Cumulative Impacts in California Current Nearshore Ecosystems

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Many activities in coastal systems produce multiple stressors.
**2005**

Are U.S. Coral Reefs on the Slippery Slope to Slime?

J. M. Pandolfi,1* J. B. C. Jackson,3,4 N. Baron,5 R. H. Bradbury,6 H. M. Guzman,4 T. P. Hughes,7 C. V. Kappel,8 F. Micheli,9 J. C. Ogden,7 H. P. Possingham,2 E. Sala3

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**2006**

Impacts of Biodiversity Loss on Ocean Ecosystem Services

Boris Worm,1* Edward B. Barbier,2 Nicola Beaumont,3 J. Emmett Duffy,4 Carl Folke,5,6 Benjamin S. Halpern,7 Jeremy B. C. Jackson,8,9 Heike K. Lotze,1 Fiorenza Micheli,10 Stephen R. Palumbi,10 Enric Sala,8 Kimberley A. Selkoe,7 John J. Stachowicz,11 Reg Watson12
A call for action:
Ecosystem Based Management

“Prioritize and coordinate management of multiple activities within a specified ecosystem”
Mapping Human Impacts
(Expert Judgment, Habitat Vulnerability)

Models of Cumulative Impacts estimate the spatial distribution of multiple stressors in coastal and ocean systems and evaluate the combined relative impacts from these stressors.
Mapping Human Impacts (Expert Judgment, Habitat Vulnerability)

- Data on human activities or associated stressors (e.g., climatic stressors, fishing, pollution, invasive species)
e.g. Commercial shipping and pollution, 1994

Halpern et al 2008 Science
Mapping Human Impacts
(Expert Judgment, Habitat Vulnerability)

• Data on human activities or associated stressors (e.g., climatic stressors, fishing, pollution, invasive species)

• Data on the distribution of different marine ecosystems (e.g., kelp forests, seagrass beds, seamounts, shallow soft-sediment)
Mapping Human Impacts
(Expert Judgment, Habitat Vulnerability)

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• Data on the distribution of different marine ecosystems (e.g., kelp forests, seagrass beds, seamounts, shallow soft-sediment)

• Assess the **vulnerability** of each ecosystem to each stressor using expert judgment

(Halpern et al. 2007 Conservation Biology; Teck et al 2010 Ecological Applications)
Mapping Human Impacts (Expert Judgment, Habitat Vulnerability)

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• Data on the distribution of different marine ecosystems (e.g., kelp forests, seagrass beds, seamounts, shallow soft-sediment)

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Vulnerability Weight

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

(Halpern et al. 2007 Conservation Biology; Teck et al 2010 Ecological Applications)
Calculating a Cumulative Impact Score

1. Layer the individual maps of stressors and ecosystems
2. Apply the ecosystem vulnerability weight
3. Calculate a cumulative impact score for every 1 km² pixel of the ocean
Mapping Human Impacts
(Expert Judgment, Habitat Vulnerability)

Halpern et al. (2008) Science
Regional Scale - Mapping Human Impacts
(Expert Judgment, Habitat Vulnerability)

Halpern et al. (2011) Conservation Letters
Ban et al. (2010) Marine Policy
Calculating a Cumulative Impact Score

1. Layer the individual maps of stressors and ecosystems

2. Apply the ecosystem vulnerability weight

3. Calculate a cumulative impact score for every 1 km$^2$ pixel of the ocean

4. Groundtruth scores to identify indicators of multiple stressors
Objectives of this Study

1. Determine if modeled impact scores reflect spatial differences in ecological degradation within coastal ecosystems

2. Identify indicators of cumulative impacts in specific habitat types
To determine whether the scores accurately reflect estimates of ecosystem health we compare diversity and composition of a suite of species from 3 habitat types:

- rocky intertidal
- kelp forest
- shallow soft sediment

with physical conditions and impact scores from the California current model by Halpern et al. (2009) Conservation Letters.
Study Region

California, USA

San Diego
Monterey
Santa Barbara

Halpern et al 2009, Conservation Letters
California Current Cumulative Impacts Model

Rocky intertidal sites cumulative impact scores:
- 12.1 - 13.3
- 10.8 - 12.0
- 9.5 - 10.7
- 8.2 - 9.4
- 6.8 - 8.1

Halpern et al 2009, Conservation Letters
California Current Cumulative Impacts Model

**Land-based**

*Examples:*
- Nutrient inputs
- Organic/inorganic pollution
- Human trampling
- Sediment increase/decrease
- Coastal engineering...

**Ocean-based**

*Examples:*
- Fishing (recreational/commercial by gear)
- Invasive species
- Ocean-based pollution
- Marine debris
- Aquaculture...

**Climate**

*Examples:*
- SST
- UV
- Ocean Acidification
Response

Rocky Intertidal

Does not include Islands
Indicators

**Rocky Intertidal**

- mussels
- *Fucus distichus*
- surfgrass
- *Ulva*
- bare rock
- articulated coralline algae
- *Endocladia muricata*
- encrusting coralline algae
- *Silvetia compressa*

Photo credits: Dave Lohse, UCSC, PISCO, MARINe
Ocean Tipping Points

Response Variables
Rocky Intertidal

Does not include Islands
Ocean Tipping Points

Response Variables
Rocky Intertidal

Predictor Variables
Cumulative Impact Score
PISCO - Physical
InVEST - Physical

Does not include Islands
Ocean Tipping Points

Response Variables
Rocky Intertidal

Predictor Variables
Cumulative Impact Score
PISCO - Physical
InVEST - Physical

PISCO
slope  rugosity  wave height limit

InVEST
wave exposure  wind  surge

Does not include Islands
**Ocean Tipping Points**

**Response Variables**
- Rocky Intertidal
- Kelp

**Predictor Variables**
- Cumulative Impact Score
- PISCO - Physical
- InVEST - Physical

- Rocky – Central & South
- Kelp – Central

Does not include Islands
Kelp Forest Indicators

- Understory kelp
- Abalone
- Rockfish
- Red algae
- Encrusting coralline algae
- YOY rockfish
- Predatory snails

Photo credits: Dave Lohse, UCSC, PISCO, MARINe
Ocean Tipping Points

Response Variables
- Rocky Intertidal

Predictor Variables
- Cumulative Impact Score
- PISCO - Physical
- InVEST - Physical

Does not include Islands

- Rocky – Central & South
- Kelp – Central
**Ocean Tipping Points**

**Response Variables**
- Rocky Intertidal
  - PISCO - Physical
  - InVEST - Physical

**Predictor Variables**
- Kelp
  - Cumulative Impact Score
  - PISCO - Physical
  - InVEST - Physical

**PISCO**
- density
- rugosity
- wave height

Does not include Islands
# Ocean Tipping Points

## Response Variables
- Rocky Intertidal
- Kelp
- Soft-Sediment

## Predictor Variables
- Cumulative Impact Score
- PISCO - Physical
- InVEST - Physical

![Map of California showing ocean tipping points](image)

- Rocky – Central & South
- Kelp – Central
- Soft – South
Indicators

Shallow Soft Sediment

Photo credits: www.sciencedirect.com, USC, NOAA
**Ocean Tipping Points**

**Response Variables**
- Rocky Intertidal
- Kelp
- Soft-Sediment

**Predictor Variables**
- Cumulative Impact Score
- PISCO - Physical
- InVEST - Physical

**Map Indicators**
- Rocky – Central & South
- Kelp – Central
- Soft – South
Results

Are diversity measures explained by physical variables and/or cumulative impact scores?

Species Richness

vs.

Cumulative Impact Score

Physical Environmental Factors
Results

Are diversity measures explained by physical variables and/or cumulative impact scores?

Species Richness vs. Cumulative Impact Score

Physical Environmental Factors

AICc Model Selection – Linear Models
Results

Are diversity measures explained by physical variables and/or cumulative impact scores?

Species Richness vs. Cumulative Impact Score in Rocky Intertidal:

1. cumulative impact score + rugosity + wave height + wind + latitude ($R^2 = 0.45$, $P = 0.008$)
2. rugosity + wave exposure + latitude ($R^2 = 0.33$, $P = 0.012$)
Results

Are diversity measures explained by physical variables and/or cumulative impact scores?

Species Richness vs. Cumulative Impact Score

Physical Environmental Factors

AICc Model Selection – Linear Models

1. cumulative impact score + rugosity + wave height + wind + latitude ($R^2 = 0.45, P = 0.008$)
2. rugosity + wave exposure + latitude ($R^2 = 0.33, P = 0.012$)

Rocky Intertidal

Kelp

surge + wave height + latitude ($R^2 = 0.45, P < 0.001$)
Results

Are diversity measures explained by physical variables and/or cumulative impact scores?

Species Richness

vs.

Cumulative Impact Score

Physical Environmental Factors

AICc Model Selection – Linear Models

Rocky Intertidal

1. cumulative impact score + rugosity + wave height + wind + latitude ($R^2 = 0.45$, $P = 0.008$)

2. rugosity + wave exposure + latitude ($R^2 = 0.33$, $P = 0.012$)

Kelp

surge + wave height + latitude ($R^2 = 0.45$, $P < 0.001$)

Soft-Sediment

“cumulative impact score” ($R^2 = 0.5$, $P = 0.01$)

“wind” ($R^2 = 0.46$, $P = 0.015$)

“wave exposure” ($R^2 = 0.43$, $P = 0.02$)
Results

Are composition of indicators explained by physical variables and/or cumulative impact scores?
Results

Are composition of indicators explained by physical variables and/or cumulative impact scores?

Composition of Indicators vs.

Climate-based Impacts
Land-based Impacts
Ocean-based Impacts
Physical Environmental Factors
Results

Are composition of indicators explained by physical variables and/or cumulative impact scores?

Composition of Indicators

vs.

RDA with AICc model selection

Climate-based Impacts

Land-based Impacts

Ocean-based Impacts

Physical Environmental Factors
Results

Are composition of indicators explained by physical variables and/or cumulative impact scores?

Wave Height + Ocean Impact + Latitude + Distance to Shelf
($R^2 = 0.28$)

Composition of Indicators vs.

Climate-based Impacts

Land-based Impacts

Ocean-based Impacts

Physical Environmental Factors

Rocky Intertidal
Results

Are composition of indicators explained by physical variables and/or cumulative impact scores?

Composition of Indicators vs.

Climate-based Impacts
Land-based Impacts
Ocean-based Impacts

Physical Environmental Factors

RDA with AICc model selection

Land + Ocean Impact Scores + Macro stipes + wave height + distance from shelf ($R^2 = 0.67$)
Results

Are composition of indicators explained by physical variables and/or cumulative impact scores?

Composition of Indicators

Climate-based Impacts

Land-based Impacts

Ocean-based Impacts

Physical Environmental Factors

RDA with AICc model selection

Land + Ocean Impact Scores + Macro stipes + wave height + distance from shelf (R² = 0.67)

Kelp

Density Understory Algae

Land + Ocean Impact Score

R² = 0.56
Results

Are composition of indicators explained by physical variables and/or cumulative impact scores?

Shallow Soft-Sediment

Ocean Impact + Latitude ($R^2 = 0.32$)
Conclusions

1. Indicators of ecosystem health are primarily related to physical variables
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2. Indicators also correlated with impact scores
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2. Indicators also correlated with impact scores
   - Model fitting suggests that power to detect these relationships is limited
     - Sample size, sampling objectives
     - Variation in impact score
     - Additivity of cumulative impacts
     - Scale mismatches
Conclusions

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2. Indicators also correlated with impact scores
   - Model fitting suggests that power to detect these relationships is limited
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     - Scale mismatches
   - The scale of the original data used to generate impact scores are very broad (e.g. climate, fishing)
Conclusions

1. Indicators of ecosystem health are primarily related to physical variables

2. Indicators also correlated with impact scores
   - Model fitting suggests that power to detect these relationships is limited
     - Sample size, sampling objectives
     - Variation in impact score
     - Additivity of cumulative impacts
     - Scale mismatches
   - The scale of the original data used to generate impact scores are very broad (e.g. climate, fishing)
   - Need local scale data to estimate local impacts
Ocean Tipping Points

Next Steps

1. Model averaging
Next Steps

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2. Add data at broader scales across the California Current for regional scale tests
Next Steps

1. Model averaging
2. Add data at broader scales across the California Current for regional scale tests
3. Add data from more degraded sites
Next Steps

1. Model averaging

2. Add data at broader scales across the California Current for regional scale tests

3. Add data from more degraded sites

4. Examine additional relationships between indicators and single/multiple stressors
Next Steps

1. Model averaging

2. Add data at broader scales across the California Current for regional scale tests

3. Add data from more degraded sites

4. Examine additional relationships between indicators and single/multiple stressors

Take Home:
Cumulative Impacts Model can be used to visualize cumulative impacts and set priorities at broad scales but could be improved using local data for local scale implementation