Applications 22:322–335. DOI:10.1890/11-0155.1.

Lenihan, H. S., J. P. Gallagher, J. R. Peters, A. C. Stier, J. K. K. Hofmeister, and D. C. Reed. 2021. Evidence that spillover from Marine Protected Areas benefits the spiny lobster (Panulirus interruptus) fishery in southern California. Scientific Reports 11:2663. DOI:10.1038/s41598-021-82371-5.

McGilliard, C. R., R. Hilborn, A. MacCall, A. E. Punt, and J. C. Field. 2011. Can information from marine protected areas be used to inform control-rule-based management of small-scale, data-poor stocks? ICES Journal of Marine Science 68:201–211. DOI:10.1093/icesjms/fsq151.

McGilliard, C. R., A. E. Punt, R. D. Methot, and R. Hilborn. 2015. Accounting for marine reserves using spatial stock assessments. Canadian Journal of Fisheries and Aquatic Sciences 72:262–280. DOI:10.1139/cjfas-2013-0364.

Moffitt, E., J. White, and L. Botsford. 2013. Accurate assessment of marine protected area success depends on metric and spatiotemporal scale of monitoring. Marine Ecology Progress Series 489:17–28. DOI:10.3354/meps10425.

Nickols, K. J., J. W. White, D. Malone, M. H. Carr, R. M. Starr, M. L. Baskett, A. Hastings, and L. W. Botsford. 2019. Setting ecological expectations for adaptive management of marine protected areas. Journal of Applied Ecology 56:2376–2385. DOI:10.1111/1365-2664.13463.

Punt, A. E. 2019. Spatial stock assessment methods: A viewpoint on current issues and assumptions. Fisheries Research 213:132–143. DOI:10.1016/j.fishres.2019.01.014.

Punt, A. E., and R. D. Methot. 2004. Effects of marine protected areas on the assessment of marine fisheries. Pages 133–154 Aquatic protected areas as fisheries management tools. American Fisheries Society, Quebec, Canada.

Sibert, J., J. Hampton, P. Kleiber, and M. Maunder. 2006. Biomass, size, and trophic status of top predators in the Pacific Ocean. Science 314:1773–1776. DOI:10.1126/science.1135347.

Wertz, S., D. Aseltine-Nielsen, T. Barnes, J. Vasques, S. Ashcraft, K. Barsky, A. Frimodig, M. Key, T. Mason, and B. Ota. 2011. Proceedings of the Marine Protected Areas and Fisheries Integration Workshop. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=42306&inline.

White, J. W., K. J. Nickols, D. Malone, M. H. Carr, R. M. Starr, F. Cordoleani, M. L. Baskett, A. Hastings, and L. W. Botsford. 2016. Fitting state-space integral projection models to size-structured time series data to estimate unknown parameters. Ecological applications : a publication of the Ecological Society of America 26:2675–2692. DOI:10.1002/eap.1398.

Appendix 5: Glossary of Key Terms

Terms Defined From in the MLPA Goals

One element of the working group's charge is to provide scientific definitions of select terms in the MLPA goals to support decadal management reviews. The terms below were selected and defined by the working group using a combination of existing definitions, supporting literature, and expert judgement.

Abundance: The total number of individual organisms, quantity of biomass, or amount (usually percentage) of covered substratum present in a given area (modified from CDFW and CA OPC 2018).

Adequate Enforcement: A combination of law enforcement, education and outreach activities that reduce non-compliance with MPA regulations to a sufficiently low level that MPAs are effective at protecting living marine resources (informed by Davis and Moretti 2005, Reef Resilience Network 2020).

Biodiversity: A component and measure of ecosystem health and function. It is the number and genetic richness of different individuals within a population of a species, of populations found within a species range, of different species found within a natural community or ecosystem, and of different communities and ecosystems found within a region. Humans are also an integral part of biodiversity and derive ecosystem services including sustenance and physical and psychological wellbeing (modified from CDFW 2018, CDFW and CA OPC 2018).

Ecosystem: The physical and climatic features and all the living and dead organisms in an area that are interrelated in the transfer of energy and material, which together produce and maintain a characteristic type of biological community. Marine ecosystems can be particularly complex due to the vastness of the marine environment, the large number of organisms, and the intricacies of the physical, chemical, biological, and social processes involved (modified from CDFW 2016, CDFW and CA OPC 2018).

Ecosystem function: The processes through which the constituent living and nonliving components of an ecosystem change and interact, including biological, geochemical, and physical processes (informed by CDFG 2008, GEO BON 2014).

Ecosystem integrity: The condition of an ecosystem that preserves its components (ecosystem structure) and the functional relationships between them (ecosystem function) in the face of an external disturbance (modified from De Leo and Levin 1997, Dorren et al. 2004).

Ecosystem structure: The spatial arrangement of the living and nonliving components of an ecosystem (modified from Kaufmann et al. 1994, CDFG 2008).

Effective (*MPA*) management: Management that achieves the goals of the MPA(s). Effective management requires learning, communicating lessons, and developing and carrying out targeted research and development projects that can support monitoring and inform adaptive management to meet the Marine Life Protect Act goals (modified from CDFW 2016).

Intrinsic value: One component of the Total Economic Value Framework that includes aspects of ecosystems and their constituent parts which have value in their own right, including their biological and genetic diversity and the essential characteristics that determine an ecosystem's integrity, form, functioning, and resilience, independent of human uses. Challenging and controversial to measure as there are multiple methods but no agreed upon standard. Potential methods include willingness to pay, willingness to accept, willingness to sell and choice experiments (informed by Krutilla 1967, NZ Resource Management Act 1991 §2(1), Fisher et al. 2008).

Minimal human disturbance: Human disturbance is the amount of change/disruption humans cause and a measure of the vulnerability of resources to a variety of harmful human activities such as noise and light pollution, habitat trampling, increased nutrient discharge, artificial coastline hardening, plastic pollution, climate change and more. Minimal human disturbance would reflect the state where these disturbances are eliminated or highly reduced (modified from US EPA 2014).

Marine protected area network: A collection of individual marine protected areas connected by larval dispersal operating cooperatively and synergistically, at various spatial scales, and with a range of protection levels, in order to fulfill ecological aims more effectively and comprehensively than individual sites could alone. The network will also display social and economic benefits, though the latter may only become fully developed over long time frames as ecosystems recover (modified from WCPA and IUCN 2007).

Natural diversity: The species richness of a community, ecosystem, and other natural area when protected from, or not subjected to, human-induced change (modified from CDFW 2016).

Natural heritage: Natural features, geological and physiographical formations and delineated areas that constitute the habitat of threatened species of animals and plants and natural sites of value from the point of view of science, conservation, human cultural interest, or natural beauty. It includes nature parks and reserves, zoos, aquaria and botanical gardens. "Natural heritage" is also what we inherit from the earth, includes ecosystem services, and an element of past, present, and future generations (modified from UNESCO 1972).

Objectives: Objectives provide quantitative support and expression for goals when written with specific, measurable, assignable, realistic, and time-bound criteria (Doran 1981). (Note: In the MLPA planning phase, objectives were treated as "sub-goals" or smaller steps toward a larger goal as defined by the MLPA. Here we aim to be more specific.)

Representative marine life habitats: Marine habitats found in California's state waters, and the ecosystems they support. Identified for protection in the MLPA planning process (e.g., rocky intertidal, sandy beach, shallow and deeper rocky reef) (modified from CDFW 2016).

Sound scientific guidelines: Guidelines for how to design MPAs to achieve their stated goals based on multidisciplinary and transdisciplinary science, including social science, according to a consensus among the panel of experts appointed to develop these guidelines (modified from CDFG 2008, CDFW 2018).

Unique marine life habitats: A habitat that is unique (or singular) within a region due to a rare combination of physical and/or biological components (informed by Roff and Taylor 2000, CDFW 2016).

OTHER KEY TERMS

The additional terms below were selected and defined by the Working Group to clarify how these terms were used throughout the report. These terms were defined by a combination of existing definitions, supporting literature, and expert judgement.

Adaptive management: With regard to the marine protected areas, adaptive management is a management policy that seeks to improve management of biological resources, particularly in areas of scientific uncertainty, by changing it based on lessons learned. Actions shall be designed so that, even if they fail, they will provide useful information for future actions, and monitoring and evaluation shall be emphasized so that the interaction of different elements within marine systems may be better understood (modified from CDFW and CA OPC 2018, CA Fish and Game Code §2852(a)).

Age structure (of a population): The distribution of individuals in a population based on their age. Contrast in age structure over space and time provides insights into impacts of fisheries or other mortality sources relative to natural mortality rates (modified from Gotelli 2008).

Attitudes (regarding MPAs): Research on stakeholder attitudes, beliefs, perceptions and preferences related to MPA issues examines the underlying motivations that may influence stakeholders' preferences, choices and actions. As such, understanding the attitudes and perceptions of stakeholders towards MPAs could help predict the likely behavior towards this management tool (modified from Wahle et al. 2003, Pita et al. 2011).

Catch data: Data collected by fishermen or fisheries biologists that provides insight into the abundance (in numbers or mass), catch rates (see CPUE), species composition, or other demographic information for fish or invertebrates removed from the ecosystem as a result of fishing activity (informed by CDFW 2018).

Compliance: The behavior of people who follow the rules, or rule adherence. Crucial to understanding compliance is the underlying motivation of behavioral responses to regulations (including economic and normative factors) (informed by Arias 2015, Bergseth and Roscher 2018, Bergseth 2018).

Concentration (of fishing effort): Changes in the distribution of fishing effort resulting from displacement of effort previously distributed within MPAs, such that effort is concentrated (less diffuse) in remaining open areas (informed by Murawski et al. 2005).

Connectivity (demographic): An exchange of individuals among local populations that can influence population demographics and dynamics. It can include: Exchange of offspring between populations through larval dispersal; Recruitment of juveniles and survival of these juveniles to reproductive age; Any large-scale movement of juveniles and adults between locations (informed by Sale et al. 2010).

Connectivity (ecosystem): Linking of places or populations through movement of organisms, nutrients, pollutants or other items between them (informed by Sale et al. 2010).

Connectivity (population): The movement of organisms from place to place (e.g., among reserves) through dispersal or migration (NRC 2001).

Consumptive: Activities that result in removal of resources such as recreational and commercial fisheries, seaweed harvesting, shell collecting (informed by CDFW 2018).

Consumptive recreation: Recreational activities that result in the removal of or harm to natural or cultural resources such as fishing, beachcombing, clam digs, and shell collecting (modified from NOAA ONMS 2021).

Cultural uses (of ecosystems): The non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, for example, knowledge systems, social relations, and aesthetic values. They may also be seen as 'cultural benefits', as they directly relate to changes in human welfare (informed by Manley et al. 2019).

Displacement (of fishing effort): The changes in fishing behavior and patterns that could occur in response to new management measures (Vaughan 2017).

Disturbance: A discrete event, either natural or human induced, that causes a change in the existing condition of an ecological system (informed by Kaufmann et al. 1994, as "ecosystem disturbance" in CDFG 2008).

Ecosystem service: Ecosystem services are the benefits (physical and psychological wellbeing) people obtain from ecosystems. These include provisioning services, such as food and water; regulating services, such as flood and disease control; cultural services, such as spiritual and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth (Blackhart et al. 2005).

Educational use: Use of MPAs for formal academic instruction, informal interpretive programs, cultural and ceremonial activities, or other educational activities (Title 14: CA Code of Regulations §650).

Fishing effort: The amount of time and fishing power to harvest fish, invertebrates, or plants, whether by individuals or vessels. For vessels fishing power includes gear size, boat size, and horsepower. Used to calculate catch per unit effort (informed by CDFW 2018).

Focal species: Species identified in the MPA Monitoring Action Plan as priority indicators for monitoring and evaluating MPAs in California and those that investigators have identified specific to ecosystems of study (CDFW and CA OPC 2018).

Habitat: The living place of an organism or community characterized by the resources and conditions present, including the physical, chemical and biological properties (informed by Krausman 1999, CDFG 2008, CDFW 2016, 2018).

Habitat diversity: The range of habitats present in a region (informed by Alsterberg et al. 2017).

Habitat quality (oceanographic, geologic, biogenic): The ability of the environment to provide conditions appropriate for individual and population persistence (Krausman 1999)

Human dimensions (of MPAs): The social, economic, cultural, and institutional aspects of MPAs which encompasses the state or change of human behavior, economic outcomes, and stakeholder attitudes, perceptions, or knowledge (informed by Charles and Wilson 2009).

Knowledge: Understanding or information about a subject gained via experience or study, either by a single person or people generally (McIntosh 2013).

Larval connectivity: The linkage among discontinuous 'local' or subpopulations of a single species that results from the movement of individuals from one group to another (Carr et al. 2017).

Larval production: Spawning and creation of larvae (modified from Meekan et al. 1993).

Larval supply: The number of larvae reaching a settlement site or appropriate adult habitat (modified from Jenkins and Hawkins 2003)**.**

Long-term monitoring: Repeated field-based empirical measurements that are collected continuously and then analyzed for an extended period of time to aid in understanding social and ecological trends and changes over time (modified from Lindenmayer and Likens 2010).

Mortality rate (fishing mortality): Denoted by F, which stands for the fishing mortality rate in a particular stock. It is roughly the proportion of the fishable stock that is caught in a year. It is also a measurement of the rate of removal from the population by fishing (modified from Blackhart et al. 2005).

Mortality (natural): Removal of fish from a population due to causes unrelated to fishing, such as predation, diseases and other natural factors, or pollution. Denoted as "M" in fisheries stock assessment models (CDFW and CA OPC 2018).

Natural community: A distinct, identifiable, and recurring association of plants and animals that are ecologically interrelated (CDFG 2008, CA Fish and Game Code §2702(d)).

Non-consumptive use: Activities that do not include removal of resources such as photography, whale watching, diving, surfing, etc. (modified from CDFW 2018).

Perceived value: The value or worth of a product or service based on an individual or group's point of view, rather than its actual price (modified from *Cambridge business English dictionary* 2011)

Perception (regarding MPAs): The way an individual observes, understands, interprets, and evaluates a referent object, action, experience, individual, policy, or outcome. There are four categories of stakeholder perceptions that might influence local support for conservation—perceptions of ecological effectiveness, social impacts, good governance, and management (Bennett 2016).

Population: All the individuals of a species living within a specific area (informed by Clark et al. 2018).

Protected species: Species identified in the MPA Monitoring Action Plan as Special Status Species (CDFW and CA OPC 2018).

Recovery: Sustained increase in the attributes of the system that provide lasting ecological and social value. At a minimum, recovery entails the return of population viability and ecological function (Ingeman et al. 2019).

Reference site: A sampling site outside of a MPA that is used to compare metrics to evaluate consequences of the MPA. Reference sites preferably differ only in the level of a regulated activity (e.g. some form of fishing) and are otherwise very similar in all other respects (e.g. habitat and other environmental conditions) (informed by CDFW and CA OPC 2018).

Resilience: The capacity of an ecosystem to absorb recurrent disturbances or shocks and adapt to change while retaining essentially the same function and structure (McClanahan et al. 2012, CDFW 2018). The ability of a coupled social-ecological-economic system and its components to absorb stressors and disturbance through resistance and/or recovery of core function, structure, and provision of services (Hofmann et al. 2021).

Self-retention (of larvae): The ratio of locally produced settlement to settlement from all origins (Lett et al. 2015).

Spacing (of MPAs): Recommended spacing to facilitate dispersal and connectedness of important bottom dwelling fish and invertebrates among MPAs (CDFG 2008 pg. 39, CDFW 2016 pg. A-35).

Species diversity: The number of different species in a particular area (species richness) weighted by some measure of abundance such as number of individuals or biomass (Bynum 2009).

Spillover (adult): Two types of spillover from MPAs can exist: ecological spillover and fishery spillover. Ecological spillover is the net movement of fish biomass from non-fished areas into fished areas. This may happen when a species exhibits density-independent movement such as home range behavior, ontogenetic shifts with increasing age, or when high densities inside MPAs lead to competition for scarce resources, causing some individuals to leave MPAs in search of food or shelter. Fishery spillover is the proportion of fish biomass available to a fishery given existing regulations and access constraints. This is most likely to occur when the rate of emigration from MPAs is low enough that MPAs provide some refuge from fishing, but high enough that a certain proportion of the population exit the MPA into fishable areas (CDFW 2018 pg. D-3).

Stakeholders: Stakeholders refer broadly to anyone with any interest in MPAs, which, since MPAs are a public trust resource, includes any member of the public within the state of California. The term "stakeholders" is widely used in management and in the scientific literature but has sometimes emphasized those with economic interest in MPAs. As this report defines stakeholders more expansively, we include communities of interest and communities of place in its definition (working group definition).

Sustainable fishery: a) Continuous replacement of resources, taking into account fluctuations in abundance and environmental variability; and b) Securing the fullest possible range of present and long-term economic, social, and ecological benefits, maintaining biological diversity, and in the case of fisheries management based on maximum sustainable yield, providing for a fishery that does not exceed optimum yield (informed by CDFW 2018).

Take (including incidental take): Hunt, pursue, catch, capture, kill, or attempt to hunt, pursue, catch, capture, or kill (CA Fish and Game Code §86) as well as collecting, handling, marking, manipulating, or conducting other procedures on wildlife, whether wildlife are released or retained in possession (Title 14: CA Code of Regulations §650).

Traditional ecological knowledge (TEK) or Indigenous traditional knowledge (ITK): While no single definition of TEK/ITK is universally accepted, it has been described as 'a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment' (Berkes 2008, CDFW 2016 pg. 6).

Wellbeing: A state of being with others and the environment, which arises when human needs are met, when individuals and communities can act meaningfully to pursue their goals, and when individuals and communities enjoy a satisfactory quality of life (Armitage et al. 2012). Gollan and Barclay (2020) present seven aspects of wellbeing: 1) environment; 2) health and safety; 3) social connections; 4) education and knowledge; 5) culture and heritage; 6) governance; and 7) local economy.

LITERATURE CITED

Alsterberg, C., F. Roger, K. Sundbäck, J. Juhanson, S. Hulth, S. Hallin, and L. Gamfeldt. 2017. Habitat diversity and ecosystem multifunctionality—The importance of direct and indirect effects. Science Advances 3:e1601475. DOI:10.1126/sciadv.1601475.

Arias, A. 2015. Understanding and managing compliance in the nature conservation context. Journal of Environmental Management 153:134–143. DOI:10.1016/j.jenvman.2015.02.013.

Armitage, D., C. Béné, A. T. Charles, D. Johnson, and E. H. Allison. 2012. The interplay of well-being and resilience in applying a social-ecological perspective. Ecology and Society 17:art15. DOI:10.5751/ES-04940-170415.

Bennett, N. J. 2016. Using perceptions as evidence to improve conservation and environmental management. Conservation Biology 30:582–592. DOI:10.1111/cobi.12681.

Bergseth, B. J. 2018. Effective marine protected areas require a sea change in compliance management. ICES Journal of Marine Science 75:1178–1180. DOI:10.1093/icesjms/fsx105.

Bergseth, B. J., and M. Roscher. 2018. Discerning the culture of compliance through recreational fisher's perceptions of poaching. Marine Policy 89:132–141. DOI:10.1016/j.marpol.2017.12.022.

Berkes, F. 2008. Sacred ecology. 2nd ed. Routledge, New York. ISBN:978-0-415-95827-1.

Blackhart, K., D. G. Stanton, and A. M. Shimada,. 2005. NOAA fisheries glossary. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. https://repository.library.noaa.gov/view/noaa/12856.

Bynum, N. 2009. What is biodiversity? Orange Grove Texts. ISBN:1-61610-086-9.

CA Fish and Game Code. (n.d.). California Fish and Game Code. Page California Fish and Game Code. https://law.justia.com/codes/california/2018/code-fgc/division-3/chapter-10.5/.

Cambridge business English dictionary. 2011. . Cambridge University Press, Cambridge ; New York. ISBN:978-0-521-12250-4.

Carr, M. H., S. P. Robinson, C. Wahle, G. Davis, S. Kroll, S. Murray, E. J. Schumacker, and M. Williams. 2017. The central importance of ecological spatial connectivity to effective coastal marine protected areas and to meeting the challenges of climate change in the marine environment. Aquatic Conservation: Marine and Freshwater Ecosystems 27:6–29. DOI:10.1002/aqc.2800.

CDFG. 2008. California Marine Life Protection Act Master Plan for Marine Protected Areas. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=113006&inline.

CDFW. 2016. California Marine Life Protection Act Master Plan for Marine Protected Areas. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=133535&inline.

CDFW. 2018. Master Plan for Fisheries A guide for Implementation of the Marine Life Managment Act. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=159222&inline.

CDFW and CA OPC. 2018. Marine Protected Area Monitoring Action Plan. California, USA. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=161748&inline.

Charles, A., and L. Wilson. 2009. Human dimensions of marine protected areas. ICES Journal of Marine Science 66:6–15. DOI:10.1093/icesjms/fsn182.

Clark, M. A., J. H. Choi, M. Douglas, OpenStax College, and Rice University. 2018. Biology 2e. ISBN:978-1-947172-52-4.

Davis, B. C., and G. S. Moretti. 2005. Enforcing U.S. marine protected areas: synthesis report. National Marine Protected Areas Center in cooperation with the National Oceanic and Atmospheric Administration Coastal Services Center. https://nmsmarineprotectedareas.blob.core.windows.net/marineprotectedareas-prod/media/archive/pdf/publications/enforcement.pdf.

De Leo, G., and S. Levin. 1997. The multifaceted aspects of ecosystem integrity. Conservation

Ecology 1. DOI:10.5751/ES-00022-010103.
Doran, G. T. 1981. There's a S.M.A.R.T. way to write managements's goals and objectives. Management Review 70:35–36. ISSN:0025-1895.
Dorren, L., F. Berger, A. Imeson, B. Maier, and F. Rey. 2004. Integrity, stability and management of protection forests in the European Alps. Forest Ecology and Management 195:165–176. DOI:10.1016/j.foreco.2004.02.057.
Fisher, B., K. Turner, M. Zylstra, R. Brouwer, R. de Groot, S. Farber, P. Ferraro, R. Green, D. Hadley, J. Harlow, P. Jefferiss, C. Kirkby, P. Morling, S. Mowatt, R. Naidoo, J. Paavola, B. Strassburg, D. Yu, and A. Balmford. 2008. Ecosystem Services and Economic Theory: Integration for Policy-Relevant Research. Ecological Applications 18:2050–2067. DOI:10.1890/07-1537.1.
GEO BON. 2014, 2021. GEO BON: The Group on Earth Observations Biodiversity Observation Network. https://geobon.org/. https://geobon.org/.
Gotelli, N. J. 2008. A primer of ecology. 4th ed. Sinauer Associates, Sunderland, Mass. ISBN:978-0-87893-318-1.
Hofmann, G., E. Hazen, D. Aseltine-Nielsen, J. Caselle, F. Chan, A. Levine, F. Micheli, J. Sunday, and W. White. 2021. Climate resilience and California's Marine Protected Area Network: A report by the Ocean Protection Council Science Advisory Team Working Group and California Ocean Science Trust.
Ingeman, K. E., J. F. Samhouri, and A. C. Stier. 2019. Ocean recoveries for tomorrow's Earth: Hitting a moving target. Science 363. DOI:10.1126/science.aav1004.
Jenkins, S. R., and S. J. Hawkins. 2003. Barnacle larval supply to sheltered rocky shores: a limiting factor? Pages 143–151 *in* M. B. Jones, A. Ingólfsson, E. Ólafsson, G. V. Helgason, K. Gunnarsson, and J. Svavarsson, editors. Migrations and Dispersal of Marine Organisms. Springer Netherlands, Dordrecht. DOI:10.1007/978-94-017-2276-6_16.
Kaufmann, M. R., R. T. Graham, D. A. Boyce, W. H. Moir, L. Perry, R. T. Reynolds, R. L. Bassett, P. Mehlhop, C. B. Edminster, W. M. Block, and P. S. Corn. 1994. An ecological basis for ecosystem management. Page 21. General Technical Report, Rocky Mountain Forest and Range Experiment Station, United States Department of Agriculture Forest Service, Fort Collins, Colorado. https://www.fs.usda.gov/treesearch/pubs/7612.
Krausman, P. A. 1999. Some basic principles of habitat use. Page Grazing Behavior of Livestock and Wildlife. University of Idaho, Moscow, Idaho, Moscow, ID. https://www.webpages.uidaho.edu/range456/readings/krausman.pdf.
Krutilla, J. V. 1967. Conservation Reconsidered. The American Economic Review 57:777–786.
Lett, C., T. Nguyen-Huu, M. Cuif, P. Saenz-Agudelo, and D. M. Kaplan. 2015. Linking local retention, self-recruitment, and persistence in marine metapopulations. Ecology 96:2236–2244. DOI:10.1890/14-1305.1.
Lindenmayer, D. B., and G. E. Likens. 2010. The science and application of ecological monitoring. Biological Conservation 143:1317–1328. DOI:10.1016/j.biocon.2010.02.013.
Manley, W., K. Foot, and A. Davis. 2019. A Dictionary of Agriculture and Land Management. First edition. Oxford University Press. DOI:10.1093/acref/9780199654406.001.0001.
McClanahan, T. R., S. D. Donner, J. A. Maynard, M. A. MacNeil, N. A. J. Graham, J. Maina, A. C. Baker, J. B. Alemu I., M. Beger, S. J. Campbell, E. S. Darling, C. M. Eakin, S. F. Heron, S. D. Jupiter, C. J. Lundquist, E. McLeod, P. J. Mumby, M. J. Paddack, E. R. Selig, and R. van Woesik. 2012. Prioritizing Key Resilience Indicators to Support Coral Reef Management in a Changing Climate. PLoS ONE 7:e42884. DOI:10.1371/journal.pone.0042884.
McIntosh, C., editor. 2013. Cambridge Dictionary. Fourth edition. Cambridge University Press, Cambridge. ISBN:978-1-107-61950-0.
Meekan, M. G., M. J. Milicich, and P. J. Doherty. 1993. Larval production drives temporal patterns of larval supply and recruitment of a coral reef damselfish. Marine Ecology Progress Series 93:217–225. ISSN:01718630, 16161599.

Murawski, S. A., S. E. Wigley, M. J. Fogarty, P. J. Rago, and D. G. Mountain. 2005. Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science 62:1150–1167. DOI:10.1016/j.icesjms.2005.04.005.

NOAA ONMS. 2021. Description of ecosystem services and methods to determine ratings. https://sanctuaries.noaa.gov/science/condition/ecosystem.html. https://sanctuaries.noaa.gov/science/condition/ecosystem.html.

NRC. 2001. Marine Protected Areas: Tools for Sustaining Ocean Ecosystem. Page 9994. National Academies Press, Washington, D.C. DOI:10.17226/9994.

NZ Resource Management Act. 1991. New Zeland Resource Management Act. https://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html.

Pita, C., G. J. Pierce, I. Theodossiou, and K. Macpherson. 2011. An overview of commercial fishers' attitudes towards marine protected areas. Hydrobiologia 670:289–306. DOI:10.1007/s10750-011-0665-9.

Reef Resilience Network. 2020. Fisheries Surveillance and Enforcement | Reef Resilience. The Nature Conservancy. https://reefresilience.org/coral-reef-fisheries-module/reef-fisheries-management/fisheries-surveillance-and-enforcement/.

Roff, J. C., and M. E. Taylor. 2000. National frameworks for marine conservation — a hierarchical geophysical approach. Aquatic Conservation: Marine and Freshwater Ecosystems 10:209–223. DOI:10.1002/1099-0755(200005/06)10:3<209::AID-AQC408>3.0.CO;2-J.

Sale, P. F., H. Van Lavieren, M. C. Ablan Lagman, J. Atema, M. Butler, C. Fauvelot, J. D. Hogan, G. P. Jones, K. C. Lindeman, C. B. Paris, R. Steneck, and H. L. Stewart. 2010. Preserving reef connectivity: a handbook for marine protected area managers. Connectivity working group, Coral Reef Targeted Research & Capacity Building for Management Program UNU-INWEH. https://i.unu.edu/media/ourworld.unu.edu-en/article/4139/CRTR_ConnectivityHandbook_001.pdf.

Title 14: CA Code of Regulations. (n.d.). Title 14: California Code of Regulations. Page Title 14. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=141277&inline.

UNESCO. 1972. Convention Concerning the Protection of the World Cultural and Natural Heritage. https://whc.unesco.org/en/conventiontext/. https://whc.unesco.org/en/conventiontext/.

US EPA, O. 2014, January 10. Indicators: Human Disturbance. Overviews and Factsheets. https://www.epa.gov/national-aquatic-resource-surveys/indicators-human-disturbance. https://www.epa.gov/national-aquatic-resource-surveys/indicators-human-disturbance.

Vaughan, D. 2017. Fishing effort displacement and the consequences of implementing Marine Protected Area management – An English perspective. Marine Policy 84:228–234. DOI:10.1016/j.marpol.2017.07.007.

Wahle, C. M., S. Lyons, K. Barba, L. Bunce, P. Fricke, E. Nicholson, M. Orbach, C. Pomeroy, H. Recksiek, and J. Uravitch. 2003. Social science research strategy for marine protected areas. National Marine Protected Areas Center in cooperation with the National Oceanic and Atmospheric Administration Coastal Services Center, National Marine Protected Areas Center, MPA Science Institute. https://repository.library.noaa.gov/view/noaa/10807.

WCPA and IUCN. 2007. Establishing networks of marine protected areas: A guide for developing national and regional capacity for building MPA networks. Non-technical summary report. https://www.cbd.int/doc/pa/tools/Establishing%20Marine%20Protected%20Area%20Networks.pdf.