How can we develop suitable indicators to inform management of ecosystems under multiple pressure?

Saskia A. Otto
University of Hamburg, Germany
Informs

Causes Action
How can we develop suitable indicators to inform management of ecosystems under multiple pressure?

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University of Hamburg, Germany
..a good indicator distils complex information or processes into a single variable..
Halpern et al. (2012, Nature)
“..a good indicator distils complex information or processes into a single variable..”
o a single e..
"..a good indicator distils complex information or processes into a single variable."
Components

The levels of DPSIR framework
- Driving forces - Pressures - State (of the oceans) - Impacts - Responses

Driving forces
Socio-economic and socio-cultural forces driving human activities that increase pressures on the oceans

Pressures
Pressures on the ocean from human activities, both land- and ocean-based

Response monitoring
How do we respond to the impacts on the ocean?

Impact
What are the impacts of the changing state of the ocean?

State
What is the state of the ocean? - “the assessment”

by Kristina Thygesen (http://www.grida.no/resources/8124)
Food web components & taxonomic resolution
Single species traits:

Blubber thickness as indicator for the nutritional status of grey seals

HELCOM core indicator report (2018)
HELCOM core indicator report 2018

\[ y = 5 \times 10^4 e^{0.0512x} \]

\[ R^2 = 0.9251 \]
Aggregated indicators per trophic guild/community
Greenstreet et al. (2011, ICES JMS)
Indicators aggregated over entire food web
Indicators aggregated over entire food web

Tomczak et al. (2013, PLOS One)
How to integrate indicators for ecosystem-wide assessment?
Data basis

e.g. for composite indicators
• **Trends**
  - easier to determine
  - not subjective
  - suitable for every indicator type

• **Status**
  - more challenging -> requires reference points
  - often needed for management
Combining single indicator trends

Otto et al. (2018, Ecol Ind)

Bornholm Basin (indicator suite: TZA, MS, rCC, Sprat, Stickle, Cod)
But, detection of trend depends on:

- sample size
- presence of autocorrelation

When $N$ is small ($< 30$) or autocorrelation is present any method will often poorly characterize the true trend.

Hardison et al. (2019, ICESJMS)
When N is small (< 30) or autocorrelation is present any method will often poorly characterize the true trend.

Figure 2. Test rejection rates of simulated time series ($p < 0.05$) among different combinations of AR(1) process strength ($\rho_1 = 0, 0.43, 0.9$) and trend strength ($\alpha = 0, 0.026, 0.051, 0.147$). Bar colour indicates the test for trend that was applied.

Hardison et al. (2019, ICESJMS)
Biological Reference Points (RPs)

- Difficult to define for some type of indicators
- Fuzzy usage of term
- Narrow to broad context

• In single-species-based stock assessment models RPs are widely used to define safe levels of harvesting for marine fish populations.

• In the context of ecosystem-based management (EBM), RPs need to be re-defined as ecosystem-level biological reference points.
• In **single-species-based** stock assessment models RPs are widely used to define safe levels of harvesting for marine fish **populations**.

• In the context of **ecosystem-based management** (EBM), RPs need to be re-defined as **ecosystem-level** biological reference points.
Working Groups on Common RPs

Working Group 36: Common Ecosystem Reference Points across PICES Member Countries

- Acronym: WG 36
- Parent Committee: FUTURE SRC
- Term: Nov. 2018 – Oct. 2019
- Co-Chair: Dr. Mary Hunsicker (Mary.Hunsicker@noaa.gov)
- Co-Chair: Dr. Xuanjun Shen (xshen@wfu.ac.cn)

WGCERP

Working Group on Common Ecosystem Reference Points:

- Affiliation: ICES
- Chair: Mary Hunsicker, Xuanjun Shen, Benjamin Franquais, Saelee Oto

The group aims at supporting, nationally and internationally, the sound use of marine ecosystem indicators in support to management.
Marine Strategy Framework Directive (MSFD)

„This Directive establishes a framework within which Member States shall take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 at the latest.“

Determination of indicator trend and status required, as well as suitable actions.
Setting baseline and threshold RPs

McQuatters-Gollop et al. (2019, FMAS)
Integrated Assessment - Baltic Sea

HELCOM (2018)

Nygård et al. (2018, JORS)
SOFTWARE METAPAPER

BEAT 3.0 – a Tool for Integrated Biodiversity Assessments

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Corresponding author: Henrik Nygård (henrik.nygaard@syke.fi)

Nygård et al. (2018, JORS)
Threshold detection to help define RPs
Threshold detection to help define RPs
Threshold detection to help define RPs

1. Which data? Which ecosystem states (S)? Which human activities (H)? Which environmental pressures (E)?

2. Are there thresholds? Which human and environmental pressures are likely to have nonlinear relationship with indicators?

3. What type of nonlinearity exists? What is the sign and functional form of the relationship(s) between pressure(s) and indicator(s)?

4. How strong are the nonlinearities? What is (are) the location and magnitude of the threshold(s)?

Tools:
- Culling (expert opinion)
- Supplementation (add indicators)
- Interpolation (DFA)
- Gradient forest
- GAM with autocorrelation and/or
  Specified functional form
- Gradient forest
- Breakpoint analysis
- Threshold GAM

S = Ecosystem state indicator(s)
E = Environmental pressure indicator(s)
H = Human Impact indicator(s)

Samhouri et al. (2017, Ecosphere)
BUT: Number and location of thresholds method-dependent

<table>
<thead>
<tr>
<th>Time series (loc of true pts)</th>
<th>AMOC</th>
<th>PELT-AIC</th>
<th>PELT-CROPS</th>
<th>bcp</th>
<th>GFT (F test)</th>
<th>Breakpoints</th>
<th>segmented</th>
<th>tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 change in mean (Hile data, #28)</td>
<td>28 (too many)</td>
<td>(too many)</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>3</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>1 change in mean (at #25)</td>
<td>25</td>
<td>25</td>
<td>13,14,23,24,25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>14</td>
<td>25</td>
</tr>
<tr>
<td>3 changes in mean (at #10,25,45)</td>
<td>none</td>
<td>10,26,46</td>
<td>10,26,46</td>
<td>26</td>
<td>26</td>
<td>10,26,34</td>
<td>20</td>
<td>10,16,26,33,45</td>
</tr>
<tr>
<td>1 break in relationship (at #10)</td>
<td>6</td>
<td>3,8,13,18</td>
<td>3,8,13,18</td>
<td>8</td>
<td>8 (6)</td>
<td>10</td>
<td>11</td>
<td>6,14</td>
</tr>
<tr>
<td>Cubic decay function</td>
<td>35 (too many)</td>
<td>none</td>
<td>32,43</td>
<td>30 (34)</td>
<td>8,26,41</td>
<td>30</td>
<td>25,35,43</td>
<td></td>
</tr>
<tr>
<td>Highly non-linear (4 breaks at #10,25,45)</td>
<td>none</td>
<td>17,32</td>
<td>17,31,39,45</td>
<td>39,45</td>
<td>33 (39)</td>
<td>10,26,43</td>
<td>11,26,44</td>
<td>16,22,32,39,45</td>
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</table>

Table 1: Comparison of number and location (loc) of change points (cpts) across time series dynamics and methods. Orange cells indicate good matches with the true dataset.

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Fig. 1. Location of the ten marine ecosystems studied (SB = Black Sea, GoG = Gulf of Gabes, NS = North Sea, SCS = Southern Catalan Sea, SEA = Southwestern Australia, SB = Southern Benguela, WC = West coast of Canada, WS = Western Scotland, WFS = West Florida Shelf, and WSS = Western Scotian Shelf). Four ecosystem modeling frameworks were used to simulate the dynamics of these ten ecosystems: Ecosim (Eu), OSMOSE, Atlantis, and multispecies state-spectrum model (SSM).
Ideally, indicators are

- sensitive
- robust
- specific to single pressures
- spatially universal
ICES Advice 2019 for cod in the greater North Sea area
Ideally, indicators are

- sensitive
- robust
- specific to single pressures
- spatially universal
**How to quantify indicator performance?**

**Semi-quantitative approach**

<table>
<thead>
<tr>
<th>INDICATOR QUALITY CRITERIA (IQ)</th>
<th>CANDIDATE INDICATORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific basis</td>
<td>ES1 – ES5</td>
</tr>
<tr>
<td>Ecosystem relevance</td>
<td>ES1 – ES5</td>
</tr>
<tr>
<td>Responsiveness to pressure</td>
<td>ES1 – ES5</td>
</tr>
<tr>
<td>Possibility to set targets within the indicator response</td>
<td>ES1 – ES5</td>
</tr>
<tr>
<td>Precautionary capacity/early warning/anticipatory capability</td>
<td>ES1 – ES5</td>
</tr>
<tr>
<td>Quality of sampling method: measurable, accurate and precise outputs</td>
<td>ES1 – ES5</td>
</tr>
<tr>
<td>Cost-effective implementation</td>
<td>ES1 – ES5</td>
</tr>
<tr>
<td>Part of an existing or current ongoing monitoring or data</td>
<td>ES1 – ES5</td>
</tr>
</tbody>
</table>

**ES6. Sum of quality scores across IQs, per indicator**

\[
\sum_{i=1}^{8} (l_i) (ES5)
\]

**Comparison of ES6 Scores for Candidate Indicators**

**SELECTION OF HIGHEST SCORING INDICATOR**

Queiros et al. (2016, FMAS)
How to quantify indicator performance?

Fully quantitative approach

- **IND data**
  - modelling trends
  - scoring criteria based on model outputs
  - visualize scores

- **Pressure data**
  - modelling IND response to pressures [accounting for non-linearity and pressure interactions]
  - assess redundancies

Selection of best performing and complementary IND suite:

- Euclidean distance in state space
- Convex hull of state space
How to quantify indicator performance?

INDperform is an R package for evaluating ecological status based on indicator performance. It includes a simple implementation of the framework, allowing many indicators to be tested within minutes. The criteria and scoring scheme can be easily adjusted. Analysis splits into train and test data, allowing robustness testing after regime shifts.

https://saskiaotto.github.io/INDperform/
Additional measure of robustness

Running analysis for 2 time periods, e.g. before and after ecosystem shifts
- Baltic example:

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Climate</th>
<th>Eutrophication</th>
<th>Fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breeding Waterbirds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wintering Waterbirds</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cod</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Zooplankton Abundance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zooplankton Mean size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diatom– Dinoflagellate Index</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyanobacteria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secchi Depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anoxic Area</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Heidrich et al. (in prep.)

Same (42%)  Different (58%)
Multiple direct & indirect effects

Bi-trophic food web model based on Multivariate Autoregressive Model (MAR)

Torres et al. (2017, Ecol Ind)
Multiple direct & indirect effects

Tri-trophic food web model based on coupled GAMs/TGAMs

Kadin et al. (2019, FMAS)

Findings call for adaptive target setting under climate change
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How can we develop suitable indicators to inform management of ecosystems under multiple pressure?

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Synthesis

- Know your target audience
- Be specific about the indicator type and role and communicate that accordingly
- For a management-relevant indicators more suitability criteria to screen and test for

Still challenging:
- Linking indicators to ecosystem change
- Using indicators to measure progress toward policy goals - ecosystem reference points still under development
Combining frameworks

Management Strategy Evaluation
- MAR
- Statistical model coupling
- Bayesian Belief Networks
- EwE, Atlantis, OSMOSE

Threshold identification
- Screening for nonlinearities
- Multimodel change point detection approach

Pre-treatment
- Selection of indicators and environmental & human pressures

Indicator performance & Pressure identification
- Statistical modelling (GAM(M)s, TGAMs)
- Cluster analysis
Thanks to

- All collaborators: Thorsten Blenckner (SRC), Martina Kadin (NRM), Marian Torres (IEO), Anna Gårdmark & Michele Casini (SLU), Christian Möllmann & Kristina Heidrich (UHAM)

- INDperform coding team: Réné Plonus, Steffen Funk, Alexander Keth (UHAM)
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