

Coral recruits to settlement plates at remote locations in the U.S. Pacific

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Abstract. Documenting the density and taxon of coral recruits to settlement plates is a widely used method of quantifying coral recruitment. Four deployments of recruitment plate arrays were made at six locations in the Northwestern Hawaiian Islands at annual or biennial intervals between 2001 and 2006. Similar arrays were deployed at Kingman Atoll, Palmyra Atoll, Baker Island, and Rose Atoll for three consecutive, 2-year periods and at Jarvis Island for one, 2-year period. Most locations with multiple deployments showed temporal variability in the density of coral recruits. In the Northwestern Hawaiian Islands, lowest average recruitment rates (8.5 and 10.4 recruits $\text{m}^{-2} \text{yr}^{-1}$) were found at Midway and Pearl and Hermes Atoll, respectively, and highest average rates were found at Maro Reef (265.3 recruits $\text{m}^{-2} \text{yr}^{-1}$). Annual rates at the five remote central Pacific locations ranged from 0.8 to 16.3 recruits $\text{m}^{-2} \text{yr}^{-1}$. The taxonomic composition of the recruits did not reflect the composition of adult coral communities. These results reveal the need for further study of coral reproductive and recruitment processes in these remote areas where little data have been collected.

Key words: corals, recruitment, settlement plates

Introduction

The reported decline of coral reefs (e.g., Pandolfi et al. 2005) necessitates improved understanding of their intrinsic capabilities for replenishment. The capacity of scleractinian corals to maintain or renew genetically diverse populations through sexual reproduction is a key attribute of reef resilience (West and Salm 2003). Recruitment patterns can be an important factor affecting the future coral community (Coles and Brown 2007).

Documenting the density and taxon of coral recruits to settlement plates is a widely used method of quantifying coral recruitment (Mundy 2000). Recruitment studies involving artificial substrata are typically conducted at locations readily accessible from land-based institutions, and the substrata are submerged for several months (e.g., Polachek, 1978; Fitzhardinge, 1985; Kolinski 2004). Studies from more isolated regions that are distant from supportive land bases are rare (e.g., Hughes et al., 1999).

The Northwestern Hawaiian Islands (NWHI) are a chain of small rocky islands, atolls, coral islands, and reefs that span ~1800 km over more than five degrees of latitude in the northwestern portion of the Hawaiian Archipelago (Fig. 1). Designated as Papahānaumokuākea Marine National Monument in 2006, they are uninhabited except for seasonal field camps or small maintenance crews at several locations. Given the expanse of the region, most

marine research activities require support from large institutional research vessels.

Situated closer to the equator but spread across more than $5 \times 10^6 \text{ km}^2$ of the tropical Pacific Ocean are five small islands/atolls (Kingman Atoll, Palmyra Atoll, Jarvis Island, Baker Island, Rose Atoll; Fig. 1) that are managed by the U.S. Fish and Wildlife Service. As in the NWHI, research is largely conducted aboard large research vessels.

No previous studies of coral recruitment have been conducted in any of these locations. A pilot study was launched in the NWHI in 2001 to examine spatial and temporal variability of the density and taxonomic composition of coral recruits at six locations by attaching settlement plates to the anchors of oceanographic instruments. Similar methods were applied to the five remote central Pacific locations beginning in 2002. This paper, which presents the results from a 5-year study in the NWHI and a 6-year study in the remote central Pacific locations, is a first look at coral recruitment in these locations.

Material and Methods

An array (“cohort”) of 16 (15 cm \times 16 cm) unglazed terra cotta plates was deployed at six locations in the NWHI (French Frigate Shoals, Maro Reef, Lisianski, Pearl and Hermes, Midway, and Kure) and five remote locations in the central Pacific (Fig. 1) for consecutive periods of ~1 or 2 years. At the end of each deployment period, the entire submerged array

and plates were retrieved and a new array with fresh plates was deployed on the same day.

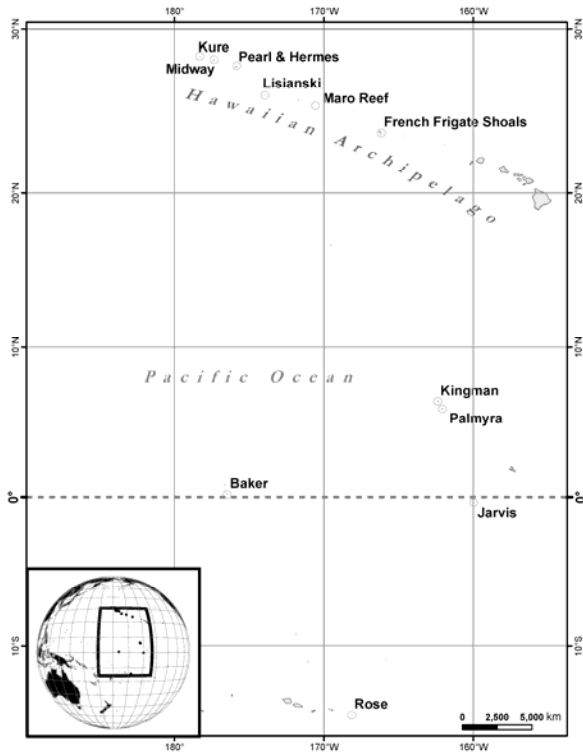


Figure 1. Deployment locations of settlement plates.

The plates were assembled in a framework of polyvinyl chloride (PVC) pipe in which grooves had been cut to hold the plates. Arrays deployed at < 10 m depth were attached with cable ties to the anchor of an oceanographic buoy. A sheltered site was selected to moor the buoy and arrays, where they might withstand the long deployments. At Baker and Jarvis Islands, there was no suitable protected shallow-water (<10 m) habitat in which to deploy a surface buoy. Instead, the PVC framework with plates was attached to an anchor in deeper water (~ 15–20 m). Of the 16 plates, 8 were placed horizontally and 8 vertically.

After retrieval, the plates were rinsed of excessive sediment and algae, frozen, and returned to Honolulu. Both sides of each plate were examined for coral recruits with a dissecting microscope. Recruits were classified in the family Pocilloporidae, Acroporidae, Poritidae, or unidentified based on skeletal criteria of Babcock et al. (2003), with the exception of the first cohort from the NWHI when this diagnostic reference was not available. Density of recruits (no. m⁻²) was calculated based on the number of retrieved plates and the available settlement surface area of each plate. In calculating annual recruitment rates (no. m⁻² yr⁻¹), densities were normalized to the number of days the arrays were deployed at each location.

Results

Northwestern Hawaiian Islands

Most locations showed temporal variability in the annual rates of coral recruitment (Fig. 2a). At all locations, the annual recruitment rate on plates deployed from 2004 to 2006 was substantially less than that of previous cohorts. The highest average annual recruitment rate (265.3 recruits m⁻² yr⁻¹) was found at Maro Reef, and the lowest average annual rates (8.5 and 10.4 recruits m⁻² yr⁻¹) were found at Midway and Pearl and Hermes Atolls, respectively.

Of the 891 recruits tallied on plates from the second, third, and fourth cohorts, 96.2% belonged to the family Pocilloporidae, 2.7% to the Acroporidae, and 1.1% to the Poritidae (Fig. 2b).

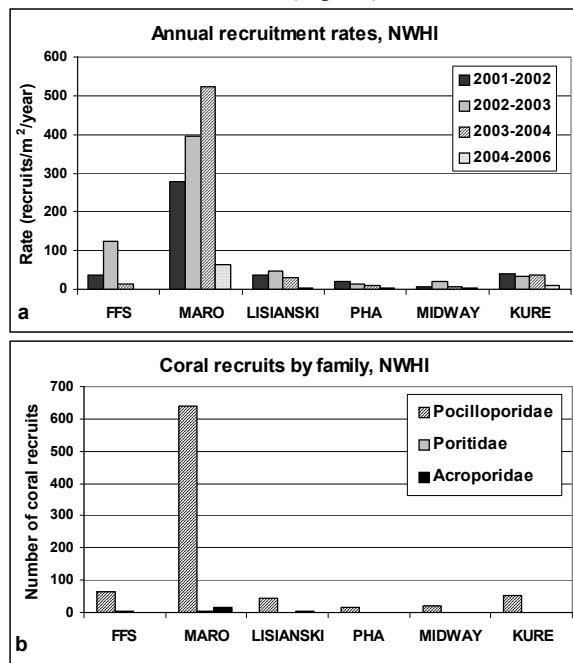


Figure 2. Coral recruitment parameters from settlement plates in the NWHI between 2001 and 2006. a. Recruitment rates (no. m⁻² yr⁻¹). b. Taxonomic composition by family. FFS = French Frigate Shoals; PHA = Pearl and Hermes Atoll

Remote Central Pacific Locations

At Jarvis Island, the entire first cohort of plates had become detached from the anchor and was not found, presumably due to the high wave energy environment. Only 9 of the 16 plates from the second cohort were recovered; hence, a third array of plates was not deployed at Jarvis. There was temporal variability in annual recruitment rates at Kingman Atoll, Palmyra Atoll, and Baker Island (Fig. 3a). At Rose Atoll, only one coral recruit was found from all three, 2-year deployments. The highest average annual rate (8.1 ± 2.8 recruits m⁻² yr⁻¹) was found at Kingman Atoll and the lowest average annual rate (0.3 ± 0.2 recruits m⁻² yr⁻¹) was found at Rose Atoll. The highest average

annual rate in the remote central Pacific locations was lower than the lowest average annual rate in the NWHI, at Midway Atoll.

Of the 68 coral recruits found from all remote central Pacific locations, 25.0% belonged to the family Pocilloporidae, 20.6% to the Acroporidae, 32.4% to the Poritidae, and 22.1% could not be identified. The relative contribution of each taxon varied by location (Fig. 3b). At Kingman Atoll and Baker Island, the dominant component of the recruiting taxa also varied by cohort. At Kingman Atoll, acroporids dominated the first cohort (80% of recruits, $n = 10$) but poritids dominated the final cohort (90% of recruits, $n = 20$). At Baker Island, pocilloporids were exclusively found in the first and second cohorts (i.e., 100% of recruits, $n = 7, 4$, respectively) but acroporids dominated the third cohort (42% of recruits, $n = 12$). At both Kingman Atoll and Baker Island, settlement plates were deployed and retrieved at comparable times of the year.

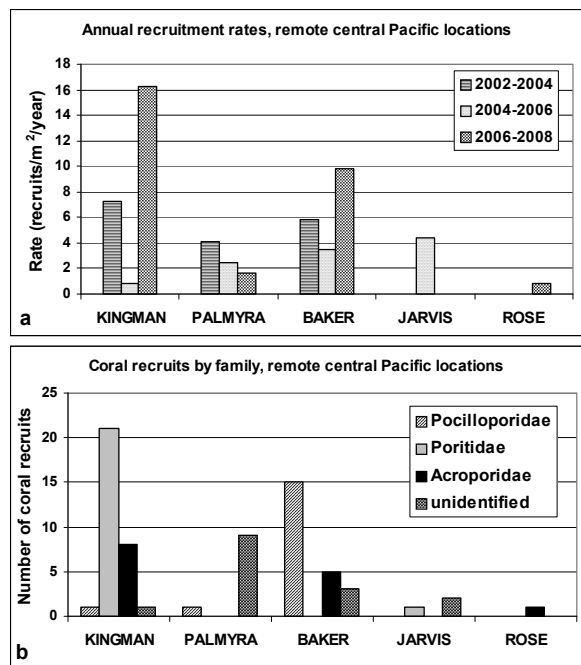


Figure 3. Coral recruitment parameters from settlement plates at remote central Pacific locations between 2002 and 2008. a. Recruitment rates ($\text{no. m}^{-2} \text{ yr}^{-1}$) b. Taxonomic composition by family.

Discussion

Northwestern Hawaiian Islands

At each location the placement of the anchor to which the plates were attached was based on protection by neighboring reef structure from severe wave activity. Consequently, the arrays were deployed in varying geomorphological habitats with variable live coral composition of adjacent reef. These habitat variations

preclude statistical comparison among locations in recruitment rates or taxonomic composition.

Kenyon (1992) determined that three species of *Acropora* are sexually mature at French Frigate Shoals from June to August, but no other studies of coral reproduction exist from the NWHI. It is reasonable to assume, however, that the mode and timing of gamete or planula release is similar to that displayed by conspecifics in the main Hawaiian Islands (MHI). With the exception of the 2003–2004 cohort, settlement plates were deployed in September and October, towards the end of the reproductive periods displayed by the suite of spawning taxa (Kolinski and Cox 2003), and likely missed the peak larval settlement period of that year. The 2003–2004 cohort, which was deployed in July and August, provided settlement substrate during more peak reproductive periods, which may account for the higher densities of that cohort at Maro Reef (Fig. 2a).

The taxonomic composition of the recruits was disharmonic with the composition of the adult coral communities in this region. The genus *Porites* dominates at all islands/atolls in the NWHI both in terms of percent cover and colony density (Kenyon et al. 2006; 2007a,b), but only ~1% of coral recruits were poritids. In contrast, pocilloporids made up >96% of the recruits although their contribution to percent cover ranges from 3.5% at Maro Reef to 33.1% at Kure Atoll (J. Kenyon, unpubl. data). Year-round release of planulae by *Pocillopora damicornis* (Kolinski and Cox 2003) may contribute to the disharmonic representation of this genus in the coral recruits. The contribution of adult acroporids to percent cover ranges from 1.5% at Laysan (Kenyon et al. 2007b) to 21.6% at Kure (J. Kenyon, unpubl. data) but only 2.7% of all the recruits were acroporids. In a 2-year study of recruitment in Kaneohe Bay, Oahu, in the MHI, Fitzhardinge (1985) observed that there was no obvious relationship between the abundance of adult colonies at a site and the number and taxonomic composition of the recruits. In a 24-year study of visible (> 0.5 cm) recruits at four sites off Kahe Point, Oahu, Coles and Brown (2007) also noted that *Pocillopora meandrina* generally had higher recruitment rates than *Porites lobata*. Nonetheless, the extreme paucity of poritid and acroporid recruits in the present study highlights the need for better understanding of coral reproductive, recruitment, and early life history processes in this region, and has important implications for recolonization by larvae should populations of these taxa be negatively impacted by natural or anthropogenic disturbances.

At all locations, annual recruitment rates calculated from the 2004–2006 cohort were lower than those of previous cohorts; this decrease was especially pronounced at Maro Reef, where recruitment declined

from 522.6 recruits $\text{m}^{-2} \text{yr}^{-1}$ to 65.0 recruits $\text{m}^{-2} \text{yr}^{-1}$ (Fig. 2a). Most islands/atolls in the NWHI experienced mass coral bleaching in 2004 (Kenyon and Brainard 2006), and responses to bleaching can include diminished reproductive capacity (e.g., Omori et al. 2001) and reduced recruitment (e.g., Obura 2001). However, *Pocillopora*, the major component of the recruits, was not heavily bleached at Maro Reef (Kenyon and Brainard 2006). The suite of causes behind this reduction in recruitment remains unclear.

The highest average annual recruitment rate was found at Maro Reef. The mesh of reticulate reefs adjacent to the lagoonal site where the plates were deployed may have facilitated retention of gametes and/or larvae compared to other NWHI locations where the neighboring reef structure was not as complex. Brown (2004) noted in the MHI that sites with higher recruitment rates were either in protected embayments or along coastlines with strong currents adjacent to reefs with high coral cover.

Remote Central Pacific Locations

The varying coral faunas and range of habitats in which the arrays were deployed at the five remote central Pacific locations preclude statistical comparison among locations. Each location is treated separately in the following discussion.

The arrays at Kingman Atoll were surrounded by a dense population of *Porites lutea* colonies. One hundred fifty-five coral and anemone species have been reported from Kingman Atoll (Brainard et al. 2005), but little is known of the timing of coral reproduction. Kenyon (2008) inferred that several episodes of spawning involving multiple *Acropora* species take place annually over 2 or 3 months beginning in late April at Kingman and Palmyra. Fresh settlement plates were deployed biennially before this inferred initiation of spawning and provided substrate for two annual periods of reproductive activity. Recruitment to the 2004–2006 cohort of plates was among the lowest rate documented in all remote central Pacific locations during the 6-year study (Fig. 3a), and the reasons behind this failure in recruitment are unclear.

The arrays at Palmyra Atoll were deployed in the lagoon, which experiences limited circulation and low coral abundance (J. Maragos, pers. comm.). One hundred sixty-eight coral and anemone species have been reported from Palmyra Atoll (Brainard et al. 2005), but little live coral is presently found in the lagoon. The consistently low recruitment rates (Fig. 3a) likely reflect the depauperate nature of coral communities in this portion of the lagoon.

The plates at Baker Island were deployed in a region of moderately high (~ 36%) coral cover dominated by *Acropora nobilis* (Coral Reef

Ecosystem Division (CRED), unpubl. data). Eighty-eight coral and anemone species have been reported from Baker Island (Brainard et al. 2005) with assemblages dominated by *Montipora*, *Acropora*, *Pavona*, and *Pocillopora*, but no studies of coral reproduction have been conducted here. The average annual recruitment rate (6.4 ± 1.2 recruits $\text{m}^{-2} \text{yr}^{-1}$) was second only to that at Kingman Atoll.

The plates at Jarvis Island were deployed in a region of moderately high (~ 40%) coral cover dominated by *Montipora* and *Pocillopora* (CRED, unpubl. data). Forty-nine coral and anemone species have been reported at Jarvis Island (Brainard et al. 2005), with assemblages dominated by *Montipora*, *Pocillopora*, and *Pavona*, but no studies of coral reproduction have been conducted here. Recruitment rates were the highest from all remote central Pacific locations for the 2004–2006 cohort (Fig. 3a), but in the absence of data from more than one cohort, other generalizations cannot be made.

The arrays at Rose Atoll were deployed in the lagoon close to a patch reef with moderately high coral cover (~ 45%) dominated by *Favia*, *Montipora*, and *Astreopora* (CRED, unpubl. data). Observations of spawning by seven species (Itano and Buckley, 1988; Mundy and Green, 1999) off Tutuila, ~340 km distant from Rose Atoll, following the October or November full moon constitute the best available data by which to predict reproductive phenology of the 111 species of corals and anemones (J. Maragos, pers. comm.) at Rose Atoll.

All Locations

Average annual recruitment rates at all locations in the NWHI were higher than those at remote central Pacific locations, although adult coral cover is lower at all locations in the NWHI than any of the remote central Pacific locations (Kenyon et al. 2006, 2007a,b; CRED, unpubl. data). Hughes et al. (1999) also noted a lack of conformity between adult abundance and recruitment on the Great Barrier Reef. The range of substrata, depths, faunal diversity, submergence times, and metrics used to report recruitment in published scientific literature (Field et al. 2007) confounds comparisons with rates in the present study. With this caution, recruitment rates from studies in the MHI range from 0.2 recruits $\text{m}^{-2} \text{yr}^{-1}$ (Polachek, 1978) to 1536 recruits $\text{m}^{-2} \text{yr}^{-1}$ (Kolinski 2004). In a study of recruitment on the Great Barrier Reef at four hierarchical spatial scales, Hughes et al. (1999) determined that recruitment by broadcast-spawning corals was most variable at the largest spatial scale (sectors, each 250–500 km apart) and least variable among reefs within sectors, each 10–15 km apart. Future studies of recruitment in the NWHI, where the islands/atolls are separated by the scale of

sectors, could benefit from a similar hierarchical design, and future studies in all locations could benefit from spatial replication.

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