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ABSTRACT

One of the primary goals of marine reserve implementation is the protection of biodiversity, current fisheries and future fish stocks. To achieve this goal, effective placement of marine reserves should ensure that incoming recruits are delivered to the protected area. Larval supply and recruitment of coral reef fishes were evaluated for both marine reserve and non-reserve sites in the upper Florida Keys. Patterns of larval supply for late-stage larvae settling to the reef were evaluated using larval light traps. Sampling efforts at two replicate reserve and non-reserve sites targeted two monthly settlement peaks during the new and third-quarter moons for each of 12 months. In addition, monthly surveys of newly-settled coral reef fishes were conducted on these reefs using SCUBA techniques. Densities of all reef fishes that had settled during the previous month (recruits < 2 cm) were quantified. Results of this study shed light on the processes influencing densities of juvenile fishes in marine reserves and non-reserve areas. Differences in larval supply and recruitment provide additional information needed to evaluate the efficacy of marine reserves.

KEY WORDS: Marine reserves, larval supply, recruitment

El Suministro de Larvas y el Reclutamiento de Oeces Arrecifales en Reservas Marinas de los Cayos Superiores de la Florida (Florida Keys, USA)

Uno de los objetivos principales de la implementación de las reservas marinas es la protectión de la biodiversidad, las pesquerías, y el futuro de los stocks pesqueros. Para lograr este objetivo, las reservas marinas deberán asegurar una localización efectiva para que los reclutas puedan alcanzar las áreas protegidas. El suministro de larvas y el reclutamiento de peces arrecifales fueron evaluados en sitios de los Cayos superiores de la Florida (Upper Florida Keys) que son reservas y no reservas marinas. Los patrones de estadios larvales cercanos al asentamiento fueron evaluados usando trampas de luces. Los muestreos fueron efectuados en dos localidades, reservas y no-reservas, concentrados en los picos de larvas de dos meses de asentamiento durante la luna nueva y tres quartos. Investigaciones adicionales fueron llevados sobre peces arrecifales recientemente asentados usando buceo (SCUBA). Los peces arrecifales que se asentaron durante los meses anteriores (reclutas < 2cm) fueron quantificados. Resultados de este estudio brinda luces sobre los procesos que estan afectando las densidades de peces juveniles en areas que son reservas y no-reservas marinas. Las diferencias en el suministro de larvas y en el reclutamiento brindan ademas información necesaria para evaluar la eficiencia de las reservas marinas.

PALABRAS CLAVES: Cayos superiores de la Florida, reservas marinas, reclutamiento

INTRODUCTION

The primary goals of marine reserve implementation are the protection of biodiversity, current fisheries, and future stocks from over-fishing. In order to protect future stocks, areas where marine reserves are established must receive an adequate supply of both larval and newly-settled fishes in order to ensure their sustainability. Recent literature contains frequent references to marine reserves as "sources and sinks" of reef fish larvae (e.g., Carr and Reed 1993, Roberts 2000), yet more data are needed on the supply of larvae and recruitment to reserves (Valles et al. 2001, Watson and Munro 2004). Ultimately, these data are necessary if we are to understand the dynamics of recruitment in marine reserves and the protection of local populations. Similar levels of larval supply may lead to similar levels of recruitment between reserve and non-reserve areas. Conversely, site-specific differences may lead to different rates of mortality for new recruits and subsequent differences in recruitment. Sites may also receive different levels of larval supply due to larval preferences for areas of higher coral cover or greater relief. Our null hypothesis was that there are no differences in larval supply, recruitment or diversity by protection level or site within the marine reserves located in the upper Florida Keys, USA.

METHODS

All field research was conducted in the upper Florida Keys, (~25^{o}N 80^{o}W) within the Florida Keys National Marine Sanctuary (FKNMS). Established in 1997, the reserve encompasses 9515 km^2 of reef track, supporting a wide variety of Caribbean and Atlantic species. Within the reserve, sites are defined by varying degrees of protection. Sanctuary Protected Areas (SPAs) are marine reserves that are considered "no-take" zones, in which all collection is prohibited (Level 7; Bohnsack et al. 1999). Other areas (non-protected areas or NSPs) are restricted to general size limits, bag limits, and gear restrictions, with all forms of collection permitted except spear fishing (Level 3). To characterize the larval supply and recruitment of newly-settled reef fishes to marine reserves and non-reserve areas in the upper Florida Keys, two SPA sites (French and Molasses) and two NSP sites (Pickles and Sand Island) were sampled from May 2003 to April 2004.

Larval supply was quantified by collecting late-stage larvae settling to the reef using larval light traps (as described in Sponaugle and Cowen 1996). Relative rates of larval supply to the SPAs and NSPs were measured during the night before and the night of the new moon and the night before and the night of the third quarter moon, resulting in four days of sampling per month. These lunar phases were chosen because previous work has shown that settlement of a variety of species typically pulses during these times in the Florida Keys (Sponaugle et al., unpubl. data). During each sampling night, up to three replicate light traps were deployed at each of the four sites (two SPAs and two NPAs). Light traps were weighted to sample a depth of approximately 2 m from the surface, and then left to collect late-stage larvae overnight. Samples retrieved the next morning were immediately preserved in 95% ethanol. In the lab, fish larvae were sorted from the preserved samples and identified to lowest taxonomic classification possible using the NOAA-NMFS SEFSC larval fish identification key (Richards In press).

To evaluate recruitment, monthly surveys of all newly-settled coral reef fishes were conducted at the same sites. Censuses were conducted in areas that correspond to the habitat preferred by new recruits—the reef matrix as well as coral rubble areas. SCUBA divers censused haphazardly-placed transects by swimming along either side of the transect tape to a length of 5 m, recording any new recruits occurring within 0.5 m on each side of the tape. Fifteen surveys were conducted per habitat area within each site, resulting in a total of 30 transects per site.

To evaluate the differences in larval supply between the SPA and NSP sites, the number and diversity of reef-associated larvae were compared using ANOVA techniques. Differences were compared between sites and between protection levels. ANOVA techniques were also used to compare the difference in density of recruits and diversity of recruits by site and protection level. Diversity was measured using the Shannon-Wiener index. Upon investigation of the record of larval supply over the sampling period, a large pulse of larvae to Sand Island on October 24, 2003 resulted in a highly skewed record of larval delivery to this site. In order to investigate the patterns of larval supply during the sampling period, this pulse was removed from further analysis.

RESULTS AND DISCUSSION

There was no significant difference in the mean numbers of larvae delivered to the four sites ($F = 2.05$, $p = 0.11$). Differences were not significant by site or protection level. Diversity of larvae, however, did differ significantly by site but not by protection level ($F = 4.07$, $p = 0.0077$). Post-hoc analysis using Fisher's LSD showed Sand Island had significantly higher diversity than Molasses or Pickles. Analysis of recruitment data yielded similar results. The density of recruits did not differ by site or protection level ($F = 2.14$, $p = 0.886$). However, the diversity of recruits was significantly different by site but not protection level ($F = 12.96$, $p = 0.000$). Post-hoc analysis using Fisher's LSD showed Sand Island had significantly lower diversity than Molasses or Pickles, and French had significantly higher diversity than Molasses or Pickles.

Upon closer inspection of the large pulse to Sand Island during the sampling period, this sample was dominated by both gerreids and haemulids. While haemulids are associated with reef areas as adults, larvae of both families settle to seagrass or mangrove habitats. Ocean color images obtained from the University of South Florida's Institute for Marine Remote Sensing (IMaRS) showed substantial movement of higher-productivity bay water along the Atlantic edge of the Keys during this period. Small pockets of water (~ 1 km) are visible in the upper Keys during the day on which the large sample was collected. Due to the relatively small sizes of these water pockets and the relatively small spatial scale over which the study sites are situated, it is possible that these oceanographic features could have led to the localized pulse in larval supply to this site.

We conclude that these four sites in the Keys did not differ significantly in either larval supply or recruitment during the sampling period. However, there were differences in diversity, though only by site. Marine reserves in the upper Keys showed no difference in larval supply or recruitment relative to non-reserve areas, and diversity did not differ by protection level. Finally, small scale oceanographic features may have played a role in the supply of larvae during this study, illustrating the importance of these features to both larval delivery and recruitment in this system.

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