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Efficacy of PIT Tags and an Autonomous Antenna System to Study the Juvenile Life Stage of an Estuarine-dependent Fish

Aaron J. Adams[1,*], R. Kirby Wolfe[1], William E. Pine III[2,†], and Bridget L. Thornton[3]

[1] *Center for Fisheries Enhancement, Mote Marine Laboratory, Charlotte Harbor Field Station, Post Office Box 2197, Pineland, Florida 33945*

[2] *Center for Fisheries Enhancement, Mote Marine Laboratory, 1600 Ken Thompson Parkway, Sarasota, Florida 34236*

[3] *Eckerd College, 4200 54th Avenue South, St. Petersburg, Florida 33711*

ABSTRACT: Many marine fishes use spatially distinct habitats as juveniles and adults. Determining which juvenile habitats are most important to sustaining adult populations (i.e., which habitats are nurseries) has proven difficult, in part due to challenges in estimating survival of juveniles in putative nursery habitats. Recent technological advances have made large-scale tagging efforts a viable approach to estimating survival of juvenile fishes by increasing recapture rates and enabling the use of individual-identification tags. These techniques, using Passive Integrated Transponder (PIT) tags and autonomous antenna detection systems (antenna), have been successfully applied in freshwater environments. This paper reports the adaptation of these techniques to estuarine mangrove creeks (salinity: 2–28‰) for research of the juvenile life stage on an estuarine-dependent marine fish, *Centropomus undecimalis*. Retention rate of PIT tags in juveniles >120 mm standard length was 100%, with no mortality. The antenna detection field covered 48% of the creek water column, and the antenna was experimentally determined to detect approximately 67% of tagged fish that swam through. Overall recapture rate of tagged fish by the antenna was >40%. This recapture rate is higher than the sparse data typical of traditional tag-recapture studies. A time-dependent Jolly-Seber model was fit to the data, providing estimates of capture probability (0.8) and weekly apparent survival (0.41) that will be invaluable in comparing juvenile habitats of different quality (e.g., natural versus anthropogenically degraded). This research demonstrates the viability of this approach to fish research in estuarine habitats.

Introduction

Many marine fishes use spatially separate habitats as juveniles and adults. Individuals transition from juvenile to adult habitats as they grow. Habitats that harbor higher densities of juveniles than other habitats have long been defined as nurseries (reviewed in Beck et al. 2001). This definition has held despite the overall lack of quantitative evidence that juveniles from these habitats survive and contribute to adult populations. The likelihood of successful migration of juveniles to adult populations can be predicted from four factors: density, survival, and growth of juveniles in putative nursery habitats; and successful migration of juveniles to adult populations (Beck et al. 2001). Unfortunately, survival is difficult to quantify and to partition from emigration. Habitat-specific survival rates may change spatially and temporally, or as individuals grow. More accurate methods for examining within-juvenile habitat factors affecting nursery function will greatly increase identification and management of nursery habitats.

Recent advances in tagging technology have allowed fisheries researchers to tag individual juvenile fish with uniquely coded Passive Integrated Transponder (PIT) tags and follow these fish through multiple life states. Until recently, recapture techniques for these fish have continued to rely on physically capturing the animal and actively scanning the animal for a tag. Further advances in tagging receiver technology have now enabled researchers to design recapture systems to passively capture animals by detecting the presence of tags in free-swimming fish via in-water antenna systems. This has generated higher recapture rates and allowed larger-scale tagging programs than previously possible.

These PIT tag and antenna techniques have been successfully applied in freshwater environments (e.g., Jepsen et al. 2000; Muir et al. 2001; Sandford and Smith 2002), but have not been widely used in marine or brackish water estuarine systems. This paper describes the adaptation of the PIT tag antenna system to estuarine habitats (salinity: 2–28‰) and demonstrates the efficacy of this approach to study the juvenile life stage of common snook, *Centropomus undecimalis*, an estuarine-dependent fish.

* Corresponding author; tele: 239/283-1622; fax: 239/283-2466; e-mail: aadams@mote.org

† Current address: Department of Fisheries and Aquatic Sciences, The University of Florida, 7922 NW 71st Street, Gainesville, Florida 32653.

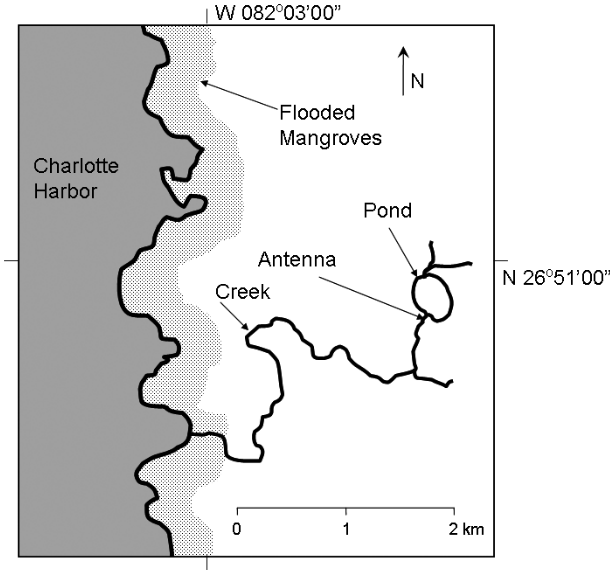

Fig. 1. Location of study site in Charlotte Harbor, Florida, USA. Antenna is at 26°51′01.2″N, 082°02′41.3″W.

Study Area

Charlotte Harbor is a 700-km^2 coastal plain estuarine system in southwest Florida (Hammett 1990; Fig. 1). The Peace, Myakka, and Caloosahatchee rivers, as well as many smaller creeks throughout the drainage area, transport large amounts of freshwater into the harbor. The harbor is connected to the Gulf of Mexico through Boca Grande Pass, San Carlos Bay, and three smaller inlets. The climate of Charlotte Harbor is subtropical; mean seasonal water temperatures range from 12°C to 36°C, and freezes are infrequent (Poulakis et al. 2003). Anthropogenic development within the watershed has stressed the estuarine system, but seagrass flats (262 km^2; Sargent et al. 1995) and mangrove shorelines (143 km^2; Kish unpublished data) continue to thrive as the dominant habitats within the estuary, and >80% of mainland shorelines are under protection (Hammett 1990; CHNEP 1999; Repenning personal communication).

This study occurred in a tidally connected pond at the head of an estuarine mangrove creek in upper Charlotte Harbor (Fig. 1). The circular (563 m circumference) pond is shallow (depth: min. = 0.5 m; max. = 1.5 m; mean = 0.8 m), fringed entirely by *Rhizophora mangle*, and has two outlets: one that is inaccessible to seine sampling and leads farther inland to a terminus, and one that connects the pond to a small creek that then flows to the open estuary. The antenna was placed at the juncture of the outward flowing creek and pond, ensuring that any tagged snook moving from the pond through the creek passed through the antenna. Below the pond, creek width ranges from 2 m in narrow passes to >60 m in wider bays, depth is shallow (<1.0 m), shorelines are lined entirely by *R. mangle*, and the bottom is mostly muddy sand. The submerged aquatic vegetation in the upper stratum is entirely *Ruppia maritima*, whereas the middle and lower strata are dominated by *Halodule wrightii*. Salinity in the pond and creek ranges from 2‰ in the wet season to 28‰ in the dry season.

Materials and Methods

Focal Species

Common snook is a tropical and subtropical, estuarine-dependent, euryhaline species that is ecologically and economically important throughout its range, especially in Florida (Taylor et al. 2000). There is insufficient information for description of life history linkages, but enough is known to allow targeted effort at specific ontogenetic stages to maximize research effort. The general life history is as follows: adult snook spawn in passes and inlets at the mouths of estuaries (Taylor et al. 1998); the larval planktonic stage is approximately 2 wk (Peters et al. 1998); and juvenile habitats are shallow, complex, mesohaline to oligohaline habitats (Peters et al. 1998). Post-settlement snook (<20 mm standard length [SL]) are first captured in Charlotte Harbor creeks in mid June (Adams and Wolfe unpublished data). Juvenile snook reach 150–180 mm SL by age-1 and are common in or near creek habitats year-round until approximately 300 mm (age-2; Taylor et al. 2000; this study), when they enter the adult population. Larger snook use open estuarine and nearshore habitats from spring through fall, and overwinter in riverine or creek habitats. Juvenile survival and the extent that different juvenile habitats provide individuals to adult populations are unknown. This study tested the efficacy of a research method designed to eventually address these shortfalls.

Tagging Protocol

Juvenile snook were captured in the study pond with a center bag seine (21 × 1.2 m, 3.1 mm mesh) between June 2004 and January 2005. All tagging occurred in the pond near the site of capture. For tagging, fish were placed on a foam board and measured (SL). A 3-mm incision was made posterior and ventral to the pectoral fin, and a PIT tag was inserted into the abdominal cavity. Tag retention rates in this study (see below) and findings on other species (Baras et al. 2000; Jepsen et al. 2002) indicate that post-tagging sutures are not necessary. After tagging, fish were held in the water gently by hand until they left under their own power. Fish unable to swim away or that bled from the wound were not released (<10).

Tag Retention and Effects on Survival

In situ caging and laboratory experiments were conducted to determine tag retention rates, effects of tagging on survival, and minimum fish size suitable for tagging. Fifty-five juvenile snook (91–280 mm, mean = 220 mm) were tagged and caged in field experiments. Immediately after tagging, fish were placed in plastic mesh cages (60 × 68 cm, 15 mm mesh; 2 fish per cage) attached to PVC poles anchored in the bottom. Cages were placed approximately 30 m from the shoreline edge on open muddy-sand bottom. Fish were scanned for the presence of PIT tags and released after 3–10 d. Fish condition at release was rated on a 1–6 scale: 1) poor health, infected or distended anus; 2) incision closing with red coloration; 3) incision closing with pink coloration; 4) incision closed with notable scar; 5) incision closed with slight scar; 6) incision closed with no scar.

To more closely monitor tagging effects, 20 juvenile snook (105–205 mm, mean = 157 mm) from the Mote Marine Laboratory hatchery were tagged using the same procedure. After tagging, fish were returned to their hatchery tank. Fish were checked after 19 d and 6 wk, and tag presence and fish condition were noted, as in the field experiments.

PIT Tags and an Autonomous Antenna System

PIT tags are currently based on two design types, half-duplex (HDX) and full-duplex (FDX), differentiated, in part, by their size and detection range. We used HDX PIT tags (23 mm length × 3.4 mm diameter, 0.6 g in air; Texas Instruments TIRFID S-2000). The HDX tags were chosen because their read range is approximately twice that of FDX tags of similar size (Korrie personal communication). The larger size and greater read range of HDX tags enabled the use of an autonomous antenna system in natural systems for monitoring tagged fish. An antenna of similar construction to that used in this study could detect fishes within the entire flow volume (4 × 1.2 m) of a freshwater stream (Zydlewski et al. 2001).

Autonomous antenna systems can increase recapture rates relative to traditional tag-recapture sampling because the animal does not have to be physically recaptured to be checked for a tag. In addition to not having to capture and handle the animal, this approach reduces or eliminates the trap response bias associated with traditional capture methods (Pollock et al. 1990). Recaptures by an autonomous antenna depend on the animal moving

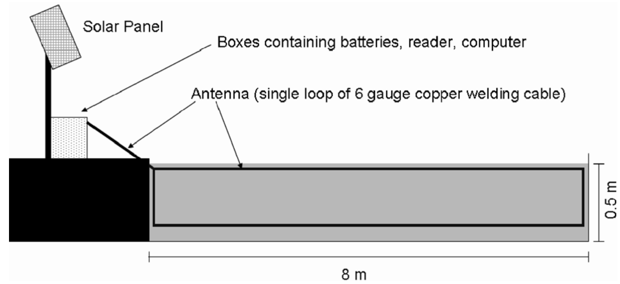

Fig. 2. Schematic of the antenna system shown in a creek cross-section view. The dimensions of the antenna loop are the same as the creek, but the antenna is shown slightly smaller than the creek dimensions for clarity.

through the detection field of the receiver, so careful evaluation of the efficacy of the receiver design is critical.

The autonomous antenna system consisted of an open loop inductor coil antenna (a single loop of 6 gauge copper welding cable) connected to tuning circuits, which were connected to a reader unit and a data logging computer (Zydlewski et al. 2001; Fig. 2). The antenna stretched across the water surface (suspended at creek center by a PVC stake) and the bottom and sides of the creek so that fish swimming in the creek had to pass through the antenna (creek width = 8 m, mean depth = 0.5 m). Experiments determined that the antenna read 60% (30 of 50 cm) of the water column, likely due to signal attenuation in brackish water. The system was powered by two 6-volt batteries, charged by a pair of 80-watt, 12-volt solar panels (model PW750, Matrix Solar), which allowed continuous operation. The batteries, tuner, reader, and computer fit into two waterproof boxes (ca. 1 × 0.5 × 0.5 m) on the creek bank. Data were downloaded to a flash card monthly.

Autonomous Antenna System Tag-Detection Efficiency

An experiment was conducted to determine the proportion of tagged fishes that would be detected as the fish swam through the antenna (i.e., detection efficiency). Fish were captured and tagged, as described above. A 15 × 2 m, 3.1 mm mesh seine was set across the creek in a u-shape, with each end tied to the sides of the antenna, and the seine forming a downstream arc away from the antenna (snook tend to move into the current). Tagged snook were released into the closed end of this open-ended enclosure, so that all fish had to pass through the antenna to exit. A total of 169 tagged juvenile snook (120–253 mm, mean = 202 mm) were released into the enclosure in batches of 15 (9 trials) and 17 (2 trials).

TABLE 1. Results of caging experiment to determine effect of tagging on juvenile snook. Values are number of fish. Condition categories are: 1) poor health; 2) incision healing, reddish coloration; 3) incision healing, pink coloration; 4) incision healed, notable scar; 5) incision healed, slight scar; and 6) incision healed. Italics = fish < 120 mm, bold = fish ≥ 120 mm SL.

Days Caged	1	2	3	4	5	6	Dead	Total
3	*2*	*1*	**4**	**1**	0	0	0	8
4	0	0	**1**	**5**	0	0	0	6
5	0	0	*1*	0	**2**	**7**	0	10
6	0	**1**	**1**	0	0	**4**	0	6
7	*4*	*2*	*1*/**3**	**1**	0	0	*2*	13
10	0	0	0	0	0	**1**	0	1
Total	*6*/**0**	*3*/**1**	*2*/**9**	**7**	**2**	**12**	*2*	44

Preliminary Population Model Application

We collapsed capture-recapture information from the seine samples and the autonomous receiver into capture histories with weekly intervals. We used Jolly-Seber open population capture-recapture models (Jolly 1965; Seber 1965) to estimate capture probability, and apparent survival (emigration or mortality) over a 27-wk period. Because tag retention was 100% and tag-related mortality of fish >120 mm SL was zero (see Results), these factors were considered minor so were not incorporated into the model. Open population models allow for changes in population demographics due to births, deaths, emigration, or immigration of animals within the study area and are generally well suited for fisheries applications lasting longer than a few weeks (Pine et al. 2003). We built a series of simple, biologically reasonable models that allowed capture probability and survival to either vary by time or to remain fixed. Survival, capture probability, and associated variances were estimated in program MARK (White 1999).

Results

Tag Retention and Efficacy of Antenna System

Fifty-five juvenile snook were tagged and caged as part of the retention study, but 11 fish escaped prior to being checked, so 44 fish were used in analysis. Tag retention was 100% in both field and laboratory experiments. All mortality and poor condition ratings occurred in fish <120 mm (Table 1), so only juvenile snook ≥120 mm were tagged for the rest of the study. In the laboratory experiment, condition was excellent (level 6) for all fish after 19 d, with no change in tag retention or condition after 6 wk. Mean detection efficiency of the antenna was 66.9% (SE = 4.2; i.e., 66.9% of tagged snook passing through the antenna were detected) and median was 66.7%.

The antenna was operable beginning in early August 2004, but was deconstructed in preparation for two hurricanes for the latter half of August. Since that time, the antenna has been operational continuously. For the purposes of this report, antenna data are constrained to the first 189 d (27 wk; September 2004 to March 2005) of operation after the hurricanes to provide a time series of continuous operation. Overall recapture rate of the antenna was 40% (i.e., 40% of 314 tagged fish were detected at least once). Antenna recapture rates did not differ by size (fish length versus number of recaptures least squares linear regression: R^2 = 0.004, F = 1.249, p > 0.2). The maximum number of weeks at large (weeks between tagging date and latest recapture by the antenna) was 27.

Preliminary Model Fit

Our best model, one that was biologically reasonable and produced small standard errors relative to the parameter point estimates, was a time dependent survival and capture probability model. Weekly apparent survival estimates ranged from 0.35 (SE = 0.09) to 1.0. Capture probability estimates ranged from approximately 0.20 to 0.90 (Fig. 3). These capture probabilities are higher than that found in many fisheries studies using open population models (Pine et al. 2003), likely because of the use of the passive array to recapture fish as opposed to physically having to sample and capture individual animals using traditional methods (see discussion). In contrast to the fully time dependent model above, we also fit a simple model with fixed apparent survival and capture probability. Parameter estimates from this model represent an average parameter value across the entire sample period and were similar to the time dependent models (apparent survival = 0.80, SE = 0.11; capture probability = 0.41, SE = 0.02).

Discussion

The utility of the PIT tag autonomous antenna system approach to monitor fishes has been proven in freshwater systems (Zydlewski et al. 2001). To the best of our knowledge, this is the first successful demonstration of this approach in a marine system at this scale (but see McCormick and Smith 2004 for smaller scale application). This approach provides estimates of survival, which is an important component of nursery habitat designation (Beck et al. 2001), and will be a useful explanatory variable for examining differences among nursery habitats in future research (e.g., are disproportionate contributions to adult populations due to differential survival within putative nursery habitats or post-nursery processes?). Since the life history of common snook is similar to other estuarine-associated species (e.g., *Megalops atlanticus, Sciaenops*

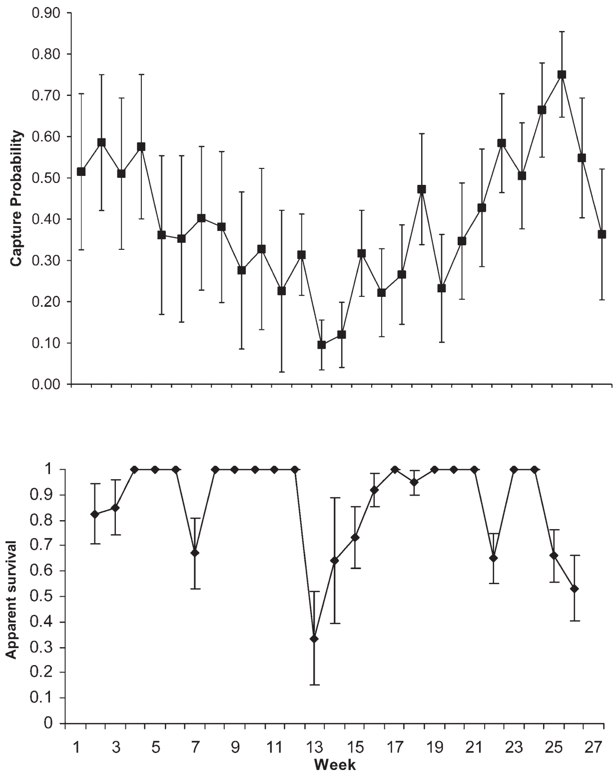

Fig. 3. Estimated capture probabilities (top panel) and apparent survival over time of juvenile snook, *Centropomus undecimalis*, within the study pond and immediately adjacent creek. Estimates derived using MARK (White and Burnham 1999), from mark-recapture data from initial capture using seines and recapture (i.e., detection of PIT tagged fish) by the autonomous antenna system.

ocellatus), this approach has strong potential for wider applications.

The findings of 100% tag retention and no tag-related mortality in juvenile snook >120 mm was expected. PIT tag retention in other species is high and tag-related mortality near zero (Harvey and Campbell 1989; Ombredane et al. 1998; Baras et al. 1999, 2000; Zydlewski et al. 2001). The deleterious effects of tagging on juvenile snook <120 mm were unexpected since smaller fish of other species have been tagged with 23 mm HDX tags (Zydlewski et al. 2001 and references therein). In this study, it appeared that the PIT tag displaced organs in the abdominal cavity, either causing internal trauma or negatively affecting gastrointestinal processes (distended anus occurred in numerous small juveniles).

The potential for increased predation risk to tagged snook was not examined in this study, but based upon capture probability and survival estimates, is likely minor. Potential predators observed regularly in this system are piscivorous birds (*Ardea herodias, Egretta thula, Casmerodius albus, Phalacrocorax auritus, Anhinga anhinga*), with seasonal (adult snook Adams and Wolf unpublished data) and occasional (*Caranx hippos*) piscivorous fishes. From our laboratory holding studies it appeared that fish swimming behavior was not negatively affected by the tagging, such that we do not suspect that tagged animals had differentially higher predation rates than untagged individuals.

Although effects of tagging on growth were not addressed in this study, they are expected to be minor. Juvenile snook >120 mm appear to be resilient to the tagging process. Effects of tagging with PIT tags on growth tend to be short lived or nonsignificant (Ombredane et al. 1998; Baras et al. 1999, 2000; McCormick and Smith 2004). Since PIT tag codes are unique, future recaptures (and length measurements) of tagged fish with seines will allow comparison of growth rates of tagged fishes (direct measurements of individuals) with estimated growth rates of untagged fishes captured in seines to determine long-term effects of PIT tags on snook growth (Nitschke et al. 2001).

The increased recapture rate of the autonomous antenna system over traditional methods increases the precision of many capture-recapture analyses, particularly for fisheries studies where recapture rates are traditionally low (Pine et al. 2003). A common problem in tagging studies to estimate survival, population size, or habitat connectivity is sparse data due to low capture probability (Pine et al. 2003). Low capture probability negatively affects the accuracy and precision of population parameter estimates and increases the uncertainty of results for estimating connectivity (Castro-Santos et al. 1996). In this study, recapture rate by the antenna was approximately 40%, and fish were at large for considerable time periods between recaptures. This is in contrast to seine sampling in this study, in which only one tagged juvenile snook was recaptured, despite >400 juveniles being captured by seine.

The utility of the continuous monitoring by this autonomous system is demonstrated during weeks 12 and 13 when large numbers of fish were captured in the seine samples (Fig. 4). This time period coincided with a cold front that likely forced snook to move upstream to avoid cooler water and seek thermal refuges. Apparent survival estimates (Fig. 3) during this interval are low (approximately 34%) either because large numbers of animals emigrated out of the sampling area or survival during that time period was very low.

In this study it was not possible to differentiate survival and emigration, but preliminary data indicate that seasonal migration may be the primary factor. Because we were sampling in the likely wintering area (the pond) and did not recapture many tagged fish by seine, juvenile snook survival

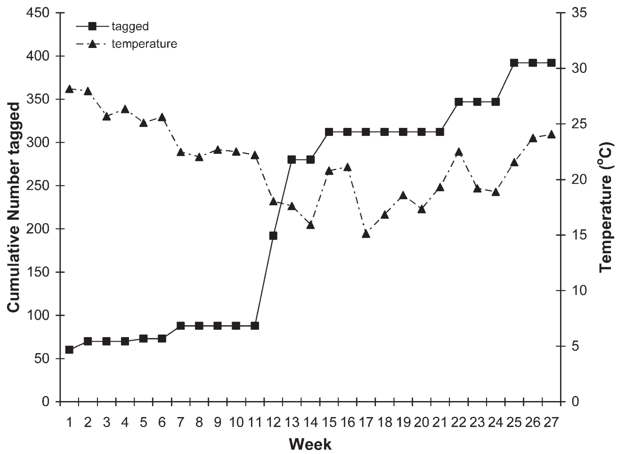

Fig. 4. Cumulative number of juvenile snook, *Centropomus undecimalis*, tagged and water temperature (°C) at location and time of tagging, by week.

may have been low during this time period due to thermal stress. Capture probability and day length were highly correlated (Pearson r = 0.76, $p < 0.001$; Fig. 5), suggesting seasonal movements within the creek system. During seasons with longer day lengths, juvenile snook movements may be more frequent or the area sampled by the antenna may be a preferred habitat during these seasons. Ontogenetic shifts also may cause many larger juveniles to permanently emigrate from the pond.

This study has shown that the PIT tag autonomous antenna approach is a viable method for examining juvenile fishes in estuarine habitats. It is anticipated that the addition of antennae at regular intervals along the creek axis will allow partitioning of survival and emigration, and provide insight of movements by juvenile snook in relation to environmental variables.

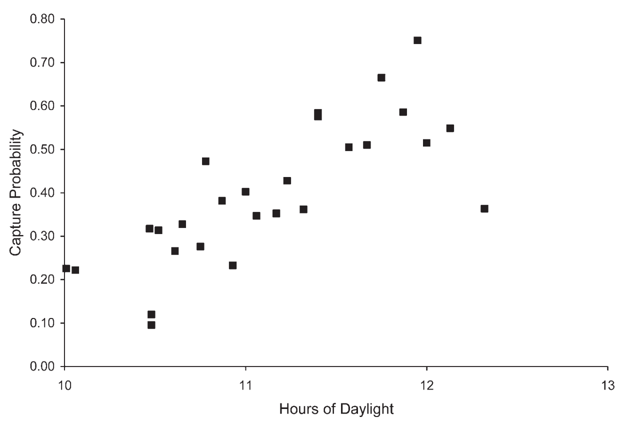

Fig. 5. Relationship between capture probability and day length for the 27-wk study period (Pearson r = 0.76, $p < 0.001$).

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