175 South Franklin Street, Suite 418 +1.907.586.4050
Juneau, AK 99801 USA www.oceana.org

Important Ecological Areas in the Ocean:

A Comprehensive Ecosystem Protection Approach to the Spatial Management of Marine Resources

Oceana Discussion Paper

Jim Ayers[1], Ashley Blacow, Ben Enticknap, Chris Krenz, Susan Murray, Santi Roberts, Geoff Shester, Jeffrey Short[2], and Jon Warrenchuk

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1. Author sequence is alphabetical and does not imply seniority.
2. Author to whom correspondence should be addressed

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I. Executive Summary

We urgently need a practical approach to preserve the health, biodiversity and resilience of marine ecosystems. Left unconstrained, the thermal and acidifying effects of rising carbon dioxide levels in the atmosphere combined with extractive uses, development, pollution, and other anthropogenic impacts on the marine environment will dramatically accelerate extinction rates in the world's oceans and the irreversible loss of valuable ecosystem services. We explicitly embrace a strategic approach to protecting the health of our coasts and oceans and reducing activities that are incompatible with ecosystem protection, all the while maintaining and promoting present and future economic benefits. This strategic approach combines the rigors of the western scientific process with the vast storehouse of local and traditional knowledge, with an emphasis on understanding and integrating the knowledge base of indigenous communities that have observed and managed their ocean resources since time immemorial. This holistic, iterative approach is necessary to ensure we have vibrant coastal communities for this and future generations. Our approach leverages science, law, policy and the public to identify and protect Important Ecological Areas (IEAs).

IEAs are geographically delineated areas which by themselves or in a network have distinguishing ecological characteristics, are important for maintaining habitat heterogeneity or the viability of a species, or contribute disproportionately to an ecosystem's health, including its productivity, biodiversity, function, structure, or resilience. IEAs include places like migration routes, subsistence areas, sensitive seafloor habitats, breeding and spawning areas, foraging areas, and areas of high primary productivity. The goal of the IEA approach is to preserve the health, productivity, biodiversity and resilience of marine ecosystems while providing for ecologically sustainable fisheries and other economic endeavors, traditional subsistence uses, and viable marine-dependent communities.

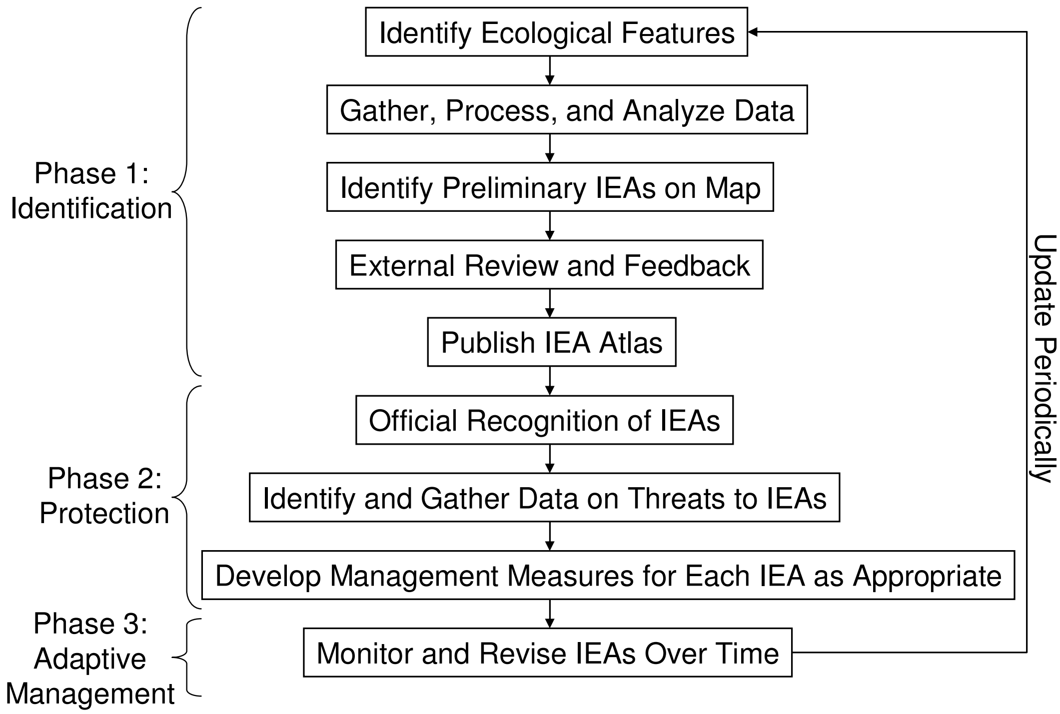
Important ecological areas can be identified either on the basis of their relative importance to a single ecological feature (e.g. the presence of rare deep sea coral) or multiple features (e.g. an area containing high primary productivity, a teeming kelp forest, and an important foraging ground). The process of identifying IEAs helps distill broad ecological principles (e.g., diversity, connectivity, productivity) into groupings of ecological features, for which we consolidate relevant datasets and map how these features are distributed through space. This process includes the gathering of existing data and acquiring additional essential data, such as local and traditional knowledge of indigenous peoples, tribes, and coastal communities. By recognizing the value of bringing indigenous people and local communities into the process, the IEA process will be more robust and create value to information that is typically overlooked in traditional planning or conservation processes. IEAs may be static or dynamic based on real-time observing, depending on the nature of the ecological features they contain.

Once IEAs are identified, we evaluate protection needs, assessing impacts, potential threats, and overall compatibility between ecological features and human activities. In some cases, area-based protective measures that limit human activities (such as time/area closures) may be warranted when damages posed by industrial activities threaten irreparable harm to the ecological services provided by an IEA. Conversely, some IEAs may not need prohibitive measures to protect them from current activities, but simply are identified to prevent potential future threats that may not currently be apparent. Efforts for restrictive sanctions for IEAs that do not face current or known future threats squander scarce political capital needed to secure protections that could be put to better use elsewhere. Ideally, all IEAs should receive the protection of monitoring, which alerts managers to emerging threats and provides other critical information useful for managers, conservation groups, local communities, and the broader public. Collecting data inside and outside IEAs over time will help determine if ecological features within IEAs are being adequately protected and can distinguish secular environmental changes from those caused by human activities. Protective measures can then be modified as needed.

IEAs are useful in a broad suite of application and policy contexts including marine spatial planning (MSP), climate change adaptation, and disaster response. Marine spatial planning is rapidly gaining political momentum. Comprehensive MSP, if done rigorously and appropriately, can benefit both industry and the environment, presenting an opportunity to fully consider current and future cumulative impacts to ecosystem health. To ensure adequate protection of the health, function, and biodiversity of coastal and marine ecosystems, IEAs must first be identified before delineating where competing uses should go. MSP benefits industry by proactively identifying and getting broad stakeholder approval for areas where development could occur with minimal impact to the marine environment. The largest benefit and primary purpose of MSP, however, should be to ensure ecosystem health and biodiversity are maintained. To do this, it is critical to protect IEAs.

IEAs can serve critical roles in responses to major disasters and catastrophes such as oil spills. Before such an event occurs, protection of the critical features in these areas increases their resilience to such events. Resource managers can also be better prepared for such catastrophes by storing necessary recovery equipment and resources in proximity to IEAs and creating response plans in relation to the location of IEAs and the features contained within them. The IEA atlas gives resource managers a comprehensive tool to understand where ecological features at risk from such events occur in space and time, and provides a systematic way to prioritize conservation, response, and restoration efforts. In summary, by presenting scientific information, thoughtful analysis, and local and traditional knowledge as an accessible atlas of IEAs, we create a powerful tool for informed decision making to promote both ecosystem health and the ecologically sustainable use of our oceans.

The Important Ecological Areas approach can be summarized in the following steps, grouped into three phases:



II. Introduction

Finding an appropriate balance between economic development and environmental impacts with the ultimate goal of ecological sustainability is arguably the most daunting problem confronting marine resource managers. Human uses of the ocean almost always have some impact on marine ecosystems, but these impacts are often masked by our lack of understanding of the prior state of the ecosystem or failure to monitor the status of affected ocean resources. As a result, resource exploitation risks compromising sustainability before impacts are recognized. The recent rise of ocean surface temperatures and acidification (IPCC 2007, Caldeira and Wickett 2005) caused by anthropogenic carbon dioxide emissions to the atmosphere (IPCC 2007) place increasing stress on marine ecosystems worldwide (Orr et al. 2005, Myers et al. 2007). These global stresses are compounded by more localized impacts from extractive ocean uses and development, including risks of catastrophic events such as the recent *Deepwater Horizon* oil rig blowout in the Gulf of Mexico. Taken together, these stresses threaten widespread species' extinctions defining a new geologic boundary between the most recent Holocene Epoch and its successor, the Anthropocene (Crutzen and Stoermer 2000).

These risks may be substantially reduced by understanding the various ecosystem structures, functioning, biodiversity and resilience that contribute to the oceans' ability to provide ecosystem services; identifying the most important areas of the ocean for maintaining ecosystem health; and then adopting targeted management measures to protect those areas' ecological integrity. Once identified, important ecological areas (IEAs) form a critical precursor for marine spatial planning (MSP) efforts to avoid unnecessary impacts while promoting ecologically sustainable use of marine resources and the environment. Protecting the ecological features that make an area important provides an efficient means of reducing anthropogenic stressors, extinction risks, loss of ecosystem services, and other undesirable and irreversible ecosystem changes.

The primary goal of the IEA approach is to maintain, restore, and protect the health, biodiversity, resilience, and functioning of the marine ecosystem. Implicit in this goal is a focus on maintaining key ecological principles including productivity, native species diversity, habitat diversity and heterogeneity, key species, and connectivity; many of these principles are identified by Foley et al. (2010). In addition the approach recognizes indigenous peoples and local communities as co-managers of ocean resources. These groups have frequently been disenfranchised from ocean resource decisions in the past. The approach seeks to bring these groups to the table and incorporate local and traditional knowledge (LTK) on equal footing with other scientific data used in management decisions, hence giving value to LTK and empowering local communities to incorporate this information into the scientific and management process. Fundamental differences in the relative contribution of marine habitats to different functions are widely acknowledged. For example, kelp forests have higher productivity than the abyssal plain, and the areas of highest density of sensitive corals on the seafloor may not necessarily be the same areas as the largest breeding colonies for seabirds. Furthermore, areas that contain a number of important features, such as high primary productivity, sea bird and marine mammal feeding areas, deep sea corals, etc., could be considered to be more important to ecosystem health than areas that contain only one of those features. In addition, the three dimensional nature of the water column contains vertical heterogeneity, which also distinguishes marine-based approaches from terrestrial ones. However, formal and consistent procedures for ranking importance both for individual features as well as across multiple functions are not well established.

The dynamics and community structure of marine ecosystems are often driven by a few key species, and we prioritize the areas used by these species within our approach. Keystone species have disproportionately strong interactive effects relative to their biomass (Paine 1966; Paine 1980; Navarrete and Menge 1996; Power et al. 1996; Soule et al. 2005). Structure-forming species (e.g., eelgrass, corals, kelp) provide food and shelter for a wide suite of species, often serving as the basis for entire assemblages of associated species. Forage species transfer nutrients and energy from low to high trophic levels and influence the structure and stability of food webs (Menge et al. 2002, Thayer & Sydeman 2007). In addition, areas important to the life histories of endangered, threatened, or rare species should receive priority attention based on the principle of maintaining biodiversity. Similar to individual species contributing differently to the structure and functioning of marine ecosystems, spatial variability results in one area contributing differently from another area to the structure and functioning of ecosystems. While all areas are almost certainly important to one aspect or another of ecosystem health, spatial variability leads to areas contributing differently to the overall health and biodiversity of our oceans within a spectrum of relative importance.

Determining "importance" requires a process for establishing and comparing relative contributions to individual or multiple ecological features. Therefore IEAs can be based on single features that are important, on the overlap of multiple features in the same area, or on a combination. Defining aggregate importance to aggregate ecosystem health inevitably requires weighting of various attributes, with the potential to generate diverse outcomes based on relative valuations of ecological features. Methods that provide a clear basis for comparing the value of ecological features both for overall ecosystem health and within specific ecological features will equip stakeholders and policy makers with more useful and transparent decision tools. The IEA approach utilizes the spatial variability in our oceans in order to better protect them; we put forth a consistent procedure for determining the relative importance of areas in the ocean to ecosystem health to help prioritize efforts designed to protect, maintain and restore the health of the coasts and oceans.

Our approach recognizes and builds on other attempts and criteria that have been used to identify priority conservation areas or hotspots in the ocean (e.g., Global Ocean Biodiversity Initiative's "ecologically and biologically significant areas (EBSAs)" on the high seas www.gobi.org; the Bering to Baja Initiative (Morgan et al. 2004); biological valuation maps as proposed in Derous et al. (2007); Fisheries and Oceans Canada's criteria for selecting ecologically significant areas (Breeze 2004); Marine Ecoregional Assessments by The Nature Conservancy and World Wildlife Fund (http://conserveonline.org/workspaces/cbdgateway/era/index_html); the National

Audubon Society's Important Bird Areas (www.audubon.org/bird/iba/); and others). The approach adds to these efforts by incorporating local and traditional knowledge, providing a comprehensive and flexible approach dealing with the full suite of ecological features, and provides transparent justification and procedure for developing management measures and monitoring. As a multi-faceted decision support tool, identified IEAs are presented together in a comprehensive atlas containing the following three components, which better allows for comprehensive policy decisions:

1. The identification of IEAs within a region, including a map of the relative importance of areas to ecosystem health and biodiversity (e.g., at intersections of multiple ecological features or features disproportionately contributing to ecosystem health).
2. For any ecological feature, identification of the areas that disproportionately contribute to the overall spatial distribution of that feature (the most important areas for each respective feature; e.g., best breeding grounds, highest concentrations of corals, etc.).
3. For any proposed or current human use, identification of the areas where such uses are compatible or incompatible with features that are important for ecosystem health or biodiversity.

We assert that identifying IEAs, while challenging, is an essential precursory step for Marine Spatial Planning efforts in order to foster ecological sustainability, and for designating appropriate levels and networks of protective management measures to promote that sustainability. Our proposed method for valuing marine habitats throughout the water column emphasizes the transparency of the assumptions used. Our overarching goal is to preserve the health, productivity, biodiversity and resilience of marine ecosystems while providing for ecologically sustainable fisheries, subsistence uses and other economic endeavors. Together healthy ecosystems and economic opportunities help provide for vibrant human communities. The cumulative and deliberate nature of the IEA approach may be tailored to provide efficient and cost-effective conservation measures that ensure the economic and ecological goods and services provided by marine ecosystems are sustained for future generations. The Important Ecological Areas approach comprises the following three phases described in more detail in the remainder of this document:

Phase I. Identify IEAs

- Identify ecological features representative of ecological principles and criteria.
- Gather, format, digitize, and analyze relevant datasets, including those generated through local and traditional knowledge, to determine the spatial distribution, density, connectivity, and intersection of ecological features.
- Have ecologists and experts as available review preliminary datasets and analyses for accuracy and completeness.
- Delineate approximate IEA boundaries based on analyses and knowledge of ecosystem functioning, and compile into a publically accessible atlas.

Phase II. Recognize IEAs and Secure a Network of Protective Management Measures as Appropriate

- Seek official recognition of IEAs by relevant management bodies.
- Identify immediate, potential, and long-term anthropogenic impacts and threats to each IEA.
- Identify conservation and management options that address and reduce threats and protect ecological features as appropriate for each IEA.
- Work with managers, tribes, enforcement officers, scientists, and stakeholders, including local communities, to develop and implement cost-effective management measures that meet ecological objectives as a network.

Phase III. Monitoring, Evaluation and Adaptive Management of IEAs

- Expand existing programs and capacity to construct and implement monitoring of IEAs and enforcement of conservation and management measures.
- Periodically consider changes to IEA boundaries, MPAs and/or conservation and management measures based on monitoring results and evaluation.

III. Identifying Important Ecological Areas

We define IEAs as geographically delineated areas which by themselves or in a network have distinguishing ecological characteristics, are important for maintaining habitat heterogeneity or the viability of a species, or contribute disproportionately to an ecosystem's health, including its productivity, biodiversity, functioning, structure, or resilience. This definition is designed to align with how key ecological principles (e.g., Foley et al. 2010) are distributed in space. The process of identifying IEAs in any particular region begins by establishing appropriate ecological criteria that represent these broad principles. Such ecological criteria (e.g., migration routes, sensitive seafloor habitats, nursery areas, etc) provide a thematic approach that groups ecological features together that serve similar ecological roles and might be vulnerable to similar impacts. Ecological features refer to specific identifiable characteristics or structures that meet the ecological criteria. Once ecological features in an ecosystem of interest are identified, the challenge is to gather specific datasets that can be used to indicate how those features are distributed in space. (See table on p. 19 for examples of ecological criteria and their corresponding ecological features).

Identifying parcels of the ocean that meet this definition requires evaluation of available data using consistent methods that highlight the assumptions used. IEAs can be identified on the basis of single valuation factors, groups of similar valuation factors that represent similar ecological criteria, or on the basis of a wide suite of ecological factors that may or may not be related. While many ecological features are static and predictable (e.g., locations of reefs, bathymetry), others are spatially and/or temporally dynamic (e.g., migration routes, oceanographic features), and our definition explicitly includes the ability to identify dynamic IEAs based on evidence of these features. The flexibility within this definition allows the identification process to provide a wide suite of outputs, including a relative valuation of areas important in both specific and broad policy contexts.

Operationally, our process for identifying IEAs begins with specification of a consistent, formal algorithm for locating places in the ocean that contribute disproportionately to one or more biological or ecological characteristics that are identified as valued. These may include habitat types; productivities; biodiversity; habitat requirements for rare, endangered or threatened species; presence of indicator species, etc. Our procedure for doing this is presented in Appendix A. Places that contribute to many of these valued characteristics are especially important, and our approach recognizes this.

The IEAs identified on the basis of our formal identification algorithm provide a spatial framework and context for identifying other ecological characteristics that are crucial to ecosystem function but are not amenable to analysis by our algorithm, such as migratory corridors, larval dispersal pathways, ephemeral oceanographic features such as gyres, places identified on the basis of local or traditional knowledge (LTK) but not well appreciated otherwise because of sparse data, and many others. The IEAs identified by our algorithm provide an efficient means of beginning the conversation with ecologists and stakeholders to identify additional IEAs not captured by the algorithm.

Our IEA definition requires consideration of data from a variety of sources, including remote sensing data, species tracking and tagging, fisheries catch, fisheries observers, surveys, side scan sonar, oceanographic observing systems, and data collected from experts and resource users. In some regions such as the Arctic and traditional fishing grounds throughout Alaska and the Pacific Northwest, observations from indigenous peoples who subsist on marine resources and who have observed their environs closely for millennia (i.e., LTK) may be among the most reliable sources of data available for identifying IEAs. Gathering and digitizing LTK is a sharing process where we receive critical information and where necessary, appropriate and possible, we reciprocate by sharing the database of information, the IEA atlas generated, and our technical GIS capacity. Methods for identifying IEAs should be able to efficiently collect information relevant for identifying IEAs from these disparate sources, accommodate differences in temporal and area coverage, and weigh them in a rational and transparent manner.

As an essentially empirical approach, our method for identifying IEAs empirically has three immediate practical advantages. First, the process can proceed on the basis of incomplete but readily available data. A detailed knowledge of ecosystem functioning is not essential, although when available such knowledge may strengthen confidence in the determinations made. Second, assembling the available data in a single geo-referenced database linked with references to literature and other sources creates a library of information that can be used to evaluate criteria for comparing and prioritizing IEAs, for evaluating potential threats to their ecological functioning presented by on-going or proposed human impacts, and for evaluating whether particular IEAs warrant additional protections through management measures. Third, the mapped distributions of marine resources and their spatial interrelations provide the essential foundation for Marine Spatial Planning.

IV. Protecting Important Ecological Areas

While identification of IEAs has inherent value for better understanding the functioning of marine ecosystems and providing information, the primary purpose of IEA identification is to guide the development of protective management measures. Identification can play a critical framing role in marine spatial planning, proposals for various types of marine protected areas, development proposals, and disaster response efforts, ensuring that the protection of ecosystem health is the first and foremost priority in such processes. Once ecological features are identified and prioritized, the next step is to consider how different existing or potential human activities subject to management impact those features. The scope of management measures and activities considered depends on the particular policy process and its objectives. For example, a process geared toward comprehensive Marine Spatial Planning will likely address more activities than processes aimed at plans for specific activities (e.g., identifying appropriate areas for wave energy or marine protected areas that only address fishing). Furthermore, some processes are able to enact highly use-specific management measures at a fine spatial scale targeted at specific activities, while others may focus on more broad management tools such as marine reserves. Regardless of the scope of political process through which IEA protection takes place, we propose a similar sequence for framing, determining, and implementing appropriate management measures.

While identifying IEAs is a prerequisite for meeting ecological sustainability goals, not all IEAs will require or even warrant restricted–use sanctions. Some human activities may be compatible with the protection of features that make an area important; or sufficient management measures may already be in place to maintain identified features. Area-based protective measures that limit human activities (such as time/area closures, marine reserves or other forms of marine protected areas) may be warranted when damages posed by resource exploitation threaten irreparable harm to the ecological services provided. Conversely, IEAs may not need to address current activities, but simply can be identified to evaluate or prevent future threats that may not currently be apparent. Therefore, the identification of IEAs provides a critical source of information relevant to overall policy analysis of spatial management, though other considerations (e.g., economics, political pressure, etc.) will also be relevant to final decisions on management. So while identification of IEAs may provide essential context for establishing an appropriate level of protective management measures, identification itself does not imply certain management measures nor the boundaries of where management measures might be placed. Once IEAs are identified, the next step is to identify which uses are compatible or incompatible with ecosystem protection in each area.

While there is still much to learn, we know that marine resources vary in their sensitivity to impacts, and that some activities cause more damage than others. For example, corals are more sensitive to trawling than high energy sandy habitats, and trawling is more damaging to the seafloor than pole fishing (Chuenpagdee et al. 2003). Allee et al. (2000) describe a method for classifying habitat types based on a variety of data sources and multiple objectives. MacDonald et al. (1996) developed sensitivity indices for different benthic habitat types, and found that fragile, slow recruiting animals are most susceptible to fishing disturbance. Zacharias and Gregr (2005) define sensitivity as the degree to which marine features respond to stresses, or deviations of environmental conditions beyond the expected range. Halpern et al. (2007) developed a threats matrix between 38 anthropogenic impacts on 23 marine ecosystems using expert opinion surveys that compared the overall severity of threat combinations.

We consider impacts to be alterations of the structure or functions of ecological features, habitats, or species. The concept of threats describes the severity to which such alterations reduce the capacity of ecosystem features to provide functions and services, and the extent to which those features can recover. Understanding the mechanisms through which impacts occur can aid in the development of management measures, particularly for activities whose impacts may not be well studied. For example, Shester (in progress) highlighted that shallow coldwater corals are more sensitive to entanglement than crushing, as their skeletons are flexible yet their attachment to the seafloor is relatively weak. As Halpern et al. (2007) describe, many activity/feature combinations have not been directly assessed, so it is appropriate to predict potential threats in a precautionary manner based on expert opinion on the plausibility of impacts and the mechanisms through which they might occur. We can use these differences in sensitivity and degree of threat to prioritize certain combinations of features and activities that are most likely to result in substantial alterations to marine ecosystems, or incompatibilities. The concept of compatibility synthesizes these concepts into common terminology that assesses the cumulative threats to the multiple ecological functions in a given area caused by a given activity. The spectrum of compatibility of any activity across different areas provides a critical lens to focus spatial management measures on key interactions where they are most likely to reduce immediate threats.

When several options for meeting a given objective are presented, the principle of cost-effectiveness in its most general sense seeks to select the option that achieves a specified objective at the least possible cost. Or, in simpler terms, the maximum return for investment—ecologically, economically, socially, and culturally. In the context of IEAs, we conceive cost-effectiveness as achieving protection of a certain specified suite of ecological features for the least cost on the user groups that will be affected by management measures. Implicit in this principle is the need to gather and analyze data on how values to respective user groups are distributed in space, so they can be compared with the ecological importance of respective areas. For example, Shester & Warrenchuk (2007) developed an approach that minimizes the displaced target species catch, while protecting coral and sponge habitat from bottom trawling in the context of Essential Fish Habitat. If protection is measured in terms of prevention and reduction of cumulative adverse impacts based on specific incompatibilities of certain uses with features present in an area, more cost-effective management measures can be developed. Given limited political capital and hence the ability to impose costs, the implication is that for a given suite of overall costs to user groups, more targeted management measures in addition to fully protected marine reserves could produce the greatest conservation benefits over the widest suite of conservation features and covering a the largest possible spatial extent.

For uses that are proposed or not yet established, the identification of IEAs may serve as an important framing tool to remove certain areas from consideration altogether. For example, in the context of identifying potential sites for wind or wave energy generation, it may be appropriate to exclude consideration of placement in some IEAs, depending on the features identified. Once these areas are off the table, additional data on potential use values in different areas as well as a comprehensive analysis for compatibility with a wide suite of ecological features (as identified in the accompanying IEA atlas) could help determine the most appropriate areas for such activities. This example illustrates the value of identifying IEAs prior to allowing expanded new activities, since it is often much more costly and politically challenging to prohibit activities in areas once already established.

V. Monitoring and Adaptive Management of Important Ecological Areas

Regardless of whether protective management measures are conferred on IEAs, their recognition and monitoring help provide critical information useful for managers, conservation groups, local communities, and the broader public. Monitoring in the context of IEAs generally refers to the process of collecting information about variables (i.e. abundance, size, temperature) over time for the purpose of detecting change (Gerber et al. 2005). The three primary objectives of monitoring IEAs are:

1. Evaluating the effectiveness of management measures in sustaining the ecosystem services furnished by IEAs;
2. Better understanding the impacts of human activities on ecological features; and
3. Distinguishing secular environmental changes from those caused by specific activities.

Existing approaches to monitoring have focused on maximizing statistical power (i.e., Thompson and Mapstone 2002), which helps determine confidence of observed changes. Ideally, a scientifically-designed monitoring system should be implemented in each IEA to ensure data are useful for adaptive management. An excellent example of a long-term monitoring program is PISCO (Partnership for Interdisciplinary Studies of Coastal Oceans http://www.piscoweb.org/), which has an existing network of coastal monitoring sites along the Pacific West Coast. In addition the Integrated Ocean Observing System (http://ioos.gov), provides a central data portal for oceanographic data useful for monitoring IEAs, and is divided into 11 regional associations in the U.S. The statistical component of monitoring is also relevant for design of IEA networks and monitoring programs, because the replication of different treatments (i.e. management measures) applied in similar areas is needed to detect change. The overall network of IEAs should be designed with adequate statistical power so the efficacy of the management measures can be confidently evaluated.

Additionally, since the social costs and benefits of spatial management measures are sometimes poorly known or predicted, emphasis needs to be placed on socioeconomic monitoring that tracks the changes to economic opportunities following implementation of new management measures for an IEA. Observations by resource users operating within or nearby IEAs provide an invaluable source of monitoring information. These data include information on the distribution and magnitude of uses before and after implementation of any management measures. If resource users collect data for monitoring, they take a more active role in the ongoing management of IEAs while providing more cost-effective monitoring.

Monitoring efforts must be developed and considered in the context of management objectives for each IEA and the specific ecological functions for which it was identified. For example, monitoring of some IEAs might focus on populations of specific species where in other cases monitoring may focus on changes in overall diversity. Gerber et al. (2005) recommend that changes in management measures should be triggered by specific monitoring results that are based on objectives set for the area. Monitoring priorities may change over time, for example monitoring a specific feature may be reduced after an objective is met. Finally, monitoring decisions should balance costs of increased monitoring effort and expected management benefits.

Results from monitoring should be communicated and discussed in an open forum aimed at using these results to inform adaptive management. The forums could take the format of regional periodic workshops to discuss the 'state of the ecosystem' with a range of stakeholders and managers. These regional ecosystem forums would provide opportunities for agencies, communities, and environmental and industry stakeholders to discuss ecosystem health and potential adaptive management measures for IEAs. The regional ecosystem forums could then make recommendations to the appropriate agency for management of activities within the IEA.

Finally, all information on the identification, monitoring, and management of IEAs should be made widely available to the public. Since relatively few members of the public may have the opportunity or resources to physically visit particular IEAs, a strong effort should be made to bring the experience to the public. A broad effort for public education and information sharing through dockside interpretive displays, ocean roadmaps, and web pages would strengthen the public's sense of ownership and responsibility for IEAs.

VI. Conclusion

The process of identifying, protecting, and monitoring Important Ecological Areas is intended to be dynamic and on-going, in the sense that it should be re-iterated as new information becomes available. It can be used both to address current threats to ecosystem health and to help guide responsible and sustainable development. Important ecological areas are not generally intended to result in marine reserves, though in certain cases reserve designation may be warranted. Nor should the boundaries of IEAs be assumed to signify where management boundaries will be located. Rather, IEAs provide useful synthesis of geospatial data to help frame policy debates and processes, particularly marine spatial planning, so that ecosystem protection is the top priority and constraint under which decisions about appropriate uses should abide.

The primary product of the IEA approach is a comprehensive ecological atlas that may be used to evaluate threats to IEAs and to formulate arguments to counter or better inform proposals for new activities when appropriate. The atlas integrates scientific and LTK information in a single, accessible resource and decision support tool. This resource facilitates rapid response in reaction to development proposals, which in many cases may be decisive in persuading modification, relocation, deferral or even cancellation if warranted.

The process of moving from IEA identification to management measures and ultimately to adaptive management and monitoring is certainly complex and will vary by political process, geography, stakeholders, and policy objectives. For this reason, the concepts and methodologies embedded within the IEA approach are designed to be flexible and adaptable to a broad suite of policy contexts. Ultimately, the value of IEAs lies in their ability to effectively prioritize conservation efforts that will protect, maintain, and restore the resilience of ocean ecosystems in the face of an ever increasing human population.

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Table: Example thematic groupings of ecological features by criteria and relevant considerations.

Ecological criteria	Description	Examples of specific features	Example references	Potential management considerations	Special considerations
Sensitive benthic habitats:	areas containing structural features and species impacted by activities that contact seafloor habitat.	Rocky reefs, corals, sponges, trawl hangs	Shester & Warrenchuk 2007 (Aleutian Islands & US west coast EFH)	Bottom contact activities, undersea cables, sedimentation	
Pelagic migratory corridors:	areas used disproportionately by one or more pelagic species during their migration to and from foraging and breeding areas.	Migration routes for whales, sea turtles, swordfish, etc.	NMFS leatherback critical habitat; Weng et al. 2007, 2008; bowhead migration; gray whale migration	Entanglement with pelagic fishing gears (drift gillnets, pelagic longlines) or obstruction by large permanent structures	May exhibit spatio-temporal variation based on ocean conditions
Foraging areas:	areas where oceanographic features support consistent and predictable high relative abundances of forage species and attract aggregations of higher trophic group predators.	Krill aggregations, spawning aggregations for key forage species	Seabird foraging hotspots (Nur et al., in press)	Activities that disrupt successful foraging; harvest of forage species	May exhibit spatiotemporal variation based on ocean conditions; determine whether area-based management affects overall availability to predators
Nesting, resting, and rearing areas:	areas where congregations of one or multiple species seek refuge as they tend to highly vulnerable offspring.	Sea turtle nesting beaches, marine mammal rookeries, seabird nesting colonies, polynyas	MLPA special closures	Direct harvest of eggs, activities that cause nest abandonment or disturbance	May require distance buffers to prevent nest/pup abandonment
Spawning and breeding areas:	areas where one or more species congregates for reproductive purposes.	Spawning aggregations for grouper, herring, squid	Zeidberg et al. 2010 (squid spawning areas)	Activities that may disrupt successful reproduction; harvest of species	
Nursery areas:	areas where larval or juvenile life stages of one or more species seek refuge and experience lower mortality rates than surrounding areas during this critical life history stage.	Kelp forests, eelgrass beds, estuaries, deep-sea corals, coastal marshes, mangroves	Mumby et al. 2004 (Mangroves as nursery areas)	Development activities, water quality, harvest of species	Species may be obligate or facultative habitat use, and may be present for certain times of the year. Habitat extent may also show annual to interannual variability (e.g. kelp).
Primary and secondary productivity:	areas where oceanographic features support consistently high primary productivity relative to other areas.	Chlorophyll concentrations, benthic infaunal biomass	Oksanen et al. 1981	Indicative of foraging areas and high diversity, important for monitoring	
Larval production and settlement areas:	areas where species with small adult home ranges and mid-range larval dispersal are found in higher numbers and/or have habitat features conducive to larval retention and survival.	Leeward areas at coastal points; kelp forests; rocky reefs	MLPA closures (SAT size and spacing guidelines)	Harvest of adults of identified species; protection of habitat features	Areas should encompass adult home range size and be arranged in a network such that spacing does not exceed larval dispersal distances
Habitat and species diversity:	areas where a high amount of heterogeneous habitat types or species are found in a small amount of area.	Multiple habitat types within small spatial extent, representative species assemblages	Airame et al. 2003 (Channel Islands reserve design)	Representative areas for monitoring; marine reserve design	Can be used as a proxy for species diversity if data on species is poor
Vulnerable species areas:	areas where high relative densities of endangered, threatened, overfished or other vulnerable species are found in high numbers.	ESA critical habitats; high habitat suitability for overfished species	IUCN, ESA listings	Activities that may take or otherwise interact with vulnerable species	

VIII. Appendices

A. Using MARXAN to Help Identify Important Ecological Areas

The limitations of methods available for identifying and comparing IEAs suggest a largely empirical approach. This approach begins with collations of spatially geo-referenced distribution data for physical, chemical and biological oceanographic parameters such as temperature, salinity, nutrients, primary and secondary productivity, etc. Of these, primary productivity is particularly important, because the biomass and to a great extent the complexity of any ecosystem is limited by it (Oksanen et al. 1981) and it can be synoptically estimated by ocean-color monitoring satellites. When available, these data on "bottom-up" factors may be augmented by data on distributions of species at higher trophic levels including fish, birds and marine mammals.

We use an adaptation of MARXAN, an algorithm originally developed to optimize the design of marine reserve networks, as an informative, quantitative tool in our approach to identifying marine IEAs. MARXAN is fundamentally a procedure for efficiently identifying minimal areas that represent specified environmental features in a region (Ball et al. 2009). Although initially developed to represent specified proportions of habitat types within the smallest cumulative area selected for inclusion in a network of proposed marine reserves (e.g., Airame et al. 2003), the same process can be applied to finding the smallest area that accounts for a specified proportion of other ecosystem features such as primary productivity, nursery grounds, or biodiversity. Finding the smallest area then amounts to identifying areas that contribute disproportionately with respect to the ecological feature of interest, which is consistent with our definition for IEAs. For example, the smallest area that accounts for 50% of net primary productivity corresponds with areas where productivity per unit area is greatest, which could be considered productivity "hotspots" within the region for the purpose of inclusion in an IEA network.

Application of MARXAN involves four procedural steps: (1) partitioning the region of interest into contiguous sites known as planning units; (2) identifying and processing the data to be included so that a value for each ecological feature of interest is assigned to each site in a consistent and comparable manner across features; (3) identifying the constraints to be imposed that determine the weight accorded to each of the ecological features and the boundary constraints on the selected areas; and (4) running the MARXAN algorithm to produce an approximation of the optimal solution under the constraints used. These steps are explained more fully as follows:

(1) Site identification: MARXAN provides a uniform framework for evaluating if scenarios of selected sites meet specified conservation targets while minimizing the total area selected. This framework is defined by a partitioning of the region of interest into contiguous sites (or "planning units") that cover the entire region. These sites may be rectangular or hexagonal in shape, but for our purposes must have equal areas and a consistent shape, though it is possible to use different size planning units in MARXAN if

appropriate. The size of the sites should be small relative to the spatial scale of data variation for each type of data used, but not so small as to extend the time for computations prohibitively. Once identified, each site retains a fixed location and is identified by an index denoted as "*i*" that is unique to each site. The Nature Conservancy's *Best Practices for Marine Spatial Planning* (Beck et al. 2009) provides guidance for the appropriate selection of geographic boundaries, planning units, and data management.

(2) Data identification and processing: Ecological features are identified based on the extent to which they represent the ecosystem principles, and can be grouped into themes representing similar classes. Ideally thematic groupings are arranged so features within each group have similar management considerations or are impacted by similar activities (See Table on p. 18). Once determined, the data types to be used for IEA identification (and associated metadata) must be collected into a database and processed for insertion into MARXAN. The only requirement for these factors besides their ecological relevance is amenability to quantitative expression (for intensive variables) or categorical expression (for extensive variables). Examples of intensive variables include primary productivity which can be expressed as grams of carbon fixed within the area considered per year and biodiversity which can be measured with any of several indices (e.g., Shannon diversity index). Extensive variables, such as habitats can be categorized into multiple types, made up as a set of polygons covering 100% of the study area. Each planning unit (grid cell) must contain a single value for intensive variables or a proportion of each category for extensive variables totaling 100%.

The database must include the spatial and temporal ranges of applicability for each data type available. Data that are too sparse in space or time, are poorly documented or unsuitable for other reasons are noted and disqualified for the MARXAN process, but could be used post-hoc to supplement the MARXAN results. Values for each factor retained are assigned to each site, which may include values of continuous variables, (e.g. productivities, densities of species per unit area sea surface or sea floor, etc), values of qualitative rankings or binary (i.e. presence/absence) data. Where data are unavailable, the value for that factor is zero. This results in a data matrix $\boldsymbol{A^*}$ of elements a^*_{ij} denoting the magnitude of factor j at site i, with a total number of factors and sites denoted by J and I respectively.

Each MARXAN formulation is optimized in terms of the data matrix $\boldsymbol{A^*}$. Each factor j has a cumulative value given as:

$$v_J = \sum_{i=1}^{I} a^*_{ij} \qquad\qquad i = 1, 2, ..., I$$

Normalizing each factor by its cumulative value over the region of interest allows consideration of different factors on a comparable basis, where these normalized values are simply $a_{ij} = a^*_{ij} / v_J$. Hence, a_{ij} is the proportion of the cumulative value of factor j that is present at site i. Site i might be regarded as important for factor j if a_{ij} is greater than the mean value $\bar{v}_J = v_J / I$ of factor j. This process results in a matrix $\boldsymbol{A}$ of normalized data, with elements a_{ij}.

(3) Selection of constraints: The problem is to find the smallest collection of sites that account for a defined proportion of the total value v_J for each factor j, meeting all specified conservation targets. Following Leslie et al. 2003, these constraints may be represented as:

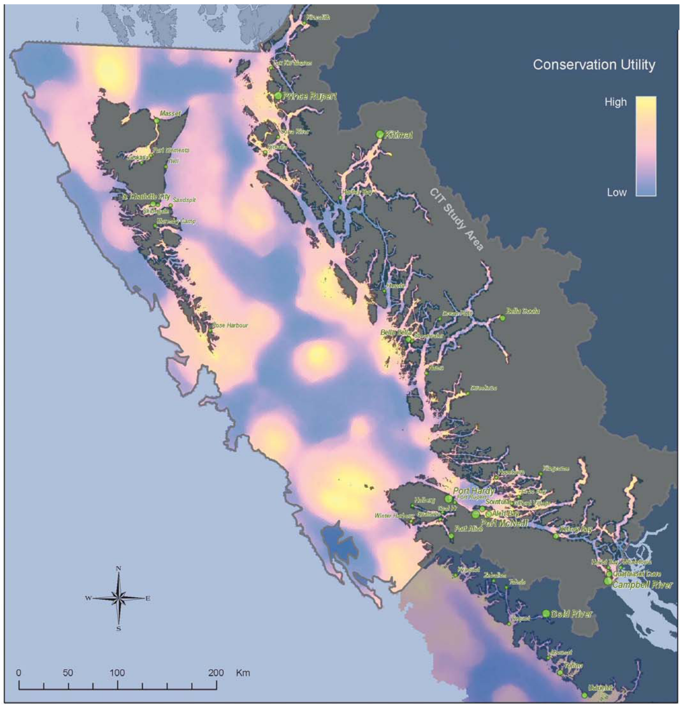
$$\sum_{i=1}^{I} a_{ij} x_i \geq t_j \ , \quad \forall j$$

where x_i is an indicator variable with a value of 1 if site i is included in the collection and zero otherwise ($x_i \in \{0,1\}$), and t_j is a threshold value that indicates the cumulative proportion of factor j that is included in the selected sites. Setting $t_j = 0.5$ would lead to a collection of sites that account for half the cumulative value of factor j. If this collection is the smallest possible, the included sites will contribute disproportionately to the cumulative value of factor j in the region. Note that setting $t_j = 1$ requires that all sites for which the value of factor j is greater than zero be included, providing a means of guaranteeing inclusion of factors deemed "important" *a priori*.

The selection of conservation targets (t_j) in MARXAN requires an explicit valuation of the importance of each factor relative to other factors. This valuation could occur through expert opinion, stakeholder consultation, or potentially through empirical estimation the relative contribution of each function to ecosystem services with known values. General principles to consider in valuation across ecological features could include but are not limited to:

- the ecological significance of respective habitats to maintaining ecosystem structure;
- the rarity of a ecological features;
- the interaction strengths of various species in food webs;
- the vulnerability or sensitivity to impacts or disturbance;
- the relative importance of various life history stages in terms of individual species population dynamics;
- the population status of respective species (e.g., endangered, threatened, healthy);
- the economic importance of respective ecosystem services; and
- perceived existence value.

In addition to the relative valuation of factors, the absolute values on a scale of 0-100% will largely determine the overall spatial coverage. Lower target values will produce results covering a smaller spatial extent and reflect the areas of highest relative importance. Using higher target values will also include areas of moderate relative importance and henceforth a larger spatial extent. Running MARXAN using a variety of scalar multipliers on the respective conservation target thresholds (t_j) and calculating the summed frequency of inclusion of each site into the selected outputs can thus illuminate peaks and valleys of relative importance (e.g., Ardron et al. 2002).



Relative conservation utility across areas in Central British Columbia generated using MARXAN analysis of multiple ecological datasets. From Ardron et al. 2002.

(4) MARXAN site selection: The core of MARXAN is the algorithm used to select a minimal number of sites that satisfy the constraints imposed. The selection proceeds by an iterative process known as simulated annealing (Kirkpatrick et al. 1983) beginning with an arbitrary selection of sites, calculating the value of an objective function, and then searching for replacement sites that decrease the value of the objective function. The value of the objective function increases with the addition of sites, but the increase can be offset if the sites added are contiguous with already selected sites. The objective function is formally[1] given as the minimization of:

$$\sum_{i=1}^{I} x_i + BLM\left(\sum_{i=1}^{I} l x_i - \sum_{i=1}^{I}\sum_{\substack{k=1,\\ i\neq k}}^{I} x_i x_k b_{ik}\right)$$

where l is the perimeter length of a site, and b_{ik} is the shared perimeter length of sites i and k. The terms in parentheses give the total net perimeter of the sites selected. The *BLM* is the boundary length modifier, which determines the weight given to minimizing the total

[1] The full objective function incorporates constraints as penalties, and when penalties are set sufficiently high is equivalent to the function presented here. The full function used in the MARXAN software is described in Ball et al. (2009).

perimeter length of the sites selected in comparison with the number of sites selected. Setting the *BLM* to zero leads to a solution that includes the smallest number of sites that satisfy the constraints identified in (3) above, and increasing the *BLM* puts an increasing premium on sites that are adjacent. This adds flexibility to the algorithm to value adjacent sites that satisfy multiple constraints at the expense of efficiency, which may be useful for identifying IEAs that are important for multiple reasons and are close together (see BLM Figure below). This formulation assumes all sites have equal costs of inclusion, though it is also possible to assign variable costs to sites based on economic, political, or other factors.

The MARXAN algorithm provides considerable flexibility for analysis of spatial data to assist in the identification of IEAs. Adjustment of the threshold parameter t_j allows different conservation targets to be assigned to the different factors, and the values selected specify precisely what "importance" means with respect to each factor. The BLM parameter adds scope for valuing sites that are close together and contribute disproportionately to satisfaction of one or more constraints, which is consistent with the notion of ecological areas that are important for multiple reasons that are aggregated: such places are especially important.

The formulation of MARXAN presented here also allows for incorporation of extensive and intensive factors, which changes the behavior of the algorithm. Applied to marine reserve design problems, early iterations of MARXAN used constraints aimed at ensuring specified representation of different habitat types (e.g., Airame et al. 2003). These habitat types may be regarded as extensive variables, in the sense that the sum of their contributions must equal the total area of a site. In contrast, variables like primary productivity or biodiversity indices are not so constrained, so their contributions to the "value" of a site are additive without bound, and in this sense may be regarded as intensive variables. This means that sites with high values for multiple intensive variables are especially "important", and their selection by the MARXAN algorithm serves to establish nuclei around which other, less "important" sites will be preferentially considered if the BLM parameter is greater than zero. If the spatial scale of the sites is small relative to the spatial variation of the factors included, this aggregation will be appropriate and should lead to a more accurate identification of contiguous areas of higher relative importance.

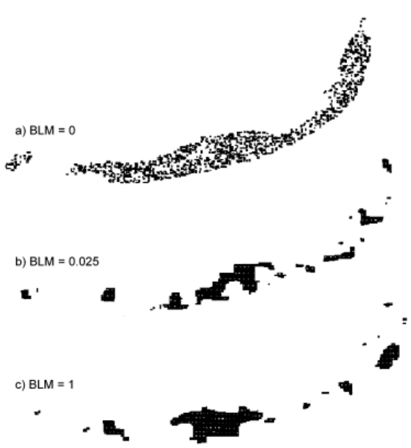
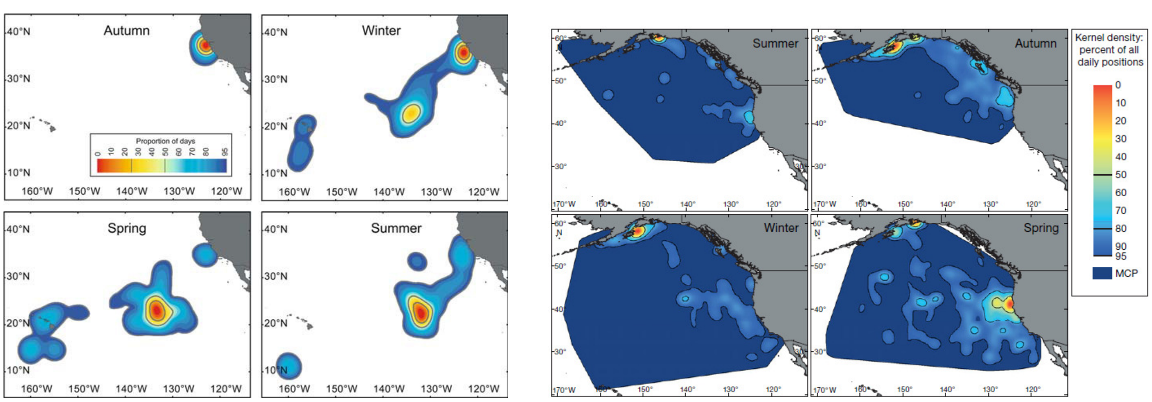


Figure: Effects of BLM choice on the degree of clustering selected units in MARXAN analysis using example of benthic habitat diversity in the Florida Keys. From Leslie et al. 2003.

The ability to force inclusion of sites by setting the threshold value $t_j = 1$ for sites where the factor is present permits recognition of "fiat" sites, such as sites that are deemed important "no matter what". These might, for example, include sites identified on the basis of local and traditional knowledge (LTK), or critical habitat for rare or endangered species. However, inclusion of such sites in this manner may introduce a computational artifact known as a "seed effect". By stipulating that some sites must be included, adjacent sites will be preferentially considered if the *BLM* has a positive value. Hence, it may be useful to run multiple scenarios with and without such sites to evaluate the magnitude of this effect on the outcome. More generally, running multiple repetitions of the algorithm with different randomly-chosen site selections initially provides an indication of the robustness of the results, as sites that are more consistently retained may be essential to any notion of IEAs in the region considered.

The procedure described above has other limitations besides vulnerability to seed effects. MARXAN does not consider uncertainty in the data or other aspects of data quality, instead assuming that all feature representations are true and all occurrences of each feature of equal value. In addition, some datasets present challenges that are not immediately conducive to the basic procedure and require either additional processing prior to use or modifications to the MARXAN parameters. Features such as migratory corridors may not be captured simply by tracking data or frequency of occurrence data as species spend less time at any point in a migration than they do at their destination. Pre-processing such data to identify relative importance of areas as migration corridors will help enable MARXAN to more adequately account for such features.

Temporal variability, both interannually and seasonally also require some attention before including in MARXAN. For many features such as foraging grounds, breeding areas, or other areas used infrequently by widely-ranging predators, the important areas may be consistently located, but they only serve those functions during specific time periods. Therefore, integrating their value over an entire year may downplay their importance in certain seasons, so breaking up the data seasonally may be necessary (see figures below).



Seasonal kernel density estimates for white shark (left, *Carcharodon carcharias*, Weng et al. 2007) and salmon shark (right, *Lamna ditropis*, Weng et al. 2008) offshore movements in the Northeast Pacific.

Other features such as ephemeral oceanographic fronts, eddies, and thermoclines may be impossible to model in MARXAN. Such features can be extremely important for various species and ecological processes, but may not be predictable in terms of occurrence within specified planning units. Such features might constitute a different type of IEA, that is identified based on real-time monitoring of such features, rather than through a static geographical boundary (e.g., areas identified in near real time by TurtleWatch).

Connectivity issues related to larval dispersal are critical for maintaining metapopulation and metacommunity dynamics (e.g., Shanks et al. 2003; Hastings and Botsford 2006), though these can be difficult to incorporate into MARXAN. Recent versions of MARXAN include additional options that may help address some of these challenges, such as specifying minimum and maximum separation distances which could be useful for larval dispersal connectivity between selected sites (MARXAN v. 1.8.10; Game and Grantham 2008). Also, including data types having widely differing coverage or sampling intensity may introduce potentially serious biases, so results should always be compared with maps of spatial sampling intensity for each of the data types included.

One major criticism of MARXAN is that it is not conducive to use by policy-makers and stakeholders, and it is complex to describe. Even though valuation decisions regarding conservation targets are explicit and transparent, many stakeholders may consider it a "black-box" and are suspect of its results, largely because its mechanics are not easily apparent and it does not have a user interface. However, there is a tradeoff between wide usability and analytical power. For example, existing interactive spatial decision support tools that may be more user friendly and accessible to the wider public (e.g., MarineMap[2]) provide information on the features contained within different geographic area boundaries and a way to visual multiple data layers, but do not synthesize or optimize available data. Therefore, while the MARXAN tool offers analytical power, it is important to consider how to best communicate its results and how it may be perceived by stakeholders.

Valuation enters the procedure in four direct ways. Even though the selection of data types may be determined mainly by availability, the decision to include a data type implies the data are regarded as important for identifying IEAs. Once selected, the choice of the threshold value t_j used reflects a second valuation decision regarding the relative importance of the data types included. While the overall relative value across features is not addressed explicitly, these thresholds allow the analyst to select different targets across features. Third, the choice of value for the *BLM* reflects the value attached to having areas identified as important for different reasons being near each other, in other words identifying fewer large contiguous areas versus a larger number of smaller separate areas, which may be useful depending on policy constraints such as management measures and enforcement. Since for some datasets and policy settings, it may be more desirable to identify a fewer number of larger IEAs, the choice of this parameter affects the degree to which spatially adjacent areas are preferentially selected over simply meeting the conservation targets. Selecting higher BLM parameters results in spatial clustering of identified areas, which while in some cases may be desirable, has the effect that greater overall area is necessary to reach the same conservation targets.

Choice of region and scale introduce the fourth type of valuation. Obviously, specification of the region determines the value of the normalization factor v_j, so changing the size of the region may change the normalization used. Consequently, an area may be identified as important at one

[2] http://marinemap.org/

scale but not at others. For example, relatively few areas would be identified in the Beaufort Sea if the region included for analysis included the Chukchi and Bering seas, because the Bering Sea is so much more productive than the Beaufort Sea. But if the region included for analysis were limited to only the Beaufort Sea, the lower normalization that would result for most ecological factors there would result in more areas being identified as important. Hence, the scale of application must be considered with care, and the clear need for such consideration emphasizes the value of methods that make all underlying assumptions explicit.

While different stakeholders may well disagree on the choices made, having a consistent, transparent framework for evaluating the consequences of different choices is a considerable advantage of our approach. Indeed, a sensitivity analysis with respect to each of these valuations may reveal important alternatives, or that identifications of some areas are insensitive to reasonable alternative assumptions, indicating their robustness at this level of identification. Presenting the outcomes of runs using multiple valuation choices and datasets in a map atlas helps show how various assumptions and groupings of data result in different outcomes.

Recognizing the limitations of the approach we have described so far, we regard MARXAN as a foundational information tool and first step that requires elaboration, review and reiteration as new data become available, rather than a rigid, determinative prescription of what areas should be formally considered to be IEAs. In addition to facilitating comparisons of multiple iterations on each of multiple alternative sets of assumptions, the results provide a point of reference for considering data types and sources that are not amenable to the MARXAN analysis, including insights from people with local and traditional knowledge, data and observations from others that were either unpublished or overlooked, and other insights from stakeholders. Also, this preliminary identification of areas that appear to qualify as IEAs provides a framework for identifying and incorporating other important ecological features such as migratory pathways, habitat connectivity, or subsistence use. The multiple iterations of MARXAN and its respective outputs thus serve as a critical first step in the overall IEA identification process. The MARXAN analyses are followed by professional and stakeholder review, incorporation of input from non-traditional sources, and re-iteration of the entire process as new data become available. Once established, these IEAs furnish the essential basis to preserve the biological engines and storehouses of the ocean.

The value of the approach presented is the ability to provide information on the most important areas for overall ecosystem health as well as areas important for specific ecological function. Together, this information will have wide applicability to a variety of policy questions and contexts. The ideal product of our IEA identification process is a compilation, or “atlas”, of maps showing various outputs of MARXAN runs as well as distribution of each individual dataset. Some MARXAN runs should include all datasets to show the globally important areas of highest overall importance across all factors, while other runs should include subsets of data organized into themes as described above. Such a thematic approach strikes a balance between looking at each feature individually versus grouping all available datasets into a single optimization. The organization of various datasets or features into themes can be useful if they contain multiple features that are impacted by the same types of uses or by species that display similar life history patterns. If data are grouped in a straightforward, transparent manner, they may be viewed as legitimate data layers as they may require less subjective valuation. For example, the Audubon Society's "Important Bird Areas"[3], which could be thought of as one theme of important ecological areas, have gained global recognition through a clear set of criteria. This formulation of IEAs can be useful for policy questions about which areas are more compatible with each type of use. Depending on the policy context, it may be more strategic to recognize the "official" IEAs as those that meet the more aggregate definition of importance for the entire ecosystem, while presenting more thematic maps as supplementary material. In other policy contexts, particularly those focused on particular types of activities or protections, the thematic maps could serve as the primary informational tools.

B. Use of IEAs in Marine Spatial Planning Efforts

Marine spatial planning (MSP) ideally seeks to promote desirable social goals by minimizing conflicts among competing uses of the ocean, reducing environmental impacts and preserving ecological resilience and key functions (Kappell et al. 2009). Marine spatial planning is rapidly gaining political momentum. It has been presented in recent legislative proposals as well as in the Obama Administration's recent establishment of a new national ocean policy (US House Resolution 2454 as introduced; IOPTF 2010). Such proactive, integrated planning is a logical extension of ecosystem-based management and the concurrent increases in ocean development from new and pre-existing ocean activities and uses. Relatively new ocean uses such as renewable energy and offshore aquaculture are competing with well established industries such as fishing, shipping and tourism for limited space and resources.

Approaches to MSP that ignore valuations of marine habitats instead focusing simply on resolving conflicts among user groups are prone to unduly compromise ecological sustainability objectives. For example, an ocean zoning approach to MSP may involve simply partitioning the ocean into mutually exclusive limited-use reservations, including zones for industrial development, fishing, shipping, tourism and marine parks. A habitat-preservation approach might involve preventing a suite of human activities in some stated proportion of each habitat type. Both approaches are liable to exposing the most important ecological areas to environmental degradation, in the first case if industrial or other uses are accorded higher priority than the ecosystem services they compromise, and in the second if the habitat types selected do not correspond with the most biologically important habitats in the region.

To successfully meet ecosystem protection goals, marine spatial planning (MSP) requires a foundation built on IEAs. While MSP is important for separating incompatible activities and reducing conflicts in addition to ecosystem protections (Kappell et al. 2009), the primary goal of MSP should be protection of IEAs, which in turn promotes sustainable management of our oceans. If IEAs are not identified first in the sequence of marine spatial planning, such efforts are vulnerable to becoming little more than ocean zoning, administering the location of competing industrial uses, streamlining permitting processes, and facilitating the organized industrialization of the marine environment.

[3] http://www.audubon.org/bird/iba/

Unfortunately there are also pitfalls to avoid with MSP. In the political realm where industrial development interests are so often paramount, a MSP process can quickly be turned from ensuring the health of marine ecosystems into a competition for ocean real estate. Such competing interests often lead to ocean zoning, where ocean activities and uses – including conservation – are designated to different areas of the ocean. Even with good intentions, such as when there is a clear goal to protect ecosystem health, zoning pitfalls are hard to avoid. Powerful stakeholders have strong incentives to exploit the political process, typically seeking territory or rights to an area and consigning ecosystem concerns to discrete spatial sectors as a secondary consideration once economic interests are fully satisfied. Surprisingly, such outcomes are often facilitated by conservationists themselves. While engaging in great battles for protection of discrete and frequently iconic patches of real estate, conservationists may miss the mark of protecting the overall health of the ecosystem. Also, their participation lends an air of legitimacy to a process that is put forward as environmentally acceptable for industry to move forward with development that further degrades our oceans.

Instead of simply dividing the ocean between competing uses, MSP provides an opportunity to focus on ecosystem health, supporting the ability of marine ecosystems to provide the goods and services on which we depend. Long-term spatial decisions for the marine environment are by definition MSP. Marine planning varies in scope from decisions about individual places and sectors to holistic efforts that are proactive and organized to integrate multiple current and future ocean uses across an ecosystem. The recent high level policy decisions have been to institute MSP at this broader more holistic and integrated end of the planning spectrum.

Comprehensive MSP – if done rigorously and appropriately – can benefit both industry and the environment. Comprehensive planning presents an opportunity to fully consider current and future cumulative impacts to ecosystem health. This is a large shift from typical ocean management where decisions about one activity are usually made in isolation. Marine spatial planning benefits industry by proactively identifying and getting broad stakeholder approval for areas where development could occur with minimal impact to the marine environment. The largest benefit, however, is ensuring that development does not degrade an ecosystem's health.

The Massachusetts Ocean Plan (2009) implemented a form of marine spatial planning in state waters out to 3 nautical miles from shore. While the plan is not comprehensive (e.g., does not address fishing), one useful approach is the identification of compatible areas for each activity, based on a series of maps for each use showing areas of potential incompatibility. For example, submarine cables were deemed not to be compatible with rocky seafloor habitat, so maps of rocky seafloor were developed to guide where cables could be laid. Creating such an atlas showing the vulnerable or incompatible areas to each activity provides a useful tool which forms a component of the IEA approach. However, our IEA approach additionally delineates relative importance of individual features and areas where multiple features overlap, so that some areas might be considered "off the table" prior to negotiations over where uses might occur and so that certain areas can be prioritized in cases where not all incompatible areas are off limits.

Building MSP around the identification and protection of IEAs brings spatial focus to ecosystem health and helps to avoid ocean zoning pitfalls. Ecosystem health is a non-spatial state of the ocean that is difficult to represent in a spatial planning process. By delineating the areas that are most critical for ecosystem health, IEAs help bring an important spatial context to ecosystem health that otherwise can be missed and potentially sidelined. A MSP process must therefore begin with the identification of IEAs. Once identified, decision makers and stakeholders will be able to give primacy to appropriate protections for IEAs and to identifying locations where ecologically sustainable development could occur. Also, ensuring that all IEAs have at least the minimum protection of monitoring allows managers to check the pulse and temperature of ecosystem health and use adaptive management as necessary to meet management objectives.

C. Use of IEAs in Marine Protected Area Processes

Marine protected areas have been formally defined in the United States by the May, 2000 Presidential Executive Order 13158 as "any area of the marine environmental that has been reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" (see www.mpa.gov). These protections may range from monitoring to "no take or disturbance" marine reserves. About 1,700 MPAs have been established in the US, encompassing nearly 5 million km^2, or about 1/3 of US territorial waters. Most of this protected area is designated as National Wildlife Refuges, National Marine Sanctuaries, or is associated with coastal National Parks or Forests (National Research Council 2001). Because they may be created by so many agencies and jurisdictions operating at all levels of government, there are correspondingly diverse goals and objectives for creating them.

Broad goals of MPAs include conserving biodiversity and habitat, managing fisheries, providing ecosystem services, protecting representative and unique areas for their intrinsic value, and protecting cultural heritage (National Research Council 2001; Lubchenco et al. 2003; Marine Life Protection Act 2004). The first three are conservation goals, which are of greatest concern here. Because of the diversity of nominating jurisdictions and agencies involved, the reasons advanced for designating MPAs to meet these goals vary and may conflict. Categories of criteria that have been used to identify candidate areas include:

1. Ecologically functional: These include places where primary productivity is high, or where physical or biological structure is complex providing shelter from predation for juveniles of various species, or where the combination of reproductive substrate, availability of food for hatched larvae and relationship to currents for dispersal to places where predators are scarce and food is abundant, etc. For example, coral reefs, kelp forests and eelgrass beds provide high primary productivity as well as shelter from predation for larval and juvenile life stages.

2. Operational: The National Marine Fisheries Service's efforts to identify essential fish habitat (EFH) ranked marine habitats according to their productivity, sensitivity to disturbance, and vulnerability (likelihood of disturbance).

3. Empirical: These may be based on compilations of available data regarding spatial distributions of marine productivity, population densities, migration pathways, oceanographic currents, etc. The degree to which these coincide may be used to prioritize areas as candidates for MPA recommendation.

4. Opportunistic: Opportunities for securing MPA status are occasionally generated by other political and regulatory factors, for example patrons wishing to establish a legacy by endowing a marine park based on local or regional uses and values as interpreted by the patron, or offsets stipulated for industrial development elsewhere, etc.

While each of these approaches has advantages, they are not equally suited to identifying which discrete parts of the ocean merit the most protection. An opportunistic approach may recommend places of little inherent ecological value. Empirical criteria are limited by the quality and quantity of data available, and ecologically functional criteria presume an understanding of marine ecosystems functioning that often is not available. Similar concerns apply to operational criteria, in that we often have little information on the role played by different habitats with respect to primary or secondary productivity, or how sensitive these habitats are, what their recovery time is from a particular disturbance, etc. Moreover, there is no guarantee the operational variables used will identify the most important areas for maintaining overall ecological integrity. Recognizing these limitations, we believe that the empirical approach, informed by ecologically functional criteria when available, offers the best chance of extending protections while preserving and ideally enhancing sustainable economic benefits.

A variety of strategies and MPA designs have been proposed or created to address the conservation goals listed above. Marine reserves are protected from all extractive or destructive activities, except perhaps for sampling required to monitor the effectiveness of the reserve. As summarized by Lubchenco et al. (2003), benefits of marine reserves include "...protection of habitat; conservation of biodiversity; protection or enhancement of ecosystem services; recovery of depleted stocks of exploited species; export of individuals to fished areas; insurance against environmental or management uncertainty; and sites for scientific investigation, baseline information, education, recreation, and inspiration (Allison et al. 1998, NRC 2001)". Some scenarios under which marine reserves may be the most appropriate management policy for an IEA are:

- Areas where many key ecological features, threats and therefore management measures combine to exclude extractive activity
- Areas that are ecologically unique
- Areas desired to preserve characteristics of wilderness and naturalness
- Areas that hold special meaning and form part of our natural heritage
- As a precaution when there is a lack of data but the area nonetheless appears to be of enhanced ecological or intrinsic value
- Areas that are particularly high in biodiversity and the objective is to protect that biodiversity
- To answer scientific questions, and provide tools for fisheries management, such as acting as a no-take reference site. In particular, reserves can help determine the efficacy of management measures that allow some limited uses and can allow scientists and fisheries managers to determine ecosystem-wide effects of fishing.

However, many scientists caution against using no-take marine reserves as a 'one-size-fits-all' approach to MPAs (Agardy et al. 2003, Hilborn et al. 2004) and acknowledge that marine reserves must be part of a larger marine conservation strategy (Allison et al. 1998). The notion of "protection" in an ocean area can be viewed in terms of the suite of uses that are prohibited or conversely in terms of whether specific ecological features within each area remain unimpacted. Typically, the more activities are prohibited within an area, the more it is assumed to be "protected". Early efforts at spatial protection focused on marine reserves (generally defined as areas where take of all marine life is prohibited), under the assumption that reserves offer the highest level of protection (e.g., MLPA). In cases where little is known about species composition, ecological functions, or how different types of activities affect ecosystem components, marine reserves offer precaution in the face of uncertainty. However, because reserves treat all types of extractive uses equally (all are prohibited), they tend to impose costs on some more benign uses with little ecological benefit. For example, if an area is identified as "important" based on features that occur on the seafloor and the objective is to protect those features, the prohibition of uses that affect only the upper water column (e.g., fully pelagic fishing operations, vessel traffic, etc.) likely have minimal benefit (if any) to those features, yet could impose significant costs on user groups. Only around 1% of U.S. waters and 0.01% of global ocean habitat is protected within no-take marine reserves in 2000 (www.mpa.gov; Pauly et al. 2000), reflecting the substantial political challenges that must be overcome to establish them. Consequently no-take reserves alone are insufficient for the scale of protection needed.

Many of the benefits of reserves are also conferred by less restrictive MPAs. Fishing regulations amount to a kind of MPA by time and area closures. The National Marine Fisheries Service designated closures in the past few years to protect essential fish habitat from bottom trawling (e.g. Shester and Warrenchuk 2007), widely recognized as the gear most damaging to seafloor habitats (e.g. NRC 2002). Restrictions such as prohibitions on bottom trawling offer more substantive protections from existing threats than designation as National Marine Sanctuaries in the U.S. Indeed, reduction of commercial fishing effort through more effective enforcement of regulations is often an especially effective means of reducing stress on marine ecosystems.

The National Research Council (NRC) recognized that the amount of protected habitat area needed to meet management goals will depend on habitat characteristics, species and management regime (NRC 2001). While targets of 20% of marine reserve habitat have been suggested by several scientists and science bodies (Boersma & Parrish 1999; Roberts 2000), other scientists have suggested 50% as the amount that should be protected (Lauck et al. 1998; Polacheck 1990). The NRC review of studies that estimated reserve area relative to management objectives ranged from 10 to 70% (NRC 2001), underscoring the arbitrary nature of a blanket 20% target for habitat protection which might not be adjusted to contexts of any particular ecosystem or relying on unrealistic assumptions such as the complete loss or destruction of the remaining percentage.

Partly as a response to the fractured jurisdictions authorized to nominate and create MPAs in the U.S., Presidential Executive Order 13158 authorized the National Atmospheric and Oceanic Administration to establish a National Marine Protected Areas Center (NMPAC). Noting that "the nation's collection of MPAs...is fragmented, complex, confusing, and potentially missing opportunities for broader regional conservation through coordinated planning and management", one of the primary purposes of the NMPAC is to foster increased coordination to promote progress toward an interconnected network of MPAs encompassing all marine habitat types with redundant representation. However, the NMPAC has no authority to nominate or create new MPAs, so its role is limited to research and advisory functions. While a large-scale interconnected network of representative habitats remains a laudable goal, establishing it is still in the hands of the various agencies and jurisdictions authorized to create new MPAs, where political hurdles are often daunting. Furthermore, while a focus on habitat representation is important, this limited focus does not explicitly address the many ecological and species-specific functions that can be addressed through a deliberate approach based on Important Ecological Areas.

In Oregon, legislation passed in 2009 that designates the State's first two marine reserves and an MPA, and further evaluates four other sites, all within IEAs identified by Oceana. The initial two state marine reserves are a subset of the identified IEAs. Further evaluation and ultimate designation of the four other sites, however, will lead to the development of an ecologically significant network of reserves and MPAs for these and other Oregon IEAs, protecting the health and biodiversity of Oregon's ocean and coastal ecosystems.

D. Use of IEAs in Disaster Response

Once IEAs are identified, protected, and monitored, they can serve critical roles in responses to major disasters and catastrophes such as oil spills. Before such an event occurs, protection of the critical features in these areas increases their resilience to such events. Resource managers can also be better prepared for such catastrophes by storing necessary recovery equipment and resources in proximity to IEAs and creating response plans in relation to the location of IEAs and the features contained within them. The ocean atlas described above can give resource managers a comprehensive tool to understand where ecological features at risk from such events occur in space. Some features are affected differently by different types of events. For example, an el Nino event may affect the availability of forage species and location migration corridors, while features most at risk from oil spills include coastal wetlands, seabird colonies, etc.

Once such an event occurs, knowing where IEAs are and their relative values to multiple ecosystem functions can provide a way to prioritize how and where to deploy limited resources (e.g., booms and skimmers). During the 2010 Deepwater Horizon oil spill in the Gulf of Mexico, Audubon's Important Bird Areas were prioritized and publicized as rationale for the areas initially selected for booming. Had a more comprehensive identification of Important Ecological Areas been available, such efforts could have been prioritized over a much wider set of species and habitats at risk.

E. Political Considerations for Protecting Important Ecological Areas

Advocacy for spatial management measures such as marine protected areas almost always faces opposition from entrenched interests. While ecologists may broadly agree that a substantial proportion of each distinctive marine habitat and their connectivity should be protected, getting such a comprehensive vision implemented through the political process is extremely challenging, at least with a single concerted effort. But it might be possible if approached incrementally. This situation, described in detail in *Compass and Gyroscope: Integrating Science and Politics for the Environment* (Lee 1993), requires a careful assessment of economic impacts, political strategy, and clear immediate and long-term goals. Using Lee's analogy, the compass refers to the desired outcome as indicated by science, here a connected network of protected areas in the ocean including all distinct habitats, and the gyroscope refers to the political process of achieving this.

Making a successful case to defer short-term economic benefits for long-term sustainability is always politically challenging. The political process is often not receptive to any of the conservation objectives listed above. Some of the most productive and important marine habitats are located in near-shore waters that fall under the jurisdiction of sub-national governments that are acutely sensitive to local interests and concerns. Even when jurisdictions are sympathetic to conservation goals in principle, there may be resistance to enacting restrictions within precisely identified boundaries, especially when multiple alternatives are available. In such cases, parties affected by sanctions on uses often argue for siting elsewhere (i.e. the "NIMBY" problem: Not In My Back Yard). The vulnerability of arguments to such objections for establishing protective management measures at a particular place decreases as follows:

1. Ecosystem protection
2. Conservation of biodiversity
3. Habitat protection
4. Refugia for rebuilding depleted populations of exploited species
5. Marine parks
6. Scientific study sites

For example, there are usually numerous candidate sites that could contribute to "ecosystem protection" in the broadest sense of the term. The requirements for refugia are constrained by the needs of the species for which protection is sought, and scientific study sites may require uniquely determined locations for which suitable alternatives do not exist. While this may seem a secondary conceptual concern, it often weighs heavily in the political negotiation process. Furthermore, restrictive sanctions may not be necessary for IEAs that are unlikely to face certain threats, and in such cases pursuit of sanctions may squander scarce political capital needed to secure protections more urgently needed elsewhere.

The realities of the political process along with the limited time available to secure protections for living marine resources at greatest risk point toward a strategic approach that embraces opportunity. No single line of argument is likely to be persuasive across the spectrum of relevant jurisdictions, yet when appropriate every opportunity for extending protection to vulnerable marine resources warrants action. As more MPAs are established, the ecological benefits accruing from their interconnectivity may become more readily defended as data on their efficacy accumulate. Thus, an incremental approach to securing protections across a network of interconnected IEAs may be more practical than trying to secure them all at once.