

FINAL REPORT

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“Defining and mapping essential fish habitat for reef fishes in Kosrae, Federated States of Micronesia.”

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INTRODUCTION

The management of a marine fishery is a difficult task and in tropical island nations, where ecologically complex ecosystems are under heavy pressure from rapidly increasing anthropogenic stress, the problem is exacerbated. In recent years, there has been increasing interest in conserving fish habitats (e.g. Benaka 1999, Nagelkerken et al. 2000a, b, 2001, 2002, Mumby et al. 2004). Identification of what habitats are important for marine fishes is difficult, because their habitat requirements are poorly understood (Cook & Auster 2005). In particular, very little is known about habitat utilization patterns of reef fish in the Pacific Islands.

Among the most commercially valuable and most vulnerable nearshore reef fishes in the U.S. Pacific Islands are the larger species such as the humphead wrasse (*Cheilinus undulatus*), the bumphead parrotfish (*Bolbometopon muricatum*), snappers (Lutjanidae) and groupers (Serranidae). These species are generally slow growing and long lived, often with delayed reproductive development. Spawning occurring in aggregations and low replenishment rates (Rhodes & Sadovy 2002, Sadovy et al. 2003a, b). These life-history traits render them particularly susceptible to overexploitation (Donaldson & Sadovy 2001). Groupers and humphead wrasse are major components of the live reef fish trade and are subject to intense fishing pressure. Catches have declined dramatically over the past few decades (Myers 1999). The humphead wrasse has been listed as 'vulnerable' by the World Conservation Union (IUCN Red List of Threatened Species, www.redlist.org) and was listed in Appendix II of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) in October 2004. In addition to their fishery value, large reef fishes are important to divers and have high tourism value (Rudd & Tupper 2002). Determining nursery habitat for large snappers, groupers and humphead wrasse may be problematic in that many large reef fishes undergo stage-dependent, ontogenetic habitat shifts. For example, juvenile serranids and lutjanids are known to settle on small patch reefs, in seagrasses, among mangrove prop roots, or in algal-dominated clumps of coral in the western Atlantic (Eggleston 1995, Sullivan & Sluka 1996, Koenig & Coleman 1998). As juvenile fish grow, their risk of predation likely decreases, while their foraging capacity and probability of survival likely increase (Tupper & Boutilier 1997). Larger size also initiates higher metabolic demands, and juveniles may need to find a more suitable habitat to meet these requirements.

In order to better manage these species, especially in terms of spatial management via marine protected areas, we require detailed information on their habitat utilization patterns. Simply identifying the habitats that fish use is inadequate, as such a broad approach to determining essential habitat does not allow for prioritization of habitats for conservation and management (Levin & Stunz 2005). A better approach would be to concentrate conservation and restoration efforts on habitats or sites that are most important for the replenishment of adult populations. The most obvious examples are spawning aggregation sites and nursery habitats. In Micronesia, Palau and Pohnpei have already implemented year-round fishing closures at known grouper spawning aggregation sites (Ngerumekaol Conservation Area and Ebiil Conservation Area in Palau, Kehpara Marine Sanctuary in Pohnpei), but to date there are no policies in place to identify or protect nursery habitats.

Beck et al. (2001) outline a more rigorous approach to determining nursery habitat. They suggest that a true nursery is a juvenile habitat that provides disproportionately greater biomass per unit area to adult populations. In order to determine if a particular habitat or habitats is truly a nursery, a suite of important ecological processes must be measured within all available habitat

types. These include density, growth, survival, and movement to adult (or intermediate) habitats (Beck et al. 2001). All of these processes may contribute to a higher production of biomass recruiting to the adult population.

The objective of this project was to determine spawning and nursery habitat (as defined by Beck et al. 2001) for 3 species of commercially valuable reef fishes in Kosrae: humphead wrasse *Cheilinus undulatus*, blacktail snapper *Lutjanus fulvus*, and humpback red snapper *Lutjanus gibbus*. *L. fulvus* and *L. gibbus* are moderately large (maximum size 40-50 cm) snappers that are common throughout Micronesia and are important reef fisheries species. Specifically, mark-recapture techniques were used to compare density, persistence, growth, and movement of newly settled and adult snappers and humphead wrasse in a variety of habitat types.

Another objective was to create detailed habitat maps for key areas of Kosrae. In order for fisheries management to incorporate essential fish habitat, information on the location and extent of such habitat must be available to managers in a format that is intuitive and readily accessible. Digital habitat maps created in a Geographic Information System (GIS) format are particularly useful in that they allow the merging of habitat data with other thematic layers, such as fish or coral abundance and distribution, fishery catch and effort, pollution sources, etc. Such maps can be used to support a wide range of coastal management activities in addition to fisheries management.

In June 1998, President Clinton signed Executive Order 13089, "Coral Reef Protection", which mandates mapping of U.S. coral reefs. Although 85% of U.S. coral reefs are located in the Pacific Ocean, only a small fraction of these reefs have been digitally mapped at a sufficient resolution for management activities. IKONOS high-resolution satellite imagery of Kosrae was made available through the Kosrae Island Resource Management Program (KIRMP). These multispectral images have a spatial resolution of 4 meters. Recent advances in the use of satellite imagery, in conjunction with field-based habitat surveys, allow the classification of distinct shallow marine habitat types based on spectral reflectance characteristics in the blue and red wavelengths. Spectral Mixture Analysis can be used to assess habitat and classify specific locations on the image to the sub-pixel level. The spatially referenced habitat data can then be used in a GIS to generate spatial databases and maps of available shallow nearshore habitats. Another method of mapping using satellite imagery is visual interpretation, where a researcher familiar with the benthic habitats of an area classifies the habitats from the image based on his knowledge of the bottom type (and based also on ground-truthing). For this project, we used a combination of Spectral Mixture Analysis, using ENVI 4.1 software, and visual interpretation. Habitat maps were created in ESRI ArcGIS 9.

SECTION I. IDENTIFICATION OF NURSERY HABITATS

MATERIALS AND METHODS

Study sites. The study was conducted at selected sites around the island of Kosrae, Federated States of Micronesia (Fig. 1). Four sites were originally chosen around Kosrae: Lelu in the east, consisting of a broad reef flat with several solution holes (deep depressions caused by freshwater percolating through the carbonate reef structure) and bordered by mangroves to the landward side and fringing reef to seaward; Utwe in the south, consisting of a shallow bay fringed with extensive mangroves and connected to the open ocean by a channel; Walung in the west, consisting of a narrower reef flat with one solution hole, fringed by mangroves at the southern

end; and Okat/Coquille Harbor in the north, a broad reef flat with extensive mangrove areas fringing Coquille Harbor. Shallow nearshore habitats were broadly classified as mangroves, seagrasses, patch reefs, reef flat, reef slope, sand/algal plains, solution holes, and tidal channels.

Intensive surveys of each of the 4 study sites were undertaken from July 2003 to February 2006. At each site, divers conducted three timed swims, each of 20 min. duration, in haphazard directions. During these swims, divers searched for juvenile (<150 mm TL) *Cheilinus undulatus*, *Bolbometopon muricatum*, large groupers and snappers. Divers recorded the presence of any juveniles and the microhabitat in which they were found. Coral heads, rubble areas, algal clumps, and any other microhabitats in which early juveniles could be hiding were squirted a very light dose of 10% solution of quinaldine sulfate. At higher doses, this anesthetic can be used to immobilize and capture fish (e.g. for mark–recapture experiments, see below). Our aim in this case was to simply flush the cryptic juveniles out of their hiding places, as visual census alone would have missed any cryptic juveniles and biased our identification of potential nursery habitats.

Our initial surveys of the 4 sites indicated that juvenile *Cheilinus undulatus* were abundant enough to conduct mark–recapture experiments at 3 sites, Lelu, Utwe, and Walung). Juvenile groupers and bumphead parrotfish were not encountered at any sites. At each site, a total of 7 microhabitat types were identified as potential nursery habitats for juvenile *C. undulatus*, *Lutjanus fulvus*, and *Lutjanus gibbus*, based on the presence of at least one juvenile in each of these microhabitats. *Lutjanus bohar*, *Lutjanus monostigma* and a number of other *Lutjanus* species were present in these microhabitats, but not in sufficient numbers to warrant specific surveys or analyses. These microhabitats included coral rubble, mangrove prop roots, seagrass beds (>50% coverage of seagrass), bushy macroalgae (>50% coverage of branching macroalgae, commonly *Laurencia* spp. or similar species), massive corals (most commonly massive forms of *Porites rus*), branching corals (e.g. *Acropora* spp., *Seriotopora* spp., and *Porites cylindricus*), and solution holes (deep depressions in the reef flat with sandy bottoms and either live or dead coral lining the rim). Solution holes were present in the reef flats of Lelu and Walung, but not found on the southern shore around Utwe, as there is no reef flat in that area. All other microhabitat types were present at all sites (see Appendices I-III for detailed habitat maps of the study sites).

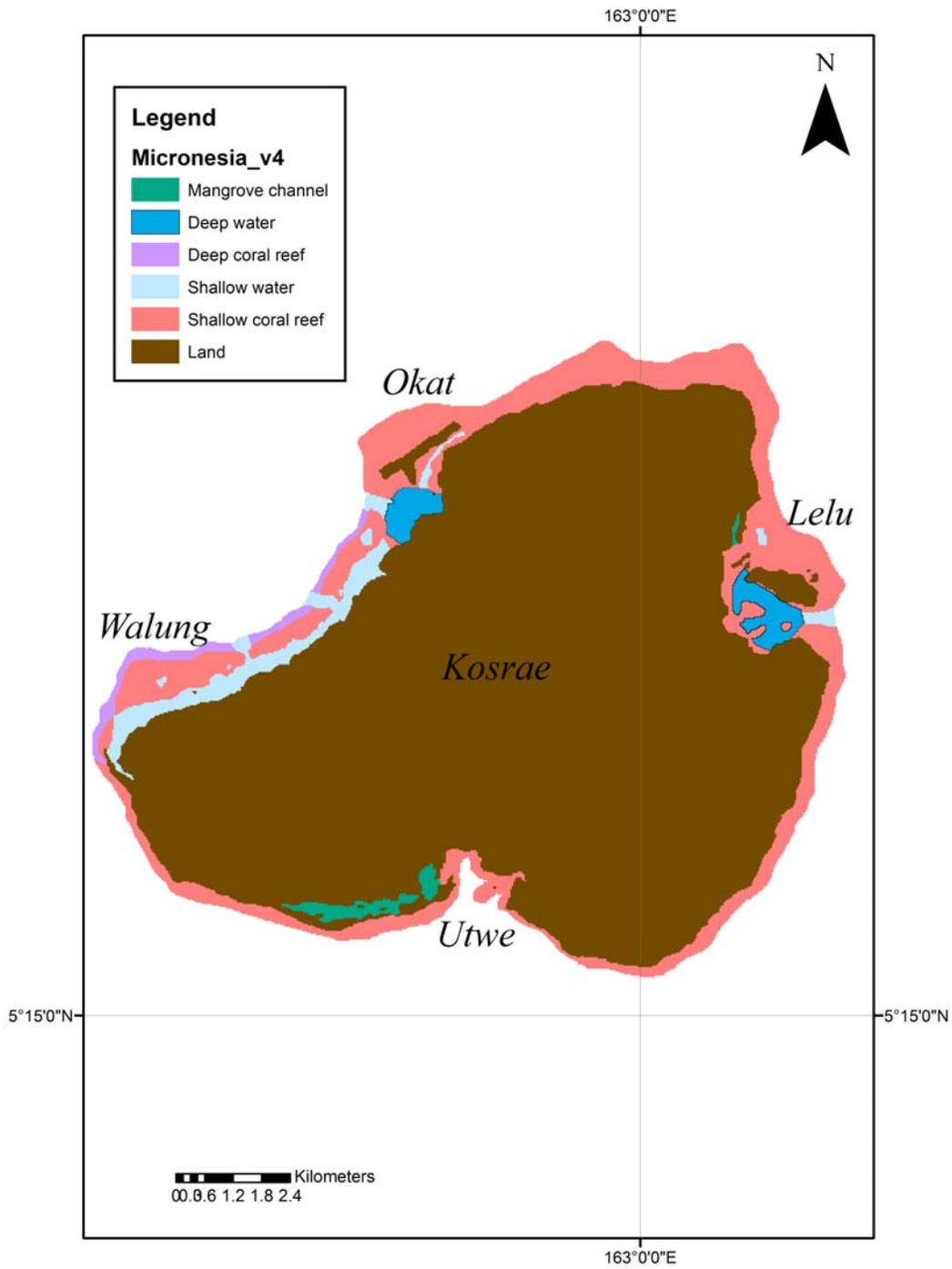


Figure 1. Map of Kosrae showing general reef morphology.

Fish habitat utilization. *Among-habitat variation in settlement:* Settlement surveys took place quarterly from August 2003 through March 2005. At each site and within each microhabitat, newly settled *Cheilinus undulatus* (i.e. all individuals ≤ 15 mm total length [TL] and newly arrived since the previous census) and snappers (≤ 25 mm TL) were visually censused monthly by SCUBA diving or snorkeling along 5 haphazardly placed 25 m \times 2 m belt transects. Each site could only be censused monthly because of the large number of transects involved in this study. Since each of the 3 sites had 7 microhabitats to be surveyed (except Utwe which had no solution holes), there were 20 site-habitat combinations, each censused with 5 replicate transects, for a total of 100 transects. Each microhabitat covered sufficient area to allow the use of 25 m transects.

Due to the large number of zero values involved in settlement surveys, all data were tested for normality using the Kolmogorov-Smirnov D-test and for homogeneity of variance using Levene's test and were $\log(x + 1)$ transformed when assumptions of parametric analysis were not met. Transformed data met assumptions of normality and homogeneity of variance. Analysis of variance (ANOVA) was used to test the null hypothesis that settlement does not differ among habitat types.

Among-habitat variation in abundance, growth, persistence, and movement: *Cheilinus undulatus* settle at a size of 8 to 15 mm TL, with a mode of about 12 mm TL (Tupper in press). This small size makes newly settled individuals inappropriate for mark-recapture studies, as the mortality associated with the marking process is likely to be unacceptably high. Tupper (in press) found that individuals of 35 mm TL and larger could be marked with $<10\%$ mortality (2 deaths in 22 trials). Thus, only individuals of >35 mm TL (about 2 to 3 wk post-settlement) were marked. In each microhabitat type, early juveniles of 35 to 50 mm TL were captured using a 10% solution of the anesthetic quinaldine sulfate. In seagrass and mangrove habitats, fish were caught using a combination of anesthetic and small surround nets. The snappers *Lutjanus fulvus* and *L. gibbus* settle at a size of roughly 15 mm, and can be marked successfully within about 1 week after settlement. All captured fish were measured to the nearest mm TL and marked *in situ* with subcutaneous injections of visible implant elastomer (Northwest Technologies, Inc.), using a different pattern of colored dots for each site and habitat. Marked fish were released immediately at their point of capture. A detailed habitat description (species of coral/algae and approximate percentage cover) was made at each capture point, and the location was recorded using a hand-held GPS unit.

The mark-recapture study began in March 2005, following the settlement surveys. Following initial tagging of the fish, growth and persistence (i.e. the reciprocal of mortality and/or emigration) of juveniles was estimated by 12 successive censuses and recaptures of marked individuals, performed 3 times weekly for 1 month along the same transects. A total of 455 recently settled *Lutjanus fulvus*, 505 *Lutjanus gibbus*, and 220 *Cheilinus undulatus* were tagged with elastomer injections. The number of fish tagged in each microhabitat was balanced between sites but not between microhabitats (Table 1). A balanced, orthogonal design was not possible because of the large variation in numbers of fish settling into different microhabitats.

At each successive census, all recaptured individuals were measured to the nearest mm TL, and their locations were recorded by GPS, as above. Cumulative percent persistence of released fish was estimated as the number in census/total number released $\times 100\%$. Note that persistence is an underestimate of true survival as the methodology cannot completely account for emigration of tagged fishes that were not recaptured in censuses of surrounding areas. To

determine movement patterns of post-settlement juveniles, points were haphazardly selected at distances of 5, 10, 50, and 100 m from each original tag/release site. These points were used as the starting points for further 25 m transects, to search for tagged fish that may have emigrated from their original tag and release point. At 3 months and 6 months post-tagging, long swims were conducted from the tagging point out to the reef slope, following the most appropriate route that juvenile fish might take (i.e., through channels in the reef flat or mangroves, etc.). The null hypotheses that neither growth nor persistence vary among microhabitats was tested using ANOVA. Persistence data is proportional and was therefore arcsine transformed prior to analysis.

Table 1. Number of recently settled juveniles tagged in each microhabitat type at 3 sites in Kosrae, Federated States of Micronesia.

Site	Microhabitat	<i>Lutjanus fulvus</i>	<i>Lutjanus gibbus</i>	<i>Cheilinus undulatus</i>
Lelu	Mangroves	75	50	0
	Solution hole	0	5	20
	Branching coral	5	5	10
	Bushy macroalgae	0	0	20
	Seagrass	50	100	10
	Massive corals	10	5	10
	Coral rubble	10	10	10
Utwe	Mangroves	75	50	0
	Branching coral	5	5	10
	Bushy macroalgae	0	0	20
	Seagrass	50	100	10
	Massive corals	10	5	10
	Coral rubble	10	10	10
	Walung	Mangroves	75	50
Solution hole		5	5	20
Branching coral		20	20	10
Bushy macroalgae		0	0	20
Seagrass		50	100	10
Massive corals		10	5	10
Coral rubble		10	10	10

RESULTS

Among-habitat variation in settlement, post-settlement persistence, and growth

Settlement

Recently settled *Cheilinus undulatus* (<25 mm TL) were found in 6 of 7 habitats (Fig. 2). Significant differences in post-settlement density were found among microhabitats but not between sites (2-way ANOVA: $F = 16.5$, $p < 0.0001$ for habitats; $F = 1874$, $p = 0.18$ for sites). A significant interaction occurred between sites and habitats because of the preference of *C. undulatus* for solution hole microhabitats, which did not occur at Utwe ($F = 2.56$, $p = 0.01$). Post-settlement density was highest in solution holes at Lelu, highest in bushy macroalgae at Utwe, where solution holes did not exist, and roughly equal between solution holes and bushy

macroalgae at Walung. Post hoc comparison tests (Tukey's honestly significant difference, HSD) indicated that microhabitats fell into 3 groups with respect to post-settlement density: 1 microhabitat (mangroves) had zero settlement; 3 microhabitats (seagrass, massive corals and rubble) had low settlement and did not differ from each other (Tukey's HSD, $p > 0.05$); and two microhabitats (solution holes and bushy macroalgae) had significantly higher density than the previous groups (Tukey's HSD, $p < 0.05$), but did not differ from each other (Tukey's HSD, $p > 0.05$).

Lutjanus fulvus settled into every microhabitat except bushy macroalgae, although it also did not settle into massive corals at Walung or the solution hole at Lelu (Fig. 2). At Lelu and Utwe, the great majority of *L. fulvus* settled into mangroves and seagrass beds. At Walung, most *L. fulvus* settled into seagrass, mangroves, or branching corals on the forereef and reef slope. Mean settlement differed significantly among microhabitat types and sites (2-way ANOVA, $F = 77.1$, $p < 0.0001$ for microhabitats; $F = 5.85$, $p < 0.03$ for sites). There was also a significant interaction between sites and habitats ($F = 5.08$, $p < 0.001$), due to the high abundance of newly settled fish in branching corals only at Walung. Post-hoc comparisons indicated that settlement was highest in mangroves (Tukey's HSD, $p < 0.05$), next highest in seagrass ($p < 0.05$), and was low but did not differ among the remaining microhabitats ($p > 0.05$). Comparing sites, settlement was significantly higher at Walung and Lelu than at Utwe (Tukey's HSD, $p < 0.05$), but did not differ between Walung and Lelu ($p > 0.05$).

Post-settlement density of *Lutjanus gibbus* also differed significantly among microhabitats, but not among sites (2-way ANOVA: $F = 118.3$, $p < 0.0001$ for microhabitats; $F = 0$, $p = 0.93$ for sites). Post-hoc comparisons indicated that settlement was highest in seagrass (Tukey's HSD, $p < 0.05$), next highest in mangroves ($p < 0.05$), and was low but did not differ among the remaining microhabitats ($p > 0.05$). It also recruited directly to branching corals on the forereef and reef slope at Walung only, resulting in a significant interaction between sites and microhabitats ($F = 5.4$, $p < 0.001$).

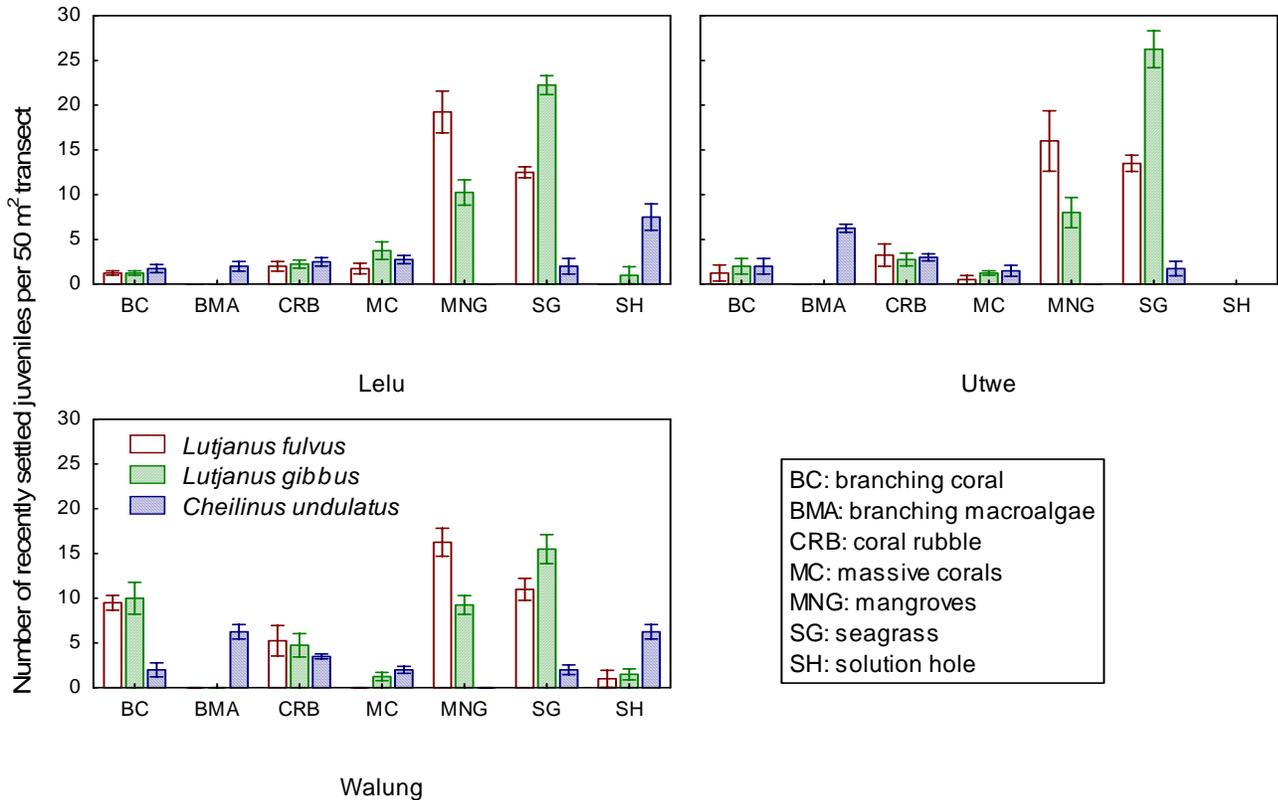


Figure 2. Mean post-settlement density of juvenile *Cheilinus undulatus*, *Lutjanus fulvus*, and *L. gibbus* in 7 habitat types at 3 sites in Kosrae, Federated States of Micronesia.

Post-settlement persistence

Of the 220 tagged *Cheilinus undulatus*, 79 individuals were resighted. All resighted individuals were recaptured. Two-way ANOVA indicated that post-settlement persistence (Fig. 3) was also significantly different among microhabitats ($F = 6.9$, $p < 0.0001$), but did not differ between sites ($F = 0.18$, $p = 0.91$). As with settlement, there was no significant interaction term ($F = 0.44$, $p = 0.51$), as persistence was highest in bushy macroalgae at all sites. However, persistence did not differ among the remaining 6 microhabitats in which settlement occurred (Tukey's HSD: $p > 0.05$ for all pairwise comparisons).

Post-settlement persistence of *Lutjanus fulvus* differed significantly among microhabitats but not sites (ANOVA: $F = 14.3$, $p < 0.0001$ for microhabitats; $F = 0.0$, $p = 1.0$ for sites). There was no significant interaction term ($F = 0.75$, $p = 0.69$). Post-hoc comparisons revealed two groups of microhabitats in which persistence differed between groups (Tukey's HSD, $p < 0.05$ for all pairwise comparisons) but did not differ within groups (Tukey's HSD, $p > 0.05$ for all pairwise comparisons). Persistence was high in mangrove, seagrass, and coral rubble, and low in branching coral, massive coral, and solution holes (Fig. 3).

Post-settlement persistence of *Lutjanus gibbus* also differed significantly among microhabitats, but not among sites (2-way ANOVA: $F = 9.5$, $p < 0.0001$ for habitats; $F = 0.04$, $p = 0.84$ for sites). There was no significant interaction term ($F = 1.1$, $p = 0.45$). Post hoc analyses (Tukey's HSD) indicated that microhabitats fell into three significantly different groups: very

high persistence in coral rubble microhabitats, moderately high persistence in mangrove, seagrass and solution holes, and low persistence in branching coral and massive coral (Fig. 3).

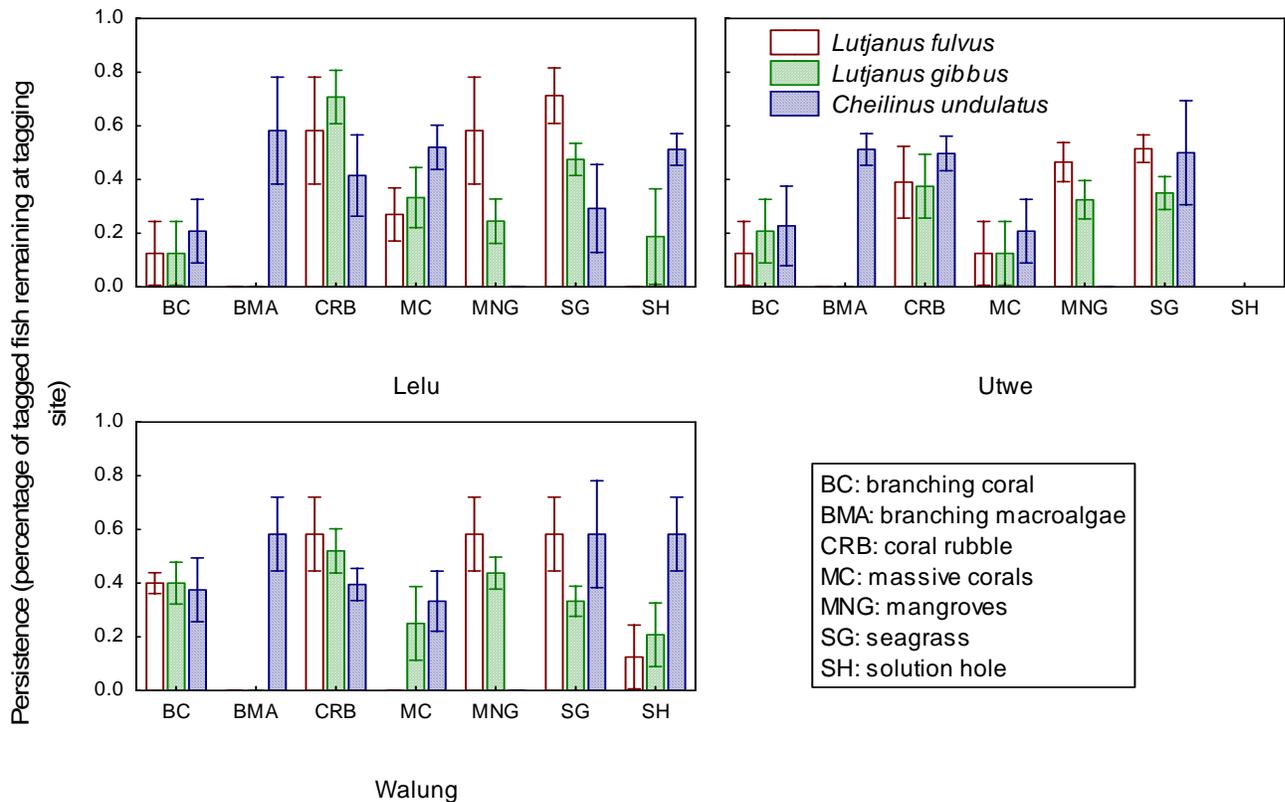


Figure 3. Persistence of juvenile *Cheilinus undulatus*, *Lutjanus fulvus*, and *L. gibbus* in 7 habitat types at 3 sites in Kosrae, Federated States of Micronesia.

Growth

Two-way ANOVA indicated that growth of recently settled *Cheilinus undulatus* (Fig. 4) differed significantly among microhabitats ($F = 9.8$, $p < 0.0001$), but not among sites ($F = 2.6$, $p = 0.11$). There was no significant interaction term between microhabitats and sites ($F = 0.78$, $p = 0.66$). Post-hoc comparisons (Tukey's HSD) of growth revealed 2 groupings of microhabitats: high growth in solution holes, bushy macroalgae, and coral rubble; and significantly lower growth in branching coral, massive coral, and seagrass. Growth of *Lutjanus fulvus* varied significantly among microhabitats and sites (2-way ANOVA, $F = 22.4$, $p < 0.0001$ for microhabitats; $F = 6.8$, $p < 0.05$ for sites). Post-hoc analyses of growth revealed 2 significantly different groupings (Tukey's HSD, $p < 0.05$) of microhabitats: high growth in mangroves, seagrasses, and coral rubble; and low growth in branching coral, massive coral and solution holes (Fig. 4). Comparing sites, growth at the Walung site was significantly higher (Tukey's HSD, $p < 0.05$) than at the Lelu Site. Growth of *L. fulvus* at Utwe was moderate and did not differ significantly from either of the other two sites. Growth of *L. gibbus* varied significantly between habitats, but not sites (2-way ANOVA: $F = 14.3$, $p < 0.0001$ for habitats; $F = 1.48$, $p = 0.23$ for

sites). There was no significant interaction term ($F = 1.45$, $p = 0.18$). As with *L. fulvus*, growth of *L. gibbus* was high in mangroves, seagrasses, and coral rubble; and low in branching coral, massive coral and solution holes (Fig. 4). These two groups were significantly different from each other (Tukey's HSD, $p < 0.05$) but no differences were found within groupers (Tukey's HSD, $p > 0.05$).

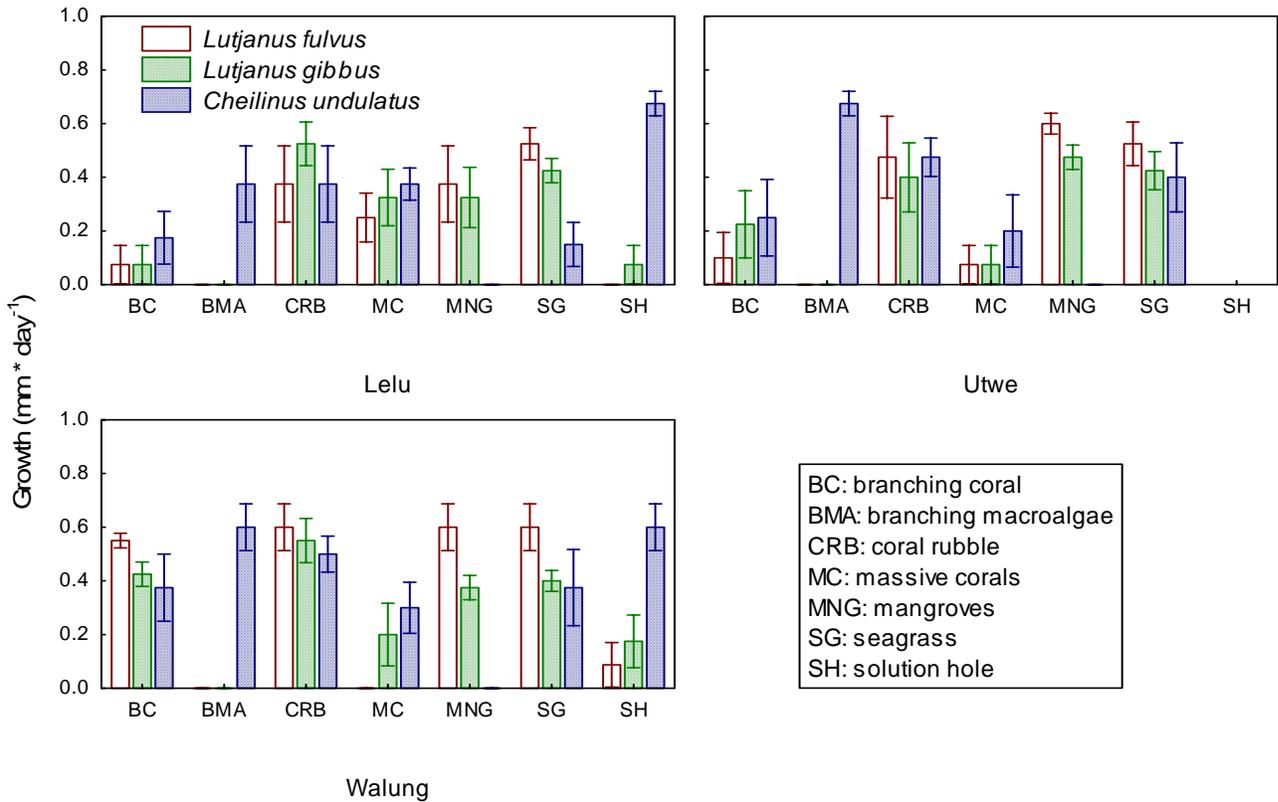


Figure 4. Mean daily growth of juvenile *Cheilinus undulatus*, *Lutjanus fulvus*, and *L. gibbus* in 7 habitat types at 3 sites in Kosrae, Federated States of Micronesia.

Movement of post-settlement fish

We recorded little movement of tagged *Cheilinus undulatus* settlers from their initial tagging sites, for approximately 3 months following settlement. All recaptured individuals <65 mm were found within 10 m of their initial tagging site in the first 3 months. After 6 months following settlement, 7 fish of 60 to 85 mm TL were recaptured in the Blue Hole, a large solution hole in the middle of the Lelu reef flat. Of these 4 originated from bushy macroalgae habitats on the Lelu reef flat, while 3 originated from a small solution hole adjacent to the causeway connecting Lelu Island to Kosrae proper (Table 2). The distance from the small solution hole to their recapture site in the Blue Hole is approximately 200 m. The distance from the capture sites in bushy macroalgae to the Blue Hole was about 100 m. At Utwe, 3 juvenile *C. undulatus* moved from bushy macroalgae along the shore of Utwe Bay to the mouth of Utwe Channel, where they inhabited live branching and plating corals, a distance of about 350 m (Table 2). Another individual moved from seagrass in the northwestern section of Utwe Bay to an area of dead coral

heads and rubble where Utwe Channel opens onto the reef slope, a distance of about . At Walung, 6 individuals were recaptured on the outer reef slope. Of these, 2 originated in the small solution hole in Walung reef flat; the remaining four were tagged in bushy macroalgae (Table 2). Of the 19 fish recaptured in after 6 months, 11 (58%) initially settled in bushy macroalgae microhabitat, 7 (37%) initially settled in solution holes, and 1 (5%) initially settled in seagrass.

Juvenile *Lutjanus fulvus* persisted in settlement microhabitats for about 1 mo before leaving for deeper lagoon waters or offshore reefs. At 3 months after initial tagging, 11 fish were recaptured at Lelu, all on dead patch reefs in Lelu Harbor and generally 700 to 1000 m from their tagging site (Table 2). Of the recaptures at Lelu, 7 were tagged in seagrass and 4 in mangroves. At Utwe, 9 *L. fulvus* tagged in seagrass in northwestern Utwe Bay were found on patch reefs at 8-10 m depth in Utwe Channel, about 500 m from their settlement site. Another 6 migrated from the mangroves west of Utwe Bay to the outer reef slope, a distance of 700 m (Table 2). At Walung, 9 *L. fulvus* were recaptured on the outer reef slope, 7 of which were tagged in seagrass beds (distance moved about 340 m) and 2 in mangroves (distance moved about 475 m). Interestingly, none of the juveniles that settled directly to the outer reef slope at Walung were recaptured any distance from their initial settlement site.

Juvenile *Lutjanus gibbus* also persisted in settlement microhabitats for about 1 month before moving to deeper habitats. The pattern and distance of movement 3 months after tagging was nearly identical to *L. fulvus*. At Lelu, 15 fish were recaptured on patch reefs in Lelu Harbor; 9 of these were tagged in mangroves about 500 m away and 6 in seagrass about 630 m away (Table 2). At Utwe, 11 *L. gibbus* migrated from seagrass in northwestern Utwe Bay to patch reefs at 8-10 m depth in Utwe Channel, about 400 m from their settlement site, while 9 migrated from the mangroves in western Utwe Bay to the outer reef slope (Table 2). At Walung, 10 *L. gibbus* were recaptured on the outer reef slope, 6 of which were tagged in seagrass beds and 4 in mangroves. As with *L. fulvus*, none of the juveniles that settled directly to the outer reef slope at Walung were recaptured any distance from their original settlement site.

DISCUSSION

Following Beck et al.'s (2001) definition of a nursery habitat as a habitat that supplies disproportionately more biomass to the adult population, all 3 species in this study actually appear to use identifiable nursery habitats. *Cheilinus undulatus* had significantly higher post-settlement density in bushy macroalgae and solution hole microhabitats. Persistence and growth were also significantly higher in these habitats than in most other available habitats. Furthermore, while only 27% of newly settled juveniles were originally tagged in bushy macroalgae, 58% of tagged older (6 months post-settlement) juveniles recaptured on deeper lagoon patch reefs migrated from bushy macroalgae microhabitat. Likewise, while only 18% of newly settled *C. undulatus* were tagged in solution holes, 27% of recaptured fish originated in solution holes. Only 1 recaptured fish settled in seagrass, and there were no recaptures from any other habitat. In Palau, another Micronesian island juvenile *C. undulatus* were found to use primarily low, branching corals (small *Acropora spp.*, *Seriotopora spp.*, and *Porites cylindricus*) with associated bushy macroalgae as a nursery habitat (Tupper, in press). As in Kosrae, juvenile (young-of-year) *C. undulatus* in Palau did not settle in mangroves, and did not use seagrass beds to any large extent. This pattern of settling to a cryptic existence within shallow areas of high-complexity corals overgrown with bushy algae has been reported for other reef fishes, e.g. the

Nassau grouper *Epinephelus striatus* (Eggleston 1995) and 3 species of pygmy angelfishes *Centropyge* spp. (Eagle et al. 2001). In Kosrae, there were very few stands of low branching coral in shallow water, so that particular habitat type was generally unavailable to settling fishes. Solution holes may have provided a good alternative to branching coral mixed with macroalgae, as they tend to be turbid with complex coral structures creating dark ledges and overhangs along the rim of the hole.

In Tanzania, Dorenbosch et al. (2006) did not find *C. undulatus* inhabiting mangroves or macro-algal flats, but did find smaller individuals (<27.5 cm TL) to be most abundant in seagrass beds. They concluded that seagrass beds may play an important role as nurseries for *C. undulatus* in Tanzania. However, Dorenbosch et al. (2006) used only visual transects to census juveniles, and, without the use of anesthetic, they may have missed many of the cryptic early juveniles in other habitats. Moreover, while *C. undulatus* in the range of 20-27.5 cm TL may be small, they are not necessarily juveniles, as females are known to be sexually mature and spawn at about 20 cm TL (P. Colin, Coral Reef Research Center, unpublished data). These results emphasize the importance of location-specific surveys in determining fish habitat utilization patterns. Regional generalizations may lead to poor management decisions if essential fish habitats differ among islands or island chains.

Mangroves and seagrass beds were obviously essential to the two *Lutjanus* species, as all recaptures of snappers 3 months after tagging were initially tagged in these two habitats. For *L. fulvus*, 21 of 35 recaptures (60%) settled into mangrove prop roots, while 14 (40%) were tagged in seagrass beds. For *L. gibbus*, 26 of 45 recaptures (58%) were initially tagged in seagrass, with the remainder tagged in mangroves. During all of our censuses in nearshore (backreef) habitats, no adult snapper were observed. However, both species were abundant on the forereef and reef slope at all 3 sites. This indicates a high level of connectivity between seagrass and mangrove habitats and nearshore coral reefs. A similar high level of connectivity between mangroves and coral reefs has been reported for the snappers *L. griseus* and *L. apodus* in Florida (Serafy et al. 2003; Eggleston et al. 2004).

Newly settled *Cheilinus undulatus* displayed strong site fidelity while in smaller size classes, and tended to remain at or very near their settlement sites for at least 3 mo post-settlement. However, after 3 to 6 mo post-settlement, a high number of recaptures occurred <100 m from the initial tagging site. This has been demonstrated for other young-of-year labrids and haemulids in tropical and temperate waters (Tupper & Boutilier 1995, 1997, Tupper & Juanes 1999). In contrast, snappers tended to leave their settlement sites within 1 month and move to deeper habitats sooner than *C. undulatus*. The snappers that were recaptured after 3 months had moved 500 to 1000 m, 3 to 5 times farther than *C. undulatus* had moved after 6 months. Given that predation on juvenile fish is thought to be lower in mangrove/seagrass habitats than on coral reefs (see Chttaro et al. 2005), it is unclear why juvenile *Lutjanus fulvus* and *L. gibbus* remained in the nursery habitats for only 3 months. One might expect the snappers to leave their settlement sites earlier if their growth rates were higher than those of *C. undulatus*, but in this study there were no differences in mean daily growth rate between any of the 3 species. Other possible reasons for the shorter persistence time of snappers in their settlement microhabitats might include an earlier shift in diet, possibly the onset of piscivory, requiring the snappers to move to less complex substrates where their predation effectiveness (i.e. capture success) may be higher. There has been much research in recent years on the role of mangroves and seagrass beds as nursery habitats for coral reef fishes. These habitats have for many years been considered nurseries based on the relatively high abundance and putative survival of juvenile fishes. A large

body of research in Bonaire and Curaçao (Nagelkerken et al. 2000a, b, 2001, 2002, Cocheret de la Morinière et al. 2002, Nagelkerken & van der Velde 2002, Dorenbosch et al. 2006), Belize (Mumby et al. 2004, Mumby 2006), the Bahamas (Chittaro et al. 2005), and the Florida Keys (Mullin 1995) suggests that mangroves and seagrass beds are important nurseries for some species of reef fish. Research in Australia (Laegdsgaard & Johnson 1995), southeast Florida (Thayer et al. 1987), New Caledonia (Thollot 1992), and Palau (Tupper in press) suggests that mangroves and seagrasses are less important than other coastal habitats in terms of nursery value for certain species. However, this discrepancy among locations in nursery value, particularly of mangroves, may simply be an artifact of the types of mangrove ecosystems studied. Areas in which mangroves were found to be important as reef fish nurseries (Bahamas, Florida Keys, Bonaire, and Curaçao) are dominated by fringing mangroves, in which salinity was high, turbidity was low, and the physicochemical environment was fairly similar to what fish might encounter on a coral reef (Cocheret de la Morinière et al. 2004). In contrast, areas in which mangroves were not important reef fish nurseries (Australia, Southeast Florida, New Caledonia, and Palau) are dominated by estuarine mangrove systems in which the salinity is low and/or variable, turbidity is very high, and the physicochemical environment very different to that of nearby coral reefs. Alternatively, the discrepancy between locations in use of mangroves may result from sampling difficulties in estuarine mangroves, including visual surveys hampered by poor visibility, problems with deploying nets or other gear among mangrove prop roots, or the presence of dangerous animals (crocodiles, alligators, bull sharks, etc.). In Kosrae, a geologically young island, there is no lagoon and there are no large bays. The mangrove systems are in close proximity to, and regularly flushed by, open ocean water, although they do extend upriver far enough along the major tributaries to provide a true estuarine environment. The difference in mangrove use between *Cheilinus undulatus* and the two *Lutjanus* species in this study may be simply a matter of physiology. *L. fulvus* is a euryhaline species well adapted to estuarine conditions; the juveniles can even be found in the lower reaches of freshwater streams. *C. undulatus* and *L. gibbus* are more stenohaline and therefore less able to handle variations in salinity.

Table 2. Recaptures of older juvenile fish greater than 3 months post-tagging. Origin refers to the habitat into which the fish originally settled and was tagged. BM = bushy macroalgae. CR = coral rubble. MG = mangrove prop roots. SG = seagrass. SH = solution hole.

Species	Site	Habitat	Depth	No.	Origin	Distance from tagging site
<i>Cheilinus undulatus</i>	Lelu	Blue Hole (massive corals)	3-4 m	4	SH	200 m
	Lelu	Blue Hole (massive corals)	3-4 m	3	BM	100 m
	Utwe	Utwe Channel (plating/branching corals)	4-5 m	4	BM	500 m
	Utwe	Utwe Channel (plating/branching corals)	4-5 m	1	SG	500 m
	Walung	Outer reef slope (massive corals)	6-7 m	3	SH	500 m
	Walung	Outer reef slope (massive corals)	6-9 m	4	BM	300 m
<i>Lutjanus fulvus</i>	Lelu	Lelu Harbor (dead patch reefs)	6-8 m	7	SG	1000 m
	Lelu	Lelu Harbor (dead patch reefs)	6-8 m	4	MG	700 m
	Utwe	Utwe Channel (massive corals)	8-10 m	9	SG	500 m
	Utwe	Outer reef slope (massive corals)	6-8 m	6	MG	1000 m
	Walung	Outer reef slope (massive corals)	8-10 m	7	SG	300 m
	Walung	Outer reef slope (massive corals)	8-10 m	2	MG	500 m
<i>Lutjanus gibbus</i>	Lelu	Lelu Harbor (dead patch reefs)	6-8 m	9	SG	1000 m
	Lelu	Lelu Harbor (dead patch reefs)	6-8 m	6	MG	700 m
	Utwe	Utwe Channel (massive corals)	8-10 m	11	SG	500 m
	Utwe	Outer reef slope (massive corals)	6-8 m	9	MG	1000 m
	Walung	Outer reef slope (massive corals)	8-10 m	6	SG	300 m
	Walung	Outer reef slope (massive corals)	8-10 m	4	MG	500 m

SECTION II. IDENTIFICATION OF SPAWNING AREAS

Our original proposal was to focus on identifying spawning areas and habitats for large, vulnerable species, including the large groupers *Plectropomus areolatus* (squaretail coral grouper) and *Epinephelus polyphekadion* (camouflage grouper), humphead wrasse (*Cheilinus undulatus*) and bumphead parrotfish (*Bolbometopon muricatum*). One interesting and very disturbing result of our surveys was that not one commercially valuable grouper of any species was seen in the entire 75 dives, including our study species. These species have been known to form spawning aggregations at Kosrae, but much deeper than elsewhere in Micronesia (e.g. 100-120 m as opposed to 40 m in Pohnpei or 10-15 m in Palau). However, no catches of these species were recorded in the Kosrae reef fishery this year. We also recorded only 3 bumphead parrotfish and 7 humphead wrasse in 75 dives at 20 sites around the island. Rumor among the fishermen we spoke to suggested that Taiwanese and Hong Kong longliners have been fishing the shelf edge illegally at night and have removed most of the groupers, humphead wrasse, and bumphead parrotfish. Unfortunately, fisheries officers could not confirm or deny this.

MATERIALS AND METHODS

Due to the low numbers (and apparent complete disappearance) of groupers in Kosrae, we changed the focus of this study to snappers (family Lutjanidae), as these are also moderately large, vulnerable reef fish, are still very abundant in Kosrae, and at present are commanding high prices in Kosrae's fish markets. We planned to specifically focus on 4 species of snapper: *Lutjanus bohar*, *L. gibbus*, *L. fulvus*, and *L. monostigmus*. However, only *L. fulvus* and *L. gibbus* were tagged in sufficient numbers to warrant analysis. Using hook and line baited with sardines, we captured and tagged 198 *L. fulvus*, 239 *L. gibbus*, 17 *L. bohar*, and 28 *L. monostigmus*, all on the west and south coasts of Kosrae between Okat and Hiroshi Point (Figure 1). This area was chosen because of favorable weather conditions and because our charter boat left from Coquille Harbor on the west coast and had a limited range. Following our tagging expeditions, we fished roughly twice weekly for another 60 days to recapture tagged individuals. Additional recaptures came from the village fishers of Walung and Coquille Harbor. No recaptures came from the fishery on the south coast, probably because the fish in that area were tagged within the Utwe-Walung Marine Park.

RESULTS AND DISCUSSION

Of the 482 tagged snapper, 47 (9.8%) were recaptured in subsequent fishing trips, including 12 *L. fulvus* and 35 *L. gibbus* (6.1% and 14.6% recapture rates, respectively). Of the 12 *L. fulvus*, 4 were tagged off Yela, south of Okat and recaptured 11 days later just outside Coquille Harbor (Table 3). The remaining 8 were tagged along the south coast, near the mouth of Utwe Bay and were recaptured in the same area over the next 24 days (Table 3). Of the 35 *L. gibbus*, 19 were caught and tagged in one day near the southwest promontory of the reef at Walung (Walung Drop-Off). Most (14) were recaptured by Walung fishermen over the next month along the reef slope between Walung and Yela. All fish had moved north along the reef. The remaining 5 tagged at Walung Drop-Off were caught on the same day (after 41 days at liberty) within 500

m of their original tagging site (Table 3). Another 16 *L. gibbus* were tagged on the forereef about halfway between Utwe Bay and the southwestern corner of the island. These were all recaptured over the next 60 days along the same stretch of reef, within 2 km of their tagging site. There were no apparent spatial or temporal patterns in movement of snappers; indeed, these species appeared relatively sedentary. No *L. bohar* or *L. monostigmus* were ever recaptured. On any given day, when snappers were recaptured, all were recaptured at the same place. This suggests that the schools these fish formed remained cohesive throughout the period of the tagging study (at least 60 days). Because *L. gibbus* is a schooling species, it is unknown if the capture and recapture of several fish at the same place and time is indicative of aggregation for spawning or simply schooling behavior. Because none of the fish were running ripe at the time of capture or recapture, the latter seems more likely.

Table 3. Recaptures of tagged adult snapper in Kosrae, Federated States of Micronesia.

Species	Tagging Site	No. recap.	Days at Liberty	Distance from tagging site
<i>Lutjanus fulvus</i> (198 tagged)	Yela (south of Okat)	4	11	500 m north
	Mouth of Utwe Bay	2	9	1 km west
	Mouth of Utwe Bay	1	13	700 m east
	Mouth of Utwe Bay	3	21	1.5 km east
	Mouth of Utwe Bay	2	24	1.8 km west
<i>Lutjanus gibbus</i> (239 tagged)	Walung Drop-Off	6	7	3.5 km north
	Walung Drop-Off	3	11	2.8 km north
	Walung Drop-Off	4	13	1.7 km north
	Walung Drop-Off	1	30	2.2 km north
	Walung Drop-Off	5	41	< 500 m north
	Mid-southern coast	7	9	1.3 km east
	Mid-southern coast	5	13	1.6 km east
	Mid-southern coast	2	36	800 m west
Mid-southern coast	2	60	1.9 km west	

Because of the very low numbers of adult *Cheilinus undulatus* encountered in Kosrae, we did not attempt mark-recapture studies with this species. We did, however, note the existence of an apparent harem at the outer edge of a reef pass on the mid-western coast. This apparent harem consisted of one large male about 75 cm long and 6 smaller individuals from 25-35 cm long, apparently females. We did not, however, witness any spawning.

SECTION III. CONCLUSIONS

In conclusion, the identification and mapping of nursery areas or other essential fish habitat (e.g. spawning aggregation sites) are critical to prioritizing habitats for conservation and restoration efforts, and indeed for any form of spatial management. To date, few marine protected areas have included specific essential fish habitat within boundaries, with the notable exception of spawning aggregation sites, which are generally small areas and easily defined. This is the case in Micronesia, where major fish spawning aggregation sites are protected year-round from fishing or other extractive activities. However, the formation of new protected areas in Kosrae, Palau, and Pohnpei has yet to include other essential fish habitats, primarily because information on such habitats did not exist. Although we were unable to properly identify spawning habitats within the scope of this project, the results of this study demonstrate that nursery habitats do exist for some commercially and culturally important reef fishes in Kosrae, and that some of these nurseries could be easily impacted by development activities, with potentially serious consequences for the adult fish populations. In addition, coastal development around Kosrae has caused increases in sedimentation that could potentially choke essential nursery habitats with silt, degrading their quality to the point that they are no longer useful as nurseries. Future land-use planning and spatial management efforts in Kosrae and elsewhere in the tropics should account for nursery areas in addition to spawning sites. For this to be realized, much more research into habitat utilization patterns of commercially important reef fish is needed.

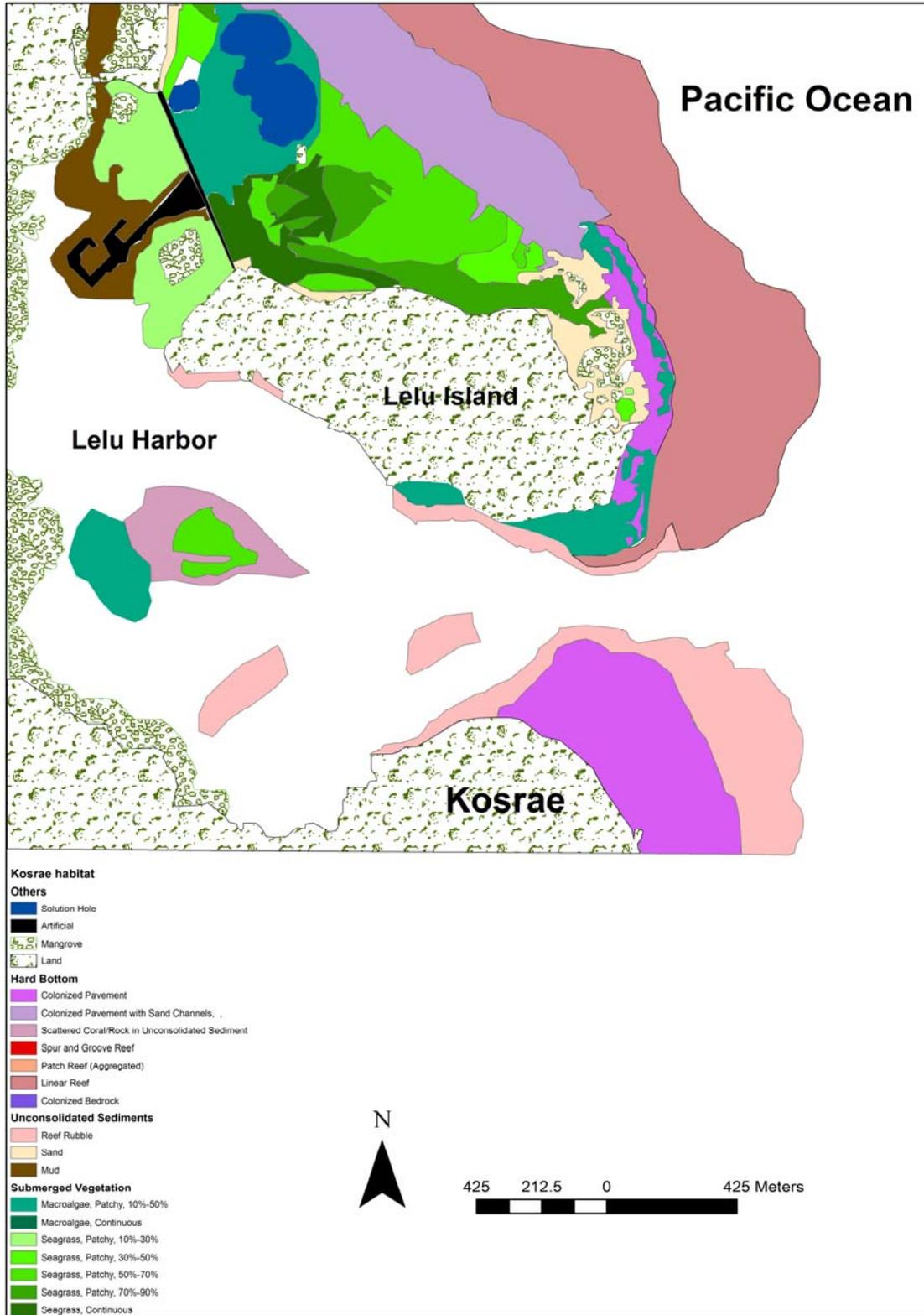
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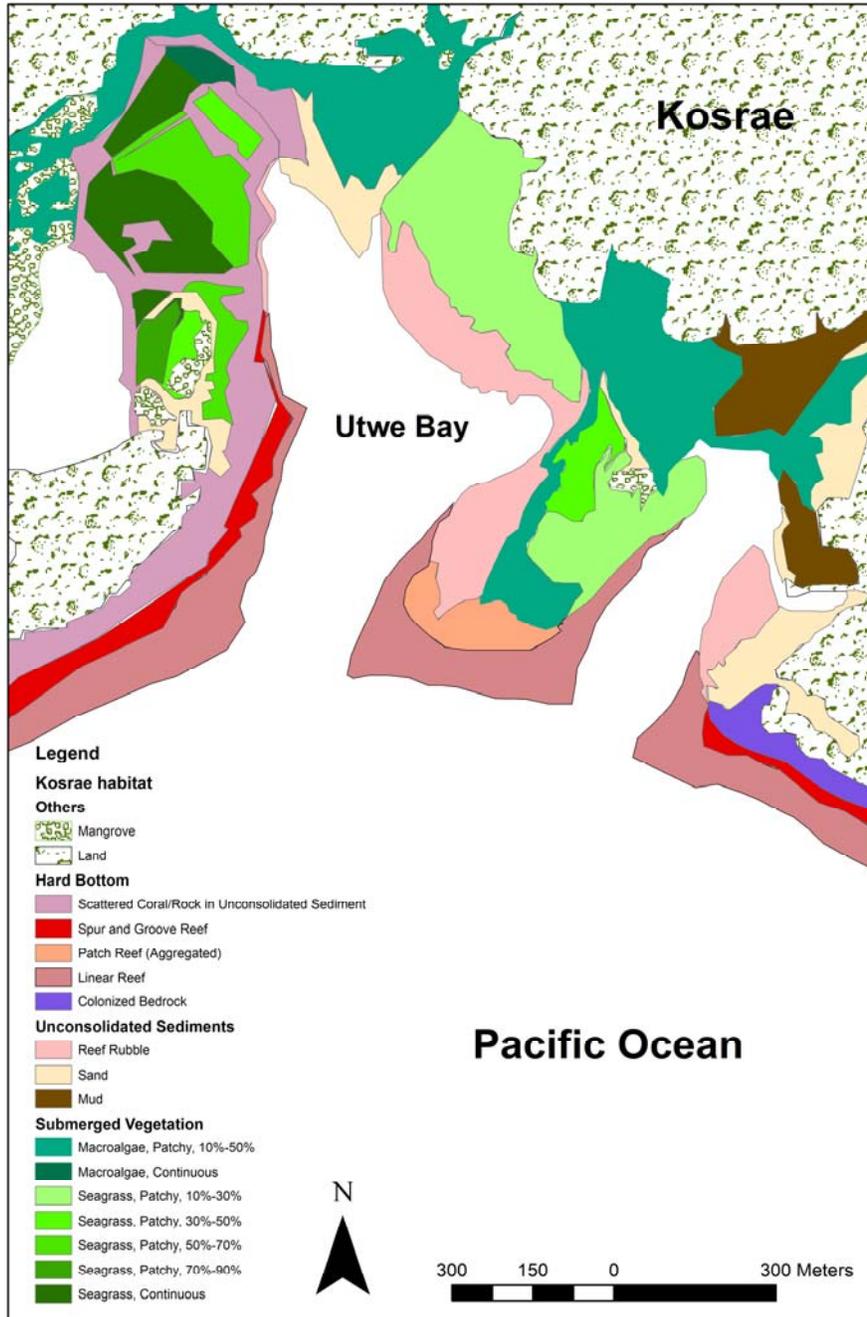
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APPENDIX 1. BENTHIC HABITAT MAP OF LELU HARBOR AND REEF FLAT



APPENDIX 2. BENTHIC HABITAT MAP OF UTWE BAY



APPENDIX 3. BENTHIC HABITAT MAP OF WALUNG REEF FLAT

