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Home range, movement rates, and habitat use of queen conch, *Strombus gigas*, in St. John, U.S. Virgin Islands

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Abstract - **The queen conch, *Strombus gigas*, is a highly valued fishery resource in the Caribbean basin, historically second only to the spiny lobster. Currently listed in Appendix II of CITES, historical surveys from the U.S. Virgin Islands have documented wide-spread reductions in population densities. Habitat use and movement patterns of queen conch differ by size and maturity status, making it important to identify areas and habitat types that can play a role in the recovery of this species. We tracked long-term movements and spatial distributions of conch in St. John, USVI, using visual surveys coupled with mark-and-recapture techniques. Juvenile conch exhibited the smallest mean home range (95% contour) and core area (50% contour) at 8470 m^2 and 2083 m^2, respectively, but had the largest aggregate home range (115,410 m^2) and aggregate core area (55,055 m^2). Transitional conch had the largest mean home range and core area at 18,203 m^2 and 4944 m^2, respectively, with an aggregate home range and core area of 113,147 m^2 and 59,067 m^2. Adults had an aggregate home range and core area of 65,045 m^2 and 29,178 m^2, with a mean home range and core area of 14,987 m^2 and 3929 m^2. Adults exhibited the highest daily movement rate at 11.36 m per day, with juvenile and transitional conch having similar rates of 4.66 m per day and 3.44 m per day, respectively. Multiple recapture events of tagged conch showed an ontogenetic shift in habitat use as maturing individuals moved from shallow seagrass habitats into deeper-water macroalgae plains.**

Keywords: **Core area, habitat use, home range, site fidelity, spatial distribution.**

Introduction

For resource managers to be most effective, they must understand the ecological interactions of their managed species' life histories. Necessary ecological data include species- and life stage-specific habitat usage patterns, habitat characteristics, home range sizes, site fidelity, and seasonal and reproductive movements (Glazer and Delgado 2006). Such information is critical when developing spatial management policies and identifying essential fish habitat for fisheries.

The queen conch, *Strombus gigas*, is a large marine gastropod ranging from the Gulf of Mexico and southern Florida throughout the Caribbean to South America. In spite of federal, territorial, and region-wide management efforts and international trade restrictions under the Convention on International Trade in Endangered Species (CITES), population levels remain low. As an important commercial species throughout its distribution, many studies have been devoted to the biology, ecology, and management of queen conch (*e.g.* Randall 1964, Hesse 1979, Brownell and Stevely 1981, Wood and Olsen 1983, Appeldoorn 1984, Stoner et al. 1988, Stoner and Sandt 1991, Davis and Stoner 1994).

Queen conch habitat utilization patterns can vary dramatically with their size and life history stage and generally follow similar, but not identical, patterns throughout their range. Managers, therefore, must identify habitat and oceanographic characteristics of the management area that may contribute to or inhibit the large-scale recovery of this species. Region-wide differences in habitat selection are illustrated by the diversity of habitat types where queen conch are most commonly found. For example, small to mid-range juveniles (~75-150 mm shell length) in the Bahamas were most commonly found in historic nursery grounds characterized by mixed intermediate density seagrasses (specifically turtle grass, *Thalassia testudinum*) and macroalgae with conch shell debris and frequent tidal flushing (Stoner and Waite 1990, Stoner et al. 1996, Stoner 1997, Stoner 2003). Juvenile conch were more abundant in coral rubble compared to seagrass, sand, and hard bottom habitats in the U.S.

Virgin Islands (Randall 1964) and Puerto Rico (Torres Rosado 1987), but were more closely associated with *T. testudinum* in the Turks and Caicos Islands (Hesse 1979), Venezuela (Weil and Laughlin 1984), and Cuba (Alcolado 1976).

Reports of movement rates and home range sizes are limited, but vary by locality and life stage. In the Turks and Caicos, Hesse (1979) reported a home range of 1000 m^2 for small juveniles (10-13 cm) and from 2500-5000 m^2 for larger juveniles (13-16 cm), but was unable to determine significant home ranges for larger juveniles and adult conch in the same area. Studies utilizing acoustic telemetry in Florida identified mean adult queen conch home ranges of 59,800 m^2 (Glazer et al. 2003) and 27,705 m^2 (Delgado and Glazer 2007). Increasing home range size and movement rates with growth may indicate a shift in habitat requirements, such as availability of food resources and shelter, leading individuals to utilize a wider variety of bottom types (Randall 1964, Stoner and Sandt 1992).

Location-specific data on ecological processes for demersal organisms with highly variable life histories, such as the queen conch, is critical to making informed management decisions. Though several studies specific to the conch populations of the U.S. Virgin Islands have reported habitat-based abundance information, there is limited data from this locale on home range sizes and locations, habitat utilization, or patterns and rates of movement. The purpose of this research was to identify preferred habitats, define home range parameters, and document movement patterns for queen conch populations on the southern coast of St. John.

Materials And Methods

Visual surveys and mark-and-recapture studies were conducted in Fish Bay, St. John, U.S. Virgin Islands (Fig. 1). Fish Bay, situated along the southern coast, is a large bay (474,107 m^2) with unrestricted access to open water and large areas of known conch habitat. Of the total area of benthic habitat in the bay, 17% (78,708 m^2) was classified as continuous seagrass, 15% (73,615 m^2) as patchy seagrass, 13% (61,892 m^2) as patchy macroalgae, 15% (70,612 m^2) as sand, 19% (89,653 m^2) as colonized bedrock or pavement, 18% (86,610 m^2) as linear reef, and 3% (13,017 m^2) as mangrove (as defined by NOAA NCCOS maps, Kendall et al. 2001). The shoreline is primarily mangrove habitat with houses built landward and extending up mountain slopes surrounding the bay. The amount and intensity of fishing activity is largely unknown, but the continued presence of newly-fished shells along the shoreline indicates consistent pressure on near-shore juvenile conch (J. Doerr, unpublished data).

Three field expeditions per year were completed during a three-year period beginning in May 2005, each lasting from 10-14 days. During each sampling period, we used snorkeling to visually survey as much of Fish Bay as possible for the presence of conch. Although we attempted to completely cover each habitat type and depth strata on each trip, surveys were limited to snorkelable depths of 10 m or less. At each conch's location we measured dissolved oxygen, salinity, depth, water temperature, air temperature, and wind speed. Spatial coordinates were collected using a portable wide area augmentation system-enabled global positioning system (WAAS GPS) unit. Siphonal (shell) length and lip thickness were measured with vernier calipers, and conch were categorized as either juvenile or adult using size limits established under the current USVI fishing regulation metrics based loosely on size at first maturity (229 mm minimum shell length or 9.5 mm minimum lip thickness).

Upon initial capture each conch was tagged with a uniquely numbered disk or T-bar anchor tag (Floy® Tag) by drilling a small hole adjacent to the edge of the lip of the shell and injecting the tag through the hole. A small drop of super glue was added to secure the tag in place. The conch subsequently deposited shell material over the drilled hole, permanently integrating the tag into the shell (<6 weeks, pers. obs.). NOAA NCCOS benthic habitat maps were used at a gross scale (1 acre minimum mapping unit) to illustrate habitat types across Fish Bay. High resolution

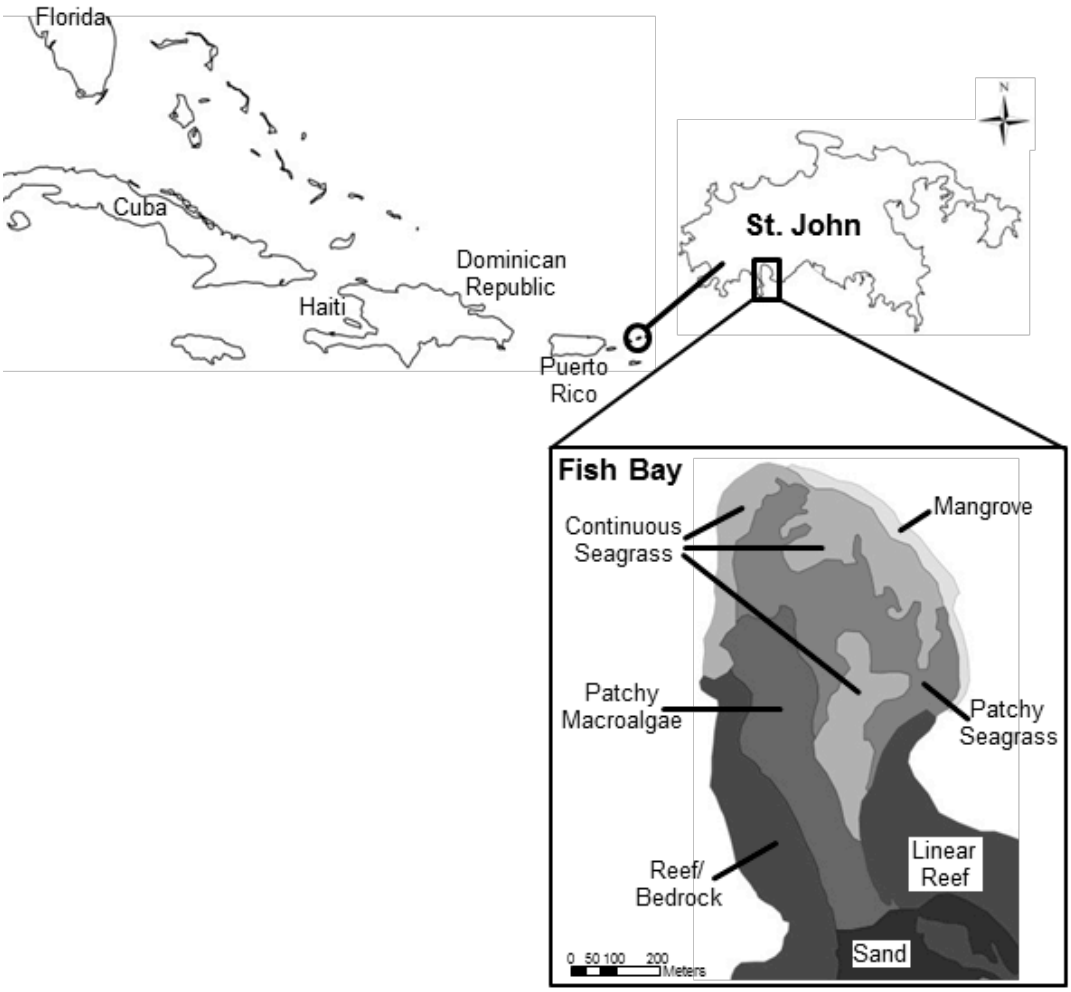

Fig. 1. Map of St. John, U.S. Virgin Islands, showing the location of Fish Bay. General habitat categories are from NOAA NCCOS Biogeography Program data.

determination of habitat type at each conch's location was completed by centering a 1-m^2 quadrat over the conch and visually identifying all benthic organisms and assessing the number of squares containing each organism or substrate type. Only the dominant species are reported here to facilitate life stage comparisons.

Spatial analysis was a sequential process. Locations of tagged conch were overlaid onto categorized benthic habitat maps (Kendall et al. 2001) in ArcView 3.1 (ESRI) to examine distributions by nominal habitat types. Depth-at-location measurements for all conch, tagged or recaptured, were added to the GIS project and depth contours were digitized. The Animal Movement Analysis Extension (AMAE) developed by Hooge and Eichenlaub (2000) was used to first evaluate site fidelity, and then calculate individual home range sizes and estimate aggregate home ranges for the different life stages. The AMAE uses known locations to determine the degree of site fidelity by generating random walk simulations and comparing the simulated movement patterns to the actual movement of the conch. These individual movement paths were tested for dispersion (the mean squared distance from the center of activity) and linearity (directed movement), and

each conch was rated as having either weak or strong site fidelity. Input data throughout the analysis were limited to conch with at least four independent capture occasions (initial capture plus three recaptures) as suggested by Glazer et al. (2003).

Probability contours of 95% and 50% were generated using a fixed kernel model with least squares cross validation, considered to be the most robust method for home range determination because it yields the most accurate estimates with the smallest variances (Powell 2000). The 95% location contour, referred to as home range, encompasses the area where there is a 95% probability that the individual tagged conch will be found (Glazer et al. 2003). The 50% contour, referred to as the core area, identifies the area where each individual spends most of its time (Hooge et al. 2001). Individual home range estimates were derived to map population distributions within Fish Bay. The mean home range of each life stage was determined from the 95% and 50% contours delineated for each individual conch, whereas the spatial extent of each aggregate home range was estimated from the union of all individual home ranges for that life stage. Aggregate home ranges and core areas were calculated for conch that exhibited both weak and strong site fidelity. This same group of conch was also used to derive minimum movement rates in meters per day, calculated as the linear distance between consecutive recapture positions divided by the number of days at large (Glazer et al. 2003). Only individual conch that exhibited strong site fidelity were subsequently used to determine the mean home range for each life stage (Hooge et al. 2001). We used t-tests to examine differences between mean home range sizes, core areas, and rates of movement between age categories of conch, applying the Bonferroni correction to account for multiple testing.

During the analysis, a subset of conch was identified that were initially captured and tagged as juveniles, but subsequently grew into the adult size class during the study. These animals were termed "transitionals" and their home ranges, core areas, and movement rates were compared to those of juveniles and adults. Length measurements for five of the transitional conch were missing from their last recapture occasion. Size-specific growth rates were calculated as change in shell length over time for Fish Bay conch and these factors were applied to estimate final lengths for these individuals. Estimated lengths were used only to confirm that these conch attained adult size during the study.

Results

Over a 3-year period we tagged 1728 conch in Fish Bay (1486 juveniles (47-226 mm) and 242 adults (230-290 mm)). There were 77 conch initially tagged as juveniles that grew to adult size during the three years of this study and were categorized as transitionals. Quadrat data showed that juvenile conch were found primarily at locations with mixed seagrasses (manatee grass, *Syringodium filiforme*, and *T. testudinum*) and macroalgae (*Laurencia spp*., *Halimeda spp*., and *Penicillus spp*.) and were typically found in shallower waters (0.5-4 m) (J. Doerr, unpublished manuscript). Adult conch were in deeper areas (from 3-8 m) where seagrasses were less dense and macroalgal species such as *Dictyota spp*., *Ceramium spp*., *Halimeda spp*., and *Avrainvillea spp*. were more abundant (J. Doerr, unpublished manuscript).

Of all conch tagged in Fish Bay, approximately 24% were recaptured at least once. The subset with sufficient recaptures to meet the assumptions of the model (captured on at least four independent occasions), was composed of 55 juveniles, 25 transitional conch, and 17 adults. These individuals were used to determine the aggregate home range and core area sizes for each life history stage (Table 1). Of this subset, only conch that exhibited high site fidelity (39 juveniles, 19 transitionals, and nine adults) were used to calculate mean home ranges and core areas (Table 1).

Juvenile conch were tracked for an average of 220 days (SE = 21.78) from a minimum of three days to a maximum of 550 days. Transitional conch were tracked the longest, with a mean of 299 days (SE = 31.61), and a

TABLE 1. Mean individual and aggregate home ranges calculated for different size classes of conch (juvenile, transitional, and adult) with a minimum of four independent capture occasions in Fish Bay, U.S. Virgin Islands. N indicates the number of conch included in each analysis of home range. Home range sizes are listed in m2, movement rates are in m per day. Standard errors for home range size estimates are stated in the text.

Age Category	N	Daily Movement Rate	Aggregate Home Range (95%)	Aggregate Core Area (50%)	N	Mean Home Range (95%)	Mean Core Area (50%)
Juvenile	55	4.66	115,410	55,055	39	8470	2083
Transitional	25	3.44	113,147	59,067	19	18,203	4944
Adult	17	11.36	65,045	29,178	9	14,987	3929

minimum and maximum of 98 and 550 days, respectively. Adult conch had the shortest mean tracking period at 58 days (SE = 13.58), with a minimum of four and a maximum of 180 days.

Compared with the other life history stages, juvenile conch had the smallest mean home range of 8470 m^2 (SE = 1527.64) and mean core area of 2083 m^2 (SE = 394.58). In contrast, juveniles had the largest aggregate home range at 115,410 m^2 (95% contour), with a core area of 55,055 m^2 (50% contour), encompassing a range of habitat types and depth zones (Fig. 2). The mean linear rate of movement for juveniles was 4.66 m per day (SE = 0.70) with a minimum rate of 0.16 m per day and a maximum rate of 29.95 m per day.

Transitional conch had the largest mean home range (18,203 m^2, SE = 3348.97) and core area (4944 m^2, SE = 1035.24), with an aggregate home range of 113,147 m^2 and core area of 59,067 m^2. Transitional conch utilized shallower seagrass habitats on the east side of the bay at juvenile sizes and then moved into the deeper macroalgal plain on the west side as they matured (Fig. 2). The mean linear rate of movement for transitioning conch was 3.44 m per day (SE = 0.64) with a minimum and maximum of 0.46 and 14.27 m per day, respectively.

The mean home range for adult conch was 14,987 m^2 (SE = 6081.96) with a core area of 3929 m^2 (SE = 1757.97). Adults had the smallest aggregate home range of the three age categories at 65,045 m^2, with a core area of 29,178 m^2, and mainly utilized the deeper macroalgae sites in the western portion of the bay (Fig. 2). This group had the highest rate of linear movement at 11.36 m per day (SE = 1.57) with a minimum of 1.47 m per day and a maximum of 21.24 m per day. Due to limited sampling of known deeper water spawning sites located at or beyond the mouth of the bay, these values are intended only to elucidate habitat use and movements of adults found within the inner portion of Fish Bay, exclusive of migrations.

There was no significant difference in either mean home range ($t = 1.528$, $p = 0.163$) or mean core area size ($t = 1.590$, $p = 0.168$) between juvenile and adult conch. There was also no significant difference between transitional and adult conch in mean home range size ($t = -0.503$, $p = 0.526$) or mean core area size ($t = -0.527$, $p = 0.486$). Both mean home range ($t = -3.048$, $p = 0.007$) and core area size ($t = -3.131$, $p = 0.006$) were significantly different between the juvenile and transitional groups. Daily movement rates varied significantly between the juvenile and adult groups ($t = 6.315$, $p < 0.001$) and the transitional and adult groups ($t = 6.536$, $p < 0.001$); however, there was no difference between juvenile and transitional conch in their rate of daily movement ($t = 1.016$, $p = 0.366$).

Discussion

The different life stages of queen conch used diverse types and areal quantities of the various habitats available in Fish Bay. Juveniles generally occupied shallower seagrass habitats while adults congregated in slightly deeper waters dominated by macroalgae and sand. Only

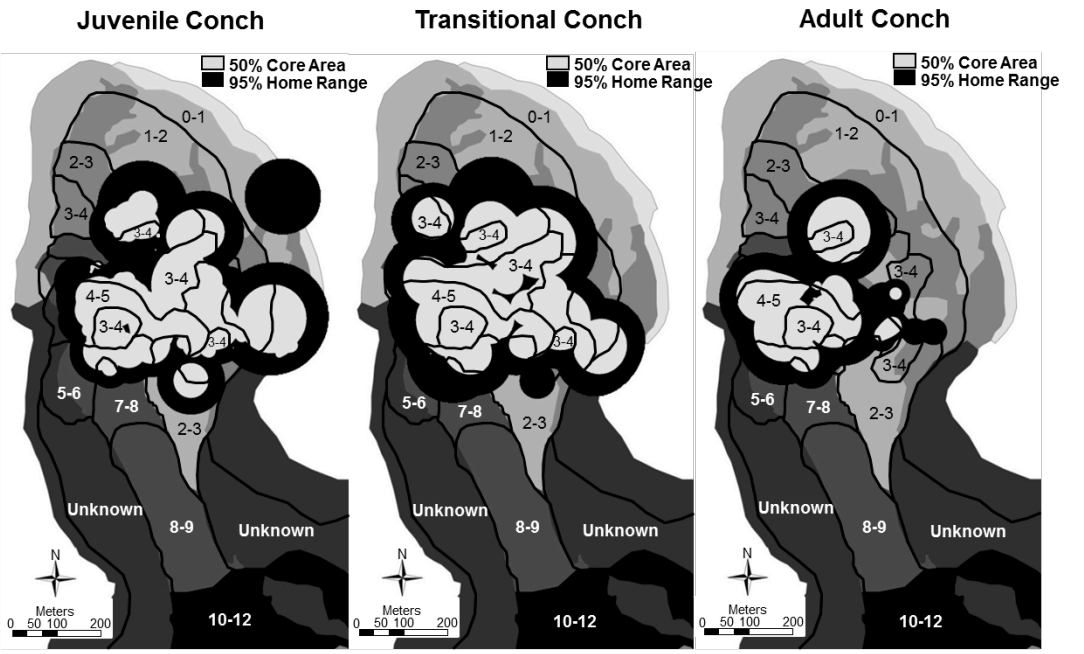

FIG. 2. Aggregate home range (95% contour) and core areas of activity (50% contour) of juvenile, transitional, and adult queen conch in Fish Bay, U.S. Virgin Islands. Habitat categories correspond to those depicted in Fig. 1; also shown are depth zones in meters.

juveniles, the life stage with the smallest mean home range and mean core area, consistently included shallow mangrove edge within their home range, typically occupying the first meter of prop root canopy (Doerr and Hill, pers. obs.). Their spatial distribution across the inner portion of the bay with localized movements within limited habitats may leave juveniles more vulnerable to reduced water quality from coastal development and shoreline fishing activity. Piles of shells from recently fished conch along mangrove beaches confirm the susceptibility of undersized conch to harvest in the artisanal fishery (J. Doerr, unpublished data).

Ontogenetic shifts in habitat use and diet are common in coral reef fishes (Eggleston 1995, Appeldoorn et al. 1997) and mobile coral reef invertebrates such as lobster (Childress and Herrnkind 1996) and small conch (Sandt and Stoner 1993). The distribution of transitional conch, encompassing much of the juvenile home range but also demonstrating a westward shift characteristic of the adult stage, indicates an ontogenetic shift in habitat utilization as maturing individuals consistently moved into deeper water habitats. The rate of movement, 3.44 m per day, and aggregate home range size, 113,147 m^2, being similar to the juveniles (4.66 m per day and 115,410 m^2), but statistically different from the adults (11.36 m per day and 65,045 m^2), may suggest that the analysis for this intermediate life stage is generally dominated by the juvenile component. The larger aggregate core area suggests that the entire population of transitional conch is associated with areas that encompass both juvenile and adult locations, and the shift to areas characteristic of the adult life stage occurs relatively quickly. Values for the mean home range and mean core area of transitional conch are approximately the sum of the adult and juvenile mean home range and core areas, demonstrating that transitional conch utilize both juvenile and adult habitat zones.

Adult conch in Fish Bay had a mean home range of 14,987 m^2, considerably smaller than the 27,705 m^2 and 59,800 m^2 reported for adults in Florida (Glazer et al. 2003, Delgado and Glazer 2007). This is at least partly a function of the

geographically limiting area of our study arena compared to the larger extent of the Keys study sites. Fish Bay is enclosed on three sides with access to deeper habitats only at the southern end. Adults are known to move progressively deeper as they mature and those in Fish Bay presumably moved out of the bay into deeper water where few recapture surveys could be conducted. This is reflected in the shorter overall tracking time (58 days) for adults than for juvenile (220 days) or transitional conch (299 days). Mature adults are also likely to have a much larger aggregate home range than reported here when migration routes, offshore habitats, and near-shore spawning grounds are considered. This study, by design, had limited sampling beyond 10 m depths and thus individual recaptures in deeper habitats and spawning grounds were insufficient to fully characterize the entire range. With the addition of long-term tracking data from continued sampling efforts, calculated estimates for aggregate home ranges would be expected to increase for this age group.

Even without including complete reproductive migrations, adults traveled the greatest distances and at greater speeds between recapture periods. The mean rate of travel, 11.36 m per day, was higher than the 1.23 m per day reported by Delgado and Glazer (2007) for conch in Florida, but substantially lower than the 50-100 m per day found by Hesse (1979) in the Turks and Caicos. Conch movements are expected to be associated with foraging, directional movement to breeding grounds, and mate location. Daily movements have been shown to be greatest in the summer (4.17 m per day) compared to spring (1.92 m per day), winter (2.10 m per day), and fall (2.32 m per day) in work in the Florida Keys, and this is suggested to be due to increased metabolic activity related to warmer temperatures and movements during breeding migrations (Glazer et al. 2003). While seasonality in our study area is likely less than in the Florida Keys, our tagging and acoustic tracking data also identify movements to deeper breeding grounds outside the mouth of the bay as the source of the higher movement rates (Doerr and Hill 2008). Adults, primarily using the deeper macroalgae and sand habitats on the west side of Fish Bay, have the smallest aggregate home range of any of the three life stages, but the proportion of mean to aggregate home range size is 0.23, indicating a much higher degree of overlap for adults in their habitat distributions. Their high movement rates indicate that they traveled constantly throughout this limited area.

Information on home ranges for juvenile conch is limited in the literature. Hesse (1979) reported home ranges of 1000 m^2 for small juveniles (10-13 cm) and from 2500-5000 m^2 for larger juveniles (13-16 cm) in the Turks and Caicos. Based on a small sample of juveniles (10.8-18.1 cm) that remained continuously within her study area for 12 months, Hesse (1979) reported home ranges from 6802 to 19,027 m^2 ($\bar{x}$ = 11,406 m^2). Tagged juveniles in Fish Bay (5-22 cm), though not separated into smaller size class bins for this analysis, had a similar mean home range of 8470 m^2. The availability and utilization of diverse habitats, such as mangrove edge, seagrass beds, sand, and algal plains, coupled with the ratio of mean home range to aggregate home range (0.07), suggests that although individual juveniles make use of a relatively small area, as a group they are spread across large proportions of the bay. Information on movement rates of juvenile conch is also limited, but the expectation for this age group would be that they utilize all accessible areas of productive habitat, balancing optimum growth with protection from predation.

For organisms that exhibit a high degree of site fidelity and thus smaller home ranges, such as queen conch, localized depletion of a population could have dramatic long-term effects on regional recovery of the species (Heupel et al. 2006). Tools such as GIS and the AMAE provide a method with which to tease apart apparently overlapping life stage distributions and evaluate parameters, e.g., individual and aggregate home ranges. By combining spatial distributions with studies of movement and habitat characteristics, species and habitat conservation issues can be addressed at the appropriate scale. As demonstrated here, home ranges for unique life history stages

must be evaluated on a local scale within the management area. Similar analyses can help to evaluate restoration strategies, *e.g.*, hatchery outplanting (Stoner 1994, Stoner and Davis 1994), identify essential fish habitat (Stoner 2003), situate marine reserves (Glazer et al. 2003), and apply ecosystem-based management principles. In this study, queen conch in Fish Bay showed subtle but identifiable shifts between habitats and locations of the bay as they matured from juvenile to adult life history stages. Effective management and conservation efforts for organisms that show ontogenetic habitat shifts must include consideration of nursery grounds and account for the degree of connectivity between juvenile and adult habitats (Gillanders et al. 2003). Habitat fragmentation and barriers to movement could have detrimental effects on populations of queen conch if they inhibit age-related shifts in habitat utilization patterns critical to the next life stage.

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