Cumulative Impacts in California Current Nearshore Ecosystems

Megan Mach, Rebecca Martone, Melissa Foley, Corina Marks, Ben Halpern, Carrie Kappel, Kim Selkoe

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Many activities in coastal systems produce multiple stressors

2006

Impacts of Biodiversity Loss on Ocean Ecosystem Services

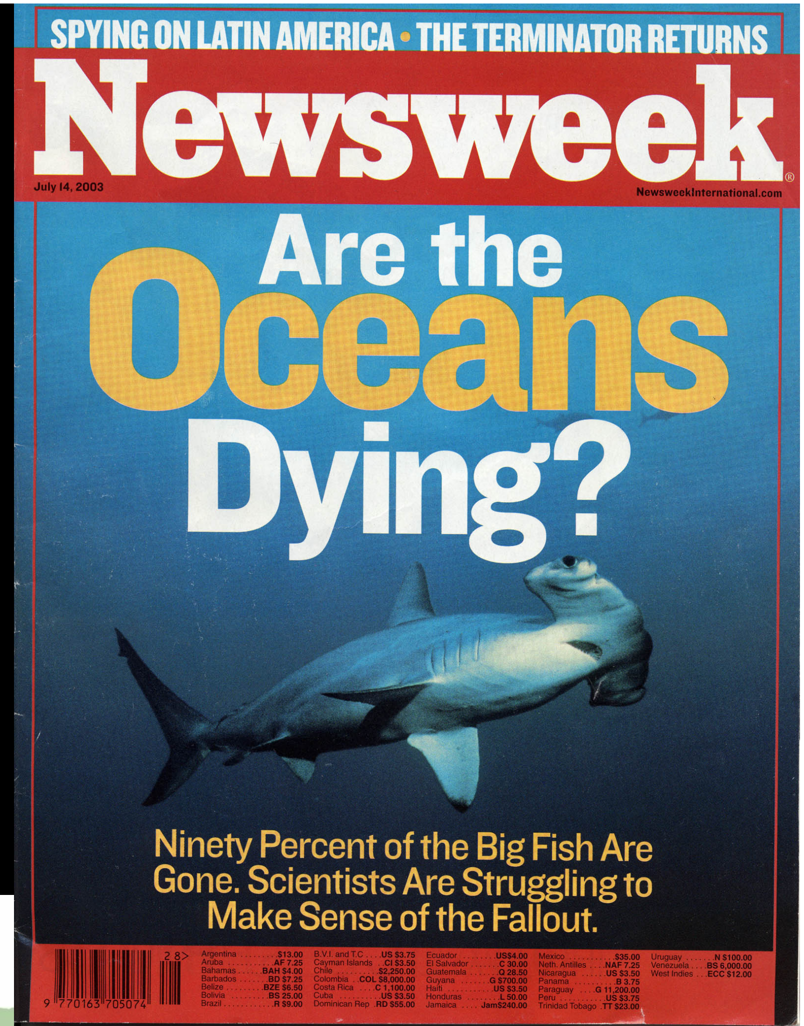
Boris Worm,[1*] Edward B. Barbier,[2] Nicola Beaumont,[3] J. Emmett Duffy,[4] Carl Folke,[5,6] Benjamin S. Halpern,[7] Jeremy B. C. Jackson,[8,9] Heike K. Lotze,[1] Fiorenza Micheli,[10] Stephen R. Palumbi,[10] Enric Sala,[8] Kimberley A. Selkoe,[7] John J. Stachowicz,[11] Reg Watson[12]

Science AAAS

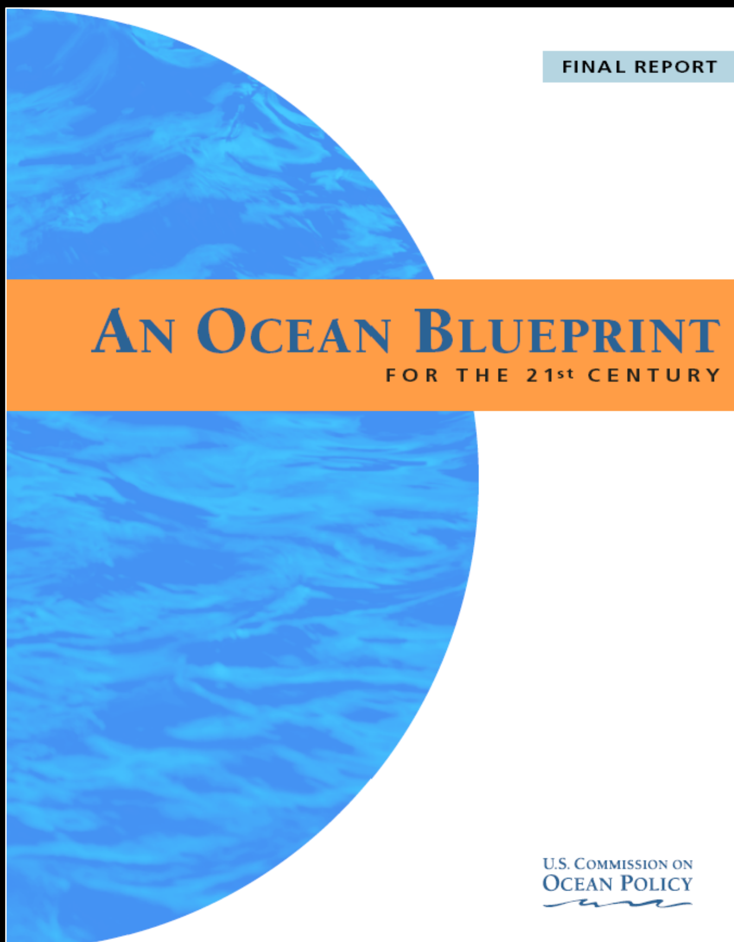
2005

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,[8] J. C. Ogden,[9] H. P. Possingham,[2] E. Sala[3]



A call for action:
Ecosystem Based Management



"Prioritize and coordinate management of multiple activities within a specified ecosystem"

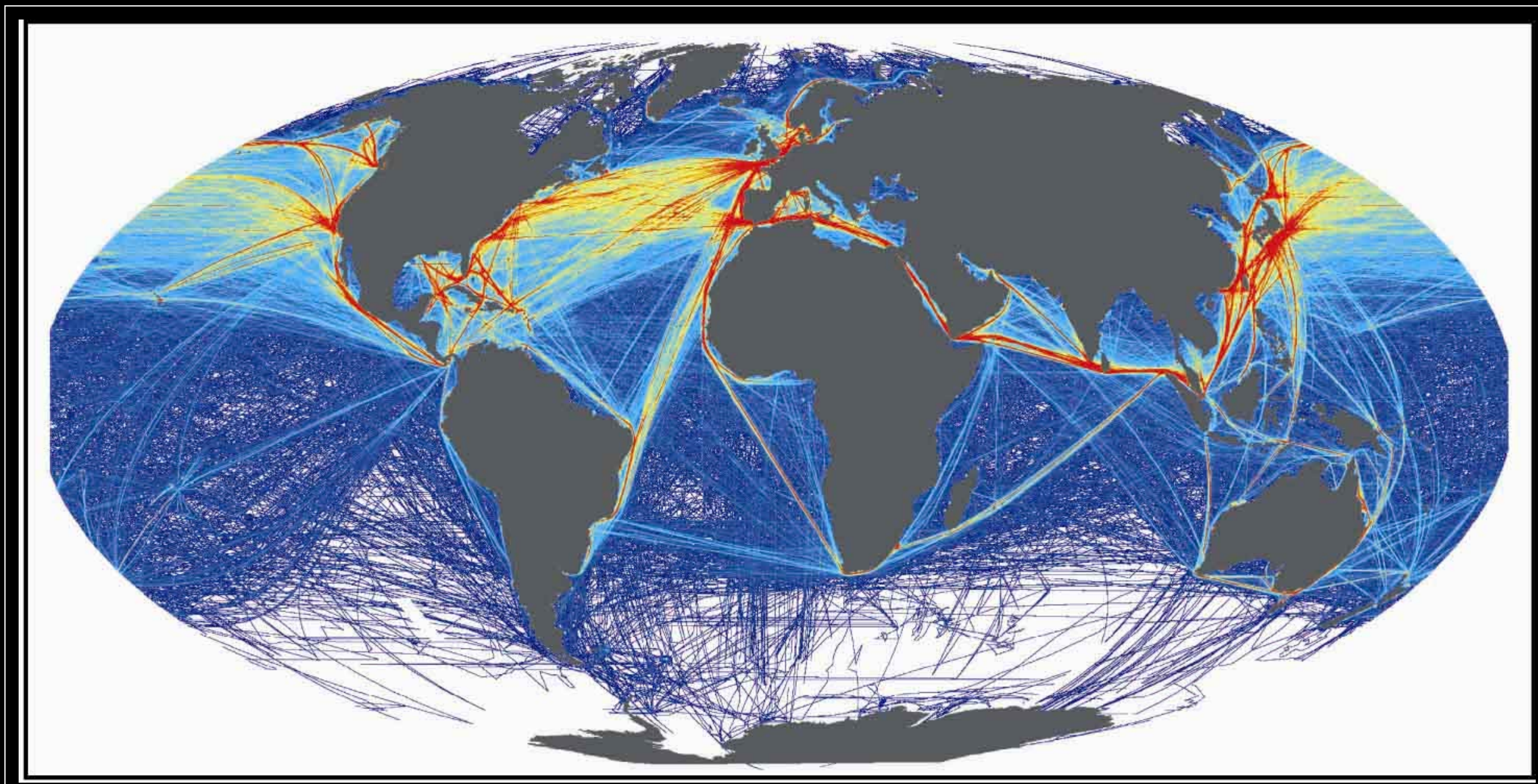
Mapping Human Impacts
(Expert Judgment, Habitat Vulnerability)

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)

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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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Spatial scale
Frequency
Functional impact
Resistance
Recovery time

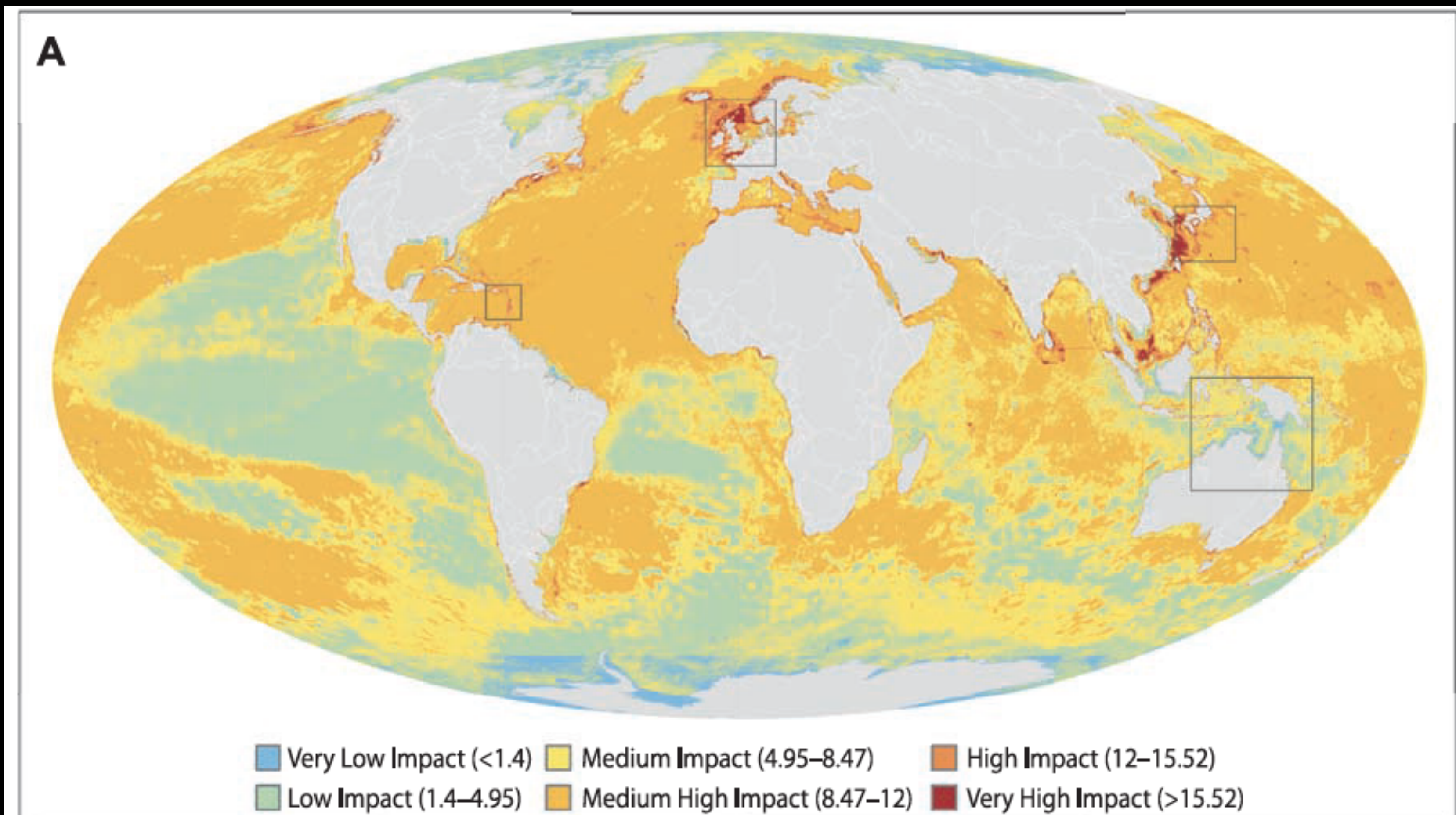
→ **Vulnerability Weight**

(Halpern et al. 2007 Conservation Biology; Teck et al 2010 Ecological Applications)

Calculating a Cumulative Impact Score

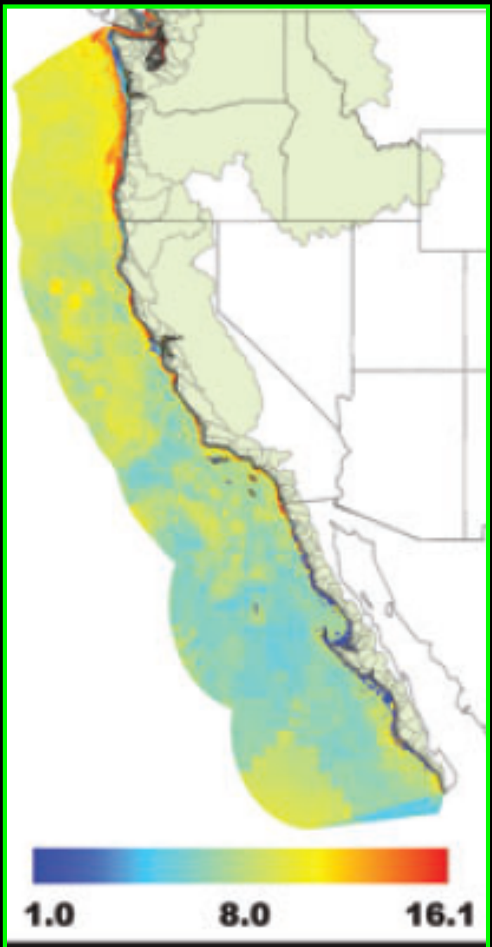
1. Layer the individual maps of stressors and ecosystems
2. Apply the ecosystem vulnerability weight
3. Calculate a cumulative impact score for every $1km^2$ pixel of the ocean

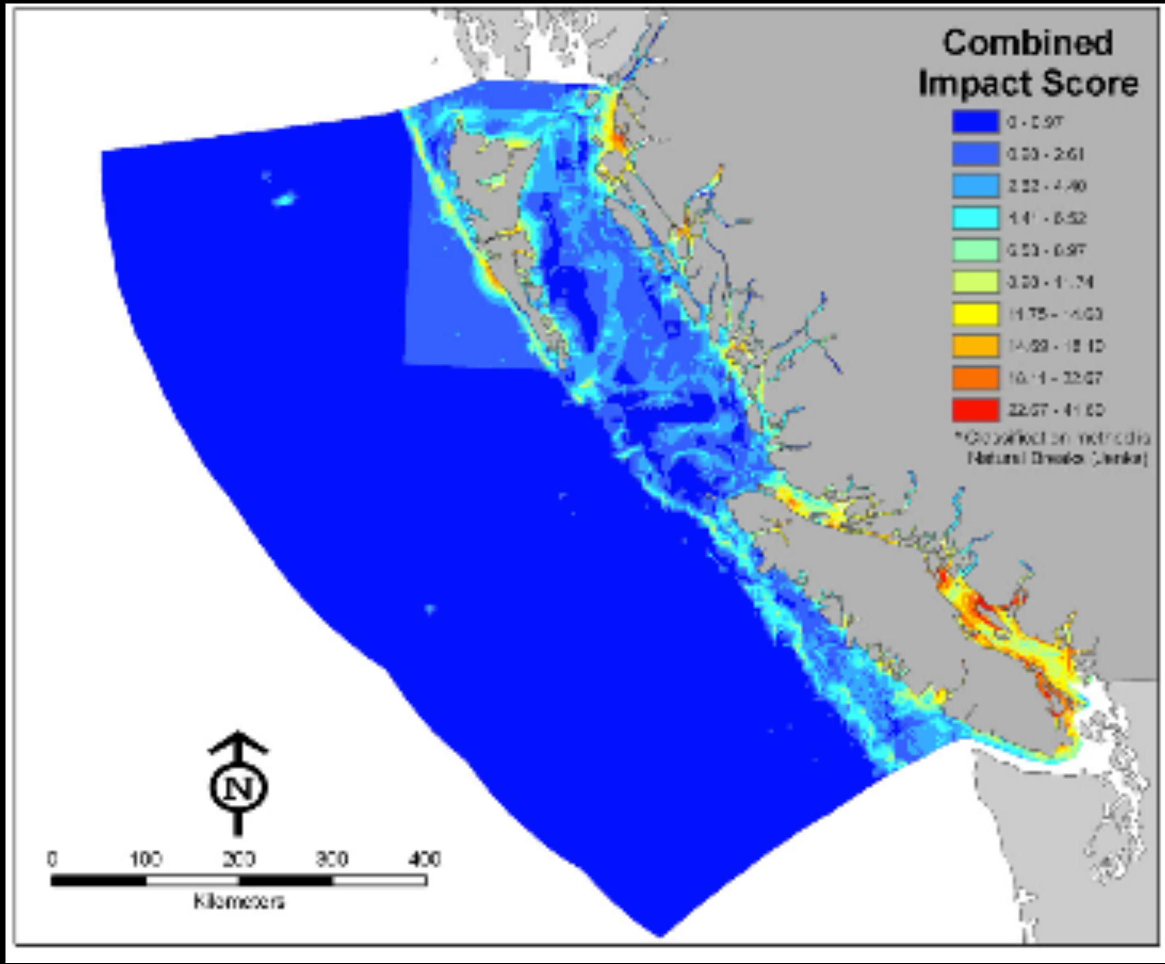
Mapping Human Impacts (Expert Judgment, Habitat Vulnerability)



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

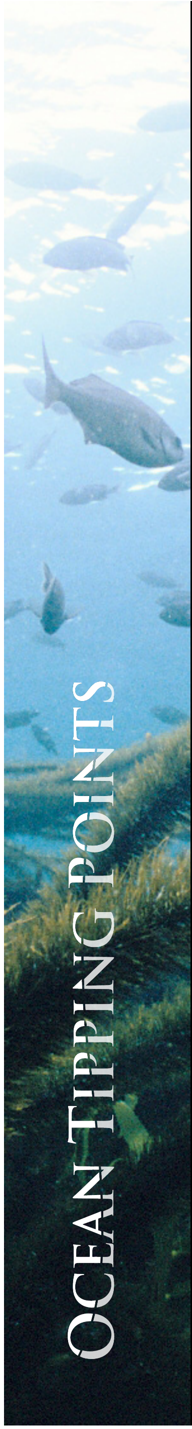
Calculating a Cumulative Impact Score

1. Layer the individual maps of stressors and ecosystems

2. Apply the ecosystem vulnerability weight

3. Calculate a cumulative impact score for every 1km^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

Methods

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:

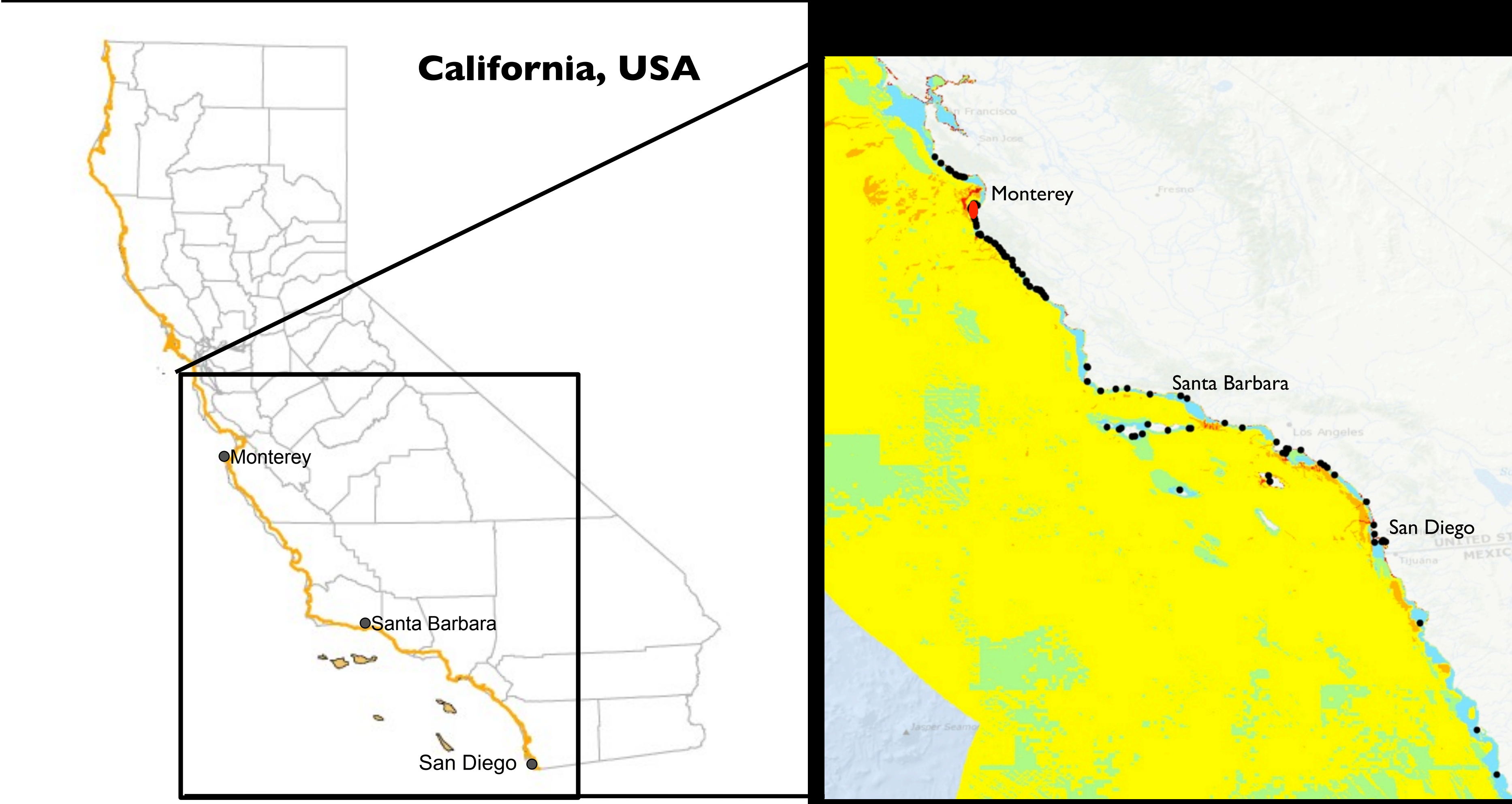
- rocky intertidal
- kelp forest
- shallow soft sediment

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

Study Region

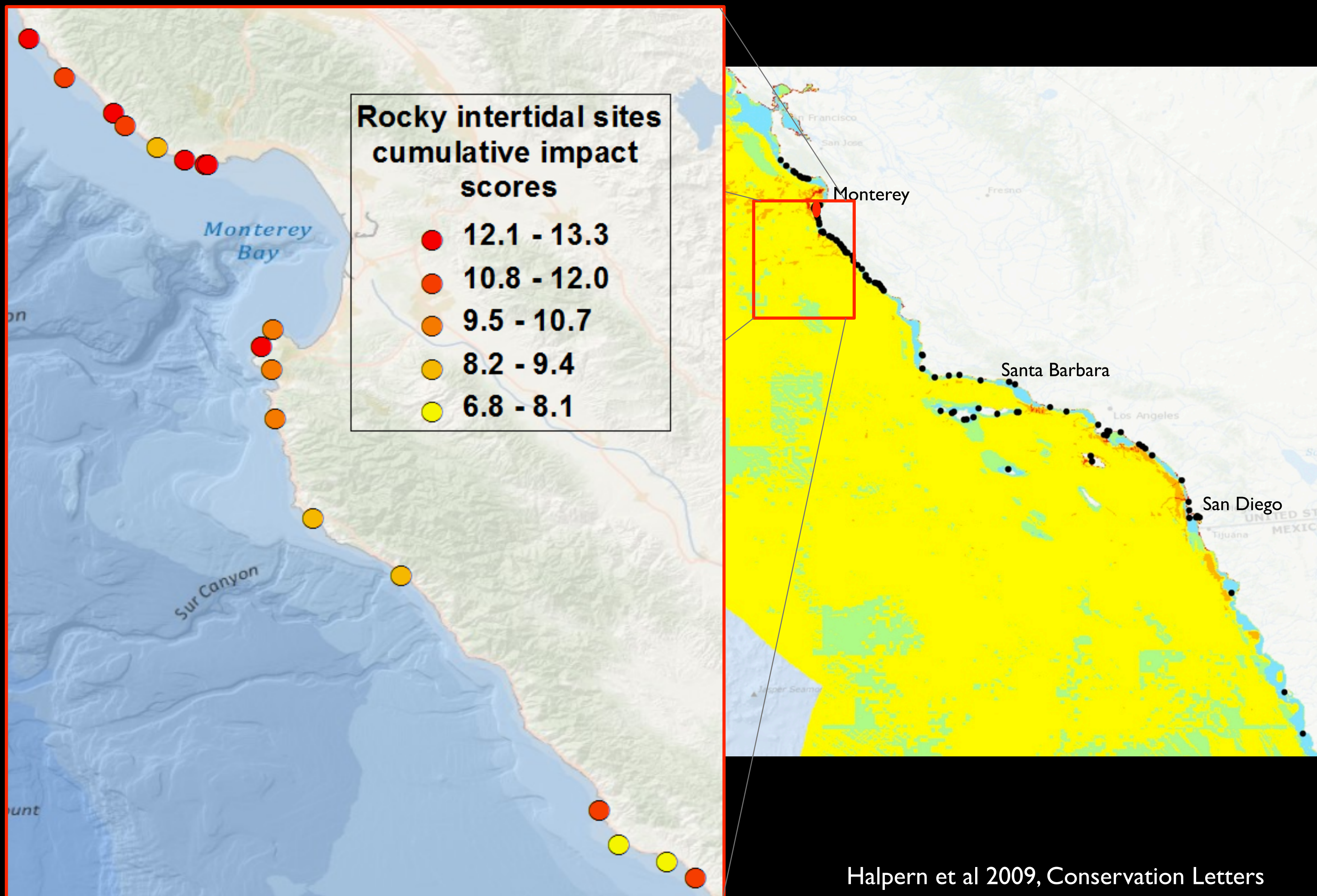
Halpern et al 2009, Conservation Letters

Study Region



Halpern et al 2009, Conservation Letters

California Current Cumulative Impacts Model



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

Impacts modeled in Halpern et al. 2009

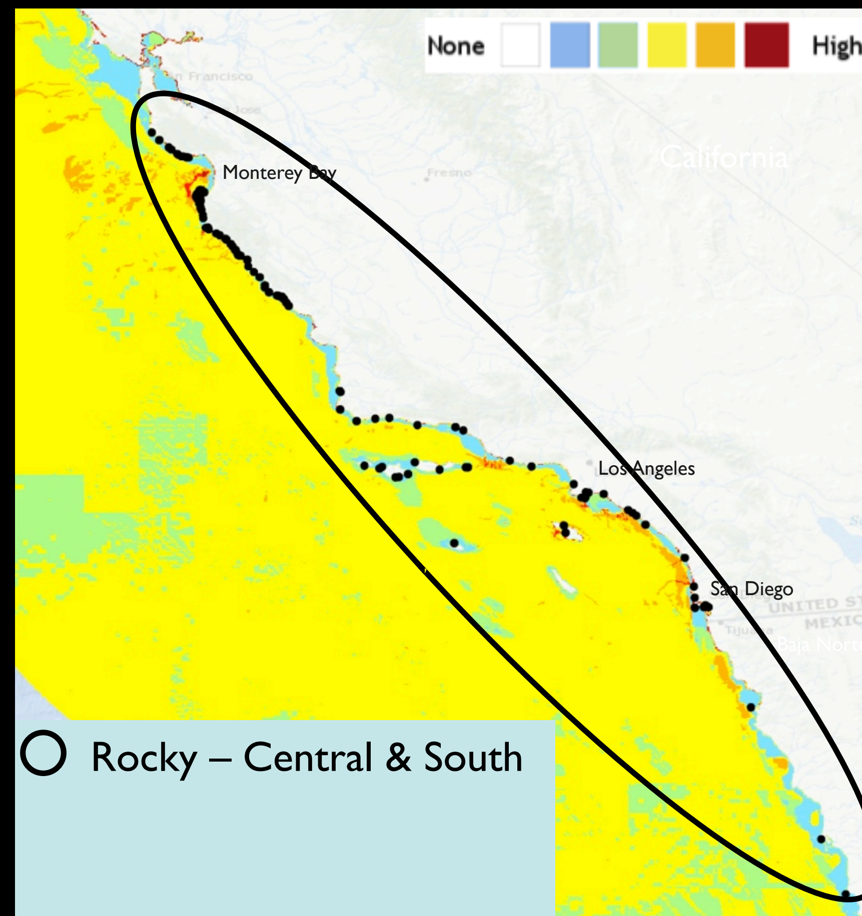
Table 1 Data details for anthropogenic drivers and ecosystems included in our analyses. Full descriptions, data sources (with expanded acronyms), and additional details and full references for sources are provided in the Supporting Information

	Code	Anthropogenic driver	Brief description	Source	Native resolution
Land-based	N	Nutrient input			
		Fertilizer and manure input	Fertilizer use for crops and confined manure (dairy farms)	USGS	1 km²
		Atmospheric deposition of nitrogen	Wet deposition of ammonium and nitrate	NADP	Point, kriged to 1 km²
	OP	Organic pollution	Pesticide use on agricultural land	Halpern *et al.* (2008c)	1 km²
	IP	Inorganic pollution			
		Nonpoint source	Impervious surface area (urban areas)	NGDC	1 km²
		Point source	Factories, mines, and other point sources	EPA	Point, converted to 1 km²
	CE	Coastal engineering	Linear extent data on consolidated and riprap structures	ESI, Google	1 km²
	DH	Human trampling	Modeled by beach attendance at each access point	MLPA, OGEO, WADOE	1 km²
	PP	Coastal power plants	Cooling water entrainment from power plants	Platts	1 km²
	SI	Sediment increase	Global warming caused increases in sediment runoff	SRTM60plus, PRISM, Syvitski *et al.* (2003)	1 km²
	SD	Sediment decrease	Sediment captured by dams	SRTM60plus, PRISM, Syvitski *et al.* (2003)	1 km²
	LP	Noise/light pollution	Satellite nighttime images of light intensity	NGDC	1 km²
	AD	Atmospheric deposition of pollutants	Wet deposition of sulfate	NADP	Point, kriged to 1 km²
	CS	Commercial shipping	Commercial shipping and ferry routes and traffic	CalTrans, WADOT, Halpern *et al.* (2008c)	1 km²
	IS	Invasive species	Modeled as a function of ballast water release in ports	Modified from Halpern *et al.* (2008c)	Modeled to 1 km²
	P	Ocean-based pollution	Pollution derived from commercial ships and ports	CalTrans, WADOT, Halpern *et al.* (2008c)	1 km²
	MD	Marine debris (trash)	Coastline trash picked up by annual beach clean-up	CCCPEP	County level, modeled to 1 km²
	AQ	Aquaculture	Salmon and tuna fish pens	Google	1 km²
Fishing	RF	Recreational fishing	Number of recreational charter boat and private skiff trips	CRFS, CPFV	1′ microblocks
	PLB	Pelagic low bycatch	Total annual catch for all gear types in this class	CalDFG, SAUP	1/2 degree and 10′ blocks
	PHB	Pelagic high bycatch	Total annual catch for all gear types in this class	CalDFG, SAUP	1/2 degree and 10′ blocks
	DD	Demersal destructive	Total annual catch for all gear types in this class	CalDFG, SAUP	1/2 degree and 10′ blocks
	DNLB	Demersal nondestructive low bycatch	Total annual catch for all gear types in this class	CalDFG, SAUP	1/2 degree and 10′ blocks
	DNHB	Demersal nondestructive high bycatch	Total annual catch for all gear types in this class	CalDFG, SAUP	1/2 degree and 10′ blocks
	OR	Oil rigs	Offshore oil platforms	NGDC, MLPA	1 km²
Climate	SST	SST	Recent anomalously high sea temperature	Halpern *et al.* (2008c)	21 km²
	UV	UV	Recent anomalously high UV irradiance	Halpern *et al.* (2008c)	1 degree
	OC	Ocean acidification	Modeled patterns of change to ocean acidity	Guinotte *et al.* (2003)	1 degree

Continued

Response

Rocky Intertidal



Does not include Islands

Indicators

Rocky Intertidal

mussels

Fucus distichus

surfgrass

Ulva

bare rock

articulated coralline algae

Endocladia muricata

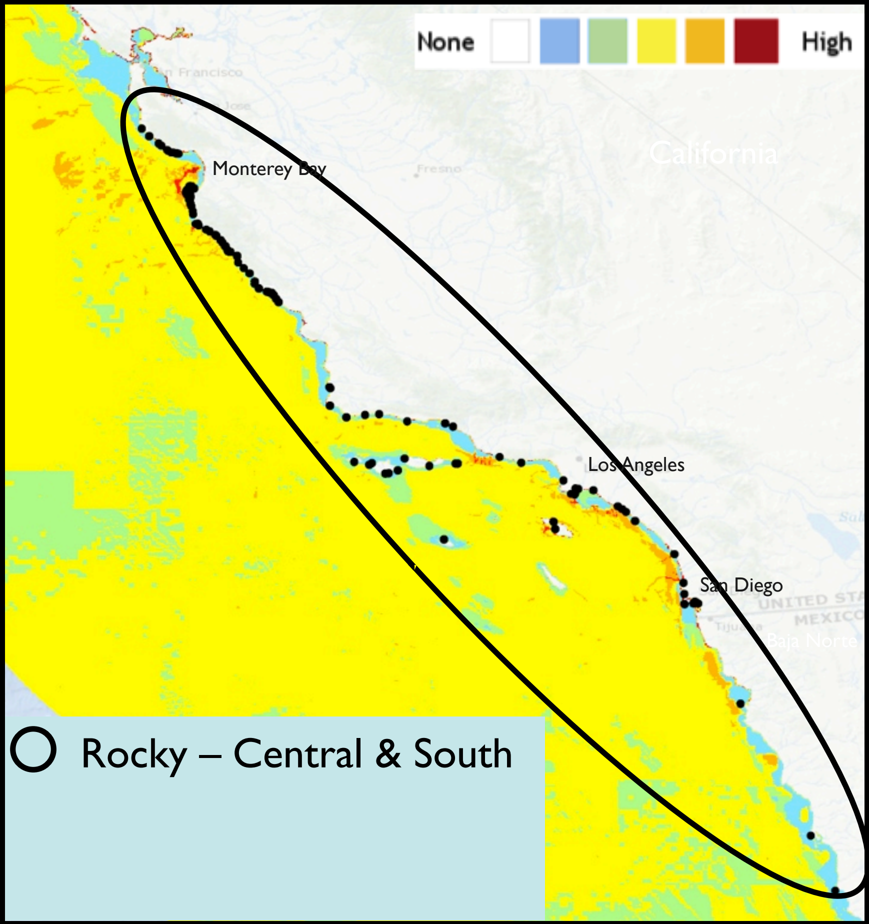
encrusting coralline algae

Silvetia compressa

Photo credits: Dave Lohse, UCSC, PISCO, MARINe

Response Variables

Rocky Intertidal



Does not include Islands

Response Variables

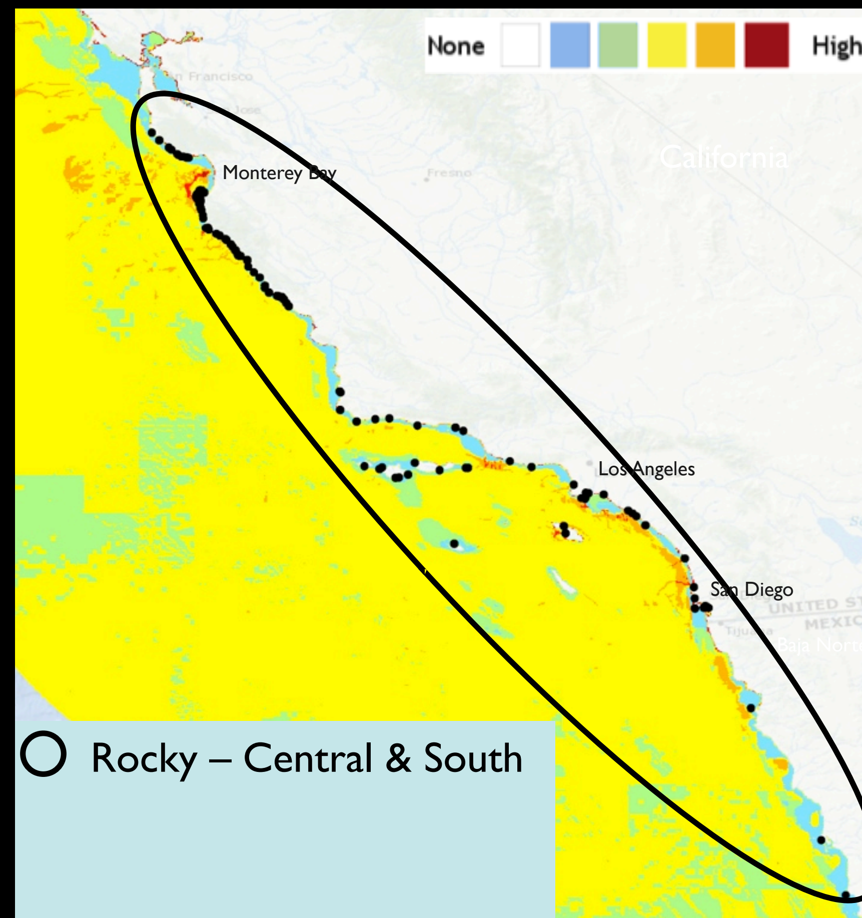
Rocky Intertidal

Predictor Variables

Cumulative Impact Score

PISCO - Physical

InVEST - Physical



Does not include Islands

OCEAN TIPPING POINTS

PISCO

InVEST
integrated valuation of environmental services and tradeoffs

Response Variables

Rocky Intertidal

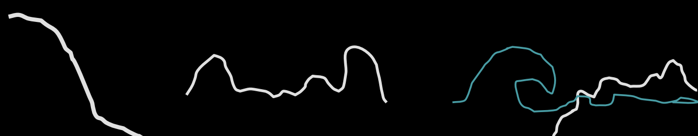
Predictor Variables

Cumulative Impact Score

PISCO - Physical

InVEST - Physical

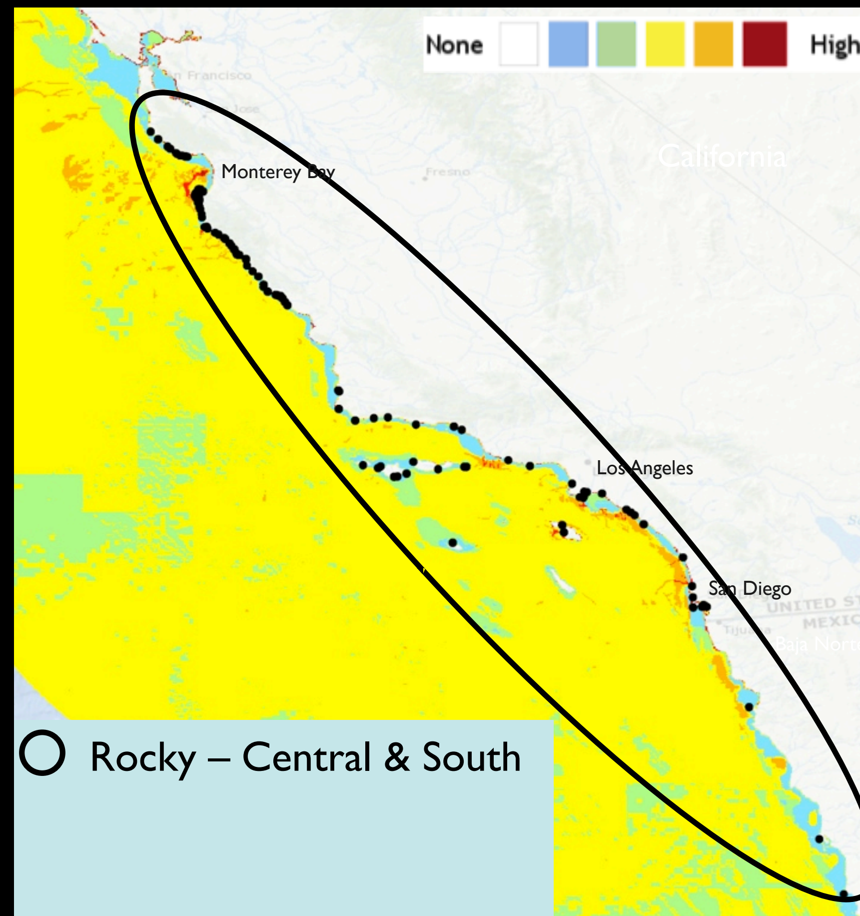
PISCO



slope rugosity wave height limit

InVEST

wave exposure wind surge



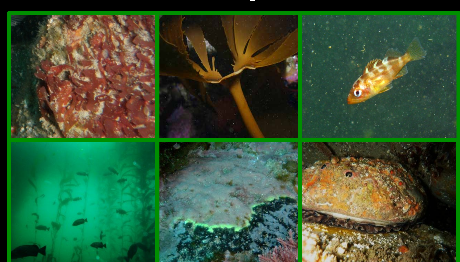
Does not include Islands

Ocean Tipping Points

Response Variables

Rocky Intertidal

Kelp

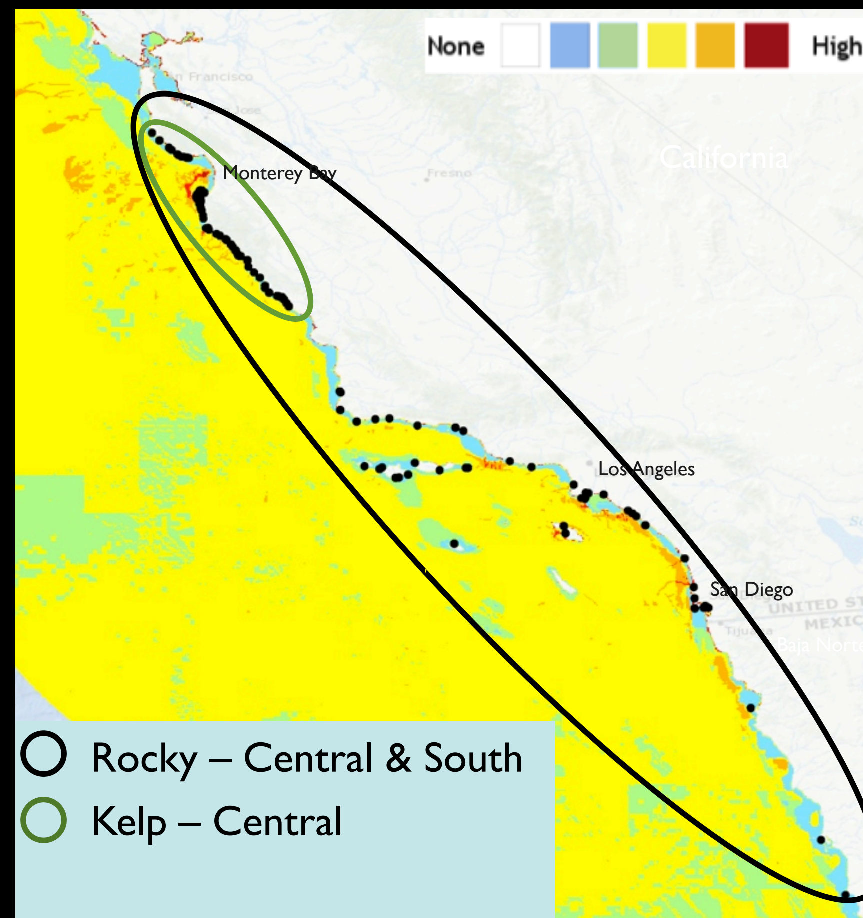


Predictor Variables

Cumulative Impact Score

PISCO - Physical

InVEST - Physical



Does not include Islands

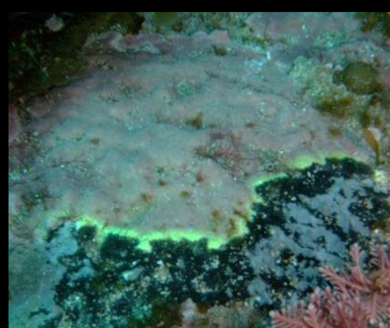
Kelp Forest Indicators

understory kelp

abalone

rockfish

red algae



encrusting coralline algae

YOY rockfish

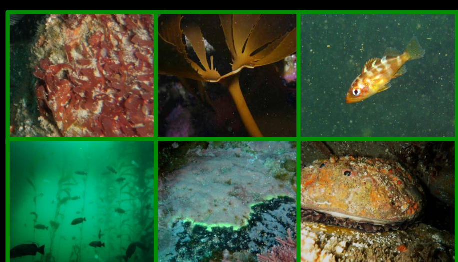
predatory snails

Photo credits: Dave Lohse, UCSC, PISCO, MARINe

Response Variables

Rocky Intertidal

Kelp

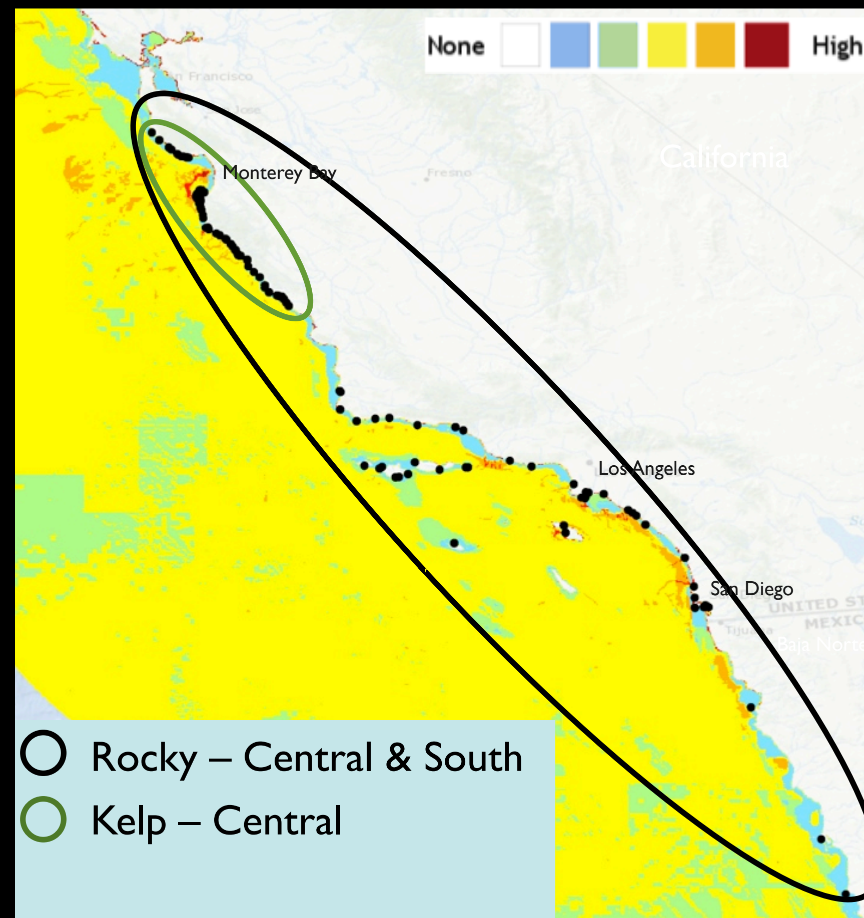


Predictor Variables

Cumulative Impact Score

PISCO - Physical

InVEST - Physical



Does not include Islands

OCEAN TIPPING POINTS

PISCO

InVEST integrated valuation of environmental services and tradeoffs

Response Variables	**Predictor Variables**

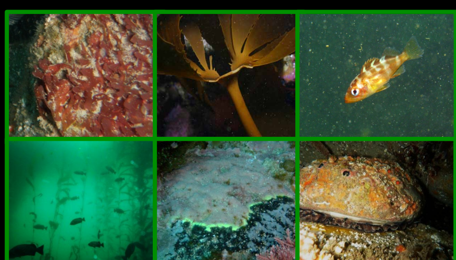
Rocky Intertidal

Cumulative Impact Score

PISCO - Physical

InVEST - Physical

Kelp

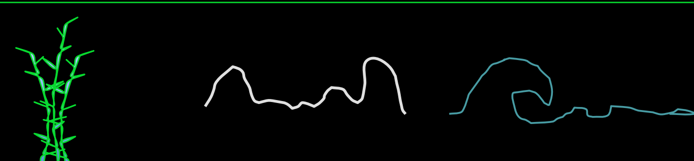


Cumulative Impact Score

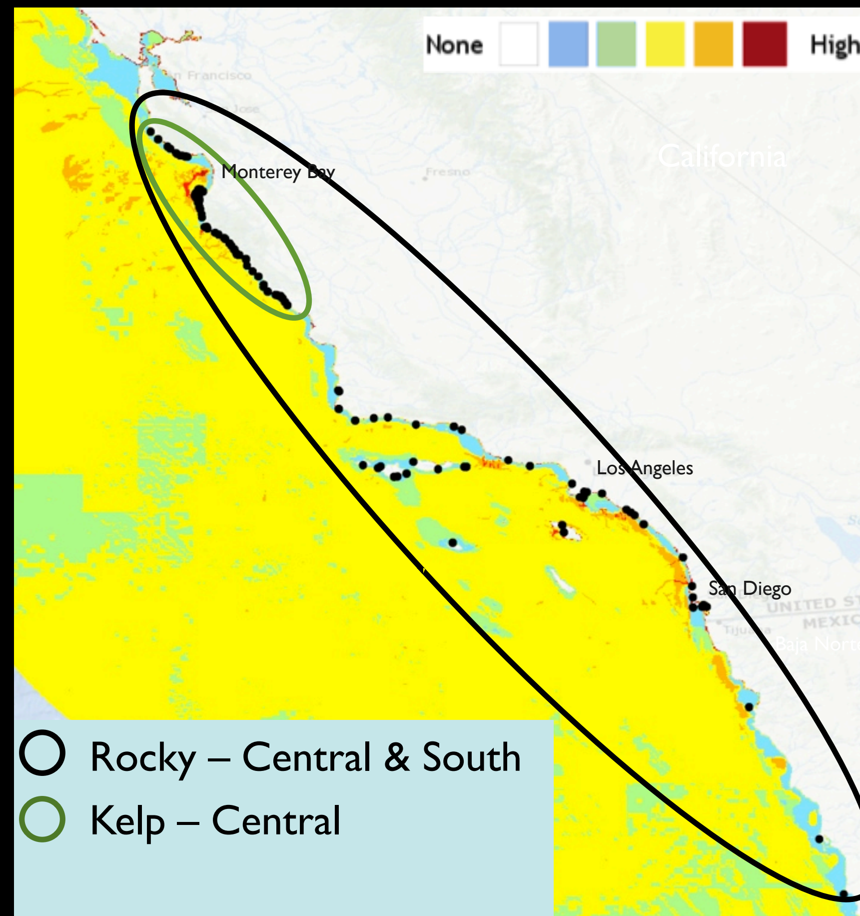
PISCO - Physical

InVEST - Physical

PISCO



density rugosity wave height



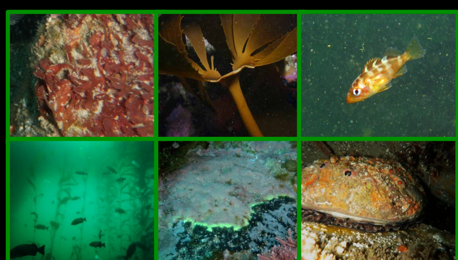
Does not include Islands

Ocean Tipping Points

Response Variables

Rocky Intertidal

Kelp



Soft-Sediment

Predictor Variables

Cumulative Impact Score

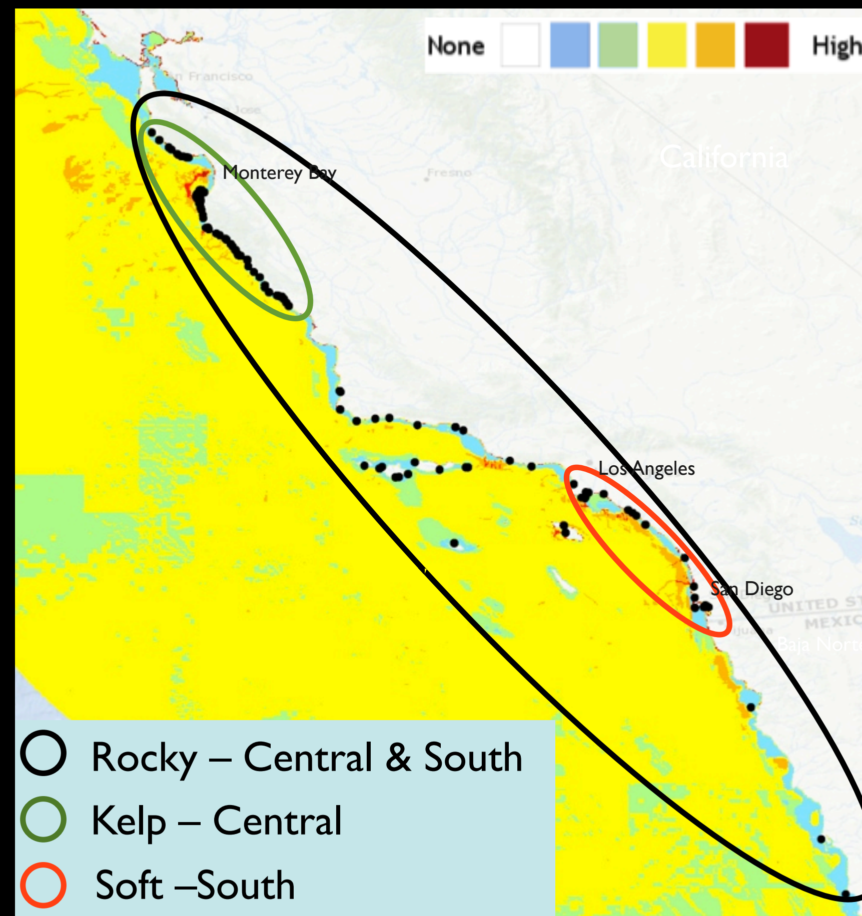
PISCO - Physical

InVEST - Physical

Cumulative Impact Score

PISCO - Physical

InVEST - Physical



Indicators

Shallow Soft Sediment

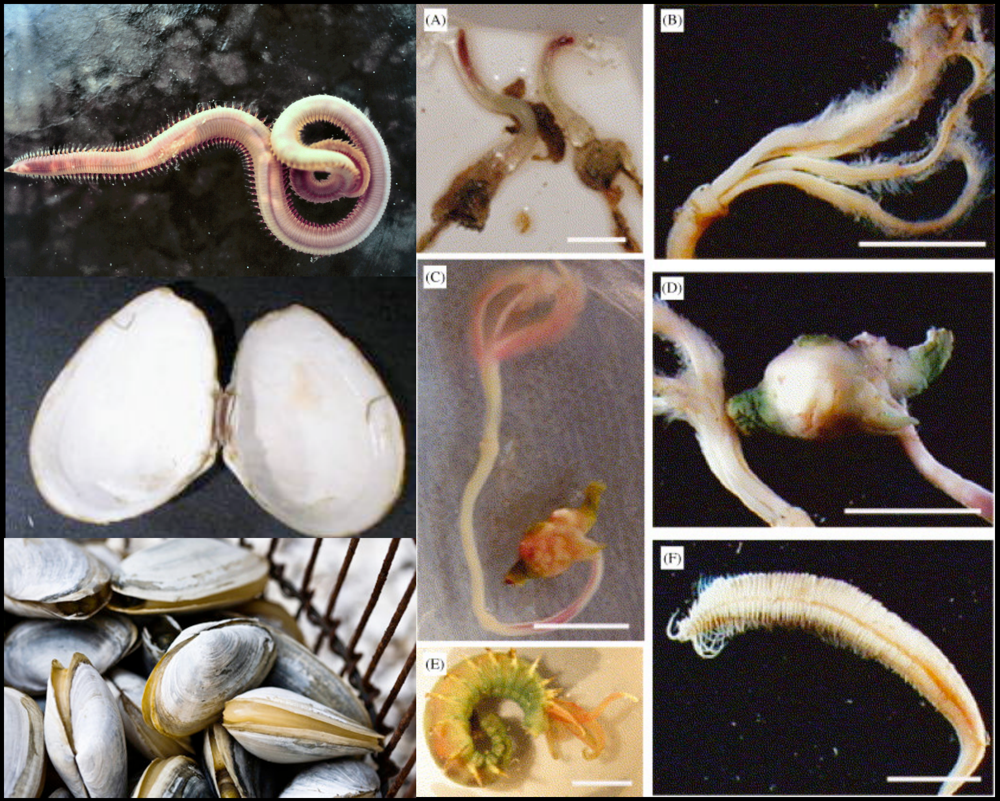
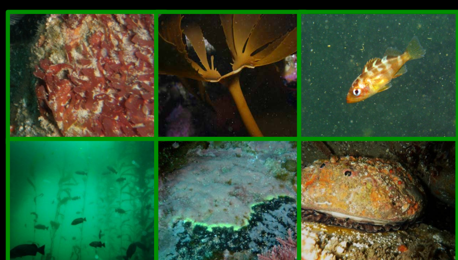


Photo credits: www.sciencedirect.com, USC, NOAA

Response Variables

Rocky Intertidal

Kelp



Soft-Sediment

Predictor Variables

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PISCO - Physical

InVEST - Physical

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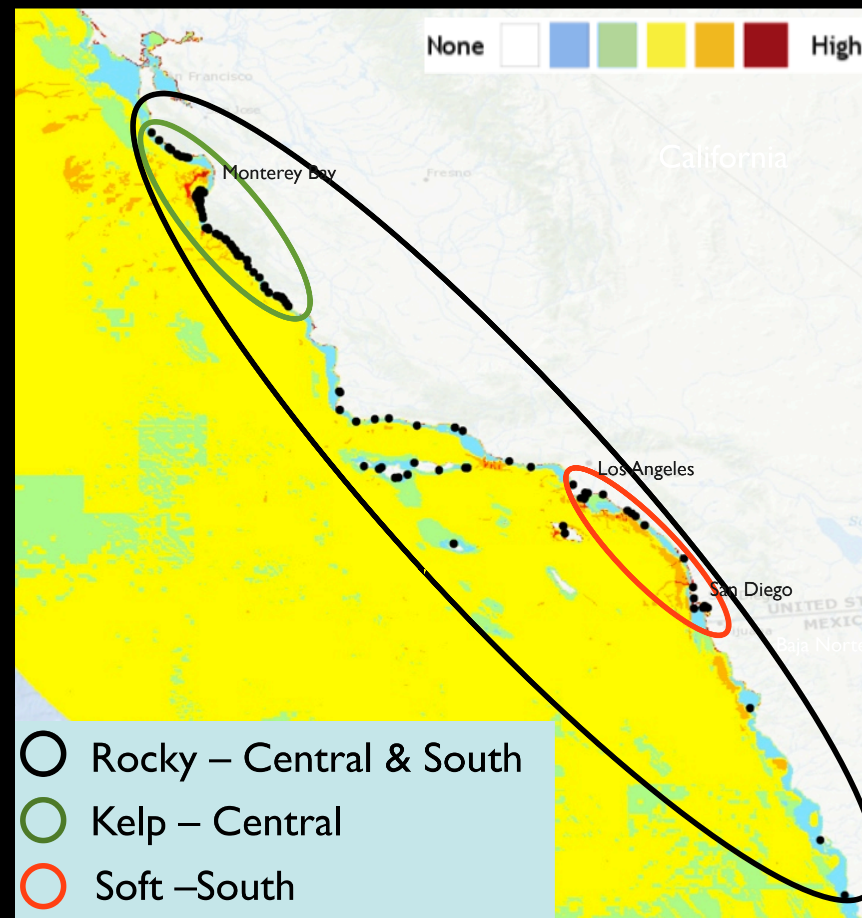

Results

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

Species Richness

vs.

Cumulative Impact Score

Physical Environmental Factors

OCEAN TIPPING POINTS

Results

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

Species Richness

vs.

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Physical Environmental Factors

AICc Model Selection – Linear Models

Ocean Tipping Points

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 ($R^2 = 0.33$, $P = 0.012$)

OCEAN TIPPING POINTS

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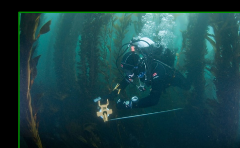
Kelp



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

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vs.

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

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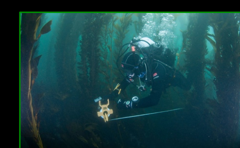

surge + wave height + latitude (R^2 = 0.45, P < 0.001)

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

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Ocean-based Impacts

Physical Environmental Factors

RDA with AICc model selection

OCEAN TIPPING POINTS

Results

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Rocky Intertidal

Composition of Indicators

vs.

Climate-based Impacts

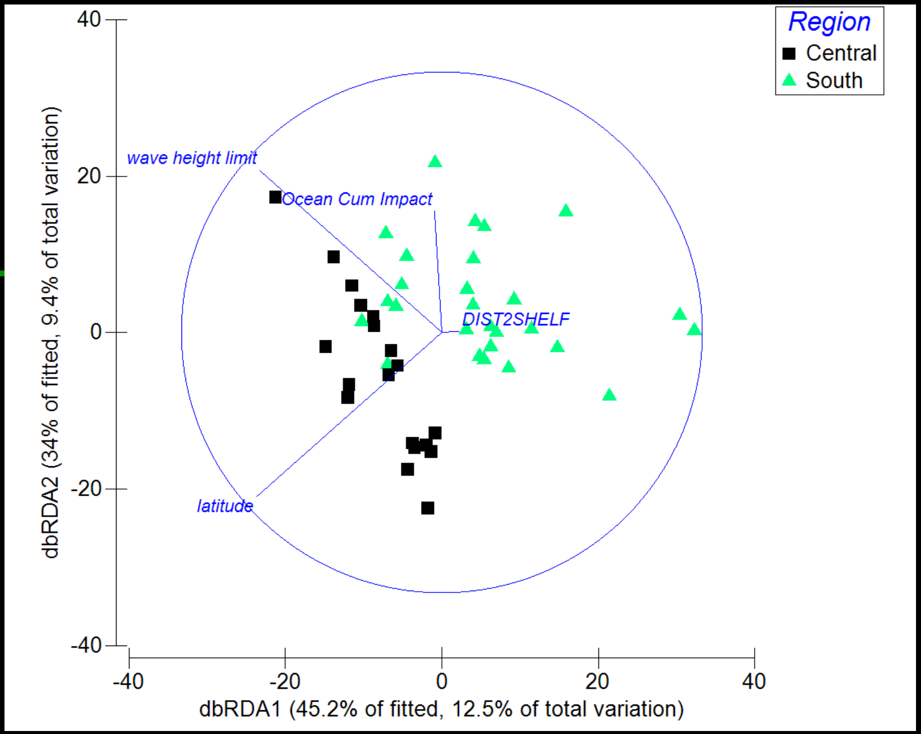
Land-based Impacts

Ocean-based Impacts

Physical Environmental Factors

RDA with AICc model selection

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

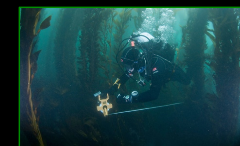


Ocean Tipping Points

Results

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

Kelp



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

Composition of Indicators

vs.

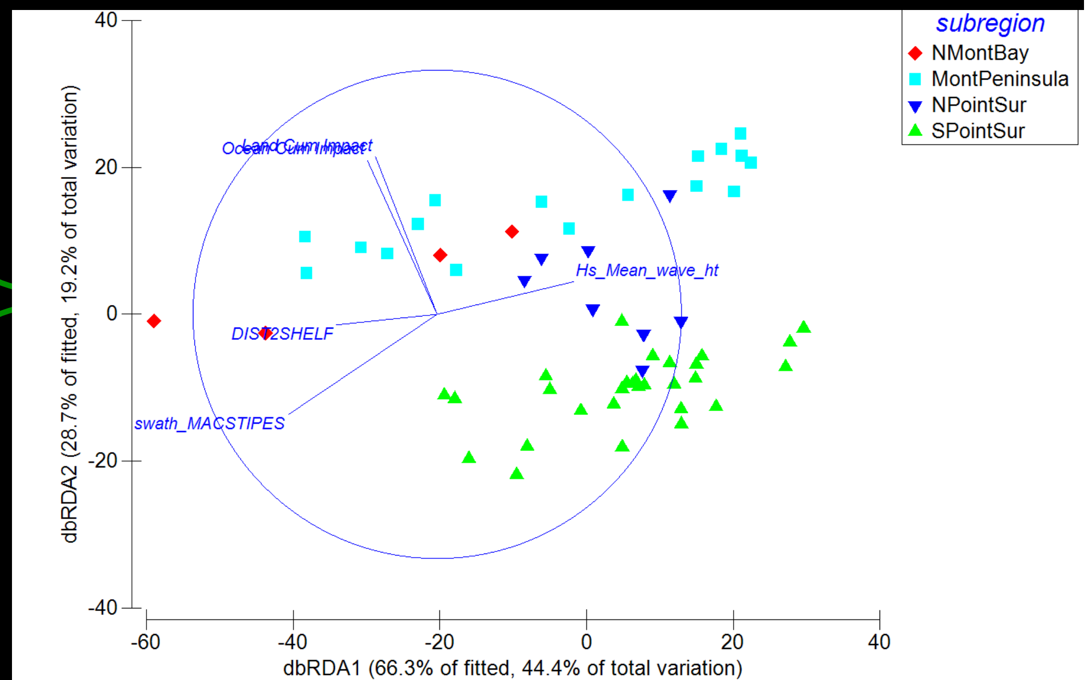
Climate-based Impacts

Land-based Impacts

Ocean-based Impacts

Physical Environmental Factors

RDA with AICc model selection

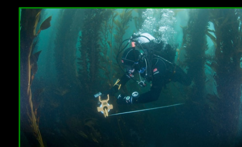


OCEAN TIPPING POINTS

Results

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

Kelp



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

Composition of Indicators

vs.

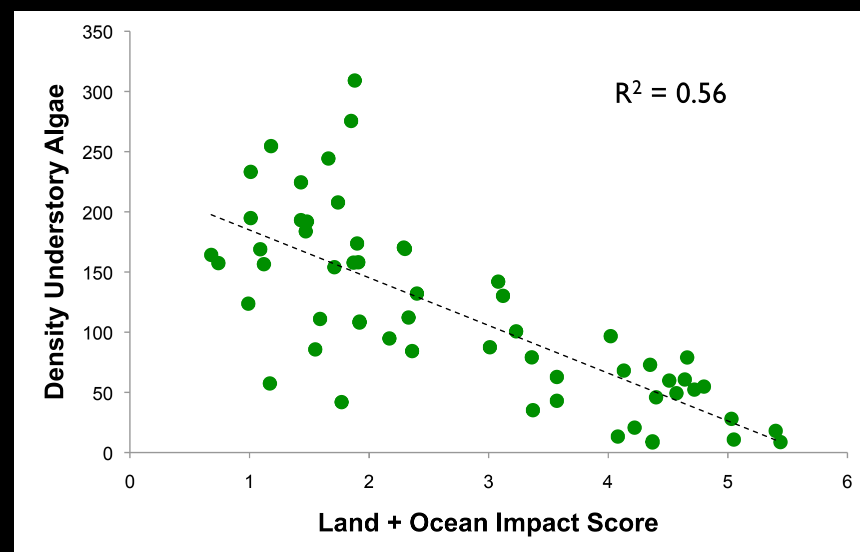
Climate-based Impacts

Land-based Impacts

Ocean-based Impacts

Physical Environmental Factors

RDA with AICc model selection



OCEAN TIPPING POINTS

Results

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

Shallow Soft-Sediment

Ocean Impact + Latitude (R^2 = 0.32)

Composition of Species

vs.

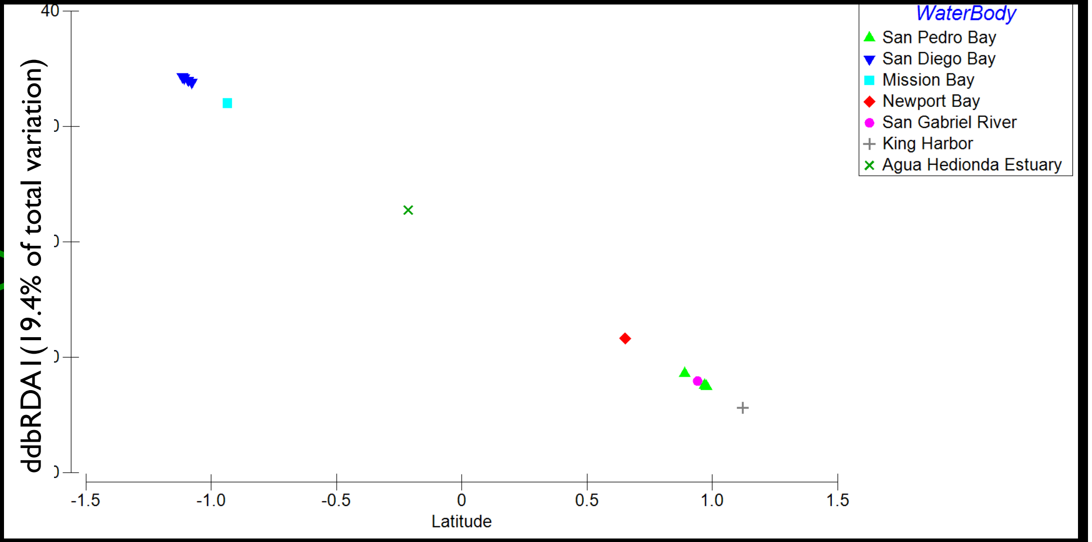
Climate-based Impacts

Land-based Impacts

Ocean-based Impacts

Physical Environmental Factors

RDA with AICc model selection



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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- 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

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)

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

Next Steps

1. Model averaging

Next Steps

1. Model averaging

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

Next Steps

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

3. Add data from more degraded sites

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

Next Steps

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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


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