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Characterizing daily movements, nomadic movements, and reproductive migrations of *Panulirus argus* around the Western Sambo Ecological Reserve (Florida, USA) using acoustic telemetry

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ABSTRACT

The movements of the Caribbean spiny lobster (*Panulirus argus*) were studied in three subregions: (1) patch reefs, (2) forereef, and (3) outlier reef, in and around the Western Sambo Ecological Reserve (WSER) (Florida, USA) using acoustic tags and receivers. The studies took place from the June 2003 through July 2007 and involved various receiver deployments such as tracking grids and emigration rings designed to track relatively short daily movements and long-distance (>1 km) movements. Daily movements were found to be highly repetitive in some individual lobsters in both the patch reef and the forereef. Some forereef lobsters shifted foraging preference between the forereef itself (63%), a shallow back reef area (10%), reef base (9%), and a deeper reef base area (4%), with undetermined making up the remainder. Approximately one-third of the patch reef resident lobsters exhibited significantly enhanced nocturnal movements during periods of low or no lunar illumination. Twenty-two nomadic movements were detected and occurred throughout the year and included individuals that moved between Western Sambo Ecological Reserve and the outlier reef south of the reserve. Lateral movements detected along the forereef were exhibited by only a few male lobsters. Reproductive migrations by reproductively active female lobsters were observed in all subregions. These movements are characterized by a sudden rapid southward move initiated near midnight. For patch reef and forereef females, the destination is deep water to the south of the forereef. Outlier reef females moved to deeper water to their south. Up to three reproductive migrations were conducted at a median interval of 25 days (16 multiple trips detected). With respect to one of WSER's stated management goals, i.e., to protect life histories, lobster movements have shown that the outlier reef subregion, located 1 km south of the southern WSER border, is integral to the spiny lobster life history and should be considered for inclusion into WSER.

1. Introduction

Ecological reserves are a relatively recent addition to the ecological management landscape of the Florida Keys. In July 1997, the National Oceanic and Atmospheric Administration (NOAA) established the Western Sambo Ecological Reserve (WSER) within the Florida Keys National Marine Sanctuary (FKNMS). The objectives of the reserve are to "protect marine life natural histories within large contiguous diverse habitats, protect and enhance natural spawning, and provide replenishment of marine life to the surrounding areas" (DOC, 1996). The performance of these objectives was put to the test through a series of monitoring projects (Keller and Donahue, 2006), of which the monitoring of abundance and size of the Caribbean spiny lobster, *Panulirus argus* (Latreille, 1804), was a part. Understanding movement patterns of lobsters can also provide a means of evaluating a reserve's potential of meeting those performance standards by providing information about habitat use, home range, migrations, retention times and spillover, and location of spawning grounds (Bertelsen and Hornbeck, 2009; Goñi et al., 2008; Hovel and Lowe, 2007).

Movement patterns of lobsters have been described in studies using a variety of techniques such as trap monitoring (Crawford and de Smidt, 1922; Davis, 1974; Lyons et al., 1981), tag-recapture with traps (Creaser and Travis, 1950; Gardner et al., 2003; Gregory et al., 1982; Hunt et al., 1991; Linnane et al., 2005; Warner et al., 1977), tag-recapture with diver surveys (Cox et al., 1997; Davis, 1974; Hunt et al., 1991; Kelly and MacDiarmid, 2003), and acoustic

Abbreviations: WSER, Western Sambo Ecological Reserve; NOAA, National Oceanic and Atmospheric Administration; FKNMS, Florida Keys National Marine Sanctuary; FWC, Florida Fish and Wildlife Conservation Commission; CL, carapace length; USNO, United States Naval Observatory; DOC, Department of Commerce.

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technology (Bertelsen and Hornbeck, 2009; Herrnkind and McLean, 1971; Herrnkind et al., 1975; Jernakoff et al., 1987; Kelly, 2001; MacArthur et al., 2008; Olsen et al., 1971; Scopel et al., 2009). While each of these techniques has its own strengths and weaknesses (see Herrnkind, 1980), only acoustic technologies offer the ability to track (e.g., Simpfendorfer et al., 2002; Giacalone et al., 2005) or reveal the location of individual lobsters regardless of water clarity, time of day, depth of water, or weather conditions. When omnidirectional recording receivers became readily available in the 1990s, larger-scale movements on the order of kilometers or tens of kilometers could be quantified and timed using gates and other configurations of receivers (Heupel et al., 2006).

Ninety years ago, *P. argus* was described as a sluggish animal and incapable of locating the same den from day to day but perhaps capable of long distance movements (Crawford and de Smidt, 1922). By the 1970s this view was changing rapidly. Traditional tag-recapture studies (Warner et al., 1977; Gregory et al., 1982) established that *P. argus* was capable of movements of tens of kilometers. Acoustic technologies were first used to study spiny lobster movement in the early 1970s. In St. Thomas, USVI, during the Tektite II project Olsen et al. (1971), used acoustic tags and directional hydrophones to describe in detail nightly movement patterns, which varied from lobsters remaining near a given den to traveling as far as 200 m to forage and returning a few hours before dawn. Some lobsters were observed to navigate both along and across surge channels and to move across open sand plains. A strong homing ability was also observed, even when lobsters had been experimentally displaced (Herrnkind and McLean, 1971). Later, Boles and Lohmann (2003) experimentally demonstrated that *P. argus* used the earth's magnetic field for orientation.

Since the 1990s, omnidirectional recording receivers have been predominately used to study spiny lobster movement. In addition, tags have been greatly miniaturized permitting tagging a wide range of size of animals (Heupel et al., 2005). Subsequent studies of spiny lobsters using either electromagnetic or acoustic tracking have for example, included determining foraging distances of *Panulirus cygnus* (Jernakoff et al., 1987) and *Panulirus interruptus* (Hovel and Lowe, 2007), general large scale movements and site fidelity of *Jasus edwardsii* (Gardner et al., 2003; Kelly, 2001); and migration and emigration of *P. cygnus* (MacArthur et al., 2008).

The movement patterns of lobsters, including *P. argus*, have been reviewed by Herrnkind (1980) and Childress and Jury (2006). Herrnkind (1980) defined three categories in basically spatial terms: (1) homing (the ability for a lobster to locate a previously occupied shelter after foraging), (2) nomadic (undirected long movements that may require more than one night that move a lobster away from its normal forage/shelter area), and (3) migratory (such as movements that take a reproductively active female from its forage/shelter area to a different area to release eggs). Childress and Jury's (2006) categories focused on temporal aspects of movement: (1) daily, (2) ontogenetic, and (3) seasonal. Daily movements in this study refer to the diurnal shelter by day and forage by night movements. Ontogenetic movements pertaining to changes in lobster shelter preferences and habitats such as when juvenile lobster mature (Bertelsen et al., 2009). Seasonal movement patterns refer to yearly cycles such as movements that characterize the reproductive season. Portions of both spatial and temporal classification systems are used herein.

This study builds upon previous work conducted in WSER (Bertelsen and Hornbeck, 2009). All these acoustic studies were designed to evaluate the performance of the Western Sambo Ecological Reserve with respect to spiny lobster movement and potential interaction with the Reserve's boundaries (see Keller and Donahue, 2006) and as such we were exploring the movements of lobsters without a preconceived hypothesis to prove or disprove. Indeed, the discovery of the reproductive migrations by females in the patch reef area in the first study directly influenced our subsequent broader area based exploration of movement over the course of a year. And finally, the inability to track lobsters within the rocky forereef area, influenced a concluding study that intensely focused on a small subset of the forereef. The overall objectives of these studies were (1) to detect and characterize daily movement patterns, emigrations, and migrations of *P. argus* throughout WSER and surrounding habitats and (2) to discuss, based on this knowledge of lobster movements, the strengths and weaknesses of the current design of WSER.

2. Materials and methods

2.1. Study site

The studies were conducted in an area that included the southern half of WSER and outlier reef located approximately 1 km south (Fig. 1). WSER protects 30 km^2, from the shoreline of Boca Chica Key to the base of the Western Sambo forereef (approximately 9 km), with an average width of approximately 3.5 km.

Although spiny lobsters are present in virtually all areas of this region at night, by day they seek shelter in hard crevices to avoid daytime predators. This behavior tends to concentrate their numbers into the various hard-bottom habitat types, primarily patch reefs, spur-and-groove forereef, and outlier reef. The northernmost hard-bottom habitat comprises numerous patch reefs within a subregion known as Hawk Channel (Fig. 1). Most of the Hawk Channel subregion consists of relatively flat (9–12 m deep) areas covered with mud, sand, or grass beds. The muddy soft-bottom areas tend to be concentrated in the northern half of Hawk Channel, and grass and sand toward the south (pers. obv.). The flats are punctuated with patch reefs that vary in size; most are approximately 100 m in diameter, but some are as large as 400 m, and others are less than 30 m in diameter. Typically they rise to within 7–4 m of the surface. Most of the patch reef surface is bare or algae-encrusted rock. The remainder consists of mostly dead coral with algae, octocorals, and sponges. The base of the patch reefs are typically surrounded by a band of rubble and octocorals 5–10 m wide. Most of the water flow is tidal and runs parallel to the axis of Hawk Channel (approximately east–west). The water clarity is typically poor, especially in the spring. Visibility is poorest near the bottom, where it is often less than 2 m. Surface visibility is typically 5–10 m. Lobster abundance varies greatly in this habitat. Diver surveys of entire patch reefs have found from zero lobsters to more than 100 per patch (FWC; unpub. data).

South of Hawk Channel near the southern boundary of WSER, the bottom rises into a rubble area that contains some live corals. In some places, the reef crest is less than 1 m from the surface at low tide. Just to the south and seaward of the reef crest are large spurs of hard bottom separated by sandy grooves. The spurs consist principally of hard coral and provide important lobster-sheltering habitat. At a depth of approximately 10–15 m the spurs flatten into an irregular hard substrate. The hard bottom continues to slope down to a sandy flat at a depth of approximately 25–30 m. Water clarity here ranges from 2 to 30 m. The bottom of the reef lies near the southern boundary of WSER. The density of lobsters in this habitat usually is from 3 to 5 lobsters per 500 m^2 but can be much greater in individual spurs (FWC; unpub. data).

On the southern boundary of the sandy mud flat is a deeper hard-bottom area called the outlier reef (Lidz et al., 2007). The outlier reef parallels the reef crest and rises from the sandy mud flat to within 10 m of the surface, then slopes back down to a depth of 30–35 m. The northern flank comprises predominately bare hard