Environmental and Anthropogenic Drivers to Basin-wide Patterns in Caribbean Reef Fish Diversity

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ABSTRACT

Mounting evidence suggests that reef fish diversity mediates reef resilience through functional redundancy and complementarily. Managing and preserving coral reef fish diversity requires an understanding of the mechanisms and environmental correlates of such diversity. Developing this understanding first requires detailed, spatially-explicit data on biotic, abiotic, and anthropogenic features of reef fish communities. We used the Atlantic and Gulf Rapid Reef Assessment (AGRRA) database in conjunction with freely available anthropogenic and abiotic geographic data to develop a broad assessment of associations between site characteristics and reef fish communities. Rather than attempting to construct a function that defines the species-abundance relationship across sites based a short list of explanatory variables, we first fit a neutral model of species diversity to the data, and subsequently modeled the site-specific residuals from this relationship. Results indicated that latitudinal gradients, fishing pressure, and interactions across tropic levels play an important role in shaping site- specific reef fish diversity. By isolating the influence of site characteristics from the region-wide pattern of community assembly, we were able to directly assess site- specific correlates to marine biodiversity.

KEY WORDS: Reef fish, diversity, neutral model, AGRRA, fishing pressure, diversity

Medio Ambiente y Factores Humanos a los Patrones de Toda la Cuenca del Caribe en la Diversidad de Peces de Arrecife

La evidencia creciente sugiere que la diversidad de peces de arrecife media resiliencia de los arrecifes a través de la redundancia funcional y complementaria. Gestión y conservación de la diversidad de peces de arrecife de coral requiere una comprensión de los mecanismos y las correlaciones ambientales de esa diversidad. El desarrollo de esta primera comprensión requiere información detallada, espacialmente explícitos sobre las características bióticas, abióticas y antropogénicas de las comunidades de peces de arrecife. Se utilizó la base de datos Atlántico y el Golfo de Evaluación Rápida de Arrecifes (AGRRA) en conjunto con libre disposición de datos geográficos antropogénicas y abióticos para desarrollar una amplia evaluación de las asociaciones entre las características del lugar y de las comunidades de peces de arrecife. En lugar de intentar construir una función que define la relación especies-abundancia en todos los sitios basados en una corta lista de variables explicativas, lo primero que ajustar un modelo neutral de la diversidad de especies a los datos, y posteriormente se modeló el sitio específico de los residuos de esta relación. Los resultados indicaron que los gradientes latitudinales, la presión de pesca y las interacciones entre los niveles tropicales desempeñan un papel importante en la formación específica del sitio diversidad de peces de arrecife. Al aislar la influencia de las características del lugar de la pauta en toda la región de la asamblea de la comunidad, hemos sido capaces de evaluar de forma directa en sitios específicos se correlaciona con la biodiversidad marina.

PALABRAS CLAVE: Peces de arrecife, AGRRA, factores humanos, diversidad

L'Environnement et les Pilotes Anthropiques de Modèles Vaste Bassin de la Diversité Poissons de Récif des Caraïbes

Une accumulation de preuves suggère que les poissons de récif diversité récifale résilience médiateur grâce à la redondance fonctionnelle et complémentaire. Gérer et préserver la diversité des poissons de récifs coralliens nécessite une compréhension des mécanismes et des corrélats de l'environnement d'une telle diversité. Le développement de cette compréhension nécessite d'abord des données détaillées, spatialement explicites sur les caractéristiques biotiques, abiotiques et anthropiques des communautés de poissons de récif. Nous avons utilisé la base de données de l'Atlantique et du golfe d'évaluation rapide des récifs (AGRRA) en conjonction avec librement disponibles anthropiques et abiotiques des données géographiques pour développer une vaste évaluation des associations entre les caractéristiques du site et les communautés de poissons de récif. Plutôt que d'essayer de construire une fonction qui définit la relation espèces-abondance dans les sites en fonction d'une liste courte de variables explicatives, nous avons d'abord installer un modèle neutre de la diversité des espèces aux données, et ensuite modélisé le site spécifique des résidus de cette relation. Les résultats indiquent que les gradients latitudinal, la pression de pêche et les interactions entre les niveaux trophiques jouent un rôle important dans l'élaboration de sites spécifiques de la diversité des poissons de récifs. En isolant l'influence des caractéristiques du site à partir du modèle à l'échelle régionale de l'assemblée communautaire, nous avons pu évaluer directement site spécifique est corrélée.

MOTS CLÉS: Poissons de récif, AGRRA, pilotes anthropiques, diversité

INTRODUCTION

Managing and preserving coral reef fish diversity requires an understanding of the mechanisms and environmental correlates of such diversity. Developing this understanding first requires detailed, spatially-explicit data on biotic, abiotic, and anthropogenic features of reef fish communities. In recent years, there has been a dramatic increase in the number and scope of collaborative, broad-scale biogeographic assessments; this is particularly true in the marine environment, where the difficulty and expense of such assessments largely precludes comprehensive assessments by individuals or even individual institutions (Pattengill-Semmens and Semmens 2003). One such collaborative program, the Atlantic and Gulf Rapid Reef Assessment (AGRRA, Marks 2004), has generated detailed site-specific biotic data from 100s of sites across the Caribbean basin. These data, in conjunction with freely available anthropogenic and abiotic geographic data from the region, offer a rich set of information on which to develop a broad assessment of associations between site characterisitics and reef fish communities (Mora 2008). In this study, we used AGGRA data to explore the relative support of hypotheses relating reef fish diversity to site-level habitat characteristics across the Caribbean basin.

METHODS

What species-abundance model best describes the relationship between richness and abundance of reef fishes across sites? Regardless of the environment, it is almost always the case that a few species are abundant, others are moderately common, while the majority are rare (Magurran 2004). Thus, diversity is a construct of both richness (the number of species) and evenness (the level of disparity in species abundances). This overt and consistent pattern in diversity and abundance across communities prompted the development of both descriptive and mechanistic models to describe this relationship. In this study, we are concerned with matching the data to a model that accurately describes the species-abundance patterns for both herbivore and predator communities across sites; as such we draw upon the Unified Neutral Theory of Biodiversity (Hubbell 2001) to describe the species-abundance patterns displayed by reef fish diversity and abundance data from 342 sites throughout the Caribbean (Figure 1). We then took the residuals from these two relationships (Figure 2) and treated them as a response in a generalized linear modeling framework in order to determine what features of sites best explain site-specific deviations in the Caribbean-wide species-abundance relationship (i.e. those sites that are more or less diverse than expected based on the number of fishes seen).

The specific variables considered as explanatory of deviations from neutrality included percent cover of macroalgae, percent cover of crustose algae, benthic complexity, percent cover of old dead coral, percent cover of recently dead coral, percent cover of live coral, percent cover of sand, Shannon (H') diversity index of coral, habitat area, index of fishing pressure, depth, wave exposure, and ecoregion (total of 8). See Semmens et al. (2010) for a more detailed discussion of these metrics and their calculations. We used the StepAIC package in R to identify the most parsimonious (lowest AIC score) model configurations for both herbivore and predator deviates.

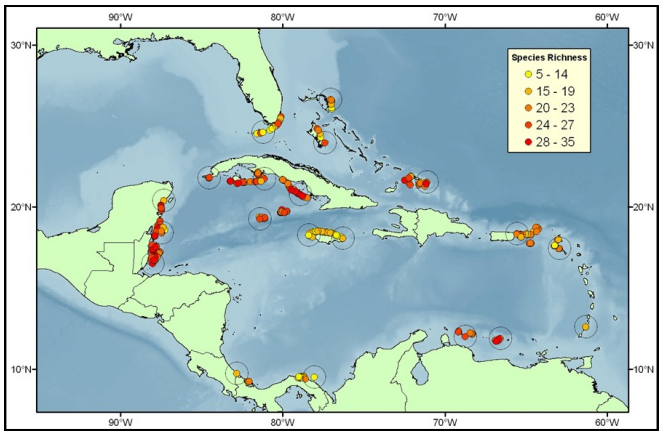

Figure 1. Map of Caribbean AGRRA sites included in the analysis, with heat colors representing reef fish species richness (Semmens et al. 2010).

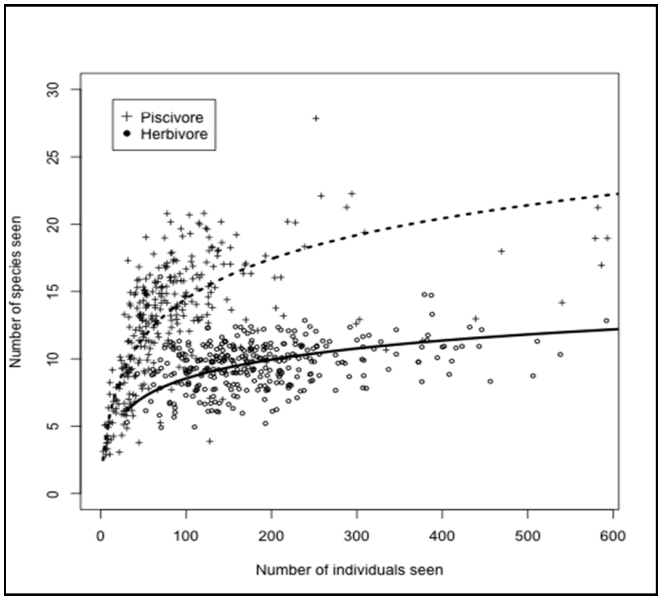

Figure 2. Plot of the best-fit lines from the neutral model of biodiversity based on AGRRA data from the herbivore and predator communities. Deviations from these lines were used as the response in analyses linking site features (e.g. habitat) to deviations from neutrality.

RESULTS AND DISCUSSION

Based on AIC scores, the models that best described site level deviates in herbivore and predator diversity were (respectively):

deviates ~ Recent Dead (neg effect) + Fishing Index (neg effect) + Ecoregion - 1

and

deviates ~ Habitat Area (pos effect) + Ecoregion – 1

In the above models, the -1 at the end of the statements specify a non-intercept model, which we used because we were modeling deviates from an unbiased fitted curve.

These results agree with recent studies identifying regional shelf area as an important predictor of diversity (Bellwood and Hughes 2001). They also suggest that fishing pressure throughout the Caribbean is having a structuring force on herbivore diversity. Finally, the impact of ecoregion, beyond habitat shelf area, suggests that intrinsic differences in diversity coupled with limited connectivity among ecoregions yield fundamental differences in diversity across major areas of the Caribbean. In concert, these findings suggest efforts to plan a Caribbean-wide biodiversity reserve network must account for human use, ecoregions, coral cover, and habitat (shelf) area as strata in design criteria.

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