Theme session H

The practical use of ecosystem indicators for decision-making

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The past decade has seen increased demand for ecosystem indicators for ecosystem based management (EBM), including new policies and directives such as the Marine Strategy Framework Directive in the European Union and the Ecosystem-Based Management Policy in the USA. There have also been significant advances in the development of marine ecological indicators. However, the uptake and use of these indicators remains a challenge for EBM. A key challenge has been to delineate thresholds in indicators from which management decisions can be made.

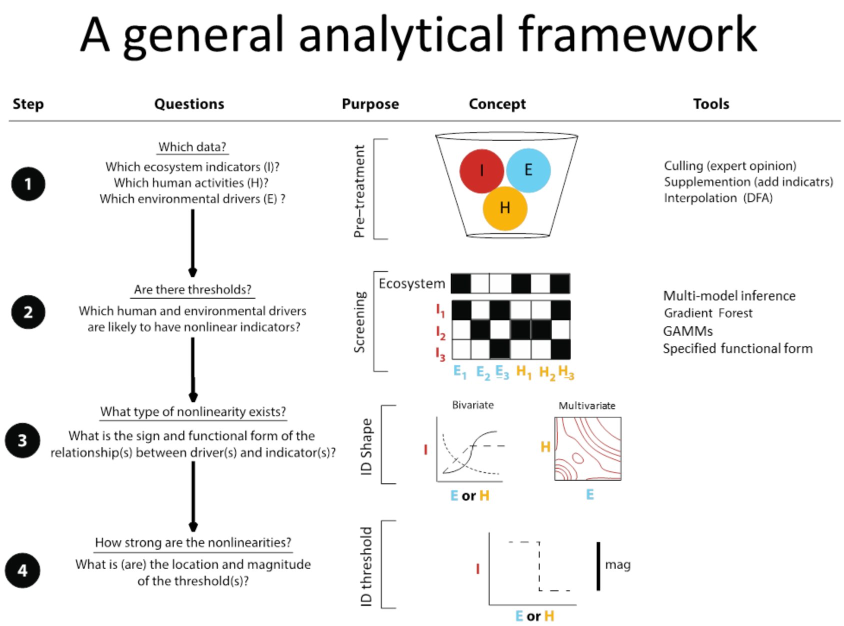
This session sought to highlight two things related to marine ecosystem indicators:

1) methods to determine where key thresholds, tipping points or other regions of non-linearity lie and from which decision criteria can be established for management concerns; and,
2) case studies where indicators are being considered for marine ecosystem-based management.

The main objectives were to explore methods to identify thresholds in ecosystem indicators and to identify lessons learned in the actual, practical use of ecosystem indicators to inform management decisions.

The eleven oral presentations and three posters discussed in this session spanned the intended scope of the session, highlighting key areas of progress in the field and where further work is required. Although the focus of the session was on the identification of thresholds in ecological indicators for practical decision making, there is a process to get to the end point where indicators can be used for management decisions. This was recognised both implicitly and explicitly during the session: implicitly from the range of presentation content, and explicitly where this was more formally addressed in some presentations and during the discussion. The figure below, presented by Gavin Fay, outlines the process used for the California Current system and was proposed as a general analytical framework (Samhouri et al. 2017)[1].

[1] Samhouri, J. F., K. S. Andrews, G. Fay, C. J. Harvey, E. L. Hazen, S. M. Hennessey, K. Holsman, M. E. Hunsicker, S. I. Large, K. N. Marshall, A. C. Stier, J. C. Tam, and S. G. Zador. 2017. Defining ecosystem thresholds for human activities and environmental pressures in the California Current. Ecosphere 8(6):e01860. 10.1002/ecs2.1860



Methodological Approaches

A number of methods are being used to identify thresholds for ecological indicators, which range from the use of expert opinion and social norms, comparison to pristine/undisturbed states to more quantitative methods such as breakpoint analysis and linear regression, Bayesian Networks, Generalised Additive Models (GAMs), Random Forest and Gradient Forest Analysis and simulation modelling. Most of the papers in this session explored the quantitative methods to explore an evaluate indicator behaviour, extending their use and application.

Thresholds of ecological indicators represent points at which a small increase in one or many pressure variables results in an abrupt change of ecosystem responses, and can therefore be used to establish reference points for management. However, due to the multidimensional properties of ecosystem responses and the pressures impacting the ecosystem, this is challenging. Therefore it is necessary to explore and evaluate the form of indicator functional response to single or multiple pressures in order to establish reference points. Statistical modelling approaches are proving to be powerful tools to explore and evaluate indicator behaviour.

Several papers used machine learning, which is a field of computer science that gives computers the ability to learn from data without being explicitly programmed, to explore the response of indicators to pressures. Tree-augmented Naïve Bayes (TAN) method is known for its high performance in classification tasks, such as predicting the class-level outcome of an interest variable given information about the other variables (Friedman et al. 1997, Zheng and Webb 2010). The method can be used to help evaluate the relative contribution of multiple factors to the indicators of environmental status, acknowledging the variation in the data (leading to uncertainty concerning the dependencies). The method is particularly useful if there is a high number of potentially relevant factors that may affect the result, and the data regarding them is heterogeneous. The analysis can be done even with a heterogeneous data set, where the variables are presented in different scales (numerical, presence/absence, etc.) and with missing data entries. As with any purely data-based method, the predictive capacity of a machine-learned model is restricted to within the range of the variables occurring in the teaching data. This may be challenge if thinking about the use of the method to planning future management strategies, to be implemented in conditions not yet seen, such as temperatures that may reach new levels due to climate change.

In addition to understanding how indicators respond to current pressures, it is also important to understand how indicators may respond to changing pressure in future, such as those that will result from climate change. Results from a GAM-modelling study from the Baltic Sea under different climate changes scenarios and food web models showed that climate change may affect the target levels and trigger points (i.e. the thresholds) of indicators, as well as the interpretation of management needs and effectiveness. It was also noted that zooplankton indicators can act as surveillance indicators and detected and further understanding of climate change influence on pelagic habitats.

Random Forest methods has been used to quantify the importance of environmental and fishing pressure variables to the value of ecological indicators, and Gradient Forest methods have been used to quantify shifts in aggregate ecological indicator response along pressure gradients and identify thresholds (Large et al. 2015). Based on this work, a multi-model approach was used for the California Current system using GAMs and gradient forest methods to explore the behaviour of ecological indicators and estimate their reference points across multiple pressures for the California Current system, providing new insights such as the greater number of non-linear responses of indicators to environmental pressures in contrast to fishing pressure. This work builds on earlier work and provides a robust approach to the estimate of reference points.

One of the drawbacks of statistical approaches such as those discussed above is that they describe relationships between indicators and pressures but they cannot discriminate between correlation and causality. This was not seen as a show stopper since there are ways to explore causality and we do not necessarily need to know if correlations are causative since they can be used as a “red flag” to indicate that something is changing rapidly. Causality can be assessed by exploring the persistence of a relationship over time, for example by splitting data into two different time periods, using the first time period to predict the second or by using expert knowledge to identify possible mechanism for a driver, which can then be used to submit hypotheses into modelling to explore further.

Model ensemble or multi-model inference approaches enable the analysis of how model selection uncertainty may be taken into account. In the California Current example above, GAMS and Gradient Forest were used to explore indicators thresholds. Results indicated multiple threshold responses to pressures, but for different indicators. This raises the question of how to interpret and use these results for strategic ocean management. A model ensemble approach was used to identify thresholds for indicator assessment that are useful to management in a risk-reward framework for the North Sea, where exploitation (reward) and conservation (risk) were traded-off. Ecological indicators were calculated from each model run and mapped onto this trade-off space to explore the risks to GES where thresholds are known, or to identify thresholds based in risks and rewards.

The challenge of identifying and understanding the effects of multiple pressures on indicators permeated presentations and discussions. Further, human-ecosystem feedbacks complicate our understanding of relationships between events and marine ecosystems. A case study from the Gulf of Mexico, where there is wide range of anthropogenic impacts affecting the ecosystem and a multiplicity of users, illustrated this point well. As with the California Current presentation, a SES conceptual modelling approach was used to define the problem, identifying indicators to assess pressure and states. A cluster analysis of these indicators revealed clear division in response around 2001/2002. Further investigation of the data, which required a transdisciplinary approach, revealed that there was a 4 fold decrease in the shrimp fishery, caused by a variety of factors, plus a 2.5 fold increase in the area of the hypoxic zone. Meanwhile, the Deepwater Horizon disaster appeared to have little effect on the ecosystem. Many of the talks brought up the challenge of interpreting the "message" of the indicators, due to the fact that anthropogenic and ambient pressures / "events" / conditions affect in concert. For this reason, the importance of transdisciplinary co-operation in understanding the ecosystem responses was underlined.

The necessity to work with stakeholders, managers, policy makers and other end-users of ecosystem indicators was deeply underscored during discussions and three examples were explicitly discussed in presentations. As noted above, the European MSFD requires ecosystem indicators, which regional bodies are required to report on. With a direct mandate, it is critical to ensure that the link between indicators and policy needs is strong. Therefore, although there are a plethora of published indicators, it was argued that for indicators to be useful to managers/policy makers, the latter have to be involved in the selection and development of indicators. This takes time, requires the building of relationships and trust, and innovative approaches to engaging managers/policy makers. For the development of pelagic habitat indicators for OSPAR, this was ultimately successful. Lessons learned through this process include that co-development from the proposal concept stage is essential and that scientists need to listen to policy advice. However, although the intent had been to also identify thresholds for the response of pelagic indicators to pressures, this was not achieved.

Most of the presentations were focussed on natural system indicators and their response to pressures. However, EBM encompasses the status of fishery-dependent communities, which are also subject to pressures. A social-ecological resilience (SER) indicator was developed with the input of stakeholders for small scale fisheries in north east Brazil. Random forest analysis indicated that social capital and occupational flexibility were the most important variable affecting SER, providing direction for how to improve SER and develop smarter management options. It was not clear however how this would be implements since fisheries management is top down in Brazil.

In the final discussion of the session, the participants discussed about the needs and ways to communicate the uncertainties to managers. A joint opinion was that advice that is given too late is not useful, and researchers should just start providing information and advice based on the prevailing level of knowledge, even if the formulation needs to be kept soft. First and foremost, it was underlined that the policy makers are not actually interested in knowing, where some threshold is thought to be, or the amount of uncertainty related to that, but rather what happens if we implement some management actions and how uncertain this outcome is. This point leads to the next step that should be taken to bring ecological indicators to practical use: the need to develop decision support tools and frameworks that provide a bridge between the scientists and the policy-makers, providing for informed decision making. One decision support framework was presented, to explore opportunities using decision support tools together with databases. The framework includes tools for a) simulating the alternative futures of the ecosystem, b) analysing alternative decisions in the light of multiple, partly conflicting decision-making criteria, and c) a Bayesian network based influence diagram to combine the ecological scenarios with a utility function. Also in this talk, the importance of co-creation of the tools was highlighted: stakeholders and end-users were involved in defining the objectives and potential futures, as well as evaluating and updating the models and tools.

There are an increasing number of tools and methods developed to evaluate the response of indicators to pressure and to evaluate their performance. One presentation developed an R-package (INDperform: an R package for validating ecological state indicator performances), specifically to share of methods and data via platforms such as GitHub and the R-Cran site. Wider use of such methods will improve our understanding of indicator response and enable a more robust approach to indicator use. A word of caution concerning homogenisation of approaches was noted, but based on the widespread use of R and the continual refinement development of methods and packages, it should not be too concerning.

To What Extent have Indicators been used in Management?
Despite a large increase in publications on ecosystem indicators for EBFM, the link between development and practical use is still not strong, even where thresholds have been identified. Several suggestions were made for why this may be the case.

- One of the issues for managers is that most of the time they do not know what management action to take if you cross a threshold (this is clearer in a single species situation where fishing is usually the main driver). EBM is much more complex and can have cascading effects.
- For example, since indicators are likely to be affected by multiple drivers, what activity is the main driver? Indicators are useful to tell us where we are, but not what to do to move in a particular direction. Models can give strategic direction, but not tactical.
- The objectives that the indicators are intended to measure are not always very clear, which makes it difficult to operationalise them. It does not help if we do not have the objectives well specified, which brings us back to the initial scoping step in Figure 1.
- In the USA, there is a recent EBM National policy, but it does not have teeth yet. Currently there is tendency to ignore it since it is a Presidential Order and not an Act of Congress.
- The relationship between some indicators and pressures is harder to define. For example, knowledge about pressure-state relationships is very poor for biodiversity indicators.
- One important question is, how we use indicators when climate change is affecting ecosystem structure and functioning? The science is still developing, but initial results from scenario results exploring the impact of climate change on food web indictors suggested differential responses under different climate conditions.
- Purely data-driven methods are not suitable for predicting in the situations where the state of the environmental conditions is expected to fall outside the former data ranges (“not yet seen” conditions)!
- Implementing MSFD has been way more complicated than we thought.

Suggestions for ways forward/lessons learned

- Work with end users to develop indicators and indicator thresholds.
- Provide interim products or prototypes that the managers and policy makers can use, explore and provide feedback within the timeframe of the project. Split the development process into parts and allow for trial and error.
- Develop a roadmap to describe the process, identify where we are now and look at risks and benefits of doing/not doing it.
- EBM legislation is very modern (e.g., MSFD -Europe, EBM and IEA policy – US) – it requires a flexible, iterative and adaptive management approach since we are not going to be able to get it all right and perfect at once.
- Fail fast, fail soft – provide best currently available knowledge.
- We need to focus on the development of indicators for the social, economics and governing systems that connect with marine systems. There is work going on within and outwith ICES, but it is far less than for the natural system.
- Share methodologies and publish data. Two presentations provided tools for use in indicator evaluation.
- Do we need to set thresholds for all indicators? It may be pragmatic to focus on the indicators for which thresholds can be estimated with greatest confidence and use other indicators as monitoring indicators. For example, plankton indicators can be used as surveillance indicators since they integrate climate and ocean conditions, are at the base of food web and thus provide environmental context.
- There is a lack of thresholds for indicators for other ocean activities e.g. wind farms.
- Keep going!