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# Movements and dispersal patterns of blue trevally (*Caranx melampygus*) in a fisheries conservation zone

Kim N. Holland\*, Christopher G. Lowe, Bradley M. Wetherbee

Hawaii Institute of Marine Biology and Department of Zoology, University of Hawaii at Manoa, PO Box 1346,  
Coconut Island, Kaneohe, HI 96744, USA

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## Abstract

The short- and long-term movement patterns of blue trevally (*Caranx melampygus*) were monitored using a combination of sonic tracking and tag-and-release techniques. All fish were captured and released on the patch reef surrounding Coconut Island in Kaneohe Bay, Oahu, Hawaii, which has been a no-fishing conservation zone for over 30 years. Sonic tracking produced fine-scale movement data from five fish for periods spanning up to 18 days. All fish displayed diel movement patterns within consistent home ranges, which encompassed different parts of the reef during the night than during the day. Movements were predominantly along the walls of the patch reef, with occasional forays to nearby sections of adjacent reefs. Four hundred and ten fish were tagged and released on the Coconut Island reef, and the recapture sites of 85 recaptured fish indicated that most did not move far from their point of release; 75.5% were recaptured within 0.5 km of their release points. Time at liberty ranged from 4 to 454 days, and distance between release and recapture sites was not related to time at liberty. Some fish were observed many times in the same areas over periods of several months. Both the tracking and recapture data indicate strong site fidelity in this species and low occurrence of long distance emigration. These behavioral traits suggest that successful husbandry of this species may be accomplished through the use of management practices such as establishing no-fishing zones.

*Keywords:* Carangids; Harvest refugia; Movements; Telemetry

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## 1. Introduction

The jack or trevally family (Carangidae) encompasses a large number of species, many of which are highly mobile, agile predators occupying niches close to the top of the food

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\* Corresponding author. Tel. (808) 236–7430, Fax (808) 236-7443, E-mail KHOLLAND@UHUNIX.UHCC.HAWAII.EDU.

chain. Their habitats range from brackish water estuaries to deep offshore reefs, and a few species are pelagic in the open ocean. Many jack species are important components of subsistence and commercial fisheries, and are primary target species for sport fishing. This is true for the blue trevally (*Caranx melampygus*; Hawaiian name 'omilu') which is a coastal, reef-associated species found throughout the tropical and sub-tropical zones of the Indo-Pacific region, where it is highly regarded as both a food and a game fish (Gosline and Brock, 1960).

Because coastal carangids are frequently heavily exploited, concerns are raised about the need for protection of stocks. However, the complexity of tropical and sub-tropical fish assemblages presents particular problems regarding the conservation and management of these resources. These ecosystems are characterized by the co-occurrence of many sympatric species which, in the fisheries of these areas, usually results in mixed harvests of target and non-target species and a variety of sizes. This is true with even the most selective fishing techniques, and in many areas, non-selective techniques such as gill-netting are common.

In response to these circumstances, fisheries conservation zones (harvest refugia) are receiving increased scrutiny as possible strategies for fisheries resource management (Davis, 1989; Bohnsack, 1990; Polacheck, 1990; Roberts and Polunin, 1991; DeMartini, 1993). Two advantages of harvest refugia are that policing a well-defined geographic area can be much easier than enforcing bag limits, quotas or minimum sizes, and the incidental mortality of discarded by-catch is eliminated. However, although increased effort is now being focused on modeling the effectiveness of refugia (Polacheck, 1990; DeMartini, 1993), the efficacy of conservation zones in protecting target species is largely untested and the models are constrained by a dearth of empirical data.

A major factor influencing the effectiveness of conservation zones is the rate of movement of fishes out of the protected area into unprotected areas (Carr and Reed, 1993; DeMartini, 1993). The transfer rate from one area to another is influenced by the 'permeability' of the refuge boundary and the size of the protected area relative to the normal movement ranges of the target species. Highly mobile species, such as the jacks, may be particularly problematic because their high mobility might quickly take them beyond the protection of a conservation zone. However, very little is known about the normal movement patterns of jacks, and acquiring this type of information was the central thrust of the current research.

Gut analyses of omilu taken from various parts of the Pacific (including Hawaii) indicate that it is predominantly piscivorous, and the type of fishes eaten suggests that feeding occurs predominantly during the daytime in comparatively shallow-water reef areas (Randall, 1980; Sudekum et al., 1991). What is not known is whether the same animals forage daily in the same areas or whether they move from one area to another, perhaps as a result of opportunistic feeding events. If omilu do show fidelity to a home range, neither the size of the range or duration of fidelity to that range are known.

## 2. Methods and study area

### 2.1. Study area

The patch reef surrounding Coconut Island in Kaneohe Bay, Oahu, has an area of 137 000 m<sup>2</sup>, with a reef wall perimeter of about 2.4 km. The coral reef wall descends steeply to a

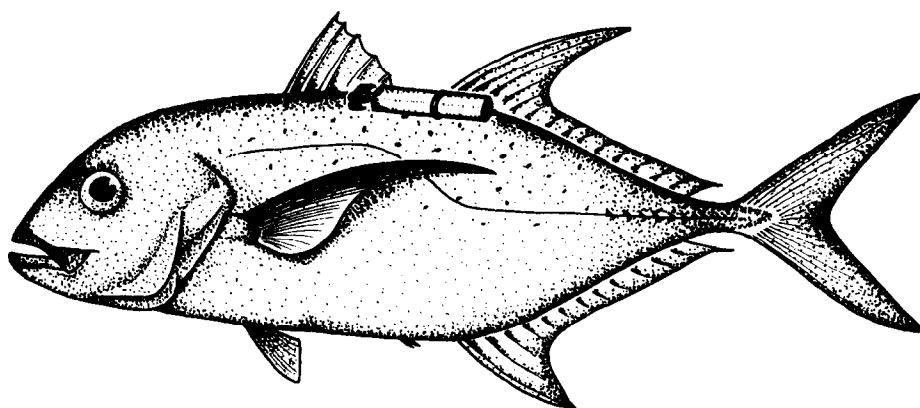


Fig. 1. External attachment of transmitter showing typical relative size.

mud and silt bay floor which is about 13 m deep. The top of the reef flat is comprised of sand and coral rubble and is covered by water depths between about 0.25 and 1.5 m, with a few deeper pools and trenches. The nearest adjacent reef is about 30 m away across a 13 m deep channel. The Coconut Island patch reef has been a no-fishing conservation zone for over 30 years, with the no-fishing zone extending 25 feet seaward from the reef perimeter. Animals moving within the confines of this area live in a virtually undisturbed environment.

## 2.2. Sonic tracking

Animals used in the tracking studies were caught either by pole-and-line or with traps at various locations around the Coconut Island patch reef. Immediately upon capture, each fish was transferred (either by net or by transfer tank) to a circular holding tank (3.0 m diameter, 1.0 m deep) where it was held for a few days to ensure it was not injured during capture. Following this observation period, a transmitter was attached to the fish and it was released at precisely the same location and time of day at which it was captured.

Sonic transmitters (Vemco, Halifax, N.S.) with individualized frequencies ranging between 50 KHz and 76 KHz were attached to the dorsal surfaces of animals anesthetized with a  $0.75 \text{ g l}^{-1}$  solution of MS-222. The cylindrical transmitters (0.8 cm diameter, 3.0 cm long), with a battery life of about 19 days, were attached to the fish with thin, 0.28 cm wide nylon straps ('cable ties'). These straps were installed by passing a 0.3 cm OD hypodermic needle completely through the dorsal musculature about 1.5 cm below the dorsal surface of the fish, inserting the tip of the strap into the tip of the needle and then retracting the needle. In this way the strap could be pulled completely through the fish. The strap was then passed through a ring on the transmitter and cinched down, forming a complete loop. In the same way, a second strap was placed halfway along the length of the transmitter to stop it from wobbling as the fish swam. When in place, the transmitter lay snugly against the side of the first dorsal fin (Fig. 1).

Following surgery, the fish was revived in a transfer tank containing clean seawater, taken to the point of original capture and released. Tracking commenced at this time. Tracking was conducted from a 5.5 m skiff equipped with a directional hydrophone, out-

board motor and navigational and communications equipment. The location of the fish was recorded every 15 min using visual compass fixes on known landmarks. More frequent positional fixes were recorded if the animal showed a distinct change in direction or speed of movement. These tracking methods have been described in detail elsewhere (Holland et al., 1992).

The movements of the fish were analyzed with a grid-square technique (Winter and Ross, 1982; Holland et al., 1993a; Holland et al., 1993b) which compiles the number of times a fish visits a particular grid cell during the track period, thereby displaying the extent of each animal's movements and highlighting areas most frequently visited. Activity rates for each fish were calculated as the linear distances travelled during sonic tracking divided by the time (duration) of the tracking session. The total linear amount of reef face utilized by each fish was defined as the distance between the most distant points along the reef visited by each fish (regardless of the frequency of the visits) during the entire track. This distance included the length of the sides of any pools or depressions in the reef flat visited by the tracked animals.

### 2.3. Tag-and-release and recapture

Fish were captured by pole-and-line fishing or by traps set around the Coconut Island reef. The fork length of each fish was measured on a foam-padded tagging board, and a serially numbered, 8.0 cm plastic tag with a barbed nylon tip (Hallprint, South Australia) was inserted into the dorsal musculature about midway along the left side of the fish. The fish was then immediately released at the site of capture. Only fish with FL  $\geq$  15 cm were tagged. Each tag carried a reward notice and telephone number. A telephone answering machine with pre-recorded information about the reward (a gift certificate at a fishing tackle shop) and instructions for leaving information ensured that callers would always get an answer when calling the telephone phone number listed on the tag.

Twenty-five *C. melampygus* of the same size as those tagged in the field were tagged and kept in captivity for 1 year. They were used to monitor tagging-related mortality, tag-shedding rates and the status of the tag wound, and to observe the overall condition of tagged animals.

## 3. Results

### 3.1. Tracking studies

Five omilu were tracked for up to 120 h (Table 1), with tracking sessions occurring over periods of up to 18 days. All the tracked fish displayed the same general behavior pattern. Daytime behavior involved patrolling back and forth along the face of the patch reef wall, with each fish often reversing direction at the same point on the reef. This patrolling pattern was frequently interrupted when the fish reached certain areas, such as indentations in the reef contour or deeper pools on the reef flat, where the fish would sometimes remain for prolonged periods before returning to patrolling the reef face. When in the patrolling mode, the fish would often swim at constant speeds for several hundred meters. Similar

Table 1  
Summary of tracking data from five *C. melampygus* around Coconut Island

Fish no.	Fork length (cm)	Track duration (hrs)	Activity rates (km h <sup>-1</sup> )		Linear reef utilized (m)
			Day	Night	
1	50.7	26	0.51	0.24	6242
2	44.0	120	0.20	0.16	4408
3	43.9	50	0.64	0.30	4730
4	39.2	72	0.19	0.10	3251
5	73.0	71	0.34	0.18	4332
		Mean ± 1SD	0.38 ± 0.17	0.20 ± 0.07	4593 ± 963

directed swimming movements were displayed when the fish were moving to or from their nighttime ranges. While three of the fish confined their daytime movements to the Coconut Island patch reef, two fish made brief excursions to sections of adjacent reefs before returning to Coconut Island. The mean total linear reef face utilized by the five fish was 4593 m (SD 963.5; Table 1).

Nighttime movements were less extensive than daytime movements, but the animals were by no means stationary during darkness. Rather, they often moved rapidly between several small sections of the reef (each about 25 m long), where they subsequently became quiescent, often spending over an hour at each site. The resultant nighttime activity rates are about 50% lower than the daytime rates (Table 1).

A remarkable aspect of the nighttime movements was that at sunset every night, all five fish went to exactly the same area of the Coconut Island reef (the north side of the patch reef and the facing wall of the adjacent patch reef). After spending nighttime hours in this northern location, they all returned to their daytime ranges around daybreak. This pattern was displayed by all the fish even though the tracks were spread over several months and the individual fish were initially captured on different parts of the Coconut Island reef. The movement patterns of three of the five tracked omilu are described below to illustrate the general behavioral patterns described above. The other two fish displayed very similar behavior.

Omilu No. 1. This fish was released at 10:20 h at the entrance to the Coconut Island laboratory lagoon where it had been captured at the same time of day, 5 days previously. The fish was initially tracked for 2 h, after which it was lost because of equipment failure. Fortunately, it was re-acquired 3 days later in the same location on the reef and tracking was resumed. This fish displayed the 'patrolling' pattern of movement that was subsequently repeated by all the other tracked omilu. Most movements were back and forth along the southern edge of the Coconut Island reef centered around the lagoon entrance. However, at 12:35 h it crossed the open water to the bay shore and spent 35 min patrolling 250 m of the fringing reef around Lilipuna pier before returning to Coconut Island reef (Fig. 2(a)).

At sunset, the fish moved to the north edge of the Coconut Island reef and spent almost the entire night shuttling between this area and the small patch reef 30 m further north (Fig. 2(b)). This behavior in this precise nighttime area was repeated by all the tracked fish. Just at first light, the fish made a rapid traverse to its daytime range on the south reef face, where it patrolled back and forth during sunrise. At 08:15 h (1.5 h after sunrise) the

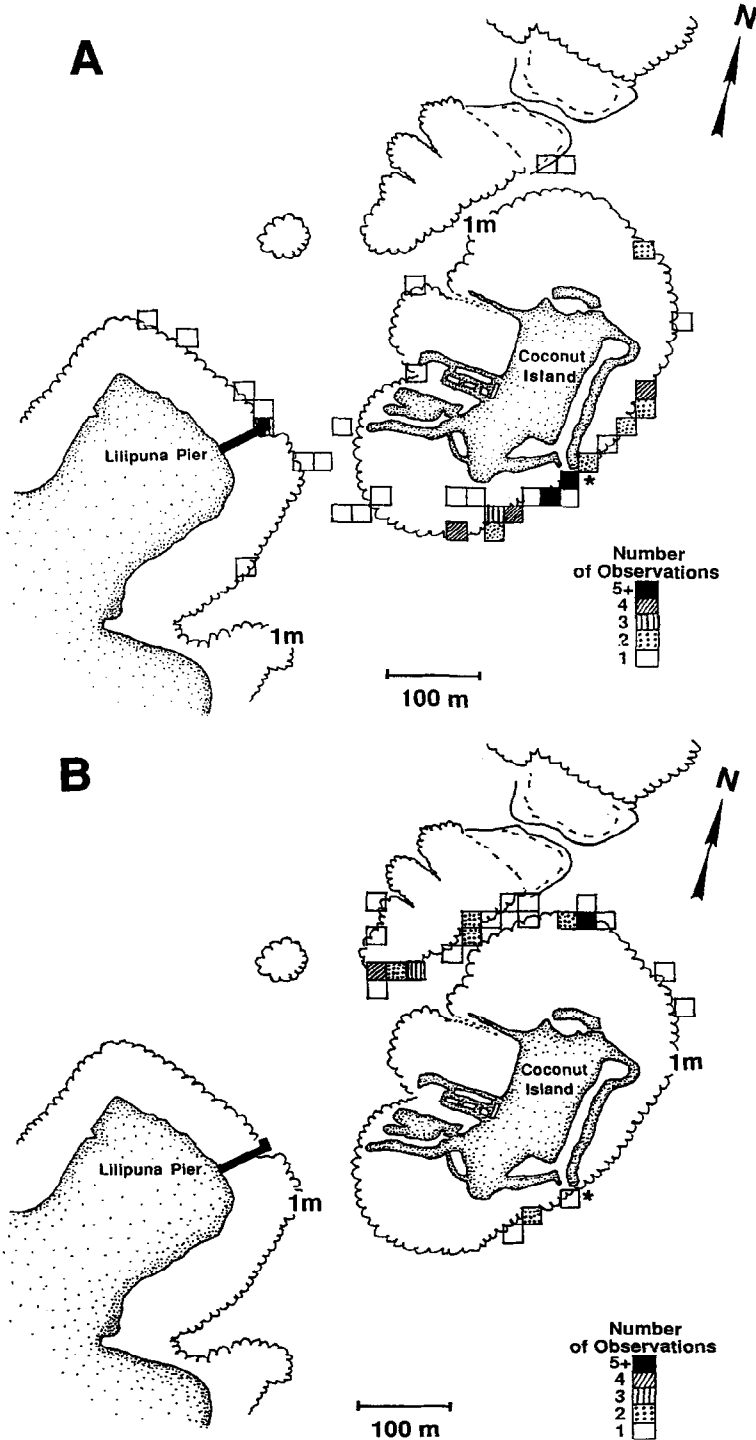


Fig. 2. (a) Daytime movements of omilu No. 1. Most activity occurred along the south side of the island, with excursions to the fringing reef near Lilipuna pier. (b) Nighttime movements of omilu No. 1. Activity is shifted to the north end of Coconut Island and the adjacent patch reef. Grid squares are 20 m × 20 m, patch reef outlines are 1 m isobaths. In this figure, and in Figs. 3 and 4, an asterisk (\*) indicates the site of initial capture and subsequent release and the start of the track.

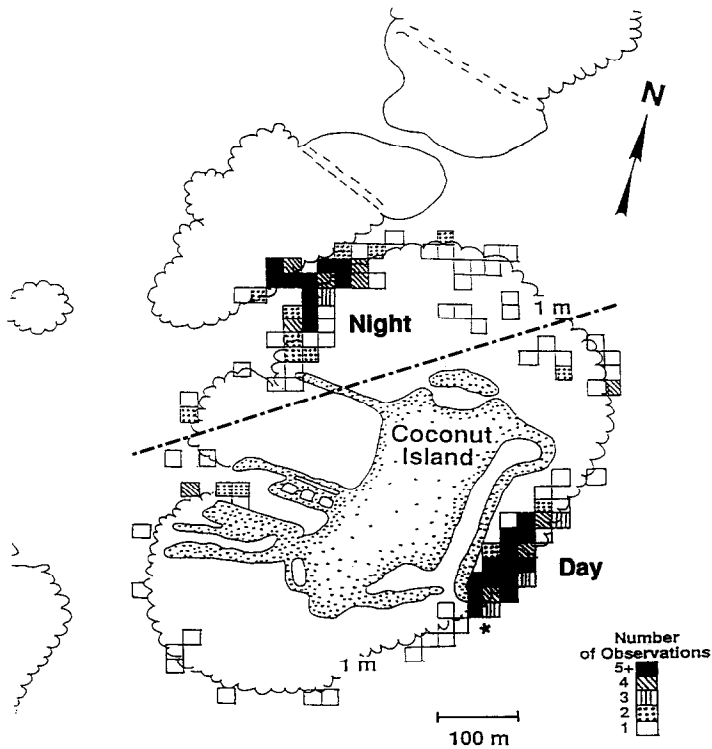


Fig. 3. Daytime and nighttime range of omilu No. 2. The data shown are from the entire 120 h of the track, which occurred over a span of 18 days. The two areas inhabited most frequently show the distinct daytime and nighttime preferred habitats. Grid squares are 20 m  $\times$  20 m.

fish again moved to the Lilipuna fringing reef, where it patrolled for 45 min before returning to Coconut Island. The track was voluntarily suspended after 24 h with the fish in the middle of its daytime Coconut Island range.

Six weeks after the track was terminated, this fish was sighted at Lilipuna dock at 08:40 h looking very healthy and with the transmitter still in place. This sighting strongly suggests that the pattern and timing of the movements observed during the tracking period were representative of the longer-term behavioral repertoire of this fish. The sighting also indicated that the dorsal placement of the transmitter is viable for extended periods of time.

**Omilu No. 2.** This fish was tracked continuously for 48 h, followed by three additional 24-h periods spanning a total of 18 days for the four periods. This fish had a strong daytime affinity for a large pool in the reef flat near the entrance to the laboratory lagoon. This pool was very close to the point of initial capture, and the fish sought refuge here for several hours immediately upon release. As with omilu No. 1, this fish spent each night on the north side of the reef, but every morning started the move into the daytime range by visiting the same reef flat pool for several hours (Fig. 3). On each of the five mornings (spanning 18 days) that this fish was tracked, it arrived in the pool within a minute or two of 06:15 h.

**Omilu No 5.** This was the largest fish tracked (73 cm FL, approximately 8.1 kg), and is close to the maximum size reported for this species in Hawaii (Sudekum et al., 1991). This

fish was tracked on five occasions spanning 13 days, including an initial continuous 24-h period. Although this fish was caught and released on the opposite (west) side of the reef from the other animals, omilu No. 5 behaved very much like the other tracked fish and spent most daytime hours patrolling the south side of the reef (Fig. 4(a)) and moved to the north side of the reef at night (Fig. 4(b)). This pattern was repeated throughout the 13-day duration of the track.

### 3.2. Tag-and-release studies

Four hundred and ten omilu, ranging in size from 17 cm to 73 cm FL, were tagged and released around the Coconut Island patch reef between August 1991 and December 1994. Of these, 85 (20.7%) were recaptured, and 11 were recaptured twice or more. Of the total of 96 recaptures (including the multiple recaptures), 66% were by research staff and 34% were by members of the general public. Time at liberty ranged from 4 to 454 days (mean 135.7; SD 120.7).

Recapture sites of all fish originally captured and released at Coconut Island are shown in Fig. 5. Four animals were recaptured at distant locations around the Oahu shoreline, but the remainder were recaptured at various locations around Kaneohe Bay. Most of the recaptures (75.5%) were within 0.5 km of the release site (Fig. 6), and 67% occurred on some part of the Coconut Island patch reef. There was no correlation between time at liberty and distance between release and recapture sites (Fig. 7). In fact, the fish with the longest time at liberty (454 days) was recaptured within 0.7 km of its point of release, whereas the fish that was recaptured at the greatest distance (72.4 km) was recaptured after 57 days.

## 4. Discussion

### 4.1. Tagging and tracking methodology

The multi-day sonic tracks obtained from these fish, the similarity of behavior among tracks, and the healthy appearance and normal behavior of instrumented fish when they were resighted or recaptured after many weeks at liberty all indicate that external transmitter attachment is a suitable technique for this species. This is fortunate because, compared with other species such as goatfish or salmonids in which transmitters were placed in the gut cavity (Mortensen, 1990; Holland et al., 1993a), omilu have very small gut cavities, thereby precluding the internal placement of transmitters.

Dart tags worked extremely well with this species. None of the jacks kept in captivity died as a result of the tagging procedure and the overall condition of the animals was very good. They fed well throughout their stay in captivity and grew at rates very similar to those of recaptured wild fish. No tags were shed by captive fish during the year-long observation period, even though the barbs of some tags were improperly placed very superficially under the skin. Some fish showed low levels of ulceration where the tag entered the skin, and a similar condition was apparent in some fish recaptured from the field. Anecdotal observations suggested that tags placed deeply into the musculature caused less irritation than more

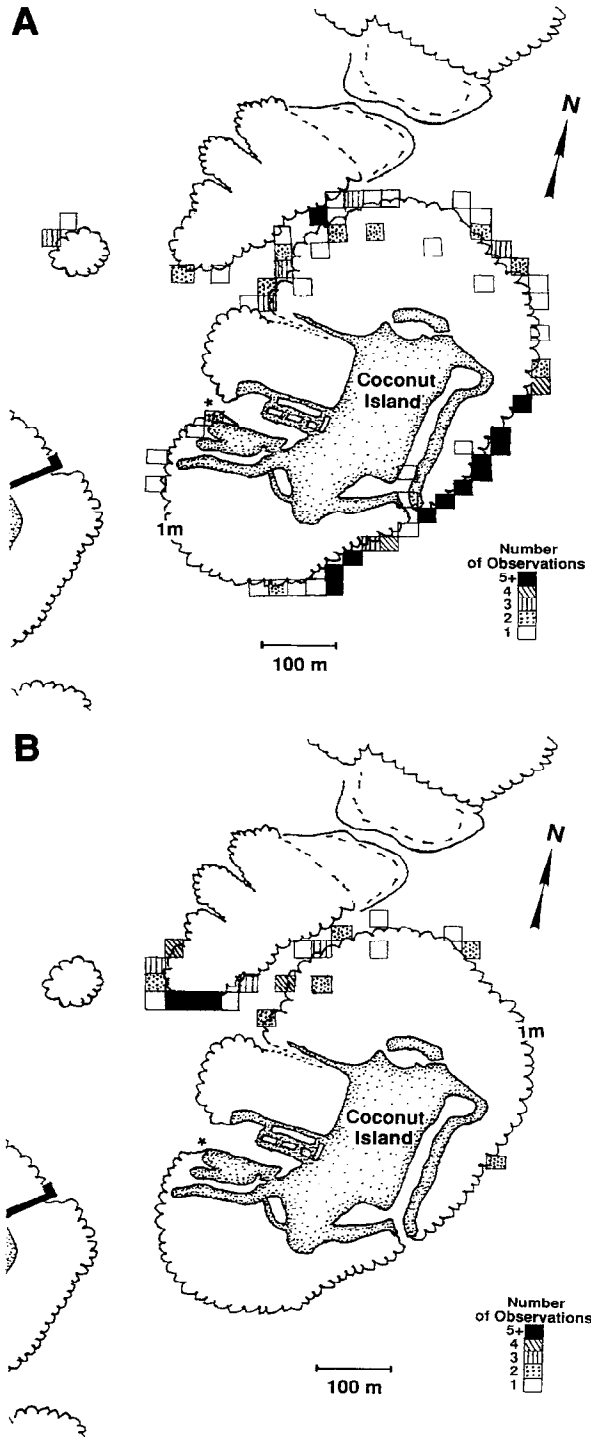


Fig. 4. (a) Daytime movements of omilu No. 5. The data shown cover the entire 13-day track. This fish spent most daytime hours on the south reef face, but was more wide ranging than most of the other tracked fish. (b) Nighttime movements of omilu No. 5. The restricted range on the north side of the island is in contrast to the wider daytime movements, but very similar in both extent and location to all the other tracked fish.

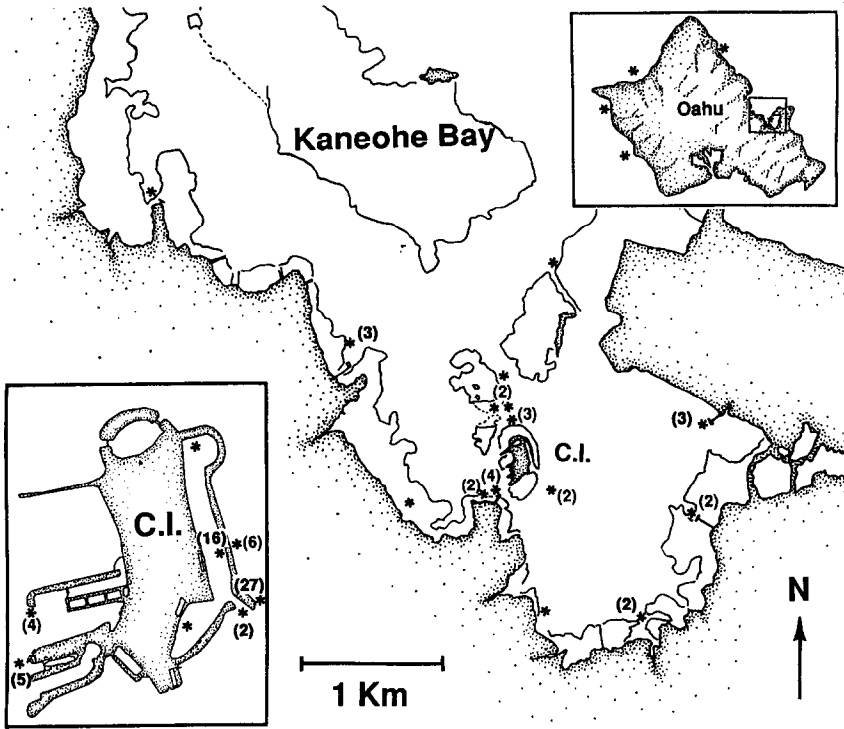


Fig. 5. Recapture sites of omilu originally tagged and released at Coconut Island (C.I.). Each asterisk represents a recaptured fish; numbers in parentheses indicate multiple recaptures at a given location. The square within the inset of the island of Oahu denotes the Kaneohe Bay study area. Contours within Kaneohe Bay are 1 m isobath.

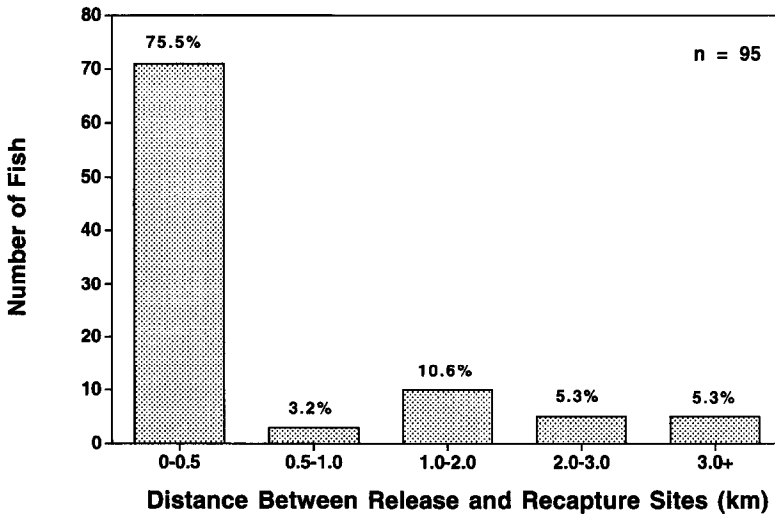


Fig. 6. Frequency of omilu recaptured at various distances from the point of original release at Coconut Island.

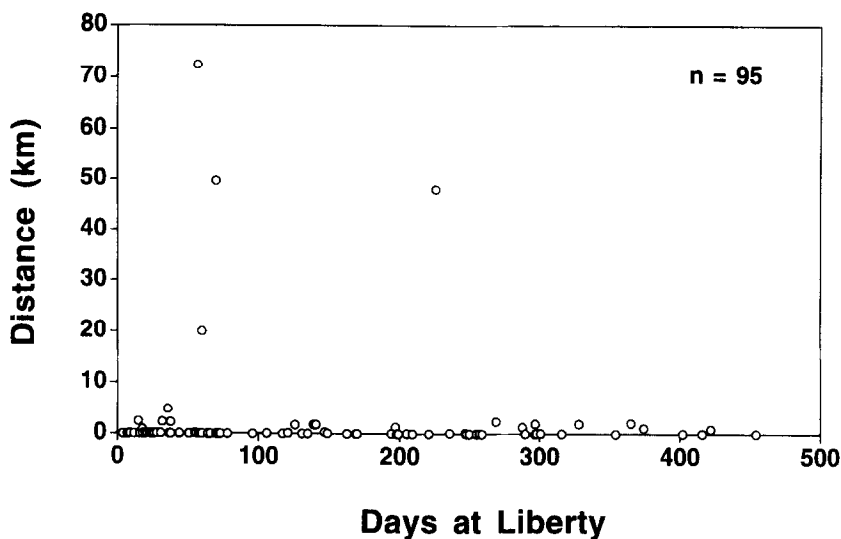


Fig. 7. Distance between original release site and location of recapture vs. days at liberty. Most omilu were caught within 1 km of the release site regardless of time at liberty.

superficially imbedded tags, possibly because the shorter exposed sections of the deeper tags vibrated less during swimming.

#### 4.2. Daily movement patterns

The tracked omilu displayed well-defined home ranges and predictable diel movements between separate daytime and nighttime sections of the home range. These are behavioral characteristics that have been observed in several other reef fish species. In fact, as more fish species are studied, this pattern becomes more apparent (Hobson, 1965). For some species, the daily migrations are movements from daytime refuges to nocturnal foraging grounds; for other species, the schedule is the opposite. The nocturnal feeding regime is exemplified by juvenile grunts (*Haemulon flavolineatum*) which move along consistent paths to feed in eelgrass beds at night (Helfman and Schultz, 1984), and in Hawaii, white goatfishes (*Mulloides flavolineatus*) regularly return to fixed schooling locations each day, but each night individual animals travel to their own geographically consistent feeding grounds which may be up to 450 m from the daytime refuging area (Holland et al., 1993a).

Although the five omilu tracked in this study were observed at different times of the year, were of different sizes and were captured at different locations, they all moved to the north side of the Coconut Island reef every night. This would suggest that there is a nightly aggregation of this species in this location. Such an aggregation is unlikely to serve a feeding function because gut analyses (Randall, 1980; Sudekum et al., 1991) indicate that omilu are daytime and crepuscular feeders. This was corroborated in the present study, in which all of our hook-and-line captures (and those of the general public who recaptured our marked fish) occurred during daytime.

Another possible explanation of the nightly movements is that they serve an anti-predation function. Many diurnally active species move to nighttime refuge areas to avoid predation

(e.g. striped parrotfish, *Scarus croicensis*; Ogden and Buckman, 1973), but in these cases the animals usually become quiescent and hide in holes and crevices. However, the omilu tracked in this study moved around at night, albeit at a slower rate than during the day, making predation avoidance an unlikely explanation for the behavior. Furthermore, there are no obvious qualitative differences between the reef areas used by day and by night which would make the nighttime area more suitable as a refuge.

It is possible that nighttime movement to the north reef area is important to some aspect of the social organization of the Coconut Island omilu population. The area may have become a traditional nighttime aggregating area for these fish, the location of which may be socially transmitted across age classes, as has been indicated for the migratory pathways of grunts (Helfman and Schultz, 1984). Small schools of omilu comprised of at least two different year classes are often observed around Coconut Island, and this could serve as a mechanism for social transmission of traditional movement patterns within the home range. An analogous phenomenon, and equally difficult to explain, might be the diurnal aggregations of sub-adult and adult hammerhead sharks (*Sphyrna lewini*) around seamounts in the Gulf of California (Klimley and Nelson, 1981). These aggregations do not appear to serve reproductive, feeding or anti-predation functions, and yet occur on a daily basis.

#### 4.3. Fishery conservation zones and management

Both the tracking data and the tag-and-recapture data indicate that omilu are strongly site-attached to home ranges. The well-defined movement patterns of the tracked fish, combined with repeated subsequent sightings of some of these same fish, indicate that their home range is very stable for periods of at least a few weeks. Additionally, the tag-and-recapture data indicate that, for the majority of individuals, fidelity to the general area is maintained for periods of at least a year. Sudekum et al. (1991) estimated that omilu reach sexual maturity at 2 years of age, at 35 cm SL (36.5 cm FL), indicating that the sonic tracking data were acquired entirely from sexually mature animals, whereas 14% of the fish captured and released with identification tags were large enough to be sexually mature. Thus, the sexually mature adults are as strongly site-attached as the sub-adults that comprise most of the tag-and-release data base. Given the high fishing pressure that exists in adjacent parts of Kaneohe Bay, the very existence of these large individuals strongly suggests that, as indicated by their tracked movements, they have spent most of their lives within the confines of the Coconut Island conservation zone.

The limited range of dispersal of recaptured omilu (75.5% within 0.5 km of the release site, 89.3% within 2.0 km) and the strong site fidelity displayed by the tracked fish both suggest that the dispersal of omilu is much less than might have been predicted for a highly mobile, piscivorous species. The total lengths of reef face used by the five tracked fish were quite similar and modest (average 4593 m) in size. These results have positive implications for the effectiveness of harvest refugia for this species, because the rate of transfer of fish across the refuge boundary has a major influence on the results of models estimating refuge effectiveness; the higher the transfer rate, the less protection is afforded to the population. Our results indicate that omilu derive significant protection from the no-fishing refuge at the Coconut Island patch reef.

Further, the effectiveness of refugia increases if species become sexually mature while under the protection of the refuge (Polacheck, 1990; Carr and Reed, 1993; DeMartini, 1993). Assuming 36.5 cm FL as size at first sexual maturity (Sudekum et al., 1991), the current data indicate that omilu show sufficiently slow dispersal rates that many juvenile omilu (Year 1) recruiting to the Coconut Island reef would become sexually mature while within the limits of the refuge. This would indicate that even quite small fisheries conservation zones (e.g. 5 km of reef face) could be an effective management option for increasing the spawning biomass of this species. The limited range of movement of the sexually mature adults indicates that refugia of this modest size would give significant protection to *C. melampygyus* broodstock.

### Acknowledgements

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