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MOVEMENTS, DISTRIBUTION AND GROWTH RATES OF THE WHITE GOATFISH *MULLOIDES FLAVOLINEATUS* IN A FISHERIES CONSERVATION ZONE

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ABSTRACT

The movements, growth rates and distribution of a population of white goatfish *Mulloides flavolineatus* were investigated using a combination of tag-and-release and sonic tracking techniques. The study site was a 137 km² patch reef which has been a no-fishing conservation zone for over 30 years. The population showed high site fidelity; 93% of recaptures occurred at the release site, with times at liberty of up to 531 days. Tracking revealed crepuscular movements away from daytime schooling sites to consistent nighttime foraging grounds up to 600 m away. The route taken between daytime and nighttime habitats was the same each night. Suround-net quadrats were used to measure goatfish densities on the nighttime feeding grounds. The high site fidelity and limited range of diel movements of these fish indicate that quite small harvest refugia can serve to effectively protect populations of mature adults, and that for most of the year, emigration of adults into adjacent fisheries was minimal.

The white goatfish *Mulloides flavolineatus* is widely distributed throughout the Indo-Pacific region. In Hawaii, it is one of several mullid species that are important food fishes, and juvenile *M. flavolineatus* are highly prized as bait. Despite their cultural and commercial importance and widespread distribution, little is known about their growth rates, age, habitat utilization, or dispersal patterns. Age and growth parameters have been described for an exploited population found in the Red Sea (Al-Absey, 1987), but similar data are not available for populations in the Pacific. Much of the existing ecological data on Hawaiian goatfishes concerns food preferences (Mahi, 1968; Holland, 1978; Sorden, 1982), which are of particular interest because several mullid species appear to be sympatric on Hawaiian reefs.

Unlike the *M. flavolineatus* population studied in the Red Sea, the data presented here were obtained from animals living within a marine conservation zone. There is increasing discussion of using fisheries conservation zones (harvest refugia) as tools for managing tropical fisheries (Randall, 1982; Russ, 1985; Davis and Dodrill, 1989; Davis, 1989; Alcala and Russ, 1990; Bohnsack, 1990; Roberts and Polunin, 1991), but very few data are available to evaluate their utility. Theoretically, harvest refugia could serve to protect reproductive adults (which can supply eggs and larvae to repopulate other areas), and could provide recruitment areas for juvenile fish which may grow and eventually emigrate into adjacent fisheries. The appropriate size of a conservation zone would be dictated by the habitat preferences, ranges of movement and degree of site fidelity exhibited by the target species. The current data were collected from a virtually unfished population, and the stock structure, diel movement, and distributional data were analyzed with respect to evaluating conservation zones as a management strategy for this species.

STUDY AREA AND METHODS

Coconut Island is situated in the middle of a patch reef in Kaneohe Bay, Oahu, Hawaii. The reef flat is comprised primarily of sand and coral rubble under water 0.25 to 1.5 m deep. The reef edge and sand flats are interspersed with sand-bottomed pools, lagoons and inlets varying in depth between

2 and 5 m. The coral and coralline algae-covered reef walls descend steeply to a mud silt bay floor approximately 13 m deep. The total sand and rubble bottomed area <5 m deep is approximately 137,000 m^2, and the reef perimeter is approximately 2.4 km long. A no-fishing conservation zone extending 8.0 m beyond the reef has been in place for over 30 years.

Long Term Movements, Growth Rates.—Preliminary visual surveys of the Coconut Island reef indicated seven consistent locations where white goatfish schooled during daytime. These locations (in the deeper pools, inlets and channel entrances around the reef) were utilized to obtain fish for a tag-and-release and recapture program. Fish were caught, tagged and released at various locations around Coconut Island (predominantly from the daytime schooling site in the east lagoon (for reference, see Fig. 6), using a fine mesh seine net. The fork length (FL) of each fish was measured on a foam-padded tagging board and a serially numbered, 8.0 cm long plastic dart tag (Hallprint, South Australia) was inserted into the dorsal musculature between the dorsal fin pterygiophores. Each tag carried a reward notice and a phone number, and posters were distributed to increase public awareness of the tag-and-release program. Fish less than 15 cm FL were not tagged but simply measured, recorded and released.

Seining in the east lagoon occurred approximately monthly over a period of 18 months. Recaptured tagged fish caught in these sets were remeasured and re-released. To reduce errors due to tagging trauma and measurement error, only data acquired from fish at liberty for >50 days were used to calculate growth rates. Visual censuses were used to determine the presence or absence of tagged goatfish at the seven daytime schooling locations around the reef. Limited visibility precluded more accurate quantification of the numbers of tagged fish present at these sites.

Short Term Movements, Habitat Utilization.—Ultrasonic telemetry was used to monitor the movements of individual fish (Holland et al., 1992, 1985). Fish to be tracked were captured at the east lagoon schooling site with a fine mesh beach seine. Following 2 days in captivity for observation, the fish was anesthetised (MS222, Argent Ltd., Seattle, Washington, USA), and the transmitter (3.0 cm × 0.8 cm, Vemco, Nova Scotia, Canada) surgically placed into the gut cavity through a 2.5 cm longitudinal incision in the abdominal wall caudad from the posterior/ventral corner of the pectoral fin. The transmitter was smeared with antibiotic cream and pushed through the incision which was then closed with gut sutures or stainless steel staples. Following surgery, each fish was kept in captivity for 6 days to ensure satisfactory recovery. It was then reintroduced into the school occupying the same daytime location from which it was originally taken.

Tracking was conducted from a 5.5 m boat. Whenever possible, each animal was tracked continuously for 48 h and then intermittently checked every few days thereafter. Position was determined every 15 min by compass triangulation from landmarks. Grid-square analysis (Winter and Ross, 1982; Holland et al., in press), tabulating the number of 15-minute observations per 20 × 20 m cell, was used to describe the habitat use patterns of individual fish.

Nighttime Distribution.—Preliminary tracking data indicated that the goatfish were foraging at night on the sandflats around Coconut Island. To determine the number of fish per square area of reef flat, fine mesh surround nets were set at night around randomly selected 30 × 30 m (900 m^2) quadrats, which had been pre-marked with corner poles during daylight. To reduce setting time, two pieces of net were drawn simultaneously from diagonally opposite poles. Captured fish were tagged and released the following morning.

Weight–Length Relationship.—Towards the end of the study, a weight–length relationship was obtained for fish collected by seine, gill-net, and spearfishing. Tagged fish coincidentally captured at this time were also measured and weighed, but were not included in construction of the weight–length regressions. The weights and lengths of the recaptured tagged fish were compared with those of untagged animals.

RESULTS

A total of 534 goatfish were tagged and released over a period of 19 months between 1990 and 1992. Four hundred sixty-nine (89%) fish were captured by seining and released in the east lagoon at Coconut Island, and the remainder were fish trapped at other locations on the Coconut Island reef. Eighty-two fish (15.4%) were recovered, with the longest time at liberty being 531 days. Ninety-three percent of recaptures were made by research staff on Coconut Island; six other fish were returned by a commercial fish market so that the precise location of recapture was unknown. Eleven fish were recaptured several times, with one animal being recaptured and released five times over a period of 165 days. Shortly after the tagging program commenced, tagged fish were observed in all of the known daytime schooling sites around the reef.

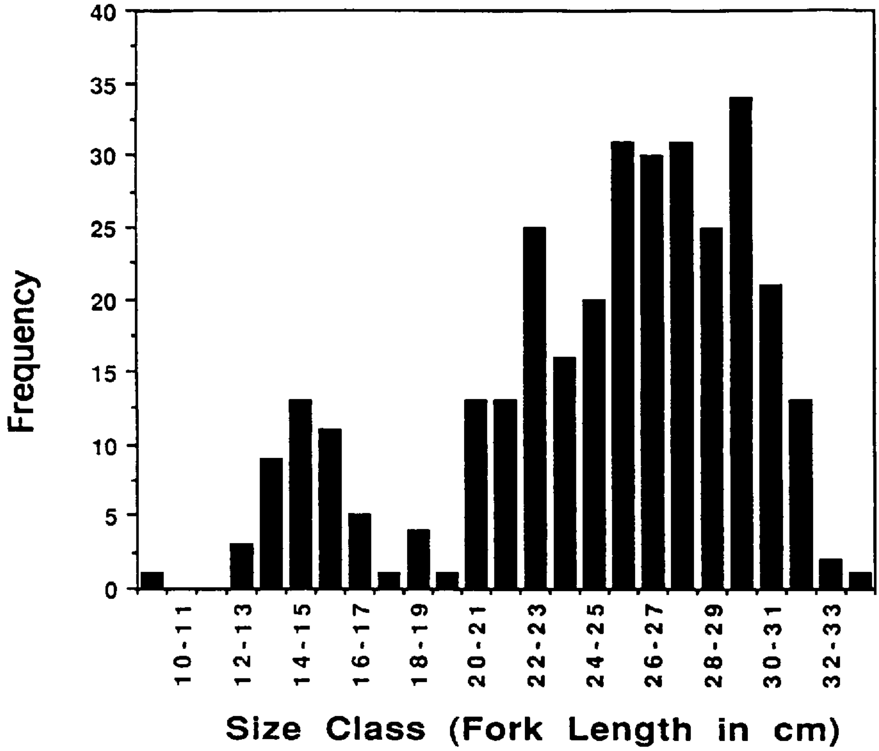

Figure 1. Length frequency histogram of goatfish (N = 323) obtained by purse seining in the east lagoon at Coconut Island in December and January.

Age Structure and Growth Rates.—Length–frequency histograms were constructed from the total combined catch (N = 323) of four seines conducted between December and January (Fig. 1). The histogram reveals one distinct mode at 15 cm. Because small juvenile *M. flavolineatus* are first observed foraging on the reef during the summer months, and based on the findings of Al-Absey (1987) the mode centered around 15 cm probably represents 1.5 year old fish. Clear cohort modes are not distinguishable in the larger sizes.

Daily growth rates calculated from fish recaptured after >50 days at liberty (N = 53) declined as the fish became larger (Fig. 2). This growth rate curve was used to back-calculate the size at 1 year (FL = 10.0 cm) of the putative 1.5 year mode from the length–frequency distribution (Fig. 1), and to estimate the length of subsequent year classes. These initial estimates were entered into a SAS-NLIN program which uses a Gauss-Newton curve-fitting technique to generate a von Bertalanffy growth curve to best fit the observed data (SAS, 1990). Resultant predicted age-at-length values (Fig. 3) matched well with the growth increments of all goatfish recaptured after being at liberty for a year or longer (N = 8). The maximum length value predicted from this von Bertalanffy curve (L = 34.2 cm) matches well with the largest animals caught (33.6 cm, N = 1; 33 cm, N = 4). Other values for the best fit von Bertalanffy curve were: t_0 = 0.36 cm; k (instantaneous growth rate coefficient) = 0.564. A Munro plot of the same data (Pauly, 1984) yielded a similar growth rate coefficient of k = 0.557.

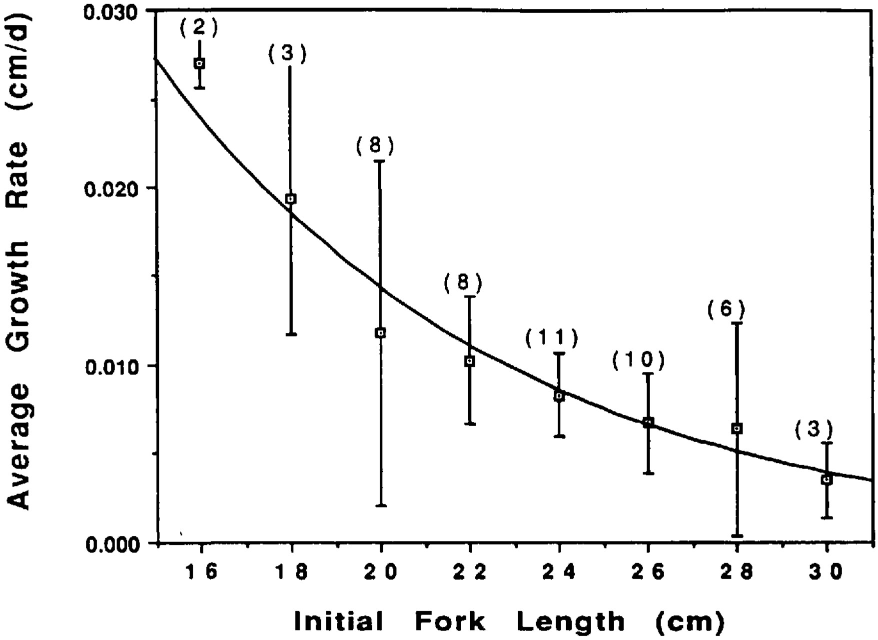

Figure 2. Growth rates of recaptured goatfish at liberty >50 days. Data were separated into 2-cm classes of initial FL. Numbers in parentheses indicate recapture sample size.

Length–Weight Relationship.—Paired length–weight data were obtained from 97 fish. The length–weight relationship is described by the equation:

$$\text{Weight} = 0.0087(\text{FL})^{3.21}. \tag{1}$$

Fourteen tagged fish (average time at liberty 347 days; range 27 to 531 days) coincidentally recaptured during the collection of length–weight data had length–weight relationships very similar to those of untagged fish (Fig. 4).

Daily Movement Patterns.—Four goatfish (FL range 28.4 cm to 31.8 cm) were tracked over periods spanning between 2 and 16 days. All fish were captured and released in the east lagoon. A clear diel pattern of movements emerged which was consistent among the tracks. During daytime, the fish exhibited quiescent behavior in schools of between about 20 and 150 individuals. Occasionally, during daytime, tracked fish would move between one location and another. About an hour before sunset, the animals became more active, often leaving their daytime haunts for nearby areas of the reef flats. As complete darkness set in, the schools dispersed and each tracked fish moved rapidly to a nighttime area on sand flats in water between 0.25 and 4.0 m deep. Each individual returned to the same area each night, and a consistent route was taken between the daytime and nighttime areas. Distance from daytime schooling site to nighttime habitat ranged between 75 and 600 m. Starting about 2 h before sunrise, the fish retraced their paths and arrived at their daytime haunts by first good light. To illustrate this pattern, a brief synopsis of the movements of two of these fish follows:

Fish No. 1 (FL = 29.8 cm). This fish was observed for four complete 24-h periods with subsequent intermittent daytime checks spanning 16 days following

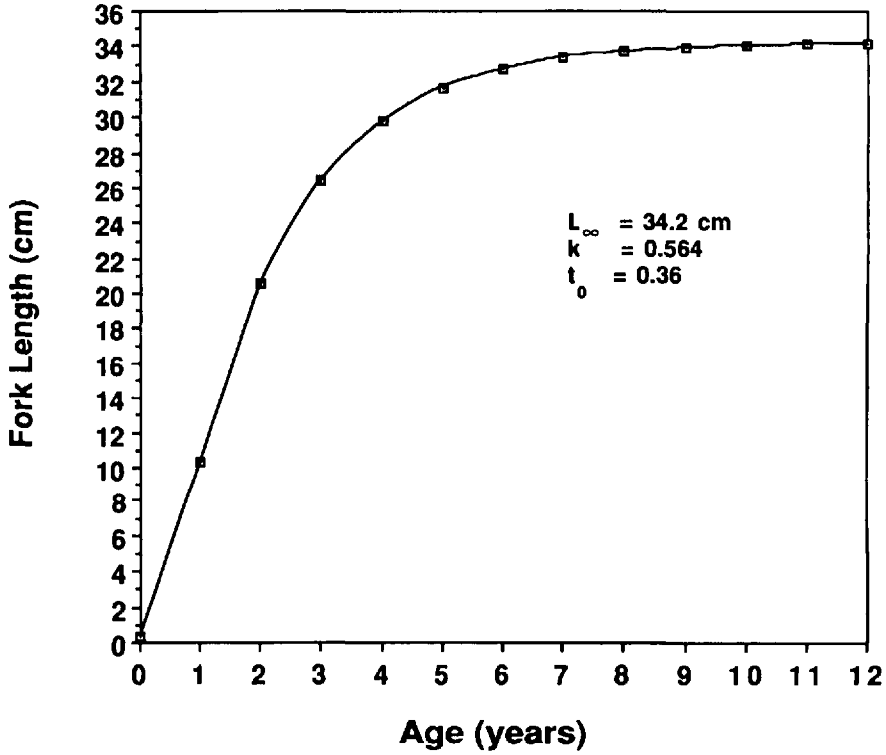

Figure 3. Best fitting von Bertalanffy curve for the growth rates obtained from fish recaptured after >50 days.

initial release. During daytime, the fish shuttled between two schools located 150 m apart. One of these schools was located in the east lagoon at Coconut Island, the other at the mouth of the channel connecting this lagoon to the outer reef slope (Fig. 5). Each evening around 1630 (1.5 h before sunset), the fish moved on to adjacent shallow sand flats which surround the island. Two hours later, as complete darkness set in, the fish moved to the edge of the reef and from there swam rapidly to an adjacent sandy patch reef 125 m south of the Coconut Island reef. Each night, the point of departure was from the same few meters of reef edge and time of departure was 1815, 1819 and 1825 on the three nights when departure was actually observed (on the first night, the fish was relocated on the patch reef after it had left Coconut Island). During nighttime, the fish remained on the top and edges of the patch reef, moving very slowly around the area. Starting two hours before sunrise, the fish retraced its steps, returning to the daytime locations between 0645 and 0730. The last acoustic observation occurred in the lagoon daytime area 16 days after release.

Fish No. 4 (FL = 31.8 cm). This fish was tracked continuously for 48 h prior to being recaptured and sacrificed so that the position of the transmitter in the abdomen could be observed and so that the transmitter could be used on another fish. Post-mortem examination found the transmitter lying longitudinally along the ventral abdominal wall. No adverse effects were observed and the abdominal incision had healed completely, leaving a small dark scar.

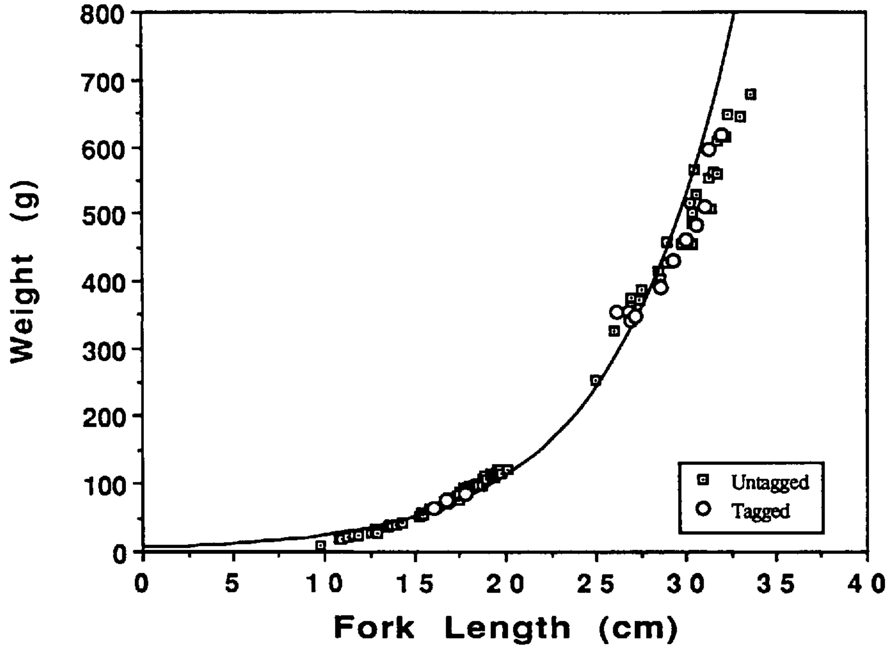

Figure 4. Computer fitted length–weight relationship for fish captured on the Coconut Island reef. For untagged fish N = 97; N = 14 for recaptured tagged fish caught during the same sampling period but not used to generate the length–weight curve.

This fish spent all daytime hours in the northeastern lagoon at Coconut Island where it was released. On both nights it left the lagoon around 1830 and travelled 600 m across sand flats close to the island to nighttime habitat consisting of shallow (<1 m of water) sand flats and a sand bottomed inlet approximately 2.5 m deep (Fig. 6). Movements during nighttime were mostly slow and confined to this well defined area. At about 0515 each morning it began to move back to its daytime location where it was recaptured on the third evening as it began its nighttime migration.

Nighttime Distribution. —The areas covered at night were described and quantified using grid square analyses. The transit paths of the fish to and from their nighttime habitats were not included in these analyses. The average total area covered at night by three of the four fish for which complete nighttime data were acquired was 8,267 m^2 (range 5,200 m^2 to 11,600 m^2), although most of the activity was confined to smaller areas within the total nighttime range (Figs. 5, 6). Average daytime habitat area for these same fish was 2,533 m^2 (range 1,200 to 3,200 m^2). During nighttime tracking, other goatfish (some with external tags) were incidentally observed foraging on the sand flats, sometimes in water as shallow as 20 cm deep.

Three areas of these sand flats were sampled twice each with 900 m^2 quadrats (Fig. 6). A mean of 7.2 (SD = 5; range = 2 to 15) fish was captured per quadrat, or one fish per 125 m^2. Seventeen percent of these were recaptured tagged fish. The number of fish caught was translated into weight per quadrat using equation (1). Mean weight captured was 1,215.2 g·quadrat^{-1} (SD = 617 g), or 1.35 g·m^{-2}.

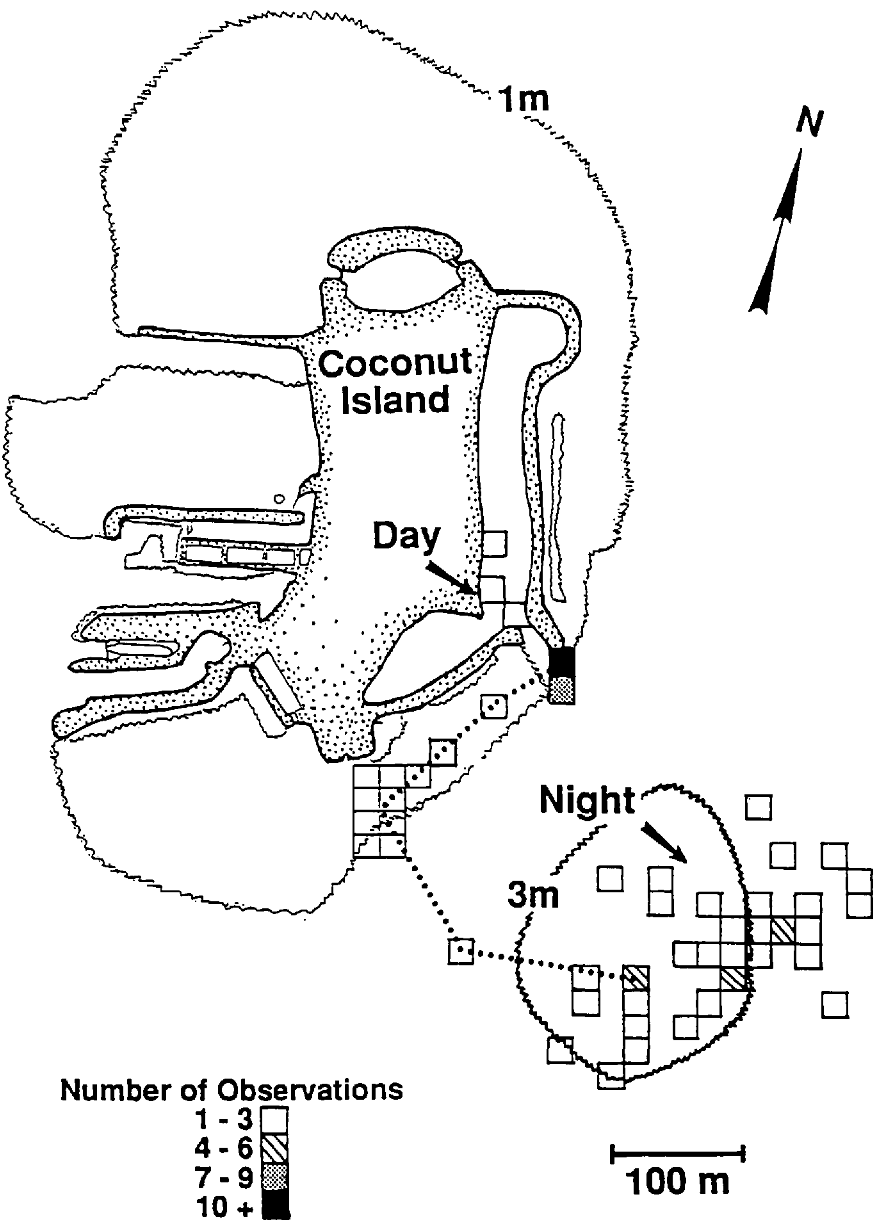

Figure 5. Diel habitat usage by goatfish number 1. Daytime was spent in the east lagoon or at the mouth of the channel connecting the lagoon to the bay. Nighttime was spent on the top and slopes of a sandy patch reef to the south of Coconut Island. Dotted line denotes route taken between the two habitats as observed over 3 day/night cycles. Grid squares = 20 × 20 m.

Discussion

The growth, distribution, and site-fidelity analyses performed in this study were largely dependent on data acquired from fish marked with dart tags, and there are legitimate concerns as to whether this technique impacts the biology of tagged animals. For instance, in the case of the long-lived sablefish (*Anoplopoma fimbria*),

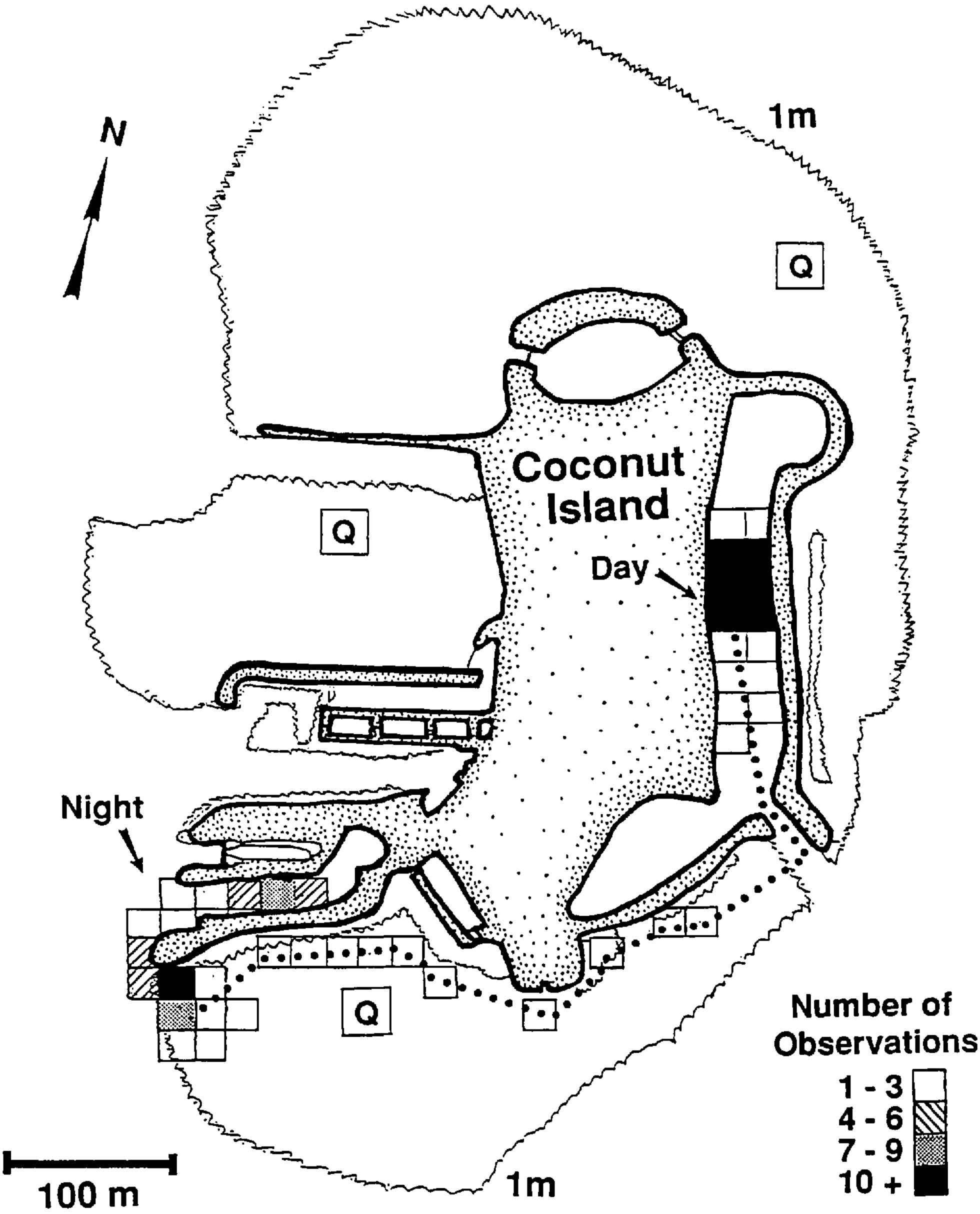

Figure 6. Diel movements of goatfish number 4 tracked for 48 h. Daytime movements were entirely within the east lagoon at Coconut Island. On both nights, the fish followed the same route (dotted line) to nighttime foraging grounds on opposite side of the island. Grid squares = 20 × 20 m. Q = three areas (30 × 30 m) where nighttime quadrats were set, with two samples at each site.

dart tags caused slower growth and maturation, and increased mortality (McFarlane and Beamish, 1990). Although length-at-age data for individual fish are not available in the current study, the similarity of length–weight relationships between tagged and untagged fish of all sizes suggests that tagging did not significantly negatively impact the goatfish. Qualitative observations of the tag wounds of recaptured tagged fish also indicated that the tags caused minimal trauma.

Similarly, the apparently normal behavior of captive fish following transmitter implantation, the quick healing of the implantation wounds, and the consistency of behavior within and among tracks, indicated that abdominal implantation of small sonic transmitters was a viable technique for reef fish of this size. As with juvenile chinook salmon (Mortensen, 1990), closing the incision wound with stainless steel staple sutures was particularly effective. The incision wound was completely healed in one fish recaptured eight days after transmitter implantation.

The predicted (34.2 cm) and observed (33.6 cm) L fork lengths are in good agreement, giving support to the accuracy of the predicted growth curve. No attempt was made to determine if males and females have different growth rates, although preliminary data indicate that there may be sexually dimorphic growth rates in some Caribbean goatfish species (Munro, 1976). Although the size at age 1 for the Red Sea and Coconut Island populations are in good agreement (about 10.5 cm, FL), the Red Sea population appears to grow much more slowly ($K = 0.269$; Al-Absey, 1987).

The tracking data confirm earlier observations of Hobson (1974) that, in Hawaii, daytime schools of quiescent *M. flavolineatus* occur in consistent locations and that these schools disperse at night when individuals depart to forage. It is on the sandflats at night that this species locates the polychaetes and small crustaceans that predominate in its diet (Sorden, 1982). Many fish species, both coastal (Hobson, 1965; Gruber et al., 1988; Holland et al., in press) and pelagic (Yuen, 1970; Klimley et al., 1988; Holland et al., 1990), have spatially separated daytime and nighttime ranges. Less common are examples of fishes following identical routes between daytime and nighttime habitats. Striped parrot fish (*Scarus criocensis*) follow predictable routes from diurnal feeding grounds to nighttime refuging areas (Ogden and Buckman, 1973). In a foraging situation similar to that of *M. flavolineatus,* juvenile grunts (*Haemulon flavolineatum*) migrate to nighttime foraging areas along predictable routes and at consistent light intensities (McFarland, 1981; Helfman and Schultz, 1984). However, the movements of the grunts were considerably shorter than those of the goatfish (Helfman and Schultz, 1984).

Both the tag-recapture data and the tracking results point to a high degree of site-fidelity in this species. The fact that 93% of recaptured fish were recovered around Coconut Island, with times at liberty ranging up to 531 days, indicates very little emigration from the home range, which was probably the recruitment site of the population as small juveniles. Schools of this size class occur on the Coconut Island reef during the summer months. A similar recruitment situation has been described for Caribbean goatfish species (Munro, 1976).

It is unlikely that the apparently strong site fidelity is due to under-reporting of tags recovered by fishermen at other locations. A contemporaneous study of the movements of carangids (Holland, unpubl. data) carrying the same types of tags resulted in frequent reporting by the public from widespread locations. Also, no tagged goatfish were ever observed in a large daytime school which occupied a site on an adjacent fringing reef 175 m from Coconut Island, again suggesting fidelity of individuals to a home range once it has become established, even if distances to adjacent areas are of lesser magnitude than the nightly feeding excursions.

This strong site fidelity bodes well for using marine conservation zones to protect populations of reproductive size adults. Their principal contribution would be in supplying eggs and larvae to adjacent reef areas because there appears to be very little post-recruitment movement of the adults from their home range. The possible exception to this would be during spawning migrations. Very few mullid eggs are found inside Kaneohe Bay (T. Clarke, pers. comm.), and it is possible that spawning adults migrate to the outer regions of the barrier reef from where their eggs are dispersed into open water. Anecdotal observations indicate that, during summer, the number of individuals in the daytime aggregations is reduced, and rebuilds during the winter. The summer reduction could be due to the migration of mature adults to the outer reef. Colin and Clavijo (1978) reported a mass spawning of the Caribbean spotted goatfish *Pseudopeneus maculatus* at an exposed area of reef which may expedite the oceanic dispersal of the eggs. If the white goatfish moves outside Kaneohe Bay to spawn, the lack of tag returns from locations other than Coconut Island suggests that mature individuals return to their original home range following the spawning event.

From a management perspective, the data indicate that prohibiting fishing on sandy patch reefs (and possibly sandy areas of fringing reefs), would conserve potential spawning biomass. In terms of harvesting strategy, protecting a suitable area for three years would produce a "marketable product" with minimal chance of loss to adjacent fisheries. These areas could possibly be seeded with juveniles (FL = 10–12 cm) to augment natural recruitment, and habitat could be enhanced by the excavation of sandy pools in otherwise shallow areas of sand flats. Based on the essentially virgin population density and weight of fish utilizing the nighttime foraging grounds around Coconut Island (1.35 $g \cdot m^{-2}$), a section of suitable habitat should support a density of about one three-year-old fish per 220 m^2 of sand flat.

Acknowledgments

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