Refining a marine ecosystem index for Alaska: developing reference points for ecosystem based- management and Integrated Ecosystem Assessments.

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Goal

The goal of this study is to develop metrics to represent the condition of marine ecosystems in Alaska that can be used (1) to establish reference points useful for Alaska's Integrated Ecosystem Assessment (IEA) and (2) to enable comparisons across ecosystems within Alaska. To accomplish this, we propose to modify recent ecosystem index approaches (e.g., the Ocean Health Index by Halpern et al. 2012) to reflect conditions and stressors that are particular to Alaska, apply the index assessment to existing data for Alaska, and conduct comparative analyses between the eastern Bering Sea (EBS) and the Gulf of Alaska (GOA) ecosystems.

Background

To address demand for ecosystem-based approaches to resource management (EBM) and to provide a framework for scientific assessment at the ecosystem level, NOAA has recently implemented a national program of Integrated Ecosystem Assessments (IEAs, Levin et al. 2009, *in prep*). In each of the Large Marine Ecosystems, an IEA is regionally specific, allowing managers to tailor IEA components (objectives, indicators, risk and ecosystem assessments, and management strategy evaluations) to the focal ecosystem. An important component of the IEA process includes developing ecosystem indicators and targets for conducting risk analyses. According to Levin et al. (2009), the goal of a risk assessment "is to qualitatively or quantitatively determine the probability that an ecosystem indicator will reach or remain in an undesirable state (i.e., breach a reference limit)". Although the risk assessment approach has only recently been applied in an EBM context, it has often been employed in the management of endangered species and multi-stock fisheries (Patrick et al. 2010), allowing resource managers to rapidly prioritize and balance tradeoffs in multiple management actions and objectives. A few authors provide guidelines for conducting risk assessments for EBM and specify that they: (1) should be transparent and based on ecosystem analysis or models that determine changes in indicators in response to changes in human-induced pressures (Levin et al. *in prep*); (2) must explicitly consider uncertainties involved in understanding and quantifying ecosystem dynamics and their positive and negative impacts on social systems (Levin et al. *in prep*); (3) should include pressures that occur on land (e.g., coastal development, etc.), in the air (e.g., weather,

climate), and in the ocean itself (e.g., shipping, fishing) (Halpern et al. 2009); and (4) need to be conducted relatively quickly, adaptable to data limitations, and easy to update (Astles et al., 2009, Samhouri & Levin 2012). Hobday et al. 2011 further define three levels of risk assessment as qualitative, semi-quantitative, and quantitative. Level 1 risk analysis qualitatively scores each human activity or natural perturbation for its impact on the focal ecosystem components, with those pressures receiving a high impact score moving onto level 2 analyses; level 2 analysis considers the exposure of an ecosystem component to a pressure and the sensitivity of the component to that pressure; and a level 3 analysis takes a quantitative approach such as is used in stock assessments and population viability analyses (Levin et al. *in prep*, Hobday et al. 2011).

In general, risk assessments begin with level 1 or 2 analyses, evaluating future effects of natural or anthropogenic processes and can be used to identify particular stressors (e.g., climate change) for level 3 risk analyses, as well as further research and management strategy evaluations. Recent activities, including ecosystem risk assessments in Puget Sound, WA (Samhouri & Levin 2012) and global Ocean Health Indices (Halpern et al. 2012), provide a framework for conducting ecosystem risk assessments for IEA as well as deriving ecosystem indices that synthesize stressors and pressures into a single ecosystem reference point (i.e., Halpern et al. 2012).

To evaluate regional variation in risk of Puget Sound indicator species to four anthropogenic pressures (i.e., costal development, industry, fishing, and residential land use), Samhouri and Levin (2012) assigned species-specific low, moderate, and high scores for 8 sensitivity (e.g., background mortality rates, fecundity, population connectivity) and 8 exposure criteria (i.e., spatial overlap, commercial value, current status). They used composite sensitivity and exposure scores to evaluate regional variation in each species risk and used multi-dimensional scaling (MDS) to identify community patterns in response to stressors.

Similarly, Halpern et al. (2012) recently completed a comprehensive global comparison of ocean health using a composite index (OHI; www.oceanhealthindex.org) that serves as a model to achieve similar metrics useful for an Alaska IEA. Using data of varying quality and availability, they were able to produce a single OHI score intended to reflect the condition of marine ecosystems relative to ten ecological, social, and economic benefits of a "healthy" ocean. The index score is the average score across the ten goals, each of which is evaluated on the basis of four dimensions: present status, trend, pressures, and resilience. The latter three dimensions are combined to create a likely future state score, which is averaged with present status to determine the overall score for the goal (Halpern et al. 2012). To address the challenges of combining disparate data types, numerical scores for individual components are calculated relative to a reference point. Halpern et al. (2012) were able to synthesize myriad data sources, which varied in quality, extent and metrics, in a consistent framework that allows for cross-goal and cross-country comparisons of absolute and relative ecosystem condition. It is also relatively transparent, quantitative, scalable, flexible, synthetic, and target-driven, and if applied towards quantifying future ecosystem health could be a powerful framework for conducting ecosystem risk-assessments for IEA.

We aim to combine the methods of both Samhouri & Levin (2012) and Halpern et al. (2012) to derive a composite index of ecosystem condition from combined risk scores for Alaskan marine habitats. This Ecosystem Reference Point (ERP), and included risk scores, will be applied directly to the Alaska IEA and reported annually in the Assessment section of Ecosystem Considerations chapter of the stock assessment and fishery evaluation report (SAFE) produced annually for the North Pacific Fishery Management Council (e.g., Zador et al., 2011). To achieve this, we will leverage efforts of an ongoing North Pacific Marine Science Organization (PICES) working group (WG-28). The working group is currently tasked with developing ecosystem indicators to characterize ecosystem responses to multiple stressors. The group seeks to identify and characterize the spatial and temporal extent of critical stressors in North Pacific marine ecosystems and identify trends in these stressors and locations where multiple stressors interact. Stressors under consideration include climate change and related mechanisms such as species invasions, changes in freshwater and sediment input, as well as fishing pressures. The group is using the methods of Halpern et al. (2009) to collect expert opinions on the spatial scale, frequency, functional impact, resistance, recovery time, and certainty of ecosystem vulnerability measures.

Our objective is to analyze the PICES WG-28 survey results for two regions in Alaska with contrasting ecological and human systems (i.e., Eastern Bering Sea (EBS) and Gulf of Alaska (GOA)) in order to: (1) develop region-specific ecosystem reference points (ERP) and habitat risk scores; (2) test the sensitivity of the ERP and risk scores to input values and ecosystem differences; and (3) use MDS to identify habitats that exhibit similar vulnerabilities and resistance to climate change and various physical and anthropogenic pressures.

Approach:

Data will be in the form of survey results that are currently being collected as part of a PICES working group activity. These data will be available in fall 2012. The survey is designed to collect expert opinion on relative rankings of twenty ecosystem pressures (i.e., various physical drivers, climate change, fishing, coastal development, pollution, maritime activities, biological processes) on various communities (e.g., soft-bottom benthic habitats, upper water column pelagic habitats). The rankings also include estimates of certainty of the level of interactions and risks. For each pressure (i) and habitat (h) interaction a vulnerability (V_{ih}) and resiliency (R_{ih}) score is calculated (1- 4; none, low, moderate, high) and weighted by habitat area (A_h). Survey participant certainty (none-high) of each vulnerability and resiliency score (ν_{ih} and τ_{ih}, respectively) is also recorded. The values are then used to calculate a habitat-specific risk score for M number of pressures, such that:

$$Risk_h \sum_{i=1}^{M} A_h \cdot \left(V_{ih} \cdot e^{(1-\nu_{ih})} + V_{ih} \cdot e^{(1-\tau_{ih})}\right)$$

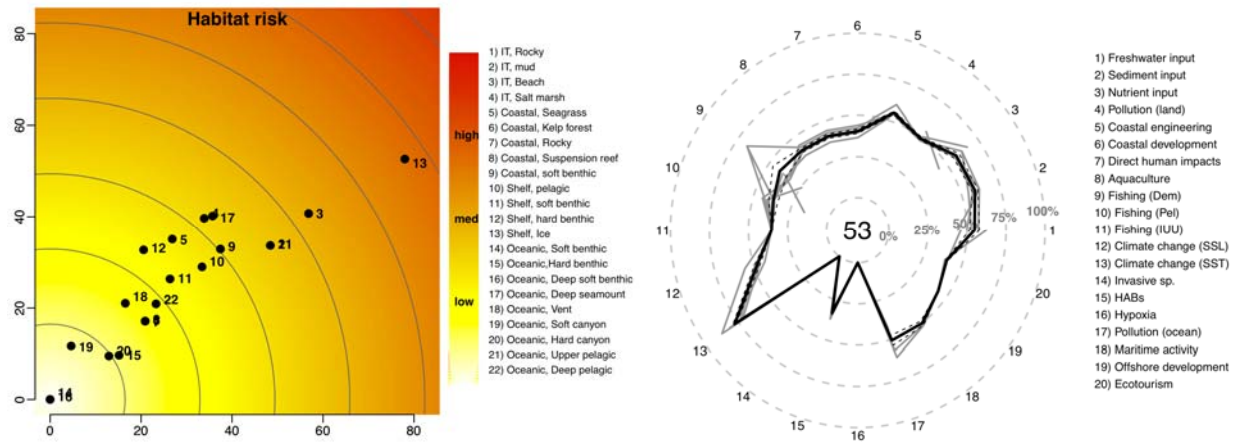

Figure 1. Preliminary EBS ecosystem risk analysis results. Left) Habitat specific risk plot. Value in the upper right represent high-risk habitats and are priorities for management and research activities (modified from Samhouri & Levin 2012). Right) Ecosystem reference point (ERP) plot. The numeric value in the center of the radar plot represents the composite ecosystem index, the lines represent individual habitat risk scores ($Risk_h$) based on vulnerability, resilience, and certainty values; outer values are higher risk, central, smaller values are lower risk (and higher certainty).

The combined scores (e.g., $ERP = \sum_{h=1}^{N} Risk_h$ or $ERP = Average(Risk_h)$) across N number of habitats thus become the overall ecosystem reference point for the system (ERP). This approach provides information on the relative risk of each habitat to combined climatic and anthropogenic pressures (Fig. 1a; $Risk_h$) as well as an overall index of the present condition of the ecosystem that can be compared to a target ERP (Fig 1b; ERP). The ERP and $Risk_h$values can also be used to evaluate the probability of dropping below a specified ERP (and/or individual $Risk_h$) threshold under status quo or future climatic and management actions.

In the proposed study we aim to evaluate the performance $Risk_h$and ERP scores as indicators of ecosystem condition for use in ecosystem assessments (both IEA and the Ecosystem Considerations chapter of the SAFE report). In particular we will use expert opinion survey data for two Alaska regions (EBS and GOA) collected as part of the PICES WG-28 project to: (1) calculate $Risk_h$and ERP values for each region, (2) evaluate the sensitivity of $Risk_h$and ERP values to changes in scoring values using a jackknife method of systematically removed values (i.e., Samhouri and Levin 2012 method), (3) evaluate performance of the approach across ecosystems with varying degrees of human and natural pressures and habitats, and (4) modify the approach of Samhouri and Levin (2012) and use multi-dimensional scaling to identify groups of co-varying habitats across stressors and regions. This study differs from the PICES WG-28 by its focus on regionally-specific and climate-change driven stressors, as well as the targeted IEA-related analysis.

Benefits:

An integral component of the IEA process is to synthesize the response of ecosystem indicators to changes in natural and anthropogenic drivers, in particular fishing and climate change. Ecosystem components identified as at risk are then targeted for management intervention and evaluated for management actions through the subsequent management strategy evaluations (Fig. 1 in Levin et al. 2012). $Risk_h$ and ERP values calculated and evaluated through this project will directly inform this step of the Alaska IEA, and will serve as a framework for ecosystem risk analysis in regional IEAs that are in development elsewhere. Further, since the $Risk_h$and ERP values can be improved through management actions as well as increased research and data quality (i.e., increase the certainty score), then this project can help identify both future management and research priorities.

The results will also have immediate utility as part of the Ecosystem Considerations chapter of the SAFE report. The Ecosystem Considerations report provides a compendium of ecosystem indicators that are synthesized to provide guidance on the state of ecosystems in the Bering Sea, Gulf of Alaska, and Aleutian Islands. A subset of these indicators is used to develop ecosystem assessments for each of the ecosystems. The results of this project can be incorporated as an individual contribution describing the findings, their significance and relevance to management, as well as important data gaps.

The Principal Investigators are directly involved with producing both the Ecosystem Considerations chapter of the annual fishery stock assessment report (S. Zador, K. Aydin) as well as the Alaska IEA (K. Holsman, K. Aydin), so incorporation should be seamless.

Deliverables:

1. Final report and presentation at the annual FATE science meeting describing management and research priorities for each of the Alaskan regions.
2. Sensitivity analyses of index dependencies and projections of future state incorporated into the Alaska IEA Risk Assessment and management strategy evaluation (ongoing).
3. Metrics incorporated into the 2013 Ecosystem Considerations chapter of the SAFE report
4. Manuscript to be submitted for publication in PlOS Bio or a similar peer-reviewed scientific journal that regularly publishes manuscripts focusing on IEA-related science.

Statement of previous FATE Funding:
Zador, S., Aydin, K., Gaichas, S. Project 10-01. A top predator index for the eastern Bering Sea. Investigated the utility of multivariate statistical techniques as a tool for developing an index of top predator trends in the eastern Bering Sea by integrating existing reproductive effort data from northern fur seals *Callorhinus ursinus* and seabirds. Indicator contributed to the Ecosystem Considerations report. Final report submitted to FATE August 2011. Manuscript for publication in review.

Zador, S., FATE FTE as of April 2011. Compiled the Ecosystem Considerations report for the North Pacific Fisheries Management Council (Zador 2011). Updated all indicators and developed a new ecosystem assessment for the eastern Bering Sea. Most recent annual report submitted September 2012.

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