Developing a Shared Research Agenda for Blue Water MPAs

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ABOUT THIS REPORT

The Nature Conservancy (TNC) and Conservation International (CI) organized a convening of thought leaders and experts in January 2019 to discuss knowledge and research gaps regarding the effectiveness of blue water marine protected areas (BWMPAs) as tools for biodiversity conservation, ecosystem protection, fisheries management, and other conservation benefits. This convening included two dozen experts from a wide range of disciplines; the primary questions addressed in the convening included the following:

- What roles/functions are BWMPAs best suited for and what optimization criteria can be derived?
- What is the current state of knowledge about the efficacy of BWMPAs across these criteria?
- What are major knowledge gaps to support BWMPA placement and design?
- To what extent must uncertainties (e.g., climate change, policy) be taken into consideration?
- What research areas should be prioritized to support decision makers with meaningful advice?

GLOSSARY

ABNJ	Areas beyond national jurisdiction
BWMPA	Blue water marine protected area
CI	Conservation International
CPUE	Catch per unit effort
DOM	Dynamic ocean management
EBSA	Ecologically or Biologically Significant Marine Area
EEZ	Exclusive economic zone
FAD	Fish aggregating device
IUCN	International Union for Conservation of Nature
KBA	Key Biodiversity Area
MPA	Marine protected area
TAC	Total allowable catch
TNC	The Nature Conservancy
PNA	The Parties to the Nauru Agreement
UCSB	University of California, Santa Barbara
UW	University of Washington

OVERVIEW

Blue water marine protected areas (BWMPAs)[1] can accelerate the large-scale protection of our oceans, but the conditions under which they can achieve a range of social, economic, and environmental objectives are still unclear. Marine protected areas (MPAs) have emerged as an effective tool to protect biodiversity, boost fisheries productivity around the world, and strengthen the socio-cultural systems of fisher communities. Today, about 12,000 MPAs exist, covering approximately 7.4 percent of the ocean.[2] While most MPAs encompass small, near-shore areas, large-scale MPAs are a relatively new development and have been poorly studied to date. There is no question that the establishment of large-scale open-ocean MPAs—here referred to as BWMPAs (i.e., those primarily focused on protecting open ocean habitats and species)—would greatly accelerate the total cover of protected ocean areas. Additionally, by unit area large-scale MPAs are also much less expensive to create and implement, and they have thus become a recent focus by governments, philanthropic institutions, and nonprofit organizations. However, gaps remain in evaluating the full-range of specific benefits of BWMPAs, and how they can realize their full potential as conservation tools.

Governments, nonprofit organizations, and philanthropic foundations have recently and significantly invested in the establishment of BWMPAs. Given increasing attention, as science-based organizations, it is a priority for us to understand the benefits this tool can deliver, and under what conditions. The ocean conservation community's current and future interests and investments in BWMPAs make this an opportune time to identify key knowledge gaps and start developing a prioritized list of research questions and hypotheses around the environmental and socio-economic impacts of BWMPAs.

On January 21-22, 2019, The Nature Conservancy (TNC) and Conservation International (CI) convened a group of experts and collaborators to co-create a shared research agenda for BWMPAs. **The purpose of the meeting was to identify gaps in scientific evidence relating to the impacts of BWMPAs and to develop a prioritized set of research priorities to address those gaps. Meeting participants identified four broad areas that would benefit from increased research**:

1. **Biodiversity**: What climate resilience and ecological benefits arise from BWMPAs and for which species/systems are BWMPAs particularly suitable?
2. **Fisheries**: What criteria increase the effectiveness of BWMPAs as a management tool for fisheries, particularly for highly migratory species?
3. **Human Dimensions**: How can BWMPAs take into consideration constituencies and benefactors and lead to positive social, economic, and cultural outcomes?
4. **Design, Governance and Management**: What enabling conditions, institutional structures, and governance systems need to be in place for an effective management of BWMPAs?

1 See definition in box on right margin of Page 6 in this report.

2 According to the MPAtlas 4.8% of the global ocean is protected by MPAs, with an additional 1.3% lying in designated but unimplemented MPAs, and 1.3% in proposed and committed MPAs (available at http://www.mpatlas.org/map/mpas/).

KNOWLEDGE AND KNOWLEDGE GAPS – A RAPID SCAN OF THE LITERATURE

A quick scan of the literature suggests that many key questions around design and impact of BWMPAs have not yet been explored empirically. In preparation of the January workshop, a rapid scan of the literature was conducted to provide a common understanding of major themes and hypotheses emerging in the broader BWMPA context. The pre-reading scan was focused on three primary impact areas associated with BWMPAs: biodiversity, fisheries, and human dimensions. The scan also explored BWMPA design, governance, and management considerations. Findings of the scan suggest that empirical studies of BWMPAs have been limited, with more emphasis on hypothesized rather than realized outcomes (Davies et al. 2018), in part because of the following:

1. Data is limited due to challenges of accessing remote and deep areas of the ocean (Big Ocean 2013), and the fact that creation of MPAs generally means losing fishing records, one of the main sources of data on open ocean environments.
2. The spatial and temporal scales of ecosystem changes is often uncertain, especially for open ocean ecosystems with large vertical and horizontal footprints and high levels of connectivity (Levin et al. 2016; O'Leary and Roberts 2018).
3. There is uncertainty about key features and complexities of open ocean species and ecosystems (Game et al. 2009).

Despite these knowledge gaps, anecdotal evidence points to the potential of well-designed BWMPAs to be effective tools for the protection of pelagic ecosystems. In particular, BWMPAs have the potential to reduce cumulative impacts[3] for a wide array of threats, and to provide many social and ecological benefits (Game et al. 2009; Koldewey et al. 2010). The thematic overview that follows explores some of the claims and actual data across a range of design and impact questions, including around biodiversity, fisheries, human dimensions, and design, governance, and management considerations.

3 Changes to the environment caused by the combined effect of past, present and future human activities and natural processes.

BWMPA DEFINITION FOR PURPOSE OF WORKSHOP

Blue water refers to open ocean ecosystems, and the species associated with them. Open ocean ecosystems contrast with coastal marine ecosystems, which are adjacent to land, including small islands. Open ocean ecosystems tend to be dominated by physical, chemical, and biological features that are highly dynamic in space and time, but there are likely strong connections between the pelagic and benthic components of these ecosystems. There are strong connections between open ocean and island ecosystems, which is why the designation of BWMPAs have been catalyzed by many island communities.

A BWMPA refers to a spatially defined area of open ocean explicitly dedicated to the protection and maintenance of marine biodiversity, ecosystems and associated cultural resources, and is managed for this purpose. MPAs are primarily a tool to manage where different activities can occur. While our definition does not restrict consideration to 'no-take' MPAs, the intent of the MPAs must be to limit the occurrence of extractive, destructive, and polluting activities inside its boundaries. In the open ocean, fishing represents the most common activity being limited by BWMPAs. Spatial management measures are sometimes used in the open ocean as a tool to manage stocks of target species, such as fisheries time and area closures. We only consider these BWMPAs where the objectives for the closure extend beyond managing the commercial species to include conservation of non-target blue water biodiversity.

Biodiversity

Large BWMPAs can protect whole ecosystems and interdependent habitats from multiple stressors, but effective MPA design requires a better understanding of ecological and environmental linkages, particularly for open ocean, pelagic ecosystems. Both open-ocean and deep-sea habitats can significantly benefit from BWMPAs (Toonen et al. 2013; Wilhelm et al. 2014). Benefits of this approach include protecting vulnerable, under-valued, and bycatch species and helping maintain trophic linkages (Travis et al. 2014). Recent research has highlighted the importance of integrated species and habitat protection in open ocean ecosystems, challenging vertically stratified management (e.g., MPAs protecting the seabed while the water column remains open to fishing), and single species approaches. For example, O'Leary and Roberts (2017; 2018) cite evidence of linkages through the water column, and between the water column and the seabed (e.g., energy production and transfer in food webs, cycling of nutrients and raw materials, shifts in habitat use, and daily and seasonal vertical migrations associated with megafauna and mesopelagic fish), and argue that mobile marine organisms provide structure-forming biomass, constituting "habitat" in the open ocean. That said, the state of knowledge on the strength and nature of these ecological and environmental linkages is sparse, which limits effective selection and design of MPAs. Critical gaps include spatial scales, potential cascading impacts due to food-web interactions between seabed and water column ecosystems, and effects of pelagic fishing on ecosystem functioning in offshore environments (O'Leary and Roberts 2018). Approaches that have been taken to develop protected areas in related data-limited ecosystems, such as the deep sea, may be useful to address similar challenges for pelagic ecosystem MPA design and implementation (Wedding et al. 2013; 2015).

Pelagic ecosystems are complex and dynamic; conservation and management of highly migratory species is difficult but feasible with good data and adaptive BWMPA design. The dynamism of the open ocean—where ecosystems shift substantially across spatial and temporal scales—poses a challenge to conventional notions of how protected areas function (Kaplan et al. 2014; Young et al. 2015). Despite this dynamism, there are important pelagic features (e.g., upwelling cells, thermal fronts, eddies) that are somewhat predictable in space and time (Alpine and Hobday 2007). However, the complexities of pelagic systems are not well understood, which can make informed decisions on MPA placement a challenge (Game et al. 2009). For pelagic species conservation, MPAs in open ocean environments are most likely to provide the greatest benefits to less mobile species since these species might spend their entire life cycle within the protected area (e.g., small ocean pelagics, and large and small nearshore pelagics) (Davies et al. 2012). Highly mobile species present more of a challenge, and modeling studies suggest that MPAs for these species should be very large or be part of a network that covers a significant portion of the species' range (Moffitt et al. 2009; Davies et al. 2012). Alternately, they could cover smaller, demographically-critical target areas such as nursery, spawning, and foraging areas or migratory routes (Game et al. 2009). Challenges arise for species that do not exhibit site fidelity, or clear spawning or feeding migrations (Kaplan et al. 2010), though this could be combatted, at least in part, through temporally variable MPAs that protect critical areas wherever these may lie at any point in time (Game et al. 2009).

The benefits of BWMPAs for highly mobile species with large ranges—such as marine mammals, turtles, sharks, tunas, and other pelagic fish—has not yet been comprehensively assessed, in terms of empirical evidence (Hyrenback et al. 2000; Davies et al. 2017; White et al. 2017). However, there is increasing evidence that mobile species can benefit from spatial protection (Edgar et al. 2014). For example, Jensen et al. (2010) showed significant and rapid increases in striped marlin abundance during two separate multi-year closures of the Mexican Exclusive Economic Zone (EEZ) to longline fishing; Young et al. (2015) demonstrated the effectiveness of a network of pelagic MPAs in the Pacific for three species of seabirds; Pala (2013) suggests that studies on tuna mobility have demonstrated that these species would benefit from closures across multiple EEZs (Sibert and Hampton 2003); and White et al. (2017) found that BWMPAs provide substantial, though incomplete, protection for grey reef sharks. Finally, it's important to recognize that because of the extensive movements of migratory species, many studies point to the need for strong complementary measures outside of MPA boundaries, such as dynamic ocean management (DOM),[4] fisheries management, and precautionary regulation of emerging industrial activities (Maxwell et al. 2015; O'Leary and Roberts 2018; Sibert et al. 2012).

BWMPAs might be a powerful mechanism to increase resilience to some climate change-induced stressors, but empirical research is insufficient to draw clear conclusions. Some have argued that large-scale BWMPAs are ineffective at protecting ecosystems from global stressors such as climate change and ocean acidification (e.g., Hilborn 2018). Others hypothesize that BWMPAs may play a role in climate adaptation and mitigation. BWMPAs might do this through, for example, providing "stepping stones" and "landing zones" for climate migrants, potentially buffering acidification through protection of open ocean mesopelagic fish via excretion of gut carbonates, and preventing release of carbon from sediments disturbed by fishing gear. BWMPAs could also increase resilience in the face of cumulative impacts through the following:

1. Protection of larger, more resilient populations with greater reproductive outputs;
2. Reduction of other human stressors;
3. Promotion of genetic diversity that provides the raw material for adaptation;
4. Protection of apex predators that confer increased ecosystem stability (Roberts et al. 2017; Wilhelm et al. 2014).

Relatively unexplored areas include the role of fish in nutrient cycling, which is critical for primary productivity, and increased fish/marine plant and animal biomass as a source of carbon storage.

4 DOM recognizes the non-stationarity of ocean environments and is defined as management that rapidly changes in space and time in response to changes in the ocean and its users through the integration of near real-time biological, oceanographic, social and/or economic data (Maxwell et al. 2015). DOM can provide a balance between ocean resource use and conservation and meet multiple objectives—for example, managing target quotas, bycatch reduction, and reducing interactions with species of conservation concern.

Fisheries

BWMPAs are gaining momentum as potential fisheries management tools that can complement conventional mechanisms such total allowable catch (TAC), gear restrictions, and seasonal closures. So far, the focus of the academic literature has focused on three areas related to BWMPAs and fisheries management; these are briefly discussed below:

Spillover: BWMPAs may increase the recruitment of eggs and larvae into adjacent fishing grounds, thereby boosting population sizes of targeted species. Many fisheries concentrate their efforts on the boundaries of MPAs (Roberts et al. 2001; Murawski et al. 2005; Di Lorenzo et al. 2016), providing evidence that these large protected areas work to increase the abundance of some important fishery species. For example, Boerder et al. (2017) found that there is evidence of fishing the line on the western boundary of the Galapagos Marine Reserve, providing stabilized catch and increased stock availability for fishers in the area. However, the larger an MPA becomes, the smaller the edge to area ratio, which, depending on the mobility of the species, may lead to less spillover (Singleton and Roberts 2014). Furthermore, under some conditions, anthropogenic impacts outside of MPAs may outpace reproduction and recruitment inside, which could result in population declines (Moffitt et al. 2009; White et al. 2017). Modelling results suggest that excessive spillover can rapidly reduce or eliminate MPA benefits, especially if combined with effort displacement (Davies et al. 2012).

Effort reduction: BWMPAs can serve as a management tool aimed at reducing fishing pressures. A prominent example was the International Commission for the Conservation of Atlantic Tunas (ICCAT) one-time area closure in the eastern tropical Atlantic that specifically targeted effort reductions (Torres-Irineo et al. 2011). However, a common criticism of MPAs is that rather than reducing fishing effort, they only displace it to other areas (Hilborn 2018; Greenstreet et al. 2009; Kaplan et al. 2010). Rebuttals include arguments that some mobile species, even highly migratory tuna or billfish, may stay within the boundaries of suitably-sized protected areas (Sibert and Hampton 2003; Friedlander et al. 2017). This topic represents a significant knowledge gap, as there have been no major, systematic analyses of whether MPAs increase fish abundance throughout a larger region (considering impacts both inside and outside of reserves), and under what circumstances (Hilborn 2018).

Management of highly migratory fish stocks: BWMPAs may conserve stocks that spawn, migrate, and forage fully or in part in the protected zone. Productive ocean features such as seamounts, near-island hotspots, and upwelling zones have been shown to act as natural aggregating sites for highly migratory species such as tuna and skipjack (Morato et al. 2008; Richardson et al. 2018; Gove et al. 2016). Yellowfin tuna have been found to utilize habitat differently depending on age and habitat productivity (Schaefer et al. 2011), and Atlantic bluefin tuna have been found to have site fidelity to spawning and foraging grounds (Block et al. 2005). Having areas where schools are not disturbed by fishing activities or other impacts such as shipping may help protect species during vulnerable life stages. Protection of key spawning grounds has been proposed as a viable conservation strategy for tuna (WWF 2016). However, more research is needed on the viability of this approach, as well as the identification of spawning sites and other areas used during critical life-history stages for targeted pelagic species. On the other hand, some argue that BWMPAs may be unnecessary, because fisheries management strategies can achieve similar management outcomes (e.g., reduce fishing effort and rebuild overexploited stocks; reduce broader ecosystem impacts via bycatch mitigation and seasonal closures) (Hilborn 2016; Costello et al. 2016; Graham et al. 2007). Uncertainty and data limitations also factor into this debate. For example, a potential weakness of BWMPAs compared to the use of fishery regulations of tuna stocks (e.g., catch limits), is that estimates of the area that would need to be closed to fishing to achieve the target reference point for spawning biomass are likely to be uncertain or have substantial errors due to model assumptions and lack of uniform distribution of individuals within the stock. In contrast, harvest strategies based on catch limits and reference points may be a more reliable way of maintaining the desired spawning biomass (Sibert et al. 2012). However, an important counterpoint is that management regulations of BWMPAs may be much simpler and cheaper to develop compared with many fisheries regulations. Additionally, questions remain about the ease of enforcement (McCauley et al. 2016).

BWMPAs might only remain a complementary tool of fisheries management, particularly when dealing with multiple tuna stocks. Assuming there are multiple tuna stocks, any decision to protect stocks with MPAs may have no impacts on other stocks outside the MPA. By definition, a tuna stock does not replenish a neighboring stock effectively, so protecting an entire stock would not help sustain catches of tuna across a broader area. Any application of BWMPAs would need to be done specifically for each self-replenishing stock of each tuna species. Given that the spatial stock structures of yellowfin and bigeye tuna are unlikely to be the same (Grewe et al. 2015; Richardson et al. 2018), it is improbable that BWMPAs dedicated to help manage a yellowfin tuna would have advantages for management of a bigeye tuna. Consequently, there would need to be a series of BWMPAs for yellowfin and another set for bigeye. This would add up to a complicated set of management arrangements compared to applying catch limits to each stock of each species. When other highly migratory species such as skipjack tuna and South Pacific albacore are added to the mix, the situation becomes even more complex.

Human Dimensions

Human dimensions of BWMPAs are poorly understood, but there is significant investment in understanding the social impacts (+/-) of BWMPAs and incorporating social, economic, and cultural benefits into their design and implementation. Human dimensions can be defined as the "the cultural, social, economic, political, and institutional factors that affect and are affected by large-scale marine conservation efforts" (Gray et al. 2017). Studies isolating BWMPAs to identify their specific and differentiated impacts on human wellbeing are not yet available; however, an analysis of human wellbeing impacts of MPAs including large (>100 km^2) MPAs—which are likely to contain blue water ecosystems within their boundaries—found that, overall, MPAs yield net benefits to human wellbeing (Ban et al. 2019). The main benefits of MPAs in this study were primarily in the economic domain in the form of increased catch, CPUE and income, and the social domain (community involvement). The primary negative impacts were associated with cost of fishing and increased conflict. It is possible that due to unique characteristics (including remoteness), inclusion of highly migratory species within their ecosystems, and possibility of being transnational, the human wellbeing impacts of BWMPAs differ substantially from other types of MPAs and would have different geopolitical and global scale equity/benefit distribution implications.

In recent years, there has been a growing interest in sustained and systematic consideration of human dimensions of BWMPAs, which can help to inform establishment, design, and management. Much of this momentum has grown from Big Ocean's 2016 "Think Tank" on Human Dimensions of BWMPAs, which identified priority topics for future research, including scoping human dimensions, governance, politics, social and economic outcomes, and culture and tradition (Gray et al. 2017) (Appendix F). Due to their sheer size, remoteness, and complex socioeconomic and political contexts, BWMPAs can produce distinctive social outcomes that warrant research attention (Kittinger et al. 2011; Gruby et al. 2017). While outcomes of conventional MPAs are usually experienced at a small scale by nearby resource users, BWMPAs tend to intersect with national and international politics and policy processes, therefore also producing outcomes at higher levels of social organization (i.e., jurisdiction-wide, regional agreements) (Gruby et al. 2017).

***Sociocultural outcomes*: Top-down BWMPA designation and management can undermine social justice or lead to disempowerment or displacement of stakeholders**. This theme is consistent with the literature and practical knowledge base from terrestrial efforts. For BWMPAs, there have been concerns over political motivation (e.g., Chagos Marine Reserve, De Santo et al. 2011), inadequate stakeholder consultation, and "ocean grabbing" by central management authorities (Bennett et al. 2015; Gray et al. 2017; De Santo et al. 2013; O'Leary et al 2018). These issues can be especially difficult for BWMPAs, since these sites can pose major challenges to sustained, comprehensive engagement with an often more remote and diverse constituency (Kittinger et al. 2011; Wilhelm et al. 2014; Davies et al. 2018). On the other hand, BWMPAs can lead to positive outcomes and have played a role in protecting cultural values and heritage (Wilhelm et al. 2014; Gaymer et al., 2014). For example, Papahānaumokuākea Marine National Monument, the world's first marine UNESCO world heritage site that is designated for both biological and cultural significance, successfully reflects Native Hawaiian values and practices (Kikiloi et al. 2017). In addition, the Phoenix Island Protected Area (PIPA)—despite its remote location—has led to perceptions of strengthened national pride and reinforcement of aspects of I-Kiribati culture (Gruby et al. 2017). BWMPAs have also played a role in validating indigenous rights in Rapa Nui and the Commonwealth of the Northern Mariana Islands (CNMI), where BWMPA processes have given local and indigenous leaders political leverage to advance territorial claims at unprecedented, jurisdiction-wide scales (Gruby et al. 2017).

***Economic outcomes*: There are concerns that BWMPAs might lead to disenfranchised fishing and mining communities; this concern has not been substantiated in practice yet**. The fishing and mining sectors make up a substantial portion of the economy of some countries (Wilhelm et al. 2014; Richmond et al. 2015). The potential displacement of small-scale fishers as well as local and indigenous communities by BWMPAs has important implications for seafood supplies, livelihoods, and food security (Friedlander et al. 2016). Counterarguments suggest that, in general, BWMPAs have been placed in areas with fewer commercial interests, which, when combined with participatory design that permits artisanal fishing, can help address these concerns (Devillers et al. 2015; O'Leary et al. 2018). In some cases, conservation financing mechanisms have helped to secure economic outcomes from BWMPAs. For example, in Kiribati, a conservation trust fund (PIPA Trust) was established by partners (including international funders and NGOs) to compensate the government for lost tuna revenue. In terms of positive impacts, some argue that BWMPAs can play a role in mitigating global economic inequity related to fisheries. For example, Palau is using its National Marine Sanctuary to "reclaim its EEZ" via processes that are directed toward crowding out foreign tuna fishing and developing a domestic fleet that could feed both visitors and residents (Wabnitz et al. 2018). However, important questions remain around whether and how this fleet will expand and what this will mean for fish prices, fishing pressure, and reef conservation, and how this will intersect with the Parties to the Nauru Agreement (PNA) and other fishing agreements (Gruby et al. 2017). Substantial uncertainty and lack of empirical data remain about the purported economic benefits that BWMPAs can deliver domestically and internationally. Furthermore, current evidence is not sufficient to determine whether such economic benefits would be sufficient to mitigate potential losses (e.g., fisheries revenue), and provide net benefits. With regards to equity, other arguments suggest BWMPAs could help reduce inequality in the distribution of fisheries benefits on the high seas—where only 10 countries capture over 71% of the total landed value (Sumaila et al. 2015, Cheung et al. 2017). From a broader perspective, benefits arising from protection, including ecosystem services such as climate and biodiversity refugia, are global in nature (O'Leary et al. 2018), whereas fishing may only benefit some groups.

Design, Governance, and Management Considerations

There is a growing body of literature on conditions that influence the impacts of BWMPAs. Here, we highlight themes in the literature focused on placement and governance challenges and enabling conditions and best practices.

***Placement and governance challenges*: BWMPAs are increasingly placed in areas of real concern, but areas beyond national jurisdiction (ABNJ) remain a major challenge for effective placement.** A common criticism is that conservation outcomes of BWMPAs are often limited by their placement, which some argue is based more on political expediency (i.e., remote, "residual" areas with minimal threats and human use, and thus relatively low conservation potential), resulting in MPAs that are not necessarily science-based, nor fully ecologically representative or well-connected at a global scale (Devillers et al. 2015). Counterarguments focus on the value of precautionary approaches and proactive ocean protection (O'Leary et al. 2018), as well as the utility of using comparatively pristine ecosystems as modern-day baselines (Big Ocean 2013). There is also new evidence that globally, cumulative impacts are significantly higher in BWMPAs than outside, refuting the critique that they only occur in pristine areas (Davies et al. 2017). Finally, challenges around effective placement are compounded by the fact that progress towards an ecologically representative global network is constrained because most of the pelagic ocean (64%)—where several migratory fish stocks are likely to be found—falls in ABNJ. Policy and regulatory mechanisms for creating MPAs in ABNJ are limited and effective governance remains a major challenge (Davies et al. 2012; Cullis-Suzuki and Pauly 2010; Game et al. 2009).

***Enabling conditions and best practices*: Moving forward, there is a need for more rigorous empirical investigation of the social, ecological, and governance mechanisms that contribute to outcomes.** A final theme worth highlighting is the nascent focus on factors that contribute to social and ecological outcomes of BWMPAs. For example, some of the factors related to success include: integration of culture and traditions, effective public and stakeholder engagement, maintenance of livelihoods and wellbeing, promotion of economic sustainability, conflict management and resolution, transparency and matching institutions and ideas, compliance and enforcement, legitimate and appropriate governance, and social justice and empowerment (Kittinger et al. 2011; Ban et al. 2017; Day et al. 2017; Gray et al 2017).

RESEARCH AGENDA

As stipulated above, the workshop aimed at identifying and prioritizing research questions that need to be addressed in order to support the design and placement of BWMPAs. As such, the meeting culminated in a prioritization exercise that consisted in the following steps:

- Based on presentations and discussions (Appendix E), a facilitated group discussion identified research questions that currently hamper the progress in the BWMPA research and management community.
- Attendees broke into small groups (resilience, fisheries, biodiversity, human dimensions and cross-cutting) to refine topic-relevant research questions that speak to each of the topics.
- After a report-out of each group, participants were given the opportunity to vote for those questions they thought were particularly relevant (i.e., urgency, transferability) and feasible to address (i.e., answerability and cost).

Prioritization of Research Topics

Together, the group honed in on a priority list of research questions, as presented below. An overview of results is provided in Figure 1.

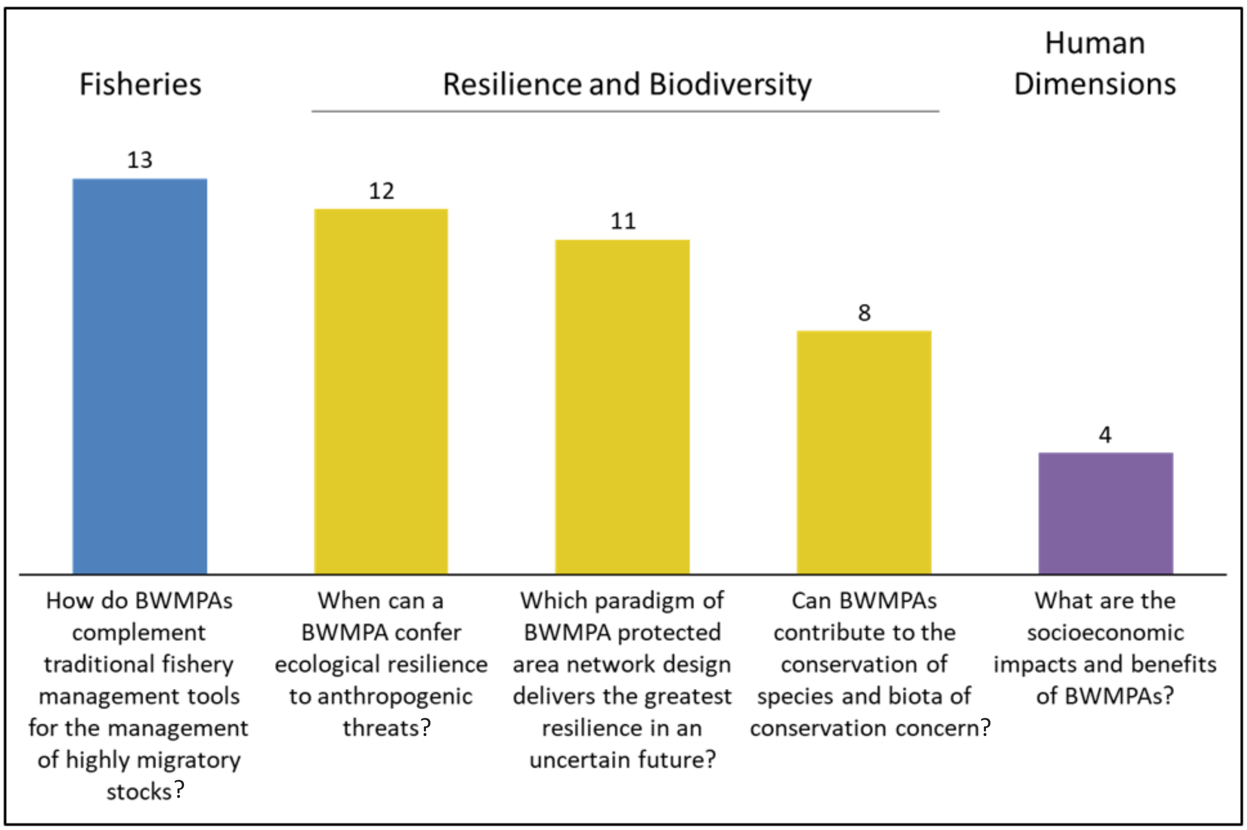

Figure 1: Outcomes from prioritization exercise. Numbers represent votes of workshop participants reflecting relevance and feasibility of each question to the broader BWMPA community (2 votes per attendee).

Biodiversity and Resilience

A few key themes emerged relative to the role that BWMPAs could play relative to biodiversity and resilience, including protection of intact open ocean ecosystems, conservation of highly migratory species, and climate change mitigation and adaptation. Specific research questions and sub-questions included the following:

- When can a BWMPA confer ecological resilience to anthropogenic threats?
  - How do threats cause fundamental changes for the pelagic ecosystem (e.g., biogeochemical cycling, habitat change, trophic structure, and extinction risk)?
  - How do BWMPAs abate key threats (e.g., climate change impacts) on pelagic systems?
- Can BWMPAs contribute to the conservation of species and biota of conservation concern?
  - What are the relevant indicators of biodiversity for assessing the impacts of BWMPAs for different objectives (e.g., social, cultural, intrinsic, ecological)?
- Which paradigm of BWMPA protected area network design (e.g., representation, ecologically or biologically significant marine areas (EBSAs), process models, or key biodiversity areas (KBAs))[5] delivers the greatest resilience in an uncertain future (e.g., impacts of climate change, new extractive industries such as deep-sea mining)? How do the different paradigms compare in terms of achieving resilience; what combination is most effective for BWMPA conservation planning?
  - Under different scenarios of uncertainty (high, low), which approach is the most effective?
  - Need to consider practical reality of which paradigms are being used and at what scale.
  - How do you define representation in the open ocean? How much representative habitat should you protect?
  - How would you develop a bioregional approach that takes into account different pelagic ecosystem types and functions? How does vertical connectivity (e.g., sea floor to surface) and temporal and horizontal spatial stability fit into a bioregionalization?
  - What is currently protected by existing MPAs? Considering the current landscape of BWMPAs, are they representative? What are the biggest gaps? How do we fill the gaps?
  - Assuming a system of BWMPAs will be designed via process models (models that optimize design for specific objectives), what are the big questions that need to be answered?
  - Assuming a system of BWMPAs will be designed via EBSAs, what are the big questions that need to be answered?
  - How do the benefits of BWMPAs for biodiversity and resilience accrue in different climate change scenarios? How do climate induced impacts affect their effectiveness?

Fisheries

Key themes related to fisheries outcomes and BWMPAs that were discussed at the meeting included: evidence of spillover effects, effectiveness of BWMPAs at reducing overfishing and/or increasing fish abundance, and impacts of BWMPAs on fishery profitability and economic performance. Priority research questions include:

- How do BWMPAs complement traditional fishery management tools for the management of highly migratory stocks? In what contexts are BWMPAs best suited as a tool for fisheries management? (e.g., what species types, fleet types, governance structures)? What are the critical design specifications that increase effectiveness of BWMPAs as a management tool of migratory stocks? For example, under what conditions do BWMPAs:
  - Increase overall abundance/biomass?
  - Affect overall catch (e.g., rate, composition), CPUE and predictability of catch?
  - Reduce the risk of overfishing?
  - Address local depletion issues?
  - Affect the spatial and temporal distribution of fisheries resources (e.g., benefits in EEZs and nearshore)?
  - Impact fishery profitability and the distribution of those profits?

5 For further reading on these concepts see here: (Representation, EBSAs and KBAs).

- Is there enough information about stocks (i.e., genetic composition, movement dynamics, mixing of stocks) to assess whether BWMPAs can serve as an effective management tool for pelagic stocks?
- How do fleet dynamics and institutional dynamics affect outcomes for BWMPAs?
- How robust are BWMPA fisheries outcomes across different scenarios of climate change?

Human Dimensions

The group recognized the excellent work of the Big Ocean's 2016 "Think Tank" on human dimensions to identify priority topics for future research and, as such, intentionally didn't go into detail on the human dimensions piece of BWMPAs. However, a few questions emerged that are not represented in that previously developed human dimension agenda that the group thought were important.

- Are there other human dimension impacts and distribution questions associated with BWMPAs that are not covered in the Big Ocean Human Dimensions research agenda (Gray et al. 2017)?
  - E.g., under what conditions would a declaration of whole EEZ management deliver positive impacts?
  - What are the appropriate measures of equity with respect to BWMPA design and management?
- What are the socioeconomic impacts and benefits of BWMPAs?
  - What are the economic costs and benefits of BWMPAs and how are they distributed?
  - How do BWMPAs impact fishery profitability and distribution of those profits?
  - How do BWMPAs impact food security?
  - Might BWMPAs divert funding away from nearshore or onshore programs that improve quality of life and food security?

Cross-Cutting

- What are the design attributes (e.g., biological, social, ecological) that determine the effectiveness of BWMPAs for different objectives (e.g., economic, food security, resilience)?
  - Do lessons from nearshore environments transfer to BWMPAs or do we need new theory?
  - What is the role of new technology in measuring the efficacy of BWMPAs?
- What key BWMPA design features determine effectiveness (for different objectives) in different ecosystems (e.g., temperate, polar, tropical)?
- What are the enforcement challenges specific to BWMPAs that may make them costly or impact their effectiveness? Are there economies of scale or new technologies that can reduce the implementation costs of BWMPAs to result in the highest biodiversity conservation benefit?

NEXT STEPS

During the final session of the workshop, meeting participants discussed several next steps and possible paths forward:

1. **Finalize and communicate the research agenda externally:**
    a. Develop a public version of the BWMPA shared research agenda (e.g., a white paper), including appropriate context and a synthesis of the meeting and the research agenda and with the objective of sharing it with funders.
    b. Publish research agenda in a peer-reviewed journal. Develop a shorter version of the research agenda that could be published in a peer-reviewed journal.
    c. Share the research agenda at global policy forums (e.g., Convention on Biological Diversity).
    d. Engage invitees who weren't able to attend; ask for input on meeting outputs.
2. **Seek additional funding:**
    a. For research projects: Develop concept notes for important research projects and share with funders.
    b. For ongoing coordination of this group and its research efforts: Develop a proposal for funding that would support additional meetings, coordination, and research support to drive the research agenda forward (e.g., SNAPP, or other funders).

TNC and CI (with support from others, like CEA), will work with participants to put a detailed workplan together based on the next steps listed above, including leads and timelines for each task.

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APPENDICES

Appendix A | Meeting Participants

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Appendix B | Content and Purpose of the Workshop

On January 20-21 of 2019, two dozen experts from a wide range of disciplines (social sciences, biodiversity conservation, oceanography, fisheries science, economics) came together in Sausalito, California to discuss the state of knowledge of BWMPAs.

Objective: Create a shared research agenda of BWMPAs. In recognition of a global trend towards 30% of MPA coverage[6] and in recognition of a limited understanding of optimal BWMPA design for its various potential purposes, the key objective of the workshop was as follows: **Develop a research agenda for BWMPAs, identifying core areas of uncertainty about their impacts (and the conditions under which those impacts may be realized) and prioritizing those that are critically important for the conservation community to address** (Detailed Workshop Agenda in Appendix B). In that context, key questions asked during the workshop included the following:

- What roles and functions are BWMPAs best suited for and what optimization criteria can be derived?
- What is the current state of knowledge about the efficacy of BWMPAs across these criteria?
- What are major knowledge gaps to support BWMPA placement and design?
- To what extent must uncertainties (e.g., climate change, policy) be taken into consideration?
- What research areas should be prioritized to support decision makers with meaningful advice?

KEY "ASSUMPTIONS" OF WORKSHOP PARTICIPANTS:

- A significant number of BWMPAs currently exist and momentum is growing to establish more BWMPAs.
- Where possible, our research agenda should be informed by the needs of decision makers and key stakeholders.
- MPAs are only one tool in a larger toolbox to conserve biodiversity and sustain ocean resources.
- Interest in understanding the human dimensions of BWPMAs has grown in recent years but was deprioritized during the workshop due to the recent Big Ocean's 2016 "Think Tank" on Human Dimensions great work on the topic.
- BWMPA impacts should be considered at multiple scales, including inside and outside MPA boundaries.
- Given the unknown nature of current and future ocean threats, applying the precautionary principal is warranted.

6 The Convention on Biological Diversity, Aichi Target 11. Accessed, April 2019.

Appendix C | Meeting Agenda

Blue Water MPAs: Building a Shared Research Agenda

Hosted by Conservation International and the Nature Conservancy

Cavallo Point, 601 Murray Cir, Sausalito CA

January 21-22, 2019

Monday, January 21st

Towards a Shared Understanding of Where We Are

8:15 – 8:45 am	**Breakfast**	**Facilitators**
8:45 – 9:10 am	**Welcome** • Workshop objectives, context, potential outputs and next steps (Mark and Jack) • Review ground rules for meeting (CEA)	Mark Zimring Jack Kittinger CEA
9:10 – 9:30 am	**Group Introductions**	All

9:30 – 11:30 am	<u>**Setting the Stage**</u>
	
	Blue Water MPAs definition and intended objectives
	
	• Brief overview of session (Eddie and Aulani | 10 min)
	• BWMPA overview (Eddie | 15 min ppt, 15 min discussion)
	  • BWMPAs defined broadly and for the purposes of this meeting (location, size, drivers, protection levels)
	  • Range of BWMPA objectives: fisheries impacts, endangered species focus, ocean wilderness, etc.
	• BWMPA trends (Aulani | 15 min ppt, 15 min discussion)
	  • Trends and proliferation of Blue Water MPAs
	  • Global conservation targets
	• Group discussion: What are the intended objectives that we hope that BWMPAs will deliver and key challenges? (Eddie and Aulani | 50 min)
		Aulani Wilhelm
		Eddie Game

11:30 – 11:45	**Break**	
11:45 – 12:30 pm	**Lunch**	

12:30 – 2:45 pm	**<u>Identify Knowledge Gaps</u>**
	
	What do we know and not know about the impacts of BWM-PAs?
	
	• Review strawman list of hypotheses typically associated with BWMPA impacts – seek input from the group: Should we add/delete any from the list? (15 min)
	• Brief presentations synthesizing current research and knowledge gaps in three key issue areas (45 min total – 15 min each)
	    • The Value of information Theory (Hugh)
	    • Biodiversity and BWMPAs (Ray)
	    • Fisheries benefits and impacts (Chris)
	    • Sociocultural impacts (‘Aulani)
	• Breakout groups each discuss a key issue area listed above (45 mins):
	    • What is currently well covered by literature/ knowledge?
	    • What are the key areas of uncertainty and knowledge gaps?
	• Breakout groups present back to full group (30 mins total/10 min each)
		Chris Costello
		
		Ray Hilborn
		
		Hugh Possingham

2:45 – 3 pm	**Break**	
3 – 4 pm	**<u>Prioritize Research Gaps</u>** • Group exercise to prioritize research gaps surfaced in earlier discussion	CEA
6 pm	**Dinner** @ Cavallo Point	

Tuesday, January 22nd

Towards a Prioritized Research Agenda

8:15 – 9:00 am	**Breakfast**	**Facilitators**
9 – 9:15 am	**Day 1 synthesis and reflections**	Meg Caldwell
9:15 – 9:30 am	**Review plan for Day 2**	Mark Zimring Jack Kittinger

9:30 – 12:15 pm	**<u>How Do We Fill Key Knowledge Gaps?</u>**
	
	Outline a shared research agenda for Blue Water MPAs
	
	    • Acquisition of empirical data
	    • Modeling approaches
	    • Technology
		Jake Kritzer
		
		Anthony Richardson

12:15 – 12:30 pm	**Break**	
12:30 – 1:15 pm	**Lunch**	
1:15 – 4 pm	**<u>Finalize the research agenda and next steps</u>** Prioritize/characterize research agenda based on: • Importance, Cost, Timeline, Feasibility of filling gaps/ answer questions; • Do any specific projects rise to the top?	CEA
4 – 4:15 pm	**Break**	
4:15 – 5 pm	**Wrap-Up and Closing**	Mark Zimring Jack Kittinger

Appendix D | Examples of possible threats BWMPAs could address

Threat	Information for blue waters
Seafloor mining	P mining (NZ, Namibia) + Peak P Methane hydrates for natural gas (biggest reserve) Hydrothermal vents for Au, Ag, Cu, Mn, Co, Zn
Fishing	Likely effects on higher trophic levels
Fishing myctophids	Mesopelagic fisheries are likely to increase in the future
Climate change	Magnitude and “direction” changes with depth
Ocean acidification	Magnitude changes with depth
Microplastics	Accumulation in the guts and tissues of pelagic species
Seismic surveys	Effects on marine mammals and fish Effects on zooplankton? Increases mortality from 19% to 45% up to 1.2 km away (McCauley et al. 2017)
Shipping	Ship strikes for cetaceans Boat-generated turbulence (Bickel et al. 2011) – Zooplankton mortality 5% vs 34% in high traffic Mortality caused by spills
Geosequestration	Iron fertilization Fertilization from depth

Appendix E I Presentations and Discussions

Edward Game (TNC) provided high-level overviews of BWMPAs, which highlighted the rapid evolution of MPAs since the early 2000s and provided an outlook of criteria that are required to maximize biodiversity and natural resource gains of MPAs over the next 10-20 years. In particular, the presentation highlighted the following points:

- In 2018, 15,345 MPAs existed globally, covering 7.4% of the ocean.[7]
- Without large-scale MPAs (including BWMPAs), it will take until 2054 to reach the 10% protection coverage of oceans; whereas with large-scale MPAs this goal could be met by 2025 (Toonen et al. 2013).
- Key goals of BWMPAs should be to protect open ocean biodiversity, ecosystems, and wilderness, and to effectively manage commercially relevant target fish stocks.
- TNC's impact hypothesis of large BWMPAs is twofold. First, resilience and genetic diversity of fish populations can be safeguarded through the reduction of overall anthropogenic mortality of both commercially relevant stocks and their bycatch. Second, increased biomass of target species will translate into biodiversity benefits of lower trophic levels.
- Uncertainties include the spill-over effect of MPAs (increased catch outside of MPAs) and the "pinched balloon" dilemma of MPAs (will BWMPAs just displace fishing effort or will they lead to a reduction in absolute fishing effort?).

In the discussion that ensued, several themes emerged:

1. **What's really the added value of BWMPAs**? Harvest control rules have fish population under control, what's the unique value addition of BWMPAs? Maybe it is the specific impact on biodiversity, balancing of trophic chains, and its role as a risk management tool. The first order question seems to be that we need to understand what impacts BWMPAs have in order to understand if they're the best tool to deliver them (and how they fit with other approaches). What are the big gaps in understanding?
2. **Evaluation of BWMPAs is complicated and time-consuming**. BWMPAs can have different goals, each of which should be evaluated separately. This is complicated by the fact that some key goals (e.g., biodiversity) lacks consistent and globally agreed-upon definitions. Some key metrics change slowly and changes are different depending on where you are on the globe.
3. **BWMPAs should take a dynamic precautionary approach**. The lack of data, the limited understanding of the highly dynamic blue water ecosystems and the uncertainties introduced by climate change calls for a precautionary design that allows for adaptive management.
4. **BWMPAs should focus on ecosystem productivity and resilience.** While these are the pillars of key BWMPA goals—such as biodiversity, fisheries, socio-economic, and cultural benefits—there is no clear understanding how to best manage for these metrics. For example, it is not clear how do define *habitat representation* in the blue water context. Nor is it clear whether BWMPA design should be based on mere representation or target a specific goal (e.g., biodiversity) and then design around relevant metrics.
5. **BWMPA design must meet the needs of governments and societies where they are.** Topics like representation vs. goal-maximization are academic discussions; design also has to be practical and fit into the scope and abilities of decision makers.

7 There was general acknowledgement that this figure is an overestimate if International Union for Conservation of Nature (IUCN) criteria for MPAs would be strictly applied. The MPAtlas lists a total of 11,805 designated MPAs, 2,611 of which are unimplemented, covering a total of 7.4 % of the total ocean area (available at http://www.mpatlas.org/map/mpas/).

Christopher Costello (UCSB) presented a series of conjectures on the economic impacts that can be expected from BWMPAs based on our current understanding of blue water ecosystems, fisheries population dynamics and natural resource economics. These include the following:

- The impact of small MPAs is limited due to the large range of movement of most marine species (particularly those of commercial interest) throughout their lifecycle. An exception might be the protection of critical areas in which spawning takes place.
- Large BWMPAs can increase total global abundance of target fish as they can contribute to the decrease of fishing effort to F=FMSY.[8]
- BWMPAs will not reduce fish catch. The effect of BWMPAs on catch is a function of B/BMSY at t0; since most stocks are at B<BMSY, the stock recovery associated with MPAs will stabilize above a BAU levels in the long term.
- BWMPAs will not reduce fishing profits since the large majority of pelagic species have B> *Bmey (biomass that maximizes profit).*
- BWMPAs reduce the risk of overfishing pelagic species; this effect is increased with MPA size. Excessive size may lock-in underfishing (low productivity due to high adult biomass).
- High seas BWMPAs can benefit adjacent EEZs as a result of potential spillover effects. Due to the smaller commons problem in EEZs (higher degree of control over resource by government), this may help with the distribution of profits.
- Similarly, transboundary BWMPAs can bring benefits to adjacent countries as these closures could help coordinate the of neighboring countries; easier to ensure others' compliance with BWMPA than with catch arrangements.
- Very large closures on the high seas will not have high economic costs. Profits in the high seas are near zero, catch is low, and there are only few countries fishing in those areas. In some cases, the little profits are made possible by subsidies to those fleets. High seas closures will likely come at low economic cost in the short-run and possible gains in long run. These closures would partly offset the market failure from subsidies.
- Fish aggregating devices (FADs) change the argument for BWMPAs. Lower cost of fishing, leads to higher fishing mortality. Could use FADs inside BWMPAs to keep fish in an MPA (increase retention).
- Improved fisheries management would be more effective than BWMPAs. For almost any fisheries management objective, BWMPAs are "second best" but they can counteract poor fishery management. However, their effectiveness would depend on resolving high seas governance, non-cooperation across EEZs. Also, there is some uncertainty in fish movements.
- Models are useful**.** Empirical evidence is sparse and models will inform the biological and behavioral parameters that need to be pinned down. As is the case for climate change interventions, BWMPAs rely heavily on models and theory and require that we are specific about objectives (e.g., food, profit, equity, global biodiversity, bycatch).

Ray Hilborn (UW) provided a short overview of knowledge and gaps related to BWMPA impact. He stressed that there are hardly any empirical evaluations of changes in abundance and catch as a result of BWMPAs and that the limited evidence suggests that benefits primarily exist when fishing pressure in year 0 is high.

- One opportunity is to focus on tuna fisheries since there is a lot of knowledge about migratory patterns which allow to model the impact of any particular MPA design in the open ocean.
- Spatially explicit models (multi-species, including tuna, billfishes, sharks and other species of interest) of specific regions would be a logical first step.

Following Chris Costello and Ray Hilborn's presentation, the discussion circled around four main themes:

1. The focus of BWMPAs should not primarily be on fisheries management. Judging BWMPAs based on their effectiveness as fisheries management tools in a vacuum might undersell their value.

8 In fisheries stock assessments, F denotes the current observable fishing mortality while FMSY denotes the fishing mortality at which maximum sustainable yield can be achieved in the long run. Similarly, B denotes fish biomass (under water) and BMSY denotes the steady state biomass that can be expected if FMSY has been in place for a long period of time.

First, BWMPAs can potentially play an important role for other purposes (ecosystem integrity and resilience, biodiversity). Second, they should be considered as one of the tools in a larger toolbox of dynamic ocean management. Focus of further research should be on their potential complementarity to other existing solutions.

2. Models might not be representative of all pelagic ecosystems. A particular weakness might be the trophic relationships in blue water environments. An additional question is whether stochastic systems are well represented by these modeling approaches. While stochasticity gives fishers a harder time (to find the fish) – thereby increasing the value of MPAs, it might also be harder to detect changes/ measure effects of BWMPAs.
3. Models can't properly predict the reaction of fishers to BWMPAs. Fleet dynamics is a weak point of ecosystem and fisheries models. Behavioral responses must be integrated into models and introduce an additional level of complexity and uncertainty. We can take ecosystem driven models of tuna populations and run them into the future, but we can't run fishing fleets into the future with any intelligence.
4. Running with current modeling approaches misses important habitat and climate change dimensions. The conservation value of habitat (for biodiversity and fisheries) must be considered. Particularly in the context of climate-change induced trends and uncertainties, we should be thinking about ecosystems in 20-30 years. An example are polar ecosystems where primary productivity and krill are moving. Our current focus (tuna in the tropics) is insufficient if we want to consider the biological and ecosystem implications of climate change.

Aulani Wilhelm (CI) introduced the perspective human dimensions into the BWMPA discussion. The key points included:

- When science meets politics, people's perspectives matter. Decision-makers are driven less by optimization algorithms solving for biodiversity and fisheries outcomes and more by perspectives and perceptions of their constituents. Human dimensions have started to be part of the scientific discourse and must be factored in to go from theory to practice.
- Objectives of BWMPAs must be framed around people's benefits. If we discuss biodiversity benefits, the question should also be "fish for what purpose, corals for what purpose"? The Ocean Health Index is a good starting point as it includes numerous optimization criteria that matter for people.
- Bring people along and bridge knowledge. The effectiveness of BWMPAs also depends on people's buy-in and their connection to the cause. Therefore, the question must also be: How do we change people's norms and behaviors? How do we connect them to the issue? At the moment, the technical and the biocultural conversations happen at separate tables, and hence our technical approaches aren't as effective as they could be. How do we make sure these worlds intersect, if we want any theoretical model to actually have an impact? The Pacific example (stories, myths and knowledge about migratory routes that connect Pacific Island peoples) shows that the idea that you can only have culture and relationship of people when it's nearshore is flawed. The open ocean also has human connection and culture which remains an untapped resource in the current technical discussion.

Appendix F | Other relevant research agendas

Knowledge Gaps and Research Priorities Identified by the Big Ocean Think Tank's Community of Practice (Gray et al. 2017)

- **Governance:** (1) What is the level of community/public engagement and empowerment at new/established BWMPAs? (2) What is the influence of differing BWMPA governance frameworks on public/stakeholder engagement and perception of BWMPAs? (3) What is the relative effectiveness of different BWMPA governance approaches?
- **Politics:** (1) What are the motives and agendas of NGO partners and stakeholders in supporting BWMPA designation and management?
- **Socio-Economic:** (1) How can a wide range of human uses and interests (economic, cultural, etc.) be best incorporated within BWMPA design and management planning? (2) What are the ecosystem services of BWMPAs and who are the beneficiaries and cost-bearers?
  What are the relative costs and benefits of BWMPAs compared to other marine management tools? (3) What is the perceived level of impact (positive and/or negative) of BWMPAs on stakeholders, including stakeholder connection to the site? (4) What is the socioeconomic value of living and cultural resources within BWMPAs? How can BWMPAs be classified in relation to different HD aspects and issues?
- **Culture and Tradition:** (1) How can cultural practices/values and traditional knowledge be best incorporated into BWMPA design and management? (2) What is the level of equity in values, particularly cultural and intrinsic values? What is the level of understanding of stakeholder values?

A Shared Research Agenda for Large-scale Marine Protected Areas (Big Ocean 2013)

- **Biological and ecological characterization:** Understand, quantify and compare the individual and collective contributions of Big Ocean sites to the total biological and ecological diversity of the globe.
- **Connectivity:** Understand the linkages of Big Ocean sites within their own site, amongst sites, as well as to other regions. In this context, connectivity does not solely refer to the biological connectivity through the movement of organisms and their larvae, but also encompasses physical connectivity through the circulation of winds and currents, as well as anthropogenic connectivity through the spread of man-made impacts.
- **Monitoring of temporal trends**: Characterize historical baselines and understand temporal trajectories of ecosystems, so that resource population levels can be fore and hind casted at various times.

Large Scale Marine Protected Areas Current status and consideration of socio-economic dimensions Chris Smyth and Quentin Hanich (2019).

- **Fish population and spillover impacts of large scale MPAs:** Identify key habitats within existing and proposed LSMPAs and assess the spillover benefits as well as extraction risk among LSMPA edges with a view towards identifying future management needs. Assess effective monitoring and reporting methods for application in studying existing and proposed LSMPAs and improve understanding of fishers' responses to existing and candidate LSMPAs.
- **Migratory species and large scale MPAs:** Identify critical habitat for migratory and highly migratory species within existing and candidate LSMPAs, use tagging and other methods to understand biology and behavior of key migratory species. Monitor fishing intensity and displaced fishing effort, and impact of adjacent fishing within LSMPAs to maximize protection for migratory species while

reducing displaced fishing effort, analyze effects of fishing on LSMPA boundaries, particularly if critical habitats are found along boundaries.

- **Better understand susceptibility of LSMPAs to climate change, as well as their role in mitigation:** Establish baselines, study design of LSMPAs to maximize resilience, and investigate management measures that could improve fisheries' resilience to climate change. Quantify and map carbon capture potential of pelagic ecosystems within LSMPAs and develop/pilot a framework for ecosystem service payments to benefit coastal communities adjacent to LSMPAs.
- **Socio-economic dimensions of LSMPAs:** Assess human dimensions, governance, political implications and impacts of LSMPA creation on social and economic indicators. Identify mitigation measures to minimize negative social and economic impacts on coastal fishing communities and develop planning and research in a manner inclusive of indigenous communities. Identify if financial incentives, inclusive design, and other measures can ameliorate negative socioeconomic impacts and increase positive impacts on coastal communities near LSMPAs.
- **Institutional arrangements**: Assess most effective governance models for LSMPAs, identify preferred mitigation/adaptation methods for adjacent coastal communities, and establish bodies to research climate change impacts on MPAs. Build knowledge of pelagic and high seas biology, ecology and biogeochemistry, and develop a performance index to assess effectiveness of LSMPAs.
- **Global science capacity to meet research needs:** Build capacity globally for socio-economic methodologies to research above agenda, with a regional focus in Asia-Pacific and developing states. Develop networks and mentoring programs to share expertise and research practices. Build local knowledge within communities and institutions in those priority regions.