Assumptions, challenges and future directions in cumulative impact analysis

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Calculating a Cumulative Impact Score

1. Layer the individual maps of stressors and ecosystems
Commercial shipping and pollution

Raw data available online from NOAA
Sea temperature positive anomalies

Created by Liz Selig, Ken Casey
Land-based pollution
Calculating a Cumulative Impact Score

1. Layer the individual maps of stressors and ecosystems
2. Apply an ecosystem vulnerability weight
Vulnerability Metric

Five Criteria:

- Spatial scale
- Frequency
- Functional impact
- Resistance
- Recovery time

Every ecosystem-by-stressor combination assessed with a survey of experts

Calculating a Cumulative Impact Score

1. Layer the individual maps of stressors and ecosystems
2. Apply an ecosystem vulnerability weight
3. Make a bunch of assumptions
4. Calculate a cumulative impact score for every pixel in the study area
5. Ground-truth scores with in situ measure of ocean degradation
Global Cumulative Impact Map

Halpern et al. 2008 Science
What CHI provides

- Ecosystem-based and ecologically ‘grounded’
- Quantitative assessment of condition
- Estimates cumulative impacts in a way that is repeatable and transparent
- Visualizes the state of the oceans
- Framework is scalable from local to global
- New data is easily added
- Objective-neutral
- Sets a baseline for monitoring future changes
- Open access on the web
Types of results

• How many co-occurring stressors
• % of ocean in different impact categories
• Top threats to an area
• % contribution of stressor(s) to overall impact
• Where are hotspots of impact for particular stressors
• Where are the most vulnerable locations
• . . . and many others
Co-occurring stressors
% contribution of fishing

Halpern et al. 2010 PNAS
% contribution of land-based stressors

Global update: change over time

Change in cumulative impact

- Permanent ice cover
- Seasonal ice cover
Global update: change over time
Where does this put us?

Assumptions, challenges, and new directions
Assumptions

• Additive impacts
Synthesis of 168 studies:

- Synergistic: 26%
- Antagonistic: 38%
- Additive: 35%
Assumptions

• Additive impacts

• Linear response to stressor intensity
# Nonlinear responses

Hunsicker et al. 2016, Eco Apps

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**Ecological response**
Species biomass and abundance

![Graph showing ecological response and driver metrics](graph.png)
Assumptions

• Additive impacts
• Linear response to stressor intensity
• Habitat response is equivalent in all locations around the world
  – Or even within a small region
Assumptions

• Additive impacts
• Linear response to stressor intensity
• Habitat response is equivalent in all locations around the world
• Historical change not a key driver
  – We have almost no spatial data for this
Sequential exploitation of a marine resource. Initiation year by location of major commercial fishery for sea urchins.

Berkes et al. 2010, Science
Assumptions

• Additive impacts
• Linear response to stressor intensity
• Habitat response is equivalent in all locations around the world
• Historical change not a key driver
• Temporal aspects of stressor input and ecosystem response don’t affect results
Arctic example: Bering Strait

Afflerbach et al. in review
Assumptions

• Additive impacts
• Linear response to stressor intensity
• Habitat response is equivalent in all locations around the world
• Historical change not a key driver
• Temporal aspects of stressor input and ecosystem response don’t affect results
• Habitat response to maximum intensity of each stressor roughly equal
A few more assumptions

- Stressor intensity is uniform within a given spatial unit
  - This is rarely true but almost never with better data
A few more assumptions

• Stressor intensity is uniform within a given spatial unit

• Habitat either present or absent in a given spatial unit
  – Without better habitat data, this is the only option
A few more assumptions

- Stressor intensity is uniform within a given spatial unit
- Habitat either present or absent in a given spatial unit
- Vulnerability weights are accurate
A few more assumptions

- Stressor intensity is uniform within a given spatial unit
- Habitat either present or absent in a given spatial unit
- Vulnerability weights are accurate
- Linear response of habitats to cumulative impacts
Key challenges

• Data gaps
  – Find a different proxy
  – Fill gaps
  – Forego inclusion
Key challenges

• Data gaps
  – Find a different proxy
  – Fill gaps
  – Forego inclusion

• Data resolution
  – Degrade to common resolution
  – Assume uniform distribution within spatial unit
  – Only combine layers with common resolution
Key challenges

• Temporal dynamics
  – With information, can map and address
  – Rarely have such temporal data
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• Spatial movement + connectivity
  – Assume nature and extent of spatial spread or level of connectivity
  – Otherwise, generally unable to address
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• Addressing 3D of oceans
Key challenges

• Use of both driver and stressor data
  – Drivers: shipping, fishing
  – Stressors: nutrient pollution, SST increases
Key challenges

- Use of both driver and stressor data
- Matching to policy
Comparing to the MSFD

11 descriptors of GES
1. Biological diversity
2. Non-indigenous species
3. Commercial fish populations
4. Elements of marine food webs
5. Eutrophication
6. Sea floor integrity
7. Alteration of hydrographic conditions
8. Contaminants
9. Contaminants in seafood
10. Marine litter
11. Introduction of energy, including noise

Key challenges
1. No integration
2. Mix of issues
3. Not comprehensive
New directions

• Adapt to species
Species-specific cumulative impacts

Maxwell et al. 2013, Nature Comms
New directions

• Adapt to species

• New stressor data
  – Global marine plastics
  – Annual sea level rise
  – New fisheries catch reconstructions
  – And many more
New directions

• Adapt to species
• New stressor data
• Improved habitat data
New directions

- Adapt to species
- New stressor data
- Improved habitat data
- Non-additive interactions
There will always be room for improvement . . .

. . . but to not address cumulative impacts would be folly.