Modelling the Response of Reef Rugosity and Fish Assemblages to Climate Change in the Caribbean

Modelando la Respuesta de la Rugosidad del Arrecife y las Comunidades de Peces al Cambio Climático en el Caribe

Modéliser les Effets du Changement Climatique sur la Rugosité du Substrat et les Assemblages de Poissons dans les Récifs Coralliens des Caraïbes

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EXTENDED ABSTRACT

A striking feature of coral reef habitats is their topographical complexity which is generated by the growth and calcification of reef-building corals. Highly rugose reefs typically support abundant and diverse biological communities which in turn provide many services to the ecosystem. In the Caribbean, such reefs were found in areas dominated by corals with complex morphological forms, such as branching *Acropora*, or large *Montastraea* colonies which generate high structural relief. Due to multiple disturbances, the recent decades have seen a major decline of these structural species across the Caribbean, resulting in a global loss of reef rugosity. As the disturbance regime on Caribbean reefs is expected to rise with climate change, there is increasing concern about the future quality of coral reef habitats and the consecutive impacts on reef-associated organisms. We developed a model of coral reef ecosystems to predict future changes in reef rugosity and potential responses of fish assemblages in the Caribbean. The model is presented here, with emphasis on (1) model assumptions and parameterisation, (2) calibration and validation and (3) preliminary results of model simulations.

The modelling approach is based on a spatially-explicit model of coral population dynamics (Mumby 2006, Mumby et al. 2006) of a typical Caribbean fore-reef system under acute disturbances (hurricanes and coral bleaching). The model represents a reef as a regular square lattice of 20 x 20 cells, each approximating 1m^2 of reef substrate and comprising different species of corals and algae. Corals are stylised by a disk which represents the planar area of the colony. Empirical relationships allow estimating colony height, surface area and volume from colony diameter, based on the assumption that corals have a dome-like shape. When corals grow, their radial extension is converted into height extension so that colony surface area (and volume) increases. When a coral dies, the carbonate skeleton is progressively eroded so that colony volume (and surface area) decreases. Reef rugosity is then estimated at each time step by the contribution of living and dead coral colonies to the actual surface area of the reef bottom. As a result, rugosity increases with coral growth but is reduced by the bioerosion of dead colonies.

The model was calibrated using data from Cozumel reefs, Mexico. Data on coral colony collected *in situ* showed (1) that colony height can be reliably predicted by colony diameter and (2) that a dome-like shape is a good proxy of the 3D geometry of many coral species, including the massive *Montastrea* species but also sub-massive forms such as *Agaricia agaricites* and *Porites astreoides*. The model was then evaluated against historical surveys (1984 – 2008) of coral cover in Cozumel compiled from published articles and reports. The global trajectory of coral cover was re-constructed using six coral populations and the disturbance regime observed during this 25 years period, with the occurrence of three hurricanes (Gilbert in 1988, Emily and Wilma in 2005) and two bleaching events (1998 and 2005). The re-constructed trajectory of coral cover was in good agreement with observations, capturing periods of decline and recovery after disturbance. In Cozumel, coral cover has globally declined from about 35% in 1984 – 1987 down to 15% in 2007 – 2008, and the model predicted a concomitant decline in reef rugosity from 2.3 to 1.5 units. Similarly to empirical observations, modelled coral cover and rugosity were highly correlated.

By providing an explicit and dynamical representation of the 3D structure of individual coral colonies, this mechanistic model offers new perspectives for modelling coral reef ecosystems. In particular, the model can be used to produce future predictions of reef rugosity and fish biodiversity in response to climate change. To this aim, coral dynamics were simulated over future decades (2010 – 2050) with random hurricanes and various regimes of coral bleaching predicted by different climate change scenarios (aggressive mitigation/no mitigation of greenhouse gas emission to limit global warming). Model simulations predicted further declines in coral cover due to accelerated bleaching events, with a progressive loss of rugosity depending on the rate of carbonate bioerosion. Mitigating greenhouse gas emission significantly slowed down the decline in the quality of the reef habitat. Using a simple empirical relationship between reef rugosity and the number of fish species

per unit area (Luckhurst and Luckhurst 1978) the model allowed projecting the rate of biodiversity loss for both scenarios.

Although preliminary, this model marks a significant step in our ability to model the dynamics of habitat structure on coral reefs. Further work is required to better describe the functional link between reef rugosity and fish assemblages, in order to provide reliable predictions of climate-induced changes in ecosystem functions (e.g., grazing intensity) and services (e.g., fisheries productivity). Such model developments are required to support the management of functionally complex reef habitats in the Caribbean.

KEY WORDS: Topographic complexity, coral cover, mechanistic model, climate change, fish diversity

LITERATURE CITED

Alvarez-Filip, L., N.K. Dulvy, J.A. Gill, I.M. Côté, and A.R. Watkinson. 2009. Flattening of Caribbean coral reefs: region-wide declines in architectural complexity. *Proceedings of the Royal Society B: Biological Sciences* **276**:3019-3025.

Luckhurst, B.E. and K. Luckhurst. 1978. Analysis of the influence of substrate variables on coral reef fish communities. *Marine Biology* **49**:317-323.

Mumby, P.J. 2006. The impact of exploiting grazers (*Scaridae*) on the dynamics of Caribbean coral reefs. *Ecological Applications* **16**:747-769.

Mumby, P.J., A.R. Harborne, J.D. Hedley, K. Zychualuk, and P. Blackwell. 2006. Revisiting the catastrophic die-off of the urchin *Diadema antillarum* on Caribbean coral reefs: fresh insights on resilience from a simulation model. *Ecological Modelling* **196**:131-148.