A telemetric study of the home ranges and homing routes of lingcod *Ophiodon elongatus* on shallow rocky reefs off Vancouver Island, British Columbia

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Lingcod *Ophiodon elongatus* are an important commercial and recreational fish in the northeast Pacific (Miller and Geibel 1973, Cass et al. 1990). In some areas lingcod show serious population declines. In Washington, after signs of depletion, the fishery was closed in central Puget Sound for 5 years (1978–83) to allow rebuilding (Buckley et al. 1984). Currently in central Puget Sound, the now tightly-restricted fishery allows only recreational use, a 6-week opening, and a daily limit of 1 fish. Similarly in British Columbia, landings and average size of the catch have declined and tighter regulations imposed (Richards and Hand 1991). Because of lingcod declines, it is crucial to understand their life-history characteristics in order to determine possible causes of decline and to help recovery efforts. One area of uncertainty regarding lingcod life history is their movement behavior.

Despite a number of studies of lingcod movements (Miller and Geibel 1973, Mathews and La Riviere 1987, Jagielo 1990, Smith et al. 1990), many questions remain about their movement patterns. Most studies describe lingcod as sedentary (Miller and Geibel 1973, Mathews and La Riviere 1987, Smith et al. 1990); yet lingcod do make migrations, and movement up to 385 km has been documented (Mathews and La Riviere 1987, Jagielo 1990). Although not verified through tagging, it is thought that most lingcod movements, including possible homing behavior, are related to spawning. Female lingcod may seasonally leave deeper reefs and move inshore to lay demersal eggs that the shallower living males guard. There is indirect evidence for the inshore movement of females; an increase of larger gravid females in the inshore catch occurs during fall months just prior to spawning (Miller and Geibel 1973).

Furthermore, some studies have indicated the homing behavior of lingcod, similar to many rocky reef fishes (Hart 1943, Williams 1957, Carlson and Haight 1972, Matthews 1990); i.e., when fish move away for any reason (including spawning, experimental displacement, etc.) they will return to areas previously occupied (Gerking 1959). In an early study in Canada, 4 of 14 displaced lingcod returned 9.7 km to original capture sites (Hart 1943). Additional evidence of lingcod homing behavior came from an attempt to enhance overfished areas by transplanting lingcod (Buckley et al. 1984). None of the transplanted lingcod were resighted at the release area (i.e., the enhancement was unsuccessful), whereas nine of the transplanted lingcod were caught close to the original capture site (190 km from release site).

Lingcod movement behavior has implications for enhancement efforts and habitat management. Attempts to rebuild populations in overfished areas by transplanting lingcod from areas of higher abundance would be unsuccessful if lingcod simply returned to their original home sites. Furthermore, movement information is valuable because if lingcod preferentially home to certain reefs, then those reefs could be designated as management reserves. Thus, any new knowledge of lingcod homing will lead to a better understanding of their movement behavior and the effect of rehabilitation efforts. The objectives of this pilot study were to use ultrasonic tagging to (1) describe home ranges and movements of lingcod on rocky reefs, and (2) determine the homing routes of displaced lingcod.

Methods

Study sites

The study was conducted during April 1990 off eastern Gabriola Island on the eastern side of Vancouver Island, British Columbia (Fig. 1). The area is characterized by extensive shallow rocky reefs and pinnacles. Depths encountered during ultrasonic tracking were in the range 3–35 m. Two reef areas were chosen for the tracking work: Gabriola reefs and Valdes reefs (each is actually a series of small, separate reefs) (Fig. 1). Both reefs are approximately 15–30 m deep, although shallower areas were sometimes encountered. Although bullkelp *Nereocystis leutkeana* is present on these reefs during the summer and fall, no surface kelp was present during this April study.

Ultrasonic tagging

The transmitters (48 × 15 mm, 18 g in air, 8.3 g in seawater) were ex-

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ternally attached using methods used for tuna (Holland et al. 1985). The nylon loop on the transmitter anchored one inelastic pull tie, with another tie wrapped around the tag's opposite end. The two pull ties were inserted through the dorsal musculature and cinched down to prevent the transmitter from dangling.

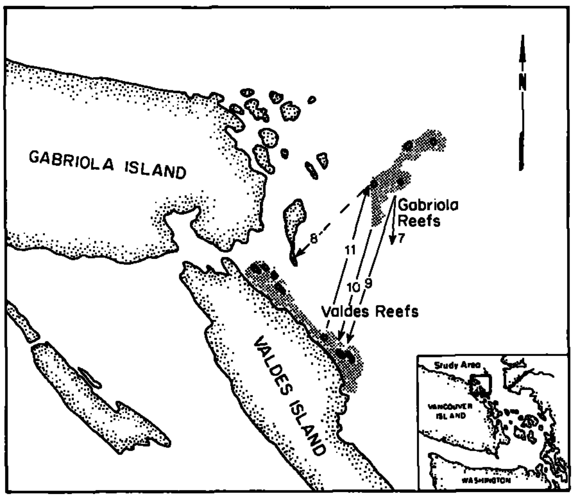

Figure 1
Map of study area and general displacement directions for *Ophiodon elongatus* fish nos. 7–11. Fish were captured and displaced in the direction shown by arrow.

Lingcod were captured on hook-and-line, placed in a seawater-filled cooler, and anesthetized (methomidate hydrochloride). After tags were attached, lingcod were allowed to recover in fresh (without anesthetic) seawater prior to release. Fish appeared completely recovered from the anesthetic and tagging procedure ~5–10 min after tagging.

Eleven transmitters with replaceable batteries (Vemco V3-1H-R pingers, Vemco Ltd., Nova Scotia, Canada B3L 4J4) were operated at five crystal-controlled frequencies: 50.0 (2 tags), 60.0 (2 tags), 65.54 (3 tags), 69.0 (2 tags), and 76.8 (2 tags) kHz, corresponding to pre-set channels on the Vemco VR-60 receiver. Tags assigned to the same channel were easily differentiated by their unique pulse period, which was automatically decoded and displayed by the receiver. To locate the transmitters, a Vemco V-10 directional hydrophone was employed from a small boat. Once a tag was located, the boat's position was determined, using LORAN-C readings, depth, and visual compass bearings of four charted features (buoys, lights, etc.), in the study area on an almost daily basis (one of 21 tracking days was missed due to boat breakdown) for the life of the transmitter (21 d battery life). One reason this study area was chosen was the presence of several flashing lights and buoys which made navigation and location determination easier, especially at night.

During 5–27 April 1990, 11 lingcod (57.0–80.6 cm total length, TL) were tagged and monitored (Table 1).

Table 1
Summary of total lengths and duration of tracking of lingcod *Ophiodon elongatus* equipped with ultrasonic transmitters in the Strait of Georgia, British Columbia, and monitored 5–27 April 1990 to measure home ranges and homing routes. Nocturnal movement occurred 24:00–06:00.

Tag no.	Sex	Length (TL cm)	Date tracking began	Duration (d)	Nondisplaced lingcod home ranges			
Controls								
1	Female	67.5	4/5/90	20	Captured and released at Valdes reefs			
2	Male	62.1	4/5/90	16	Captured and released at Valdes reefs			
3	Male	59.5	4/9/90	19	Captured and released at Valdes reefs			
4	Male	69.8	4/8/90	15	Captured and released at Gabriola reefs			
5	Female	80.6	4/9/90	12	Captured and released at Gabriola reefs			
6	Female	68.4	4/9/90	15	Captured and released at Gabriola reefs			
					Displaced lingcod homing routes			
					Distance moved (km)	Total time to return (h)	Movement rate (m/h)	Nocturnal movement rate (m/h)
Experimentals								
7	Male	66.2	4/12/90	14	1.0	40	25	83.3
8	Male	57.0	4/16/90	12	2.2	Did not return		
9	Male	64.0	4/19/90	9	2.8	60	48	233.3
10	Male	64.5	4/23/90	5	2.8	35	80	233.3
11	Male	69.5	4/25/90	3	2.8	33	85	233.3

Up to seven tagged fish were deployed within the study area at one time. One procedure was conducted on two rocky reefs to determine the home ranges of lingcod during the day, night, and periods of strong current which were predicted up to 14.8km/h (8.0kn) (Canadian tide and current tables, Canadian Hydrographic Service 1990). Six lingcod were captured, tagged, released, and monitored at the original point of capture, either Gabriola reefs area or Valdes reefs. Their geographic locations were determined on an almost daily basis (the only exception being 18 April) for the duration of the tag battery life.

To determine the homing routes of displaced lingcod, five males were captured, tagged, and displaced up to 2.8km in two opposite directions (Fig. 1). Four of the five displaced fish were moved south, while one fish was moved north. Because there was no information on the time required for lingcod to home, the first fish was moved a short distance (1km) to allow enough time to track its homeward movement. Of the remaining four lingcod, one was displaced 2.2km, and three were displaced 2.8km. The movements were then monitored almost continuously, with occasional rest breaks, until the transmitter batteries expired. Displaced fish were individually tracked because they required continuous monitoring. When the displaced fish were first released, an attempt was made to stay with the fish for several hours to detect any homeward movement.

The field schedule started with two teams each working 12h on the boat for a full 24h coverage. After the first few days of field work, we changed the schedule to devote our efforts to covering nighttime lingcod movement (16:00–08:00). The entire study covered 21 tracking days during 5–27 April (only 18 April was canceled due to boat problems) for a total of 336 tracking hours. When the nondisplaced fish were first released, an entire day was spent tracking those fish. Subsequently, each fish was periodically (about 15–20 times/tracking day) checked for its position, which allowed several tagged fish to be concurrently monitored. The five displaced fish were followed one at a time to ensure that their homing route could be detected.

On two separate dates, I conducted scuba observations to search for tagged lingcod and to collect information not available through telemetry. When a signal cannot be located, it was impossible to determine whether the tag battery has died or the fish has left the area; hence, I searched underwater for two tagged fish in their last recorded location after the signal could no longer be detected. Also, to determine the accuracy of telemetric locations, I used scuba observations to compare underwater positions of tagged fish with those provided by telemetry. Once the directional hydrophone positioned the boat directly over the tag's signal I then anchored the boat, descended, and searched for the tagged fish.

Results

Nondisplaced fish (controls)

The six lingcod (three females and three males) tagged and released at Gabriola and Valdes reefs were generally found close to release sites during the day, night, and periods of swift current. When relocated, the six lingcod were essentially in the same position (latitude–longitude differences were within 0.01–0.02 nmi, which is the normal resolution of the LORAN unit). Thus, there was no detectable difference in their home range size. Fish were monitored for 12–20d ($\bar{x}$ 16.2+2.9d) until the tag batteries expired.

These telemetry findings were verified by visual (scuba) resightings of two tagged lingcod. After determining the position of an ultrasonic tag, I later (within a few minutes) observed the tagged fish sitting on the bottom. These visual sightings also verified that the tags were still attached to the fish. Furthermore, after the signal had apparently died on two tagged fish, I searched underwater and saw the two tagged lingcod in their last recorded telemetry position.

The six individual lingcod were also monitored on six separate nights when the current ranged from slack to 10.4km/h (5.6kn) for a total of 50h of nighttime observation. Home ranges were similar to those observed in the day. However, signals were louder suggesting that the fish were out in the open, i.e., not under a rock (Matthews et al. 1990).

Displaced fish (experimentals)

The five displaced lingcod remained close to release sites and did not move for several hours following release (Figs. 2–6). These first few hours (both during the day and night) following release may be a recovery period in response to capture, handling, and tagging. Subsequently, four of the five displaced fish moved back to the capture site. Each fish had returned to the capture site by the end of the second night following release. Return trips were confined to the immediate vicinity of the Gabriola and Valdes Islands study area.

The four homing lingcod (nos. 7, 9–11) remained near the release site for 4–6h and returned to home sites in 33–60h (Figs. 2–5). These four fish started their homeward movements at night (20:30–06:00), and movement terminated once it became light at ~06:00.

No clear pattern was detected in the homeward movement, as lingcod did not appear to follow obvious features such as depth contours or currents. Homing lingcod traversed depths of 5–35m. Occasionally the

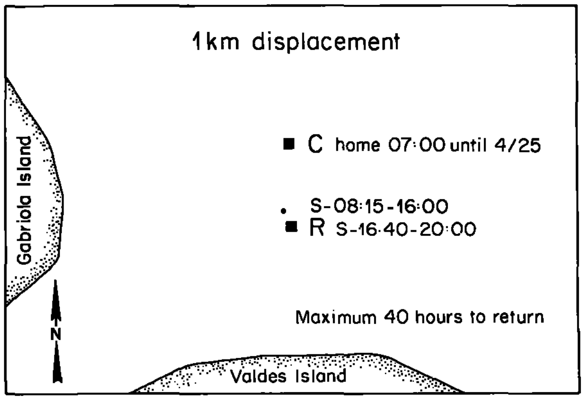

Figure 2
Positions of *Ophiodon elongatus* fish no. 7 (66.2 cm male) captured from site C, moved 1 km south to release site R, and monitored 12–25 April. S = stationary.

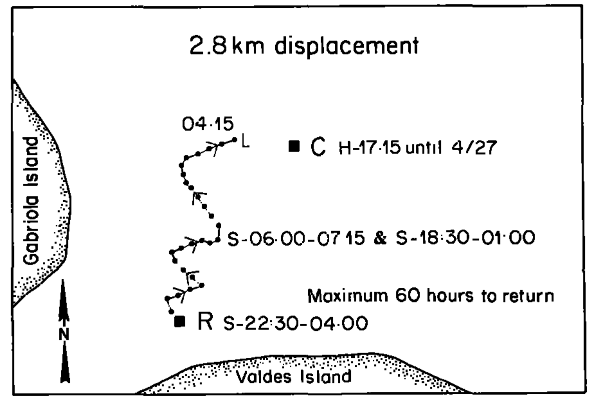

Figure 3
Positions of *Ophiodon elongatus* fish no. 9 (64.0 cm male) captured from site C, moved 2.8 km south to release site R, and monitored 19–27 April. S = stationary, L = temporarily lost.

signals became quite strong, suggesting homing lingcod were traversing areas without much rock relief. Lingcod encountered the deepest water (35 m) when crossing open areas. The four lingcod returned to their original capture sites where they remained until the transmitter batteries died or the tracking project was completed.

The first displaced fish (no. 7, a 66.2 cm male) was caught on 12 April in 10 m of water, moved 1 km south, and released in 18 m of water (Fig. 2). Because this was the first release and I did not know what movement to expect, I stayed directly over the fish from release time (16:40) until 20:30. However, no movement was detected. When I returned the following morning (07:30), the fish had moved about halfway (500 m, Fig. 2) back to the capture site. I stayed with the fish from 07:30 to 16:30, but no additional movement was detected. When tracking resumed the following morning (07:00), the fish was back at the original capture site where it remained for 12 d (until 25 April) when the battery apparently died. This fish moved at least 1 km, the displacement distance, in ~40 h. Because all homeward movement of the fish apparently occurred at night, the remaining displaced fish were tracked at night.

Fish no. 9 (64.0 cm male) was captured on 19 April in 12 m of water, tagged and moved 2.8 km south, and released into water 18 m deep (Fig. 3). It was stationary from release at 22:30 until 04:00 when it moved in a northerly direction for 2 h and stopped. Tracking was terminated at 07:15; when it reconvened at 18:30, the fish was in the same location. At 01:00 it moved to the northwest and the northeast until 04:30 when its signal was lost. Tracking was terminated at 08:30, and when

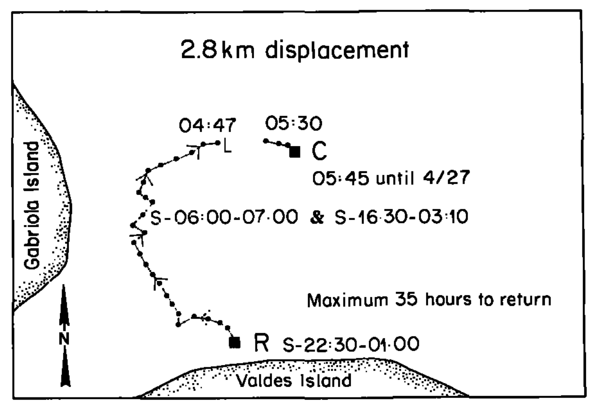

Figure 4
Positions of *Ophiodon elongatus* fish no. 10 (64.5 cm male) captured from site C, moved 2.8 km south to release site R, and monitored 23–27 April. S = stationary, L = temporarily lost (04:47–05:30).

it resumed at 17:15 the fish was back at the capture site. I assumed that the fish homed between 04:30 (when the signal was lost) and daybreak because all other lingcod movement occurred at night. It remained at the capture site for 7 days until tracking ended on 27 April. The 2.8 km return trip was completed in less than 60 h.

Fish no. 10 (64.5 cm male) was captured in 10 m of water, tagged and displaced 2.8 km south, and released in water 18 m deep (Fig. 4). The fish was stationary for 2.5 h after release (22:30–01:00) and moved sporadically from 01:00 to 06:00. The fish was stationary from 06:00 to 07:00 when tracking ended. When tracking

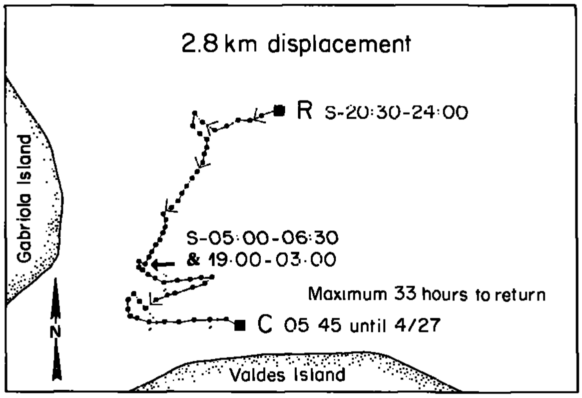

Figure 5
Positions of *Ophiodon elongatus* fish no. 11 (69.5 cm male) captured from site C, moved 2.8 km north to release site R, and monitored 25–27 April. S = stationary.

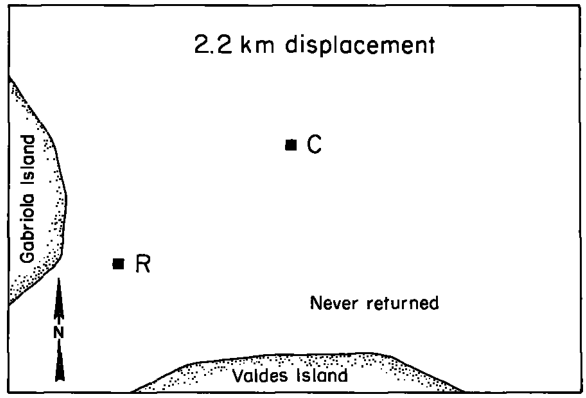

Figure 6
Positions of *Ophiodon elongatus* fish no. 8 (57.0 cm male) captured from site C, moved 2.2 km south to release site R, and monitored 16–27 April.

reconvened at 16:30, the fish was in the same position where it remained until 03:15. It then moved from 03:15 to 04:47 when the signal was temporarily lost. When relocated at 05:30, it was followed back to the capture site (05:30–05:45). It was at this site 4 days later that tracking stopped. The 2.8 km return trip took about 35 h.

Fish no. 11, a 69.5 cm male, was captured in 15 m of water, tagged and displaced 2.8 km to the north, and released in 12 m of water (Fig. 5). The fish remained stationary from release (20:30) until 24:00, when it moved to the west and south until 05:00. It remained at this position until tracking ended at 06:30. Later that day, the fish was relocated in the same location where it remained until 03:00. At this time the fish moved southeast and southwest and reached its original capture site at 05:45. It remained there until 27 April when tracking ended. The 2.8 km return trip took ~33 h.

One fish did not return from displacement. Fish no. 8, a 57.0 cm male was caught, tagged, and transplanted 2.2 km (Fig. 6) to the release site. Tracking continued for 12 d, during which time the fish apparently remained at the release site and no movement was detected. Because I was unable to make scuba observations at this site, it is possible that the tag was shed, which would also result in a stationary signal.

Lingcod took 33–60 h to return from their 1.0–2.8 km displacements for an average homing speed of 59.5 m/h (Table 1). Actually, their movement rate was faster since they moved only at night. If averaged over the total period when movement was documented (6 h, 24:00–06:00) for two consecutive nights (total of 12 h) then the rates are 83.3–233 m/h ($\bar{x}$ 195.8 m/h or 1175.0 m/d).

Discussion

Similar to intertidal fishes (Williams 1957) and several species of rockfishes (Carlson and Haight 1972, Matthews 1990), lingcod are another rocky reef fish capable of homing. Ultrasonic tracking is limited by low sample sizes due to tag cost and labor-intensive tracking. This study represents the first attempt to use ultrasonic telemetry to research lingcod movement behavior, but this was limited to displaced males soon after their nesting season. Additional work is necessary to determine whether males behave differently (e.g., do not home) at other times of the year. Telemetry would also be valuable to determine whether females make inshore-offshore movements to relocate previously used areas.

Lingcod movement occurred at night (24:00–06:00, Figs. 3–5) sometimes under dark, moonless skies. Little work has been done on fish vision in cold-temperate water systems (see review in Loew and McFarland 1990). Nevertheless, water at night is darker and has lower visibility than during the day, and as Ebeling and Bray (1976) point out, "...the relatively turbid, temperate waters are often a dark and gloomy place at night." Moreover, during our April tracking study, most nights were overcast and rainy, further reducing the water's visibility. The low visibility at night presumably precludes lingcod from using visual landmarks which usually requires precise recognition of specific features such as coral heads or rocks (Hasler 1966, Reese 1989). Still, an important question remains: Why should lingcod move at night when visibility is better during the day? Perhaps their nocturnal movement is to avoid predation since lingcod sometimes crossed flat, open areas that had no hiding places. Locally, harbor seals feed on lingcod, and recently their numbers have dramatically increased (Olesiuk et al. 1990). On the other hand, perhaps lingcod are simply more active at night, as my nighttime home-range observations indicated, which would explain their nighttime movement.

Lingcod homing was fairly directional and confined to the immediate area of Gabriola Island. In contrast, when displaced shorter distances (500 m), copper and quillback rockfishes, which co-occur with lingcod, moved along a bimodal northwest–southeast axis and sometimes retraced that path before finally moving in a westerly direction that led to their home site (Matthews 1990). After displacement, initial movement of lingcod was in the homeward direction only, i.e., no back-and-forth movement between the release site and home site was observed. The more direct and nocturnal homing in lingcod suggests they are navigating rather than orienting along one compass course or relying on olfactory cues. Orientation can be ruled out (Baker 1978, Able 1980) because lingcod successfully homed from north and south displacements. It is currently unknown whether rocky-reef fish, including lingcod, recognize olfactory cues.

Lingcod homing was fast in comparison with copper and quillback rockfishes, which took 8–25 d to return from 500 m displacements (Matthews 1990). From an analysis of a large-scale tagging program during 1982–87, Smith et al. (1990) estimated that mean dispersal rates for male and female lingcod were 500 m/d and 1040 m/d, respectively, similar to those observed in the present study (1173.7 m/24 h). Presumably, lingcod movement rates vary depending upon seasonal requirements (e.g., feeding, spawning, etc.).

Several hypotheses could explain why the smallest male (no. 8) did not return from displacement. Perhaps lingcod do not develop a resident or homing response until they are older and larger. The length-maturity relationship is determined by their geographic area (Richards et al. 1990), and the 50% maturity level for male lingcod at a similar latitude off the west coast of Vancouver Island is 57.1 cm. Thus, if fish no. 8 (57.0 cm) was not sexually mature, it may have lacked the ability to home. Buckley et al. (1984) also noted a lack of homing in small male lingcod. In that study, after 4.5 yr, the smallest transplanted lingcod (a 57 cm male) remained close to the release site after most transplanted lingcod had apparently homed. Alternatively, the lack of homeward movement could be due to tag shedding, which would also produce a stationary signal.

This study revealed new information on lingcod homing behavior. After displacement up to 2.8 km, lingcod moved at night back to home sites within 60 h and followed a fairly direct route. Because this was a pilot study and I displaced only male lingcod, more tracking studies are needed to increase sample sizes, include females, and attempt longer-distance transplants. Whether they home and reuse spawning areas will be important to document, as this information is crucial if lingcod preserves are established. It does appear that transplant attempts to rebuild lingcod stocks may be ineffective with larger, older males but may be successful if the lingcod are moved before they reach a certain size or age.

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