Predicting the Global Distribution of Hermatypic Coral Reefs

Vitalis Dubininkas\textsuperscript{1,3} & Stanley Mastrantonis\textsuperscript{2,3}

\textbf{A B S T R A C T}

Events of coral bleaching allude to the significant impact of climate change and anthropogenic pressure upon marine ecosystems, particularly upon the diverse taxa of photosynthetic corals. Fortunately, advances in ecological modelling methodologies and geographic systems provide scientists with a range of useful tools that can inform management and mitigate potential impacts. The present study aims to predict the spatial distribution and habitat suitability of hermatypic coral reefs by quantifying their fundamental niche. Using ArcGIS 10.3.1 and its spatial analyst extension, the extent of the world’s oceans was overlaid with a high-resolution, equal-area grid. Subsequently, geostatistical tools from the geostatistical analyst were used to interpolate point data from NOAA’s oceanographic databases to create RASTER prediction surfaces. By interfacing the spatial overlays and environmental data with a statistical interface (R), several models, incorporating elements of machine learning, were created to predict the habitat suitability of coral reefs. It was observed that depth, sea-surface temperatures, salinity, and pH significantly affected the likelihood of observing coral reefs. Areas of marginal-to-high predicted suitability were used to approximate the global distribution of habitat for hermatypic coral reefs. Model outputs indicated that suitable habitat equates to 3.53 ± 0.18\% of the ocean. Importantly, the outputs and data generated by this study have the potential to inform future studies regarding coastal eco-systems and how the spatial extents of coral reefs relate to marine bio-diversity.

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\textbf{Theme:} Ocean Solutions, Earth Solutions – SCGIS Turns 20: A Look at the Past, Present, and Future of Conservation GIS

\textbf{Location:} Asilomar Conference Grounds; Pacific Grove, California

\textbf{Session & Time:} Marine Ecology; 10:30 – 10:50, 17/07/2017

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Outline

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Research Rationale

Methods

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Identifying the keystone organism of coral reefs.

Introduction
Introduction

Environmental Factors that Affect Hermatypic Corals

- Bathymetry
  - Light attenuation

- Sea-surface temperatures
  - Metabolic rates of coral & their symbionts

- Salinity
  - Metabolic rates of coral & their symbionts

- pH
  - Calcification rate of coral & the metabolic rate of symbionts
Can the Maldives save its coral reefs?

by Nicki Shields, CNN
Updated 6:41 AM ET, Fri April 28, 2017

Great Barrier Reef
Opinion

We must act immediately to save the Great Barrier Reef
Jules Howard

This spiralling, three-dimensional coral maze is bleached for the second year in a row, but it can recover – if we act immediately

‘Unprecedented’: Third straight year of global coral bleaching to target U.S. reefs, scientists say

By Chris Mooney  June 20, 2016
Coral reef off of the coast of Heron Island, Australia. (WBUR News)

Coral reef off of the coast of Croatia. (Gettyimages)

Coral reef off of the coast of South Africa. (PBase)
Research Rationale

Given the limitations of previous studies, the purpose of this study is to create a model which synthesizes empirical observations of coral presence and environmental conditions; to predict the spatial extent and distribution of coral reefs, based on the fundamental niche of hermatypic corals.
Methods

- Sea-surface temperature, pH, and salinity data were sourced from NOAA (2013)
  - Point data interpolated into continuous surfaces using the ArcGIS geostatistical analyst – IDW Algorithms

- Regional-scale bathymetric data was sourced from GEBCO (2016)
  - “Stitched” together to form a single data layer representing the extents of the world’s oceans

- Known coral reef locations were obtained from ReefBase (2016)
  - Intersected with the environmental and bathymetry data layers
  - These observations formed the basis of presence values within the distribution model (N = 5,140)
  - Pseudo-absences were derived on the basis of 40 – 200 km radial buffers around each of the presence observations
Methods

- A prediction layer was created for the entire ocean
  - Included environmental, presence, and pseudo-absence data
  - Grid squares of 20 km$^2$ overlaid the prediction layer
  - At each grid square, the corresponding values were extracted and imported into R ($N = 2,354,392$)

- A generalized linear model (A), generalized additive model (B), and a classification and regression tree (C) were fit to the data

- Models were used to predict the habitat suitability for coral reefs for the extent of the oceans (World Aitoff: Datum, WGS 1984; Spheroid, WGS 1984)
A: Generalized Linear Model

B: Generalized Additive Model

C: Classification and Regression Tree Model
GLM

Video available at: https://www.youtube.com/watch?v=JTADYcWdpP8
Model Validation: Statistical Methods

- Model sensitivity were assessed and validated using receiver-operator characteristics (ROC) curves

- Where an area under the curve (AUC) of 1.0 would indicate a model that flawlessly fit the input data, and an AUC of 0.50 would indicate model predictions that are no better than random chance
Model Validation: Case Studies
Scientists Have Discovered a 600-Mile Coral Reef

It's at the mouth of the Amazon River.

ROBINSON MEYER | APR 21, 2016 | SCIENCE

First Photos of New Amazon Coral Reef System Released

The reef was found in an unlikely place after scientists chased a rumor that it might exist.

An extensive reef system at the Amazon River mouth

Rodrigo L. Moura1,2, Gilberto M. Amado-Filho1, Fernando C. Moraes1,2, Pollana S. Brasileiro1, Paulo S. Salomoni1,2, Mich...
Moura et al. (2016) documented 12 species of scleractinians, 8 species of octocoral, and 2 species of black coral.

Relatively shallow environment (50-200 m), which is subject to high levels of sedimentation, as well as seasonal fluctuations in salinity and pH.

Our generalized linear model predicted the presence of hermatypic coral reefs to be 60-70%.
Tropical Reef Corals: Tolerance of Low Temperatures on the North Carolin

Ian G. Macintyre¹, Orrin H. Pilkey²

DOI: 10.1126/science.166.3903.374

Abstract

Individual heads of two species of reef or hermatypic coral, Solenastrea hyades (Dana) and Siderastrea siderea (Ellis and Solander), occur on rock outcrops on the inner continental shelf off North Carolina in waters where winter bottom temperatures are as low as 10.6°C. These temperatures are significantly lower than previously assumed minimum temperatures for the survival of tropical reef corals in their natural environment.
Macintyre & Pilkey (1969) documented 2 species of scleractinian coral, as well as a few species of mollusks and annelids.

Relatively shallow environment (20-30 m), which is subject to high levels of sedimentation, as well as seasonal fluctuations in temperature (10°C – 30°C+).

Our generalized linear model predicted the presence of hermatypic coral reefs to be 20-30%.

Fig. 1. Areas of reef corals in Onslow Bay off North Carolina.
Conclusions

- Using areas of marginal-to-high predicted suitability ($p \geq 0.50$), the combined results of the three models showed suitable habitat for hermatypic coral reefs to be $3.53 \pm 0.18\%$ of the world’s oceans; which is a notably larger estimate than previous approximations.

- Nevertheless, calculations of pristine habitat ($p \geq 0.90$) were noted to be much less than this value (~1\%).

- Study limitations: primary substrate availability & temporal-independence.

### Table 1: Previous approximations of the spatial extent of hermatypic coral reefs.

<table>
<thead>
<tr>
<th>Coral Reef Habitat (km²)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>150,000 – 1,500,000</td>
<td>Newell 1971</td>
</tr>
<tr>
<td>1,440,000</td>
<td>Milliman 1974</td>
</tr>
<tr>
<td>617,000</td>
<td>Smith 1978</td>
</tr>
<tr>
<td>112,000</td>
<td>De Vooy 1979</td>
</tr>
<tr>
<td>1,500,000</td>
<td>Copper 1994</td>
</tr>
<tr>
<td>584,000-3,930,000</td>
<td>Kleypas 1997</td>
</tr>
<tr>
<td>255,000</td>
<td>Spalding &amp; Grenfell 1997</td>
</tr>
<tr>
<td>12,766,179 ± 659,946</td>
<td>Dubininkas &amp; Mastrantonis</td>
</tr>
<tr>
<td></td>
<td>(this study)</td>
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</table>
Future Implications

- Marine fisheries, wildlife tourism & the petroleum industry.

- Coral reef restoration & conservation.

- Implications for future studies
Questions ?
References

References


References


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References


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Appendix

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Research was conducted between 01/2016 – 06/2016. The results were first informally presented at Marine Scotland Science (Aberdeen, Aberdeenshire, U.K.) on 17/08/2016.

The results were formally disseminated at the 20th annual conference of the Society for Conservation GIS (17/07/2017), held at Asilomar Conference Grounds (Pacific Grove, California, U.S.A.).