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Movements of hatchery-reared lingcod released on rocky reefs in Puget Sound

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Abstract Fourteen sub-adult hatchery-reared lingcod (*Ophiodon elongatus*) were released onto reefs in South Puget Sound, Washington, USA to evaluate their movement behavior. Acoustic telemetry revealed variation in movement among individuals that was related to body size. Larger lingcod tended to leave the release reef sooner than smaller lingcod. Four lingcod left the reefs less than 10 days after release, while three lingcod left between one and 4 months after release. Seven lingcod remained at the release reefs for the entire 5-month study, though they did make apparent short-term (< 24 h duration) excursions away from the reefs. Data suggest that the frequency and duration of excursions increase with age and size in both wild and hatchery lingcod. Movement data from these hatchery lingcod and previously published studies on wild lingcod are compared.

Keywords *Ophiodon elongatus* · Acoustic telemetry · Stock enhancement · Hatchery · Behavior

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Introduction

Stock enhancement, the process whereby fish are reared in hatcheries and released into nature (Bell et al. 2006), may aid the recovery of wild populations. For stock enhancement to be successful at rebuilding natural populations, released hatchery fish must survive and reproduce at near-natural rates, behave like wild conspecifics, and for some species, exhibit fidelity to release sites. However, hatchery rearing might reduce survival and adaptive behaviors after release into the wild (Brown and Day 2002; Huntingford 2004). For example, high mortality rates may occur after release if anti-predator behaviors are not adequately developed during ontogeny in the hatchery (review: Olla et al. 1998). Artificial environments may alter wild-typical movement patterns if natural cues experienced early in life are necessary for fish to display natural movement patterns as adults (Pacific salmon: Dittman and Quinn 1996). Further, some species of wild fish that are translocated have shown homing behavior back to the original site of capture (rockfish and lingcod: Matthews 1990, 1992; Yamanaka and Richards 1993; Reynolds et al. 2010), raising the question of whether hatchery-reared fish will display fidelity to the release site after they are "displaced" from the hatchery.

Stock enhancement may be a potential tool for the management of lingcod (*Ophiodon elongatus* Girard), which are economically important to commercial and recreational fisheries along the west coast of North America, from Alaska to California. Due in part to overfishing, average catch declined 36% from a coastwide average annual catch of 4501 mt between 1980 and 1989 to an average annual catch of 2876 mt between 1990 and 1997 (Jagielo and Wallace 2005). Beginning in 1998, fishery restrictions were enacted and coastal lingcod were declared rebuilt in 2005 (Jagielo and Wallace 2005). Similarly, lingcod historically made important contributions to fisheries in Puget Sound, a large glacially formed estuary in Washington State (Bargmann 1982). However, while lingcod stocks have been declared rebuilt on the coast, strong fishing restrictions remain on Puget Sound lingcod.

Stock enhancement programs can take many years to carefully plan, develop, evaluate, and refine (Blankenship and Leber 1995). As a first step, small-scale releases may improve assessments of the potential for released hatchery fish to survive, behave naturally, and bolster fish stocks. In this study, telemetry-tagged hatchery lingcod were released into South Puget Sound and tracked with acoustic receivers to determine how long hatchery-reared fish would survive and remain near the release sites.

Materials and methods

Egg collection and rearing are detailed in Rust et al. (2005). Briefly, wild-spawned eggs were collected in winter 2000 from the marine area south of the Tacoma Narrows Bridge (South Puget Sound, hereafter SPS) and reared at the NOAA, Northwest Fisheries Science Center, Manchester Research Station near Port Orchard, Washington, USA (Fig. 1). Eggs were brought into 20 L incubators, and transferred to mesocosm bags at hatch. Lingcod were transferred to shore-based tanks at metamorphosis, and then to net pens at approximately 150–250 mm.

On 2 August 2004, 14 age-4 lingcod (seven males, 522–575 mm; seven females, 602–719 mm) were implanted with acoustic tags (VEMCO, V13P-1H-69 k coded transmitter, dimensions: 44 mm length by 13 mm diameter). Acoustic tags emit long-range acoustic pulses that allow continual monitoring of an animal's movement. The tags allowed for the unique identification of each tagged individual, and also emitted depth data. The acoustic pulses were emitted every 40–120 s throughout the life of the tag (326 d for acoustic emissions and 244 d for depth sensor data emissions).

Methods for surgical intraperitoneal implantation of acoustic tags in adult lingcod followed those successfully used by Griffin (2000). Tags were inserted through an approximately 1.5 cm incision midway between the pectoral fins and anus, and gently moved anteriorly before suturing. Sex, length, and weight were recorded at the time of tagging. Males were identified by the presence of narrow and pointed genital papillae. After surgery, fish were held for several days of pre-release monitoring. One fish died within 48 h post-surgery. Its acoustic tag was recovered and implanted in another hatchery lingcod of the same sex.

On 12 August 2004, the 14 tagged lingcod were transported with a boat to two reefs comprised of rocky relief outcroppings (Fig. 1). Zee's Reef was designated a marine conservation area in 2002 (W. Palsson, pers. comm.) by the Washington Department of Fish and Wildlife (WDFW); approximate depths in the area ranged from 3 to 25 m. The second release reef was Itsami Reef, an artificial reef constructed by WDFW near Johnson Point (Hueckel and Buckley 1987; Fig. 1). Depths in the area generally ranged from 9 to 40 m. At each reef, the fish were placed in mesh bags and brought by SCUBA divers to the bottom for release. Four females and three males were released at Zee's Reef; four males and three females were released at Itsami Reef.

Pulses from the acoustic tags were recorded by submerged VEMCO VR2 acoustic receivers. Similar research using this acoustic equipment has indicated high detection probabilities up to a range of 500 m (VEMCO Inc., pers. comm.). Two receivers were

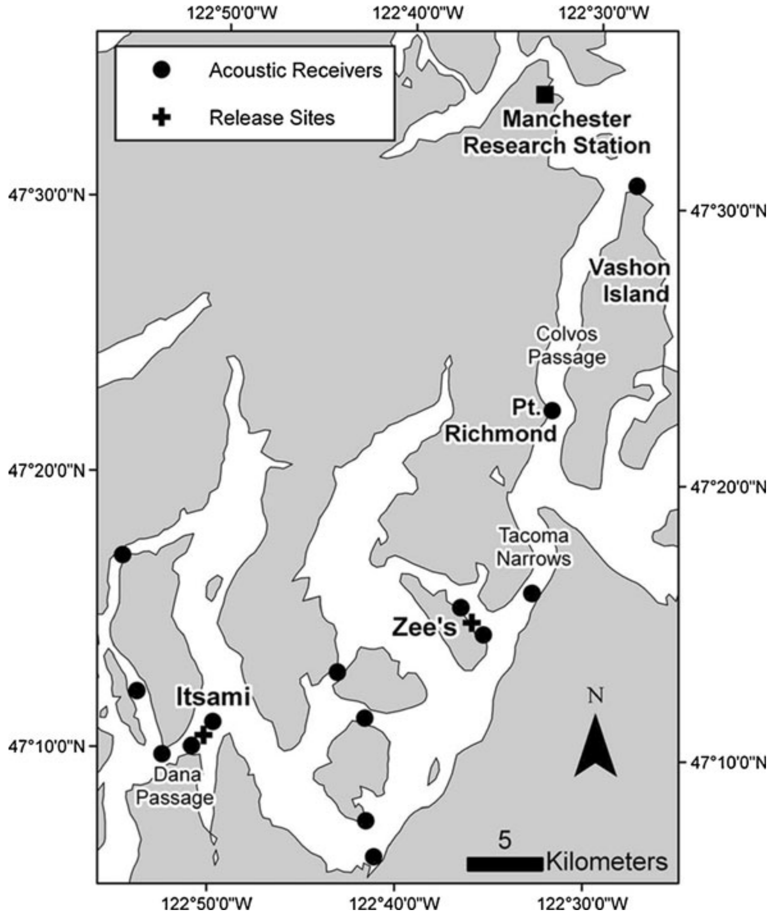

Fig. 1 Map of South Puget Sound, Washington, USA, with approximate locations of submerged acoustic receivers and release sites. The pairs of receivers flanking each release site were closer to the release sites than depicted but were spaced further apart on the figure to prevent symbols from overlapping. Plus symbols represent release sites

deployed at each release site (Fig. 1) in an attempt to cover the entire reef and to provide redundancy in case of receiver failure or loss. Each receiver was attached midway on a 7.6 m line that was anchored to a 1 m auger and suspended in the water column by a 28 cm diameter trawl float. Receivers were deployed by SCUBA divers at Zee's reef on 24 June 2004, and at Itsami Reef on 7 August 2004. Receivers were removed for data retrieval and replaced by SCUBA divers at Zee's reef on 21 September 2004, and at Itsami Reef on 25 September 2004. Final recovery of all acoustic receivers occurred from 22 to 23 January 2005. All receivers were functioning at the time of recovery. Data were also accessed from VR2 receivers deployed by other researchers for separate projects, allowing for the detection of movement to areas off the release sites (Fig. 1).

Detection data can be erroneously interpreted as fish survival and site residency when an active acoustic tag is expelled or if a fish dies and remains within the range of receiver detection. A fish was considered to be alive at least until their last detection on a new receiver (indicating fish movement) or to the last time its tag transmitted a depth change that could not be explained by the predicted tidal height plus tag resolution (0.44 m resolution). A predator that consumes a tagged fish and leaves the range of receivers could be erroneously interpreted as a tagged fish that leaves the site. However, since predators would excrete the tag within several days, any additional tag movement after several days would confirm that the fish was alive when it left the site. Survival rates cannot be determined once a fish leaves the range of the receivers; therefore estimated survival durations for each fish should be considered minimums. Equipment and acoustic properties can periodically result in false tag detections. Typically, a false detection may be indicated by a single detection that is not accompanied by another that same day (Dagorn et al. 2006). A fish was therefore considered to be present at the release reef on a particular day only if there were two or more detections that day (see also Starr et al. 2004, 2005). Since body size, sex, and location differences have been suggested to affect movement in lingcod (Hart 1943; Mathews and LaRiviere 1987; Jagielo 1990), general linear models (binomial distribution, logit link) were used to test whether the proportion of days spent at the release reef (days spent at reef divided by duration of study) was predicted by body length at release, sex, site, or the interaction between body length and sex. Male body length did not overlap with female body length, so body length and sex were perfectly confounded. Consequently, we centered body length by sex and site for analyses.

The method of assigning presence at the reef based on a minimum of two acoustic detections per day is sensitive to excursions away from the reef that lasted more than one day (Starr et al. 2004; Starr et al. 2005). Lags between detections occurring on the same day were interpreted as fish movement away from the reef ("apparent short excursions"). However, lags can also occur when a fish is inside the monitored area if an acoustic pulse is temporarily obscured by an acoustic shadow (in structurally complex habitat) or ambient acoustic noise such as that from turbulent water conditions, boat traffic, or other acoustic tags (Heupel et al. 2006; Simpfendorfer et al. 2008). To minimize these false absences, lags that lasted less than one hour were excluded from analyses. While the possibility of false absences cannot be ruled out, the results from this study show that lags between detections correlate with biological variables, which would not be expected if the lags were due to abiotic interference. This lends support to the interpretation that lags in this study represent real fish movement away from receivers. Only lingcod that were detected at least twice per day, every day, for the duration of the study, were analyzed because only this group contained enough individuals (n=7) and a wide-enough range of data (several months) to allow statistical analyses. A generalized linear mixed model (Poisson distribution, log link) was used to test whether the number of days since release and body length at release predicted the frequency (number per day) of apparent short excursions. A linear mixed model was used to test whether apparent short excursion duration was significantly predicted by body length at release or the number of days since release. Data were log-transformed. The residuals were slightly skewed on a normal probability plot, but this was accepted given the robustness of linear models and the strength of the resulting p-values (Neter et al. 1996).

Results

Seven of the 14 lingcod were present at the reefs every single day throughout the duration of the study (hereafter termed 'residents,' Table 1). All of these fish had depth changes greater than would be expected from an expelled tag or dead fish, within one day of the end of the study, indicating that the fish were alive (Table 1). The number of days spent at the release reef decreased with body length at release (Fig. 2; general linear model, chi-square=1049.56, df=1, p<0.001), and was significantly affected by sex (general linear model, chi-square=58.47, df=1, p<0.001), site (general linear model, chi-square=203.94, df=1, p<0.001), and the interaction between sex and length (general linear model, chi-square=91.86, df=1, p<0.001). There was no fishery monitoring component to this study, but a recreational angler incidentally caught one of the lingcod almost 5 years later at the release reef (Table 1). The angler noticed the acoustic tag and notified the Washington Department of Fish and Wildlife.

The seven resident lingcod were also used in analyses that provided information on apparent short excursions from the reef that were shorter than 1 day in duration. The average resident lingcod made 0.5 apparent short excursions per day, each lasting an average of 157 min. The frequency of apparent short excursions was not significantly related to fish length at release (generalized linear mixed model, F=2.07, df=1, 1152, p=0.15), but increased with the number of days since release (generalized linear mixed model, F=189.22, df=1, 1152, p<0.001, Fig. 3).

Apparent short excursion duration increased significantly with fish length at release (linear mixed model, F=11.31, df=1, 5.17, p=0.019, Fig. 4), and the number of days since release (linear mixed model, F=33.78, df=1, 600.38, p<0.001, Fig. 5).

Discussion

Both hatchery-reared lingcod released in the current study and wild lingcod released in previous studies

Table 1 Fourteen lingcod were released on Zee's Reef and Itsami Reef in Puget Sound, Washington State. Table shows release reef, lingcod length at release, sex, and the date each lingcod left the reef for more than 1 day. Five of the seven lingcod that left for more than 1 day were never again detected at the reef. The seven lingcod that "did not leave" the reef were still present at the reef when the study ended on 22 January 2005 (Zee's Reef) or 23 January 2005 (Itsami Reef)

Release reef	Length (mm)	Sex	Fish ID#	Release date	Date left reef	Most recent evidence fish was alive
Zee's	719	F	93	8/12/2004	8/12/2004	Periodically in Tacoma Narrows (8/17/04 to 10/12/004)
Itsami	686	F	85	8/12/2004	10/10/2004	At Dana Passage (10/11/04); Back at Itsami (12/5/04 to 12/18/04)
Itsami	647	F	83	8/12/2004	11/1/2004	At Pt Richmond (11/4/04 to 11/10/04); At Vashon Island (11/10/04)
Itsami	602	F	82	8/12/2004	Did not leave	Depth change of 10 m in 7 min on 1/22/05
Zee's	665	F	86	8/12/2004	Did not leave	Depth change of 5 m in 4 min on 1/22/05
Zee's	612	F	84	8/12/2004	Did not leave	Depth change of 2 m in 21 min on 1/22/05
Zee's	676	F	81	8/12/2004	Did not leave	Depth change of 21 m in 1 min on 1/21/05
Zee's	575	M	89	8/12/2004	8/12/2004	Not detected after leaving release reef
Itsami	526	M	87	8/12/2004	8/19/2004	Back at Itsami (8/29/04 to 9/4/04); At Dana Passage (9/4/04)
Itsami	536	M	88	8/12/2004	8/20/2004	Not detected after leaving release reef
Itsami	534	M	91	8/12/2004	11/25/2004	Not detected after leaving release reef
Itsami	526	M	92	8/12/2004	Did not leave	Caught by recreational angler at release reef in 2009
Zee's	522	M	94	8/12/2004	Did not leave	Depth change of 11 m in 2 min on 1/21/05
Zee's	550	M	90	8/12/2004	Did not leave	Depth change of 10 m in 4 min on 1/21/05

have exhibited substantial within-population variability in range of movement. In this study, half of the hatchery-reared lingcod were at the release reefs every day for the entire study. The 2009 capture of one of the fish on the release reef shows that hatchery-reared lingcod can stay at or return to release reefs several

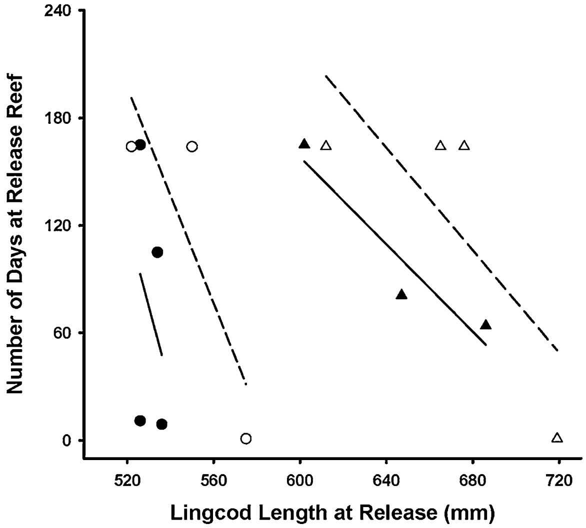

Fig. 2 Larger lingcod tended to leave the release reefs sooner than smaller lingcod. Itsami Reef is represented by solid symbols and lines. Zee's Reef is represented by open symbols and dashed lines. Triangles and circles represent females and males, respectively

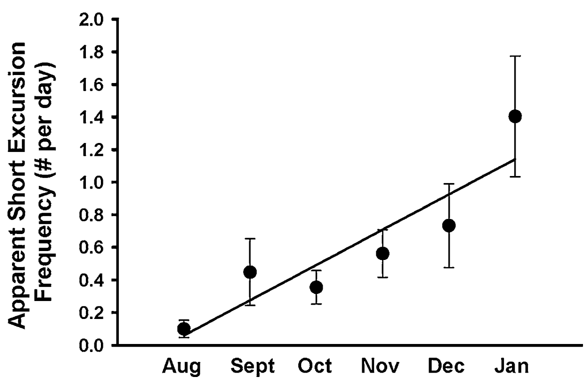

Fig. 3 Apparent short excursion frequency increased with the number of days since release. Acoustic detection lags greater than one hour in duration were interpreted as instances where lingcod left the reef (apparent short excursions). These excursion analyses were only conducted for the seven lingcod that were detected at the release reef at least twice every day. Each data point represents the month's excursion frequency averaged over all lingcod (±SE), but data analyses were conducted on the original daily data (not averaged over each month)

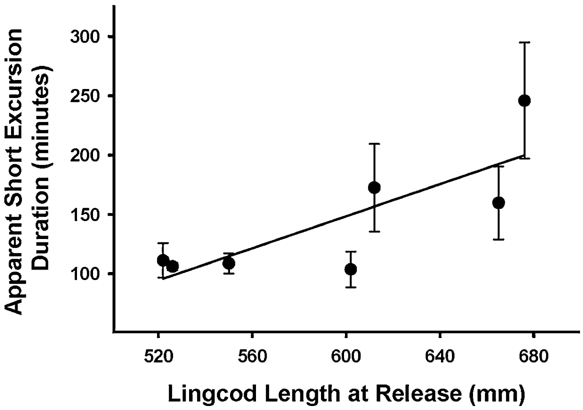

Fig. 4 Lingcod that were larger at release spent more time away from reefs during apparent short excursions. Acoustic detection lags greater than one hour in duration were interpreted as instances where lingcod left the reef (apparent short excursions). These excursion analyses were only conducted for the seven lingcod that were detected at the release reef at least twice every day. Each data point represents a single lingcod's average excursion duration (±SE) over the entire study, but data analyses were conducted on the original data (not averages)

years after release. In contrast, the other seven lingcod apparently left the release reefs between a few hours after release and 4 months after release. The possibility that predators removed these tagged fish from the reef can be excluded for four of the seven lingcod, which were detected at other locations (hence

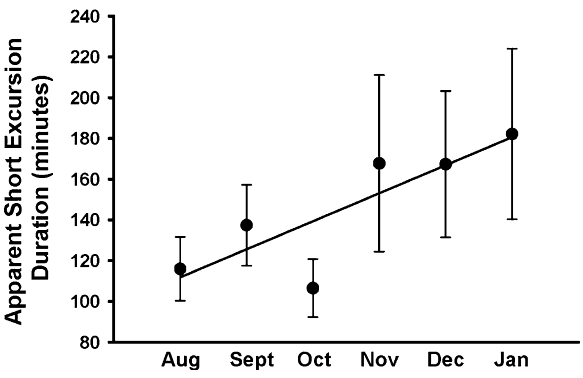

Fig. 5 Apparent short excursion duration increased with the number of days since release. Acoustic detection lags greater than one hour in duration were interpreted as instances where lingcod left the reef (apparent short excursions). These excursion analyses were only conducted for the seven lingcod that were detected at the release reef at least twice every day. Each data point represents the month's excursion duration averaged over all lingcod (±SE), but data analyses were conducted on the original daily data (not averaged over each month)

moving) between 9 and 69 d after leaving the reef (average: 39 d).

Movement variation among individuals is consistent with a recent study that tracked acoustically-tagged wild lingcod to describe space use within the home area (Tolimieri et al. 2009). Space use varied as a function of diel and tidal cycles, but in different ways depending on the particular individual (Tolimieri et al. 2009). Movement variation among individuals has also been observed in mark-recapture studies ranging from the Seymour Narrows to Neah Bay, where 81% to 91% of recovered wild lingcod moved less than 8 km (5 miles) from the release site and 9% to 19% moved a greater distance (Hart 1943; Jagielo 1990). In contrast, Mathews and LaRiviere (1987) found that half of the wild lingcod in northern Puget Sound were recaptured less than 8 km from the release site, while the other half were recaptured from a greater distance, leading them to propose that movement variation may also exist among populations. In a recent acoustic tracking study in Prince William Sound, 45% of wild lingcod dispersed from the release site (Bishop et al. 2010).

Variation in lingcod movement among hatchery individuals (this study) and among wild individuals (previous studies) is paralleled in salmonids, where the tendency to stray varies among wild individuals within a population, among wild populations, and among hatcheries (Quinn 1993; Waples 1999). Similarly in wild tilefish, site fidelity varied among individuals within a season, but also between seasons (Yokota et al. 2006). Controlling for release season, hatchery tilefish appeared to show greater site fidelity than wild fish, though the authors suggest that hatchery rearing temperature may have caused this difference. As we learn more about how hatchery practices may affect variation in fidelity to release sites, it may be possible and preferable for hatchery release group behavior to match the variation in site fidelity of receiving populations.

This study and previous studies can improve our understanding of some of the causes of variation in movement. Some of the among-individual variation in lingcod movement in this study was explained by body size and sex. Similarly, variation in wild lingcod movement has been attributed to differences in body size (Bishop et al. 2010), sex (Jagielo 1990; Smith et al. 1990), and sexual maturity (Hart 1943; Jagielo 1990). Male and female lingcod off the Pacific coast of Canada reach sexual maturity between 500 and 620 mm and 600–670 mm respectively (Richards et al. 1990). Some of the hatchery lingcod (males: 522–575 mm; females: 602–719 mm) in the present study were probably reaching sexual maturity, which may have contributed to the variation in movement behavior.

Lingcod movement might also be influenced by habitat characteristics of the release site (Ritter 2008). More lingcod remained at Zee's Reef for the full duration of the study than at Itsami Reef. Zee's Reef is a naturally-formed reef composed of bedrock and hardpan outcroppings, boulders, caves, and crevices. Itsami Reef is an artificial reef created in 1982 from pieces concrete sidewalk, curb, and slabs piled upon each other up to almost two meters high, resulting in a matrix with crevices, overhangs, and a complex geometry (Hueckel and Buckley 1987; Mark LaRiviere, pers. comm.). Larger sample sizes and a different experimental design are necessary to determine the influence of site characteristics on movement variation.

Stationary acoustic receivers in this and previous studies have provided the ability to quantify the duration of excursions from a home reef. Starr et al. (2005) used stationary acoustic receivers to track 83 wild lingcod for up to 14 months in Alaska. They observed periods of site fidelity that were frequently interrupted by excursions lasting a median of about 2 d (range=1−299 d). In contrast, mobile acoustic receivers used to track acoustic-tagged wild lingcod off Vancouver Island, British Columbia for 12 to 50 d did not detect excursions from the release site (Matthews 1992; Yamanaka and Richards 1993). Stationary receivers used to track acoustic-tagged wild lingcod in Prince William Sound detected few excursions over the course of the study (Bishop et al. 2010). Most of the lingcod in the present study also made few long-term (> 1 d) excursions. Starr et al. (2004, 2005) hypothesized that lingcod make excursions away from the home area to feed. If so, differences in the frequencies of long-term excursions among studies may relate to differences in the local availability of lingcod prey items.

Excursion differences among studies may also reflect natural increases in excursion frequency and duration that may occur as lingcod age and grow. This could reflect increased food needs or decreased vulnerability to predators (e.g., Dahlgren and Eggleston 2000). This ontogenetic increase in excursions is supported by Starr et al. (2004, 2005), who tagged fairly large lingcod (female average: 99 cm, male average: 87 cm) and observed a greater number of long-term excursions than Matthews (1992), Yamanaka and Richards (1993) and the present study. All three of the latter studies tagged smaller lingcod (female averages: 72 cm, 51 cm, and 66 cm, respectively; male averages: 64 cm, 49 cm, and 54 cm, respectively). A recent study that also detected few long-term excursions tagged lingcod that averaged 63 cm (Bishop et al. 2010). Further, in the present study, apparent short excursion frequencies increased with days since release (age), and apparent short excursion durations increased with days since release (age) and with body size at release. Thus, a positive relationship between excursions and body size or age is supported by trends among studies, comparisons of different-sized lingcod in this study (effect of body size at release), and longitudinal observations (effect of days since release) of those individual lingcod in this study.

In addition to effects of age and growth on short and long excursions, age and growth may also affect dispersal (leaving without return). In this study, the number of days at the release reef significantly decreased with lingcod length at release. This relationship was largely driven by the tendency for the smallest individuals to remain at the release site for the entire study (controlling for sex and site). Similarly in wild lingcod, size at tagging was negatively correlated with tendency to remain at the release site (non-dispersal) (Bishop et al. 2010).

Previous studies have documented how hatchery rearing can impede the expression of natural, adaptive behavior (Olla et al. 1998; Brown and Day 2002; Salvanes and Braithwaite 2006). While this study was not designed to provide a direct comparison between telemetry-tagged wild and hatchery lingcod, the hatchery-reared lingcod displayed behavioral patterns that have been reported for wild conspecifics. Additional important questions include how exact proportions of moving and staying individuals compare between wild and hatchery-origin fish when season and site are standardized, whether hatchery fish will stay at release sites for longer periods of time, show similarities or differences with wild fish in other behavioral traits, ultimately reproduce, or have negative impacts on wild fishes; and how these parameters vary as a function of release age and study location

(Leber 1995; Fairchild et al. 2005). Future studies that combine acoustic tagging and traditional tagging methodologies with ecological, genetic, and health monitoring of wild and hatchery individuals should enable an evaluation of the costs and benefits of stock enhancement (Liao et al. 2003; Bell et al. 2008).

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