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Long-Term Migratory Behavior of Undersized Spiny Lobsters *Panulirus argus* (Latreille) on the Bermuda Island Shelf

C.R. Evans
University of Southampton

A.P.M. Lockwood
University of Southampton

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Á. Ý. KRISTMUNDSDÓTTIR, R. C. BARBER, AND J. R. GOLD, *Center for Biosystematics and Biodiversity, Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas 77843.*

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LONG-TERM MIGRATORY BEHAVIOR OF UNDERSIZED SPINY LOBSTERS *PANULIRUS ARGUS* (LATREILLE) ON THE BERMUDA ISLAND SHELF.—Knowledge of the migratory behavior of an exploited marine species is required for effective management (Harden Jones, 1968; Gregory and Labisky, 1986). Such data facilitates identification of stocks (Cushing, 1968; Gregory and Labisky, 1986). Knowledge of migratory behavior also helps fishermen to increase catch per unit of fishing effort by more effective trap fishing along migration routes (Gregory and Labisky, 1986). Data on population movements therefore not only contribute to the conservation of the stock, but permit more economical use of traps, fuel, and labor.

The movements of a large number of spiny lobsters *Panulirus argus* in South Florida were studied by Gregory and Labisky (1986); the high exploitation rate in Florida resulted in a large proportion of short-term tag recoveries, and consequently the overall pattern of movements described in the paper represented short-term movements taking place during the fishing season (Gregory and Labisky, 1986). Longer-term migrational patterns were not followed.

Short-term migration patterns of *P. argus* lobsters at Bermuda were studied in the 1950s (Sutcliffe, 1952, 1953). The objective of the present study was to determine the longer-term migration patterns of lobsters on the island shelf of Bermuda in order to facilitate the management of the species both there and elsewhere in the Caribbean.

Materials and methods.—The principal tool employed for the trapping and marking work was the traditional 4′ × 4′ × 2′ Bermudan arrowhead trap constructed of 1.5″ hexagonal wire mesh on a spice-wood or rod-iron frame with a single entrance funnel. Undersized animals were marked with numbered Floy spaghetti tags like those used by Davis (1978). The tag was inserted with the injection gun into the abdominal muscle mass (the dorsolateral extensor muscle) just behind the posterior margin of the carapace and slightly to the right of the mid-dorsal line, to miss the gut.

Trapping and tagging of undersized lobsters was carried out at the southwestern and northwestern ends of the island shelf from Aug. 1986 to Sep. 1987. Traps were baited with fish waste and set in "white holes" (sand-floored depressions in the reef) at the northeastern end of the shelf and on the reefs themselves at the southwestern end. Animals were returned to the sea after sexing, measuring, and tagging. Frequently this involved displacing the lobsters between 50 and 200 m as the commercial fishing vessel moved during handling.

Commercial trap fishermen were made aware of the tagging program at a seminar, and cooperated in the return of tags. Information on tag number and date and location of capture was obtained from commercial fishermen during the remainder of the lobster season.

Results.—The records of a tagging study of the movement and dispersal of undersized lobsters (*Panulirus argus*) are shown in Table 1. Females traveled further in 1986–87 (median distance traveled: 12.6 miles) than males (3.5 miles) ($P < 0.05$, Mann-Whitney U-test) and moved faster than males: for females mean ground speed was 0.11 miles/day (standard error, 0.039) and for males mean ground speed was 0.051 miles/day (standard error, 0.018) ($P < 0.10$, t-test). Sample standard deviations were 0.14 and 0.083 miles/day, respectively.

Movements along the depth contour around the atoll system were made in both clockwise and counterclockwise directions around the island shelf. The records of such movements within the field study period (August 1986–September 1987) are separated and detailed in Table 2. The median distances traveled were 13 miles (counterclockwise) and 1.8 miles (clockwise) for six and five animals, respectively. A Mann-Whitney U-test showed that the me-

TABLE 1. The migrations of young spiny lobster (*Panulirus argus*) post-recruits on the Bermuda Platform. List of individual migrations recorded (mark, distance, days out, period out, depth, and direction and type of movement).

Sex	Mark	Miles traveled	Days out	Period out	Type of movement	Depth (fathoms)	Direction
M	T175	7	31	Dec. to Jan.	cca	28 to 28	NW to SE
F	T182	3.5	42	Dec. to Jan.	cp	28 to 6	SW to NE
F	T225	15	29	Dec. to Jan.	cca	28 to 28	S to N
M	T190	5.5	38	Dec. to Jan.	cp	28 to 6	E to W
M	T043	1	98	Oct. to Jan.	cca	5 to 5	SW to NE
F	T117	0.75	305	Nov. to Sep.	cf	—	—
M	T042	0.05	15	Oct.	—	—	—
F	F067	13	68	Sep. to Nov.	cca	5 to 5	SE to NW
F	T234	<0.5	24	Feb. to March	—	—	—
M	T228	<0.5	58	Jan. to March	—	—	—
M	T557	<0.042	14	July to Aug.	—	—	—
M	T338	<0.25	38	July to Aug.	—	—	—
M	T605	<0.012	3	July	—	—	—
M	T312	0.042	46	July to Aug.	—	—	—
M	T466	<0.012	49	July to Aug.	—	—	—
M	T312	<0.012	10	Aug.	—	—	—
M	T566	<0.125	18	Aug. to Sep.	—	—	—
F	F005	2.9	21	Sep.	cca	30 to 30	NE to SW
F	F006	0.22	28	Sep. to Oct.	ccc	30 to 30	SW to NE
F	F013	0.66	7	Sep.	ccc	30 to 30	SW to NE
M	F063	>2	7	Sep.	ccc	30 to 30	NE to SW
M	F065	>3.3	21	Sep.	ccc	30 to 30	NE to SW
M	F086	0.93	21	Sep. to Oct.	ccc	30 to 30	N to S
M	T605	<0.042	27	July to Aug.	—	—	—
F	T983	2.5	17	Aug. to Sep.	cp	4 to 4	E to W
F	F055	>25	375	Sep. 1986 to Sep. 1987	cca	30 to 33	S to N
M	T684	1.4	35	Aug. to Sep.	cp	5 to 3	NE to SW
F	T303	1.0	161	Apr. to Sep.	cp	6 to 6	N to S
M	T605	<0.012	27	July to Aug.	—	—	—
F	T963	<0.25	3	Sep.	—	—	—
M	T466	<0.25	28	Aug. to Sep.	—	—	—
M	T566	<0.25	3	Sep.	—	—	—
F	T963	<0.25	7	Sep.	—	—	—
M	T566	<0.25	7	Sep.	—	—	—

Key to marks: T = tag, F = tail-fan mark.
Key to type of movement: cca = the positions of marking and recapture indicate movement along a depth contour of the Bermuda Platform in a counterclockwise direction, ccc = along depth contour in a clockwise direction, cp = across depth contours in an inward, inshore direction, cf = across depth contours in an outward direction, — = no calculation made.
It should be noted that animals were marked at the westernmost point of the Bermuda Platform (the southwest edge), off the south shore of the island (south shore edge), at the easternmost point of the Bermuda Platform (eastern edge), and from this last area as far west and north as the shelf edge north of North Rock. The period to which the data apply is August 1986 to September 1987.

dian distance traveled by undersized animals in a counterclockwise direction around the shelf was greater than that traveled clockwise ($P < 0.05$). Eleven out of 13 movements of 1 or more miles' range took place in the autumn and winter, between the months of August and March, the exceptions being two recorded movements spanning the closed season April to Sep. [i.e., one from April to Sep. and one from Sep. to Sep. (1 year later)].

The long-distance migrations are mapped in Figure 1, including details of the more recent tag returns after periods at large of up to 2 years. All the long-term migrations of more than 5 miles' range were in a counterclockwise direction around the reef system of the island shelf (Fig. 1).

Discussion.—Gregory and Labisky (1986) found that lobster ground speeds within each release site (two in Florida Bay and three at the Atlantic Reefs of the Lower Florida Keys) did not

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TABLE 2. The distance traveled in the migrations along the depth contour recorded in Aug. 1986–Sept. 1987 (from Table 1).

Distance traveled counter-clockwise			Distance traveled clockwise		
Sex	Miles	Days out	Sex	Miles	Days out
M	7	31	F	0.22	28
F	15	29	F	0.66	7
M	1	98	M	2	7
F	13	68	M	3.3	21
F	2.9	21	M	0.93	21
F	25	375			
TOTAL	63.9 miles		7.11 miles		
MEDIAN	13 miles		1.8 miles		
MEAN	10.7 miles		1.4 miles		
SD	8.9 miles		1.2 miles		
n	6		5		
SE	3.6 miles		0.54 mile		

S = sample standard deviation. S.E. = standard error on the mean.

differ significantly between females and males, and at only one (Atlantic) site did mean ground speeds (±SE) differ between juveniles (0.5 ± 0.06 km/day) and adults (0.2 ± 0.09 km/day). The latter indicates that undersized lobsters may travel faster than adult lobsters. The migrations of the Florida study were short-term, and related to (1) offshore migration of juveniles from the nursery areas, (2) migration at the onset of the autumnal storms [reported by Kaniciruk and Herrnkind (1978) for the Bahamas], and (3) migrations associated with reproduction (Gregory and Labisky, 1986). In contrast, the Bermudan movements comprise longer-term migrations, in a less intensive fishery (Evans, 1988), with animals out for periods of up to 2.2 years. The two locations are also subject to different oceanographic phenomena. Lobster movements in Florida Bay were predominantly to the west and southwest and at greater speeds than those of Atlantic lobsters, which exhibited more localized movements and moved slower and over shorter distances, with greater "multi-directional dispers-

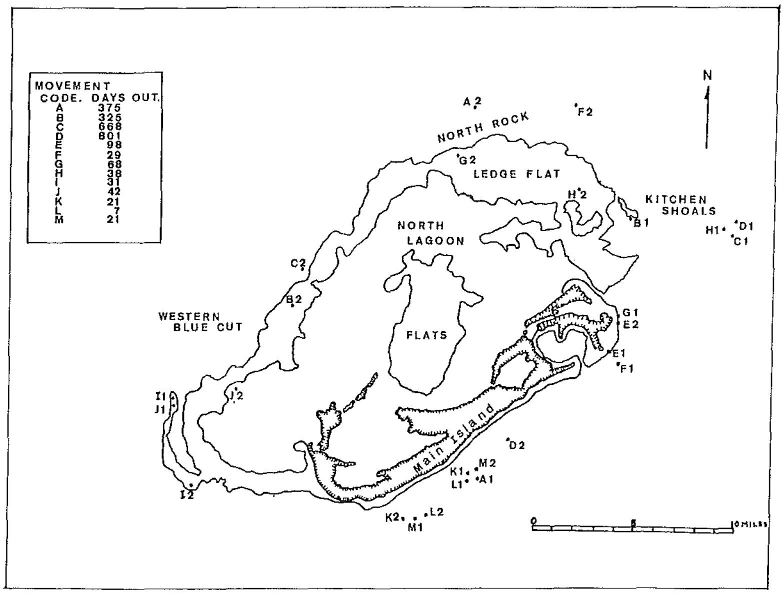

Fig. 1. Map showing the long-term migrations of undersized *P. argus* spiny lobsters in the Bermudan fishing grounds. Each letter refers to the movement of one animal. A letter followed by the number 1 indicates the position tagged. The same letter followed by the number 2 indicates the location recaptured. The boxed movement code legend in the diagram indicates the time interval between tagging and recapture. Movements were relatively rapid and may have been initiated as a result of displacement in the course of measuring, tagging, and return to the sea. The shortest distance between the points of release and recapture indicate travel in a counterclockwise direction around the island shelf in all cases except three, and two of these are much shorter in range than the majority of the movements. The third apparently clockwise movement was that of lobster D, out for 2.2 years; it could have traveled in a counterclockwise direction. Lobster C was out for 1.8 years and could also have traveled in a clockwise direction to its location of recapture. It is also possible that these movements comprised more than one circuit of the island shelf.

al" (Gregory and Labisky, 1986). The mean "displacement velocities" were 0.01–0.03 miles/day in the Atlantic and 0.15–0.35 miles/day in Florida Bay. The mean ground speed for females (0.11 miles/day) and for males (0.051 miles/day) at Bermuda falls between the speeds encountered at the Florida Bay and Atlantic sites.

The counterclockwise movements recorded in Table 1 all occurred in the winter months except for one migration of a year's duration (Sep. 1986–Sep. 1987). Since lobsters are not targeted for fishing during the summer months, this result is to be expected. However, there is only one record of a counterclockwise movement spanning the closed season, which suggests that counterclockwise movements chiefly occur in the winter months.

In winter, water temperatures on the island shelf fall below those in the open ocean (Morris et al., 1977) and winter density of surface waters is higher. The circulation pattern of the surface water becomes cyclonic (counterclockwise/center-seeking); less dense surface water flows over the edge of the island shelf, across the reef-front terrace and into the lagoon (Boden and Kampa, 1953; Morris et al., 1977). As this water approaches the center of the vortex, the water cools, sinks to the bottom, and flows across the lagoon floor to cascade down the slope of the Bermuda Pedestal, serving to renew the waters of the island shelf (Boden and Kampa, 1953; Morris et al., 1977).

Sutcliffe's work indicated that breeding migrations (centripetal and centrifugal) associated with mating, hatching of eggs, and release of phyllosoma larvae (Sutcliffe, 1952, 1953) occur largely in April through Oct. During these months, the summer circulation system, which has a weaker, anticyclonic flow, is established (Boden, 1952; Morris et al., 1977).

Orientation and movement of lobsters in water currents has been studied by Newland et al. (1988). These researchers found that the Norway lobster *Nephrops norvegicus* adopted a downstream orientation, and usually walked downstream, in response to water current speeds of 0.07–0.20 m/sec (0.16–0.45 miles/h), and that the body of *Nephrops* was most effectively streamlined when it adopted a downstream orientation. Measurements showed that lobsters with this orientation experienced the least hydrodynamic drag and the greatest down-force. Water flow is perhaps obstructed by the cephalothorax and the claws and/or antennae appended.

These same physical factors may thus also cause Bermudan lobsters *Panulirus argus* to walk downstream in a counterclockwise water circulation and to undertake the isobathymetric movements recorded. This is supported by Herrnkind's (1985) description of a downstream orientation of *P. argus* in mesocosms.

Population field studies on the spiny lobster *P. guttatus* at the northeastern end of the island shelf resulted in evidence of a centripetal breeding migration of *P. guttatus* lobsters, but no evidence of long-term migratory behavior (Evans and Lockwood, 1994).

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C. R. EVANS AND A. P. M. LOCKWOOD, *Department of Oceanography, University of Southampton, Highfield, Southampton, Hampshire, United Kingdom. Present address (CRE): Department of Fisheries and Marine Resources, PO Box 165, Konedobu, Papua New Guinea.*

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AERIAL SURVEYS FOR SEA TURTLES IN SOUTHERN GEORGIA WATERS, JUNE, 1991.—All sea turtle species occurring in U.S. waters are protected under the Endangered Species Act of 1973 (PL93-205). Under Section 7 of the Endangered Species Act, all Federal agencies must ensure that their actions do not jeopardize the continued existence of endangered or threatened species or result in the destruction or adverse modification of critical habitats. Necropsies suggested that at least nine of the 93 sea turtles involved in a major sea turtle stranding event in spring 1991 along coastal Georgia had been impacted by U.S. Army Corps of Engineers (USACOE) hopper dredging activities in the Brunswick River Entrance Channel.[1] In addition, observers onboard dredges working in the channel documented 23 sea turtle takes during late March until early June, including one critically endangered Kemp's ridley (*Lepidochelys kempii*). As a result of this stranding event and the unusually high number of incidents involving sea turtles during the first 5 weeks of the dredging project, the USACOE requested that we utilize aerial reconnaissance to document the distribution and relative abundance of turtles in the vicinity of the Brunswick River Entrance Channel.

Aerial surveys for sea turtles in the western North Atlantic have been conducted in coastal waters from Nova Scotia to Key West and the Gulf of Mexico, and in the Chesapeake Bay and the Pamlico-Albemarle Estuarine Complex (Fritts et al. 1983; Thompson[2]; Keinath et al. 1987; Schroeder and Thompson 1987; Lohoefener et al. 1990; Thompson et al. 1991; Shoop and Kenney 1992; Epperly et al. 1995a,b). Although differences in environmental factors exist among surveyed areas, one which may affect the sightability of turtles is turbidity. Thompson et al. (1991) theorized that a lack of contrasting carapace coloration reduced the number of green (*Chelonia mydas*) and Kemp's ridley sea turtle sightings in the Gulf of Mexico aerial surveys. Thus, turbid waters may reduce the ability to sight sea turtles because of a diminished contrast of the carapace against the water's surface. We tested the feasibility of utilizing aerial surveys as a means to identify areas of high sea turtle abundance in relatively turbid inshore waters of the southeastern U.S. and determined the distribution and relative abundance of sea turtles in southern Georgia waters.

Methods.—We employed aerial survey methods similar to those used for surveys of inshore North Carolina waters (Epperly et al. 1995a). Estuarine and nearshore waters between 30°42.0′N and 31°11.5′N were divided into 12 strata based on geography (Table 1, Fig. 1). Areas of each stratum ranged from 9–84 km^2. Survey coverage averaged 31% in the inshore strata, and 14% in the offshore strata, with the exception of St. Simons Sound, St. Andrew Sound, and St. Mary's Entrance, where coverage averaged 26%. Surveys were conducted daily from 2–9 June, 1991 between 0745 and 1430 hours EST as weather permitted and lasted 7–35 minutes, depending on the size of the stratum. Surveys extended south of the Bruns-

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[2] Thompson, N. B. 1984. Progress report on estimating density and abundance of marine turtles: results of first year pelagic surveys in the southeast U.S. Unpublished report. National Marine Fisheries Service, Miami, Florida. 60 p.