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Examination of Lingcod, *Ophiodon elongatus*, Movements in Southeast Alaska Using Traditional Tagging Methods

by

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Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

Traditional external tagging studies provide a relatively inexpensive way to obtain movement information over large temporal and spatial scales and may supplement more expensive, data-intensive tagging studies. The Alaska Department of Fish and Game (ADF&G) has tagged 9,174 lingcod (*Ophiodon elongatus*) opportunistically with dart tags from 1996 to 2011 in Southeast Alaska with 453 fish recovered. This traditional large scale study complements an acoustic tracking study conducted from 1999 to 2001 at the Pinnacles Marine Reserve in Southeast Alaska where tagged lingcod were observed to have high site fidelity despite frequent forays outside the reserve. In that study, most tagged lingcod moved out of the acoustic receiver range (>2 km) every few days before returning, with 10% of tagged fish remaining out of range for weeks or months (Starr et al. 2004). The ADF&G dart tagging data also indicate lingcod have high site fidelity: the majority of Southeast tagged lingcod remained ≤5 km of their release site; however, 34% of dart tagged lingcod were recaptured >10 km from their release site. These fish may be moving frequently as observed in the acoustic study or performing less frequent directed movements. In addition, our study indicates a small proportion of the population may perform long range, possibly directed movements, with 7% of lingcod recovered at distances >60 km from their release site. We attempted to explain variability in distance traveled by lingcod with the variables of sex, days at liberty, and release length nested by sex using an ANCOVA model. However, this model explained little of the variability in distance traveled (R-squared=0.07). Although the complex movement patterns of lingcod were not explained well by a simple linear model; our study indicates lingcod movements may differ by sex with a larger proportion of females travelling >5 km than males.

Key words: lingcod, tagging, movement, *Ophidon elongatus*, Southeast Alaska

INTRODUCTION

Lingcod are a valuable groundfish species that occur in the eastern North Pacific Ocean from the Gulf of Alaska to Baja California (Mecklenburg et al. 2002). Lingcod are targeted and captured as incidental catch in sport and commercial fisheries. The Alaska Department of Fish and Game (ADF&G) has management authority for lingcod in state and federal waters. In Southeast Alaska, ADF&G does not conduct stock assessment surveys for lingcod. Rather, lingcod are managed using guideline harvest ranges (GHR) set in regulation for each management area. The guideline harvest level (GHL) is set annually and has been at the upper range of the GHR since 2000. GHLs are determined based on historical commercial fishery Catch per Unit Effort (CPUE) and biological data from lingcod sampled in the commercial fisheries. The GHL is allocated in regulation between commercial (directed, longline, salmon troll, and groundfish jig fisheries) and sport fisheries. Other management tools in Southeast Alaska include: seasonal closures (December 1 through May 15) for commercial (no closure for longline fisheries taking lingcod as incidental catch), sport, subsistence (only for spear and diving gear), and personal use fisheries to protect nest-guarding males; minimum size limits (27 in from tip of snout to tip of tail) in commercial fisheries; and slot size limits and daily bag limits in sport fisheries. No size limit restrictions exist for subsistence or personal use fisheries.

Tagging studies provide opportunities to gain insight into a species' movements and their associated behaviors. Lingcod have been tagged along the Pacific coast with traditional external tags (Mathews and LaRiviere 1987; Cass et al. 1990; Jagielo 1990; Smith et al. 1990) that provide release and recovery information and with acoustic tags (Matthews 1992; Starr et al. 2004; Greenley 2009; Tolimieri et al. 2009; Beaudreau and Essington 2011) that provide information on daily movements within the range of the receivers.

Lingcod tagging studies indicate that lingcod have high site fidelity but are not necessarily sedentary. For example, acoustic tagging studies have demonstrated that lingcod exhibit "homing" behavior but may perform frequent excursions outside the range of the acoustic receivers (Starr et al. 2004; Greenley 2009). Lingcod have shown to have small home ranges

(Greenley 2009; Tolimieri et al. 2009; Beaudreau and Essington 2011) and generally use rocky reefs during foraging (Beaudreau and Essington 2011). However, a small percentage of lingcod also travel great distances, e.g. >50 km (Mathews and LaRiviere 1987; Jagielo 1990). Lingcod movements may differ by sexes during the reproductive season. Males arrive to the spawning grounds prior to females to set up territories and remain after spawning to guard egg nests through incubation (Cass et al. 1990); while females leave nesting grounds soon after spawning and return to deep water (Martell et al. 2000). In addition, small immature fish may be displaced from nesting areas during the spawning season by larger mature fish as suggested by changes in encounter rates and length frequencies observed during scuba surveys (Martell et al. 2000).

A long-term dart tagging study has been conducted on lingcod in Southeast Alaska by ADF&G since 1996 with tagging occurring from the Fairweather Grounds to central Baranof Island (Figure 1). This tagging study provides information on lingcod movements across Southeast Alaska over a long time period using a large spatial data set. In addition, while tag recovery information in acoustic studies is limited to within the range of acoustic receivers, this study provides information on long-range movements of lingcod.

OBJECTIVES

1. Tag and release lingcod in northern Southeast Alaska using external tagging techniques.
2. Describe lingcod movements across Southeast Alaska. Determine if there are trends in movements specific to male or female lingcod or by maturity.
3. Compare the movements of lingcod in Southeast Alaska to acoustic and traditional lingcod tagging studies in other areas of the Pacific coast.

METHODS

A total of 9,174 lingcod were tagged in Southeast Alaska from 1996 to 2011. Tag releases occurred annually, but 87% of fish tagging occurred from 1996 to 2002. While lingcod were tagged in all months of the year, 95% of fish were tagged between April and September. The objective was to tag as many lingcod as possible in outside waters in northern Southeast Alaska during designated lingcod tagging trips and opportunistically during other groundfish surveys. As a result, lingcod were captured for tagging on 14 vessels and with several gear types: dinglebar troll[1] (70%), rod and reel (21%), longline gear (9%), and mechanical jig (1%). Lingcod were tagged along the outer coast of Southeast Alaska from Yakutat to Cape Ommaney and offshore at the Fairweather Grounds in the commercial Lingcod Management Areas of East Yakutat (EYKT), Central Southeast Outside (CSEO), and Northern Southeast Outside (NSEO) (Figure 1). Tagging was performed in "hot spots" where lingcod were caught commercially and known to be densely populated due to good habitat; these areas included the Cape Edgecumbe area around Kruzof Island in CSEO and the offshore Fairweather Grounds, located in EYKT. Lingcod were also tagged along the coast between Yakutat and Cape Spencer, where a commercial fishery occurred, to determine if there was movement of fish from the coast to the Fairweather Grounds. In addition, lingcod were tagged in other areas along the coast of Baranof and Chichagof Islands with the intention to distribute lingcod tag releases throughout northern

[1] Dinglebar gear is trolling gear that consists of a main troll wire that runs directly from the block to the water with a heavy bar attached to the bottom and a line with up to 13 lead-headed jigs attached to the main troll wire approximately 1 m above the bar (Gordon 1994).

Southeast Alaska. Tagged lingcod were released at water depths of 4–201 m with an average depth of 57 m. In the Fairweather Grounds and along the coast of Chichagof Island, more fish were tagged in deeper waters of 100–201 m compared to other tagging locations (Table 1).

Prior to release, gender and fork length (cm) were collected. Gender was determined externally; males were distinguished from females by a urogenital papilla covering their anal vent.

Fish were tagged with lavender or yellow dart tags with unique identification numbers in order to match release and recovery information. Tags were inserted into the flesh on the left side of the fish under the first dorsal fin. The latitude and longitude for each tagged lingcod was recorded at release.

Tags were labeled with the ADF&G phone number to allow sport and commercial anglers to report tag recovery information, including date, depth, and location (latitude and longitude) of capture, and sex and length of fish. In return anglers received a tag reward hat or T-shirt and were entered into a cash drawing.

Lingcod tag release and recovery data were mapped in ArcGIS. Lingcod recoveries included fish that were re-released or harvested; as a result, a particular lingcod may have been recovered more than once. An ET Geo Wizards tool (version 11.0 for ArcGIS 10.2) was used to create direct paths between fish release and recovery events. Paths were then edited around land masses, and the length of each edited path was calculated. To obtain total distance traveled by a particular lingcod, tag paths were summed for each recovery event. Directional movement was determined using the linear directional mean spatial statistics tool in ArcToolbox. Days at liberty were calculated by subtracting the recovery date from the release date.

An ANCOVA model was fitted to these data to determine predictors of distance traveled. Because few males or small females were tagged in the EYKT and NSEO management areas, only lingcod tagged in the CSEO management area were included in the ANCOVA analysis in order to have a more complete representation of sex and size classes. Sex, days at liberty, and release length nested by sex were explored as possible predictors for distance traveled by lingcod. Release length was nested by sex, because lingcod are sexually dimorphic throughout their range (Hart 1973; Cass et al. 1990; Love 1996) as demonstrated in the substantial difference in the length distribution between males and females (i.e., females have a greater mean length and a wider range of lengths than males) (Figure 2). A log transformation of the response variable distance traveled was used in the model in order to obtain normally distributed model residuals. To determine which factors may be important to the model fit, an F test was performed using the ANOVA function from the R car package (Fox and Weisberg 2011). The full model was compared with alternative models that did not include all the predictors, and the preferred model was selected based on the Akaike information criterion (AIC).

Lingcod tagging data were further examined by performing two sample z-tests to determine if there were significant differences in lingcod movements by sex, maturity, and release management area. Lingcod recoveries were grouped by 5 km bins to examine movements; fish were considered to have strong site fidelity if they were recovered at distances ≤5 km and to be long distance travelers if they were recovered at distances >60 km. Only CSEO management area data were used to test for differences in movements by sex and maturity, because few males were tagged in other management areas and to remove confounding factors due to differences in habitat by management area. Females were categorized as immature (≤780 mm) or mature (>780 mm) based on the length at 50% maturity (L_{50}) for female lingcod in Southeast Alaska (ADF&G

unpublished data). Movements of male lingcod by maturity were not examined, because few tagged males could be categorized as immature based on the L_{50} in Southeast Alaska of 550 cm (ADF&G unpublished data).

The substrate induration of the seafloor was overlaid with lingcod tag recoveries to determine if fish were generally more associated with soft, mixed, or hard bottom. Substrate data were available from seafloor mapping surveys off Kruzof Island and the Fairweather Grounds (Figure 3). Backscatter data from Kruzof Island, backscatter and multibeam bathymetry from the Fairweather Grounds, and direct observations from a submersible were used to classify the seafloor into habitat type by Moss Landings Marine Laboratories' Center for Habitat Studies (Greene et al. 1999). The habitat type was reduced to substrate induration of soft, mixed, and hard. In the surveyed areas, soft substrate was typically composed of sand. Mixed substrate was unconsolidated soft sediment covering rock or some combination of gravel, cobble, pebble, or sand. Hard substrate was composed of rock, which included pinnacles, granite outcrop, bedrock, volcanic rock, boulders, rocky pavement, or sandstone.

RESULTS

Five percent (453 fish) of the tagged lingcod were recovered from 1996 to 2011. Five of these lingcod were recovered more than once resulting in 458 recovery events with 61 fish re-released and 397 fish harvested. A similar number of males (4,507 lingcod) and females (4,214 lingcod) were tagged; sex was indeterminate for 215 fish and not observed for 238 fish. Females had a larger average size and a greater range of lengths than male tag recoveries (Figure 2). Although a similar proportion of males and females were tagged, a larger proportion of females were recovered (0.65 of sexed fish) with a recapture rate of 6.7% for females compared to 3.4% for males. Approximately half (53%) of the recovered lingcod were captured with rod and reel, 23% with longline, and 18% with dinglebar troll; the remaining 5% were captured with power troll, hand troll, and mechanical jig gear. Although, females were only tagged in greater proportions than males with longline gear (0.86); larger proportions of females were recovered with dinglebar (0.70), longline (0.88), and rod and reel (0.54) gear types (Table 2). Males and females were tagged in similar proportions with dinglebar gear and a higher proportion of females were tagged with rod and reel gear (0.54).

The full model had the lowest AIC value relative to reduced models indicating support for selecting the full model as the best model to predict distance traveled by lingcod. An F-test indicated that sex was a significant variable with a p-value of <0.01; days at liberty ($p=0.0568$) and release length nested by sex ($p=0.0590$) were not significant. Yet, the adjusted R-squared (0.07) for the full model indicates the explanatory variables explained less than 10% of the variability. Also, there does not appear to be a distinct relationship between distance traveled and days at liberty; however, the average number of days at liberty increases for lingcod recovered at greater distances (Figure 4; Table 3).

The majority (0.55) of lingcod were recaptured within 5 km of their release location; however, a small proportion (0.07) of lingcod were recovered over 60 km from their release site (Figure 5). An exponential decline occurs in the distance lingcod are recovered from their release site (Figure 5). A significantly larger proportion of females compared to male lingcod were recovered at distances >5 km from their release site ($p=0.0006$, $\alpha=0.05$; Figure 5). In addition, female lingcod were recovered from a larger range of distances from their release location (0.03–778 km) than male lingcod (0.06–347 km) (Figure 6). A smaller proportion of immature females traveled >5 km than mature females; however, this difference was small (0.04) and not significant (p=0.7, α=0.05). Sample sizes of females by maturity classification were small; consequently, power was insufficient to test for significant differences in proportions.

Lingcod were generally recovered near the area that they were released; however, a small proportion of recoveries occurred far from their release site. The majority (85%) of recoveries from fish released in the Fairweather Grounds occurred in the Fairweather Grounds; the remainder were recovered as far away as Yakutat Bay (>120 km) and Prince William Sound (>480 km) (Figure 1). Most (64%) lingcod recoveries from fish tagged around Lituya Bay remained in that area, and the majority (80%) of lingcod recoveries from fish tagged in the CSEO management area (mostly around Kruzof Island) were recovered <20 km from their release site (Figure 1). However, some fish released in CSEO migrated north along the coast of Chichagof Island or south along the coast of Baranof Island. Three lingcod traveled >340 km to the Queen Charlotte Islands, Canada, and one fish traveled >778 km to Prince William Sound, Alaska (Figure 1). Lingcod released in NSEO management area were recovered along the coast of Chichagof and Kruzof Islands with half traveling >20 km from their release site.

Although general trends in lingcod movement by management area were similar, there were some differences in the distances lingcod traveled by management area. Lingcod released in EYKT management area (including the Fairweather Grounds and the mouth of Lituya Bay) traveled a greater average distance (50 km) between their release and recovery location than those released from CSEO management area (18 km; majority of tag releases around Kruzof Island). There was no significant difference in the proportion of lingcod that traveled >5 km by management area (p=0.4060); however, there was a significant difference by management area for the proportion of lingcod that traveled distances of >60 km (p=0.00008, α=0.05; Figure 7). The trends for female movement by management area were similar with no significant differences in the proportion that traveled >5 km by management area (p=0.7, α=0.05); however, a greater average distance was traveled by female lingcod in EYKT (58 km) compared to CSEO (20 km) with a significantly larger proportion traveling >60 km in EYKT (p=0.002). Male movement by management area was not analyzed separately due to the small number of males tagged in EYKT.

Sex segregation of lingcod occurred by depth and area with mid- to large-sized females in deeper water compared to males and smaller females. Dart tag data provide lingcod location by sex at a finer resolution than available from the directed dinglebar fishery, which is executed with long fishing sets that may cover large distances; as a consequence, catch information is not available by latitude and longitude. Females were recovered at a larger range of depths (11–329 m) and a greater average depth (92 m) compared to males (13–190 m; average depth of 48 m). Around Kruzof Island, males were generally recovered inshore in waters less than 100 m, whereas females were recovered inshore and in deeper offshore waters (Figure 8). Smaller females (≤780 mm) were distributed more inshore (≤100 m) compared to mid-to-large sized females (>780 mm; p=0.000) as indicated by capture depths at tagging around Kruzof Island (recoveries were not used for this comparison because few small tagged females were recovered). The majority of fish tagged (79%) around Lituya and Palma Bays were males; releases and recoveries in this area were in waters less than 50 m (Figure 9). Only females were recaptured in the waters around Yakutat Bay (Figure 9), and few males were released or recovered in the Fairweather Grounds where recovery depths were greater than 50 m (Figure 10). This is consistent with the sex ratio of lingcod observed in the directed commercial fishery landings from the Fairweather Grounds; only 26% of samples were males.

The average direction of lingcod movement differed by area and sex. Lingcod that were tagged in the Fairweather Grounds generally moved north (350°) towards Yakutat Bay; however, only four out of the 66 tag recoveries in the Fairweather Grounds were recovered in Yakutat Bay. Lingcod released in CSEO management area tended to move northwest (316°). Movement differed by sex for lingcod released in CSEO management area. On average, males moved north (354°) compared to females that moved more offshore in a northwest direction (301°). The direction of movement by sex was not examined for the Fairweather Grounds where only two male lingcod were released.

Tagged lingcod were predominately recovered from rocky habitat. In the Fairweather Grounds, 81% of tagged lingcod recoveries occurred directly over hard substrate with 94% of recoveries within 0.25 km of hard substrate; in the Kruzof area, 86% of the recoveries were over hard substrate with an additional 2% within 0.25 km of hard substrate (Table 4). It is possible a higher percentage of the Kruzof recoveries occurred in close proximity to rock, because substrate type is unknown in unsurveyed areas.

DISCUSSION

This study provides information on lingcod movements across Southeast Alaska from a historical data set covering a long time period and a large geographical area. Lingcod movements observed in this study are consistent with acoustic studies conducted at the Edgecumbe Pinnacles Marine Reserve in Southeast Alaska (Starr et al. 2004) and in Carmel Bay, California (Greenley 2009).

Female lingcod had a higher recapture rate than males in our study, possibly due to their greater prevalence in deeper waters where lingcod harvest is concentrated. Females are generally distributed into deep offshore waters (Mathews and LaRiviere 1987; Cass et al. 1990; Gordon 1994; Jagielo 1990; Love 1996); consequently, they may be more available to capture by lingcod fisheries (Table 5). This sex segregation by depth occurs around Kruzof Island where the majority of our tag releases and recoveries are located (Figure 8). In addition, movement data suggest that females which predominately travelled northwest moved farther offshore than males which tended to move north; as a result, females may have become more accessible to fisheries in deeper waters. In contrast, other tagging studies had similar recapture rates for males and females even though a disproportionate number of males were tagged in shallow nearshore waters (Mathews and LaRiviere 1987; Jagielo 1990).

Lingcod have complex movement patterns that appear highly variable within a population; as a result, it is difficult to model lingcod movements with a simple linear model using only dart tagging data. External dart tag data are limited in resolution and only provide release and recovery information with no movement information in between; consequently, it is difficult to model distance traveled by lingcod without more detailed movement information. Very little variability in distance traveled by lingcod was explained by the variables (sex, days at liberty, and release length nested by sex) of our preferred model. However, there was some relationship between distance traveled by sex and with days at liberty, which provides some insight into lingcod movements. We would expect that the distance traveled may increase with the days at liberty; even though lingcod have high site fidelity, some of the frequent excursions from their "home site" and some of the rarer long distance trips made by some lingcod may be captured in the dart tagging data as the days at liberty increase, especially if some of these movements are seasonal. In our study we did observe that lingcod that traveled ≥5 km from their release site had a greater average days at liberty than those that traveled less than 5 km from their release site, and that lingcod that moved the farthest from their release site also tended to have the longest days at liberty.

Lingcod movements occur on multiple spatial and temporal scales: (1) lingcod perform daily movements within their home ranges (Tolimieri et al. 2009; Beaudreau and Essington 2011), which may expand during the day and with the flood tide (Tolimieri et al. 2009), (2) they make frequent excursions outside these home ranges (Starr et al. 2004), and (3) they may perform long distance migrations (Jagielo 1990; Starr el al. 2004). Our Southeast Alaska tagging study corroborates these spatial patterns for a broad geographic area and a long temporal scale. Early traditional tagging studies indicated that lingcod were sedentary, because the majority of recoveries occurred close to their release location (e.g. Chatwin 1956). However more recent acoustic studies demonstrate lingcod have high site fidelity (Starr et al. 2004; Greenley 2009; Bishop et al. 2010) but may move frequently (Starr et al. 2004; Greenley 2009). The majority of the recoveries in our study occurred <5 km from their release site with 30% of recoveries <1 km from their release site, indicating lingcod may generally move within a small home range; however, close to half (45%) of recoveries occurred at distances >5 km from their release site suggesting as in Starr et al. (2004) that lingcod may be performing excursions outside their home range (Figure 5). From dart tagging data alone, it is not possible to determine if lingcod are performing frequent excursions to and from a home site or less frequent directed movements; however, the acoustic study performed in Southeast Alaska indicated lingcod move frequently, at least 2 km every few days (Starr et al. 2004). These excursions may be related to feeding and vary in distance and duration dependent on prey availability. Lingcod diet may be predominately composed of species that co-inhabit rocky reefs (Beaudreau 2009). However, prey species seasonally available on rocky reefs are an important component of their diet, i.e. migrating salmon in Southeast Alaska (noted on fishermen logbooks) and pelagic prey in the San Juan Islands, which compose 11% of lingcod diet and are the most energy dense contribution of the diet (Beaudreau 2009; Beaudreau and Essington 2009). In time periods that seasonal prey are not available it is likely that lingcod may need to perform offshore excursions to supplement these items.

Similar to other lingcod traditional tagging studies (Mathews and LaRiviere 1987; Jagielo 1990), we documented a small proportion of the population that performed long range migrations (up to 778 km) in Southeast Alaska. Starr et al. (2004) observed that lingcod at the Edgecumbe Pinnacles Marine Reserve in Southeast Alaska remained outside of the range of acoustic receivers for weeks or months and potentially moved long distances in the interim. These long absences from a particular home site may be related to feeding or reproduction. However, fish that traveled these long distances in our study were generally not recaptured during the spawning season. If these trips were related to reproduction, then it is likely that these fish took up residence after spawning.

Lingcod movements may vary by sex, size, and maturity; differences may be related to reproduction, feeding, and distribution by depth. A larger proportion of females were recovered >5 km from their release site than males (Figure 5), and females released in CSEO management area generally traveled more offshore than males that traveled north. Some of the differences in movement direction and distance traveled by sex may be due to differences in depth distribution by sex; females are distributed into deeper water than males which typically reside inshore

(Figure 8; Mathews and LaRiviere 1987; Cass et al. 1990; Gordon 1994; Jagielo 1990; Love 1996). Our tagging efforts were focused in shallow inshore waters (Table 1); consequently, females that were tagged inshore while feeding may have been recaptured closer to their "home sites" in deeper offshore waters. In addition, smaller females, which are distributed more inshore than larger females (Forrester 1973; Greenley 2009), may have performed ontogenetic movements offshore. Males may not need to migrate to reproduce, because they are already distributed in inshore waters that overlap spawning grounds. However, mature females distributed offshore may need to migrate inshore to suitable spawning grounds (Martell et al. 2000); though, with dart tagging data it is not possible to attribute movements specifically to spawning. Females may also move more than males because they have a larger average body size (Figure 2; Hart 1973; Cass et al. 1990; Love 1996). An increase in the length and duration of lingcod excursions may occur with increased body size as observed in Prince William Sound and Puget Sound (Bishop et al. 2010, Lee et al. 2011). As fish grow in size, the increase in energetic demands may outweigh the risk of predation, which is reduced with body size, when making longer foraging movements outside of more sheltered habitats. Lingcod observed in the Southeast Alaska Pinnacles acoustic study have a greater number of long excursions than lingcod observed in Prince William Sound or Puget Sound tagging studies, which may be related to the larger average body size of tagged fish at the Edgecumbe Pinnacles Marine Reserve (Starr et al. 2004; Bishop et al. 2010; Lee et al. 2011).

Variability in the movements between lingcod released in CSEO and EYKT management areas may be due to differences in the availability and location of suitable feeding and nesting grounds. CSEO management area has rocky nearshore waters with shallow and deep habitat in close proximity (Figure 8), whereas EYKT management area consists of shallow nearshore waters around Lituya and Palma Bays and deeper rocky habitat 50 km offshore at the Fairweather Grounds (Figure 9; Figure 10). Limited shallow water habitat in the Fairweather Grounds may result in migration of small lingcod to distant nearshore waters after displacement by mature territorial males during the reproductive season; such displacements have been observed in the Strait of Georgia (Martell et al. 2000). Few small, young lingcod are captured in the Fairweather directed commercial fisheries compared to those in CSEO management area (Figure 11; Figure 12). In the Fairweather Grounds, small lingcod may be quickly displaced by larger lingcod, or small lingcod from coastal areas may wait to migrate offshore to the Fairweather Grounds until a particular size or age. Such ontogenetic migrations have been observed in Prince William Sound for acoustically tagged lingcod that dispersed from nearshore to offshore waters once they attained lengths of 500 mm (Bishop et al. 2010). Some differences in lingcod movements by release location may also be due to local differences in food availability.

Lingcod are found over a variety of substrates, including rock, boulders, cobbles, pebbles, mud, and a combination of these bottom types along the west coast (Love 1996; Yoklavich et al. 2000; Tissot et al. 2007); however lingcod occur at the highest densities in rocky habitats (Yoklavich et al. 2000; Tissot et al. 2007). Our tagging study supports these data; the majority of lingcod tag recoveries in Southeast Alaska occurred on or near rocky reefs. Lingcod are known to utilize rocky reefs for foraging (Beaudreau and Essington 2011) and for reproduction (LaRiviere et al. 1981; Cass et al. 1990; O'Connell 1993). Acoustic tagging data from the San Juan Islands, Washington suggests that some lingcod exclusively use rocky reefs for summer foraging; whereas, other lingcod perform offshore excursions to feed (Beaudreau and Essington 2011). In addition, lingcod use rocky habitat for spawning; females lay large egg masses on rocky bottom in areas of high currents or wave action, which is necessary for egg aeration (Cass et al. 1990).

Males set-up territories in rocky reefs prior to spawning and remain after egg fertilization to guard "nests" for up to seven weeks until egg incubation (Cass et al. 1990).

MANAGEMENT IMPLICATIONS

Movement patterns observed for lingcod in Southeast Alaska provide guidance for the management of this species. Use of management techniques, such as area and seasonal closures, and size restrictions to commercial and sport fisheries may provide sustainable healthy lingcod populations.

Marine protected areas (MPAs) have the potential to provide protection to lingcod stocks and augment nearby fisheries. For an MPA to be an effective management tool, the daily, seasonal, and annual movements of a species should be considered in the design. Lingcod have high site fidelity; consequently, small MPAs may provide protection to localized depletion from overfishing. However, lingcod also perform frequent excursions from their "home sites" (Starr et al. 2004) and may perform long distance migrations. It may not be possible to protect lingcod throughout their range of movements, because large reserves may be impractical—both hard to establish and enforce. Small reserves may be effective in protecting lingcod at their "home sites" and may allow lingcod to attain larger average sizes than possible in their absence (Palsson and Pacunski 1995). Fishing closures at the Edgecumbe Pinnacles Marine Reserve (approximately 3 km^2 and located offshore Kruzof Island near many of our lingcod release sites) protects dense populations of lingcod while they utilize this reef and prevents damage to essential lingcod habitat by fishing gear. Starr et al. (2004) suggests that fishing outside this reserve might be enhanced because lingcod perform homing behavior and frequent short excursions. Other marine reserves have been shown to augment adjacent fisheries as well (e.g. Roberts et al. 2001). In the absence of marine reserves, lingcod populations may have some resiliency to localized depletion because lingcod perform frequent excursions from their "home site" and because some lingcod perform long-range movements. The ability of lingcod to perform long range movements may also allow them to repopulate heavily fished areas or move to new reefs if their "home" reefs are damaged due to anthropogenic or environmental events. In addition, these long distance travelers provide connectivity between lingcod populations and may increase genetic diversity of lingcod populations if they reproduce in their new home.

The natural population structure of lingcod could be affected by high levels of localized fishing, because lingcod have differential movements by sex and possibly size. Smaller lingcod and males may be more vulnerable to capture than larger females, which move more. However, minimum size restrictions in Southeast Alaska commercial fisheries and slot limits (with one trophy fish allowed annually) in the sport fishery may provide protection for small, immature fish, as well as some of the largest, most fecund individuals.

Male lingcod have restricted movements during the nest guarding season (Low and Beamish 1978). Seasonal closures, such as the spawning season closure to sport and commercial lingcod fishing in Southeast Alaska, provide protection to male lingcod during this time period when they are aggressive (LaRiviere et al. 1981; O'Connell 1993) and therefore more susceptible to capture.

The ongoing, long-term tagging of lingcod in Southeast Alaska provides information on total movements of lingcod over long time scales that, when combined with detailed acoustic tagging studies, can provide a complete picture of lingcod movements. These data on lingcod movement patterns at daily, seasonal and annual time scales can aid fisheries managers in setting sustainable fishery quotas, size restrictions, and appropriate seasonal and area closures in lingcod fisheries.

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TABLES AND FIGURES

Table 1.–The proportion of lingcod tagged in each depth zone by release location.

	Depth zone (m)	
	4–100	101–201
Around Kruzof Island	0.89	0.11
Biorka Island to south Baranof	0.98	0.02
Chichagof-north Salisbury Sound	0.29	0.71
Cross Sound	1.00	0.00
Fairweather Grounds	0.59	0.41
Lituya/Palma Bay	1.00	0.00
Yakutat Bay	1.00	0.00

Table 2.–The proportion of lingcod tag releases and recoveries by sex and gear type. Note the sample sizes are small for mechanical jig and hand troll gear which had less than ≤1% of releases and recoveries.

	Tag releases		Tag recoveries	
Gear type	Females	Males	Females	Males
Dinglebar	0.50	0.50	0.70	0.30
Rod and reel	0.25	0.75	0.54	0.46
Hand troll	0.00	0.00	0.50	0.50
Longline	0.86	0.14	0.88	0.12
Mechanical jig	0.20	0.80	0.00	1.00
Power troll	0.00	0.00	0.55	0.45

Table 3.–The average days at liberty for distances traveled by lingcod from their release location.

Number of Lingcod	Distance traveled (km)	Average days at liberty
218	<5	978
105	5–24	1,076
37	25–59	1,331
27	≥60	1,806

Table 4.–Lingcod recoveries by substrate type.

Substrate	Fairweather Grounds	Kruzof Area
Soft	13%	2%
Mixed	6%	12%
Hard	81%	86%

Table 5.–The average depth of lingcod tag recoveries by gear type. Only gear types with ≥5% of the recoveries were included. No lingcod were released with power troll gear.

Gear	Average release depth (m)	Average recovery depth (m)
Dinglebar	54	72
Rod and reel	29	61
Longline	139	124
Power troll	-	59
All gear types	56	77

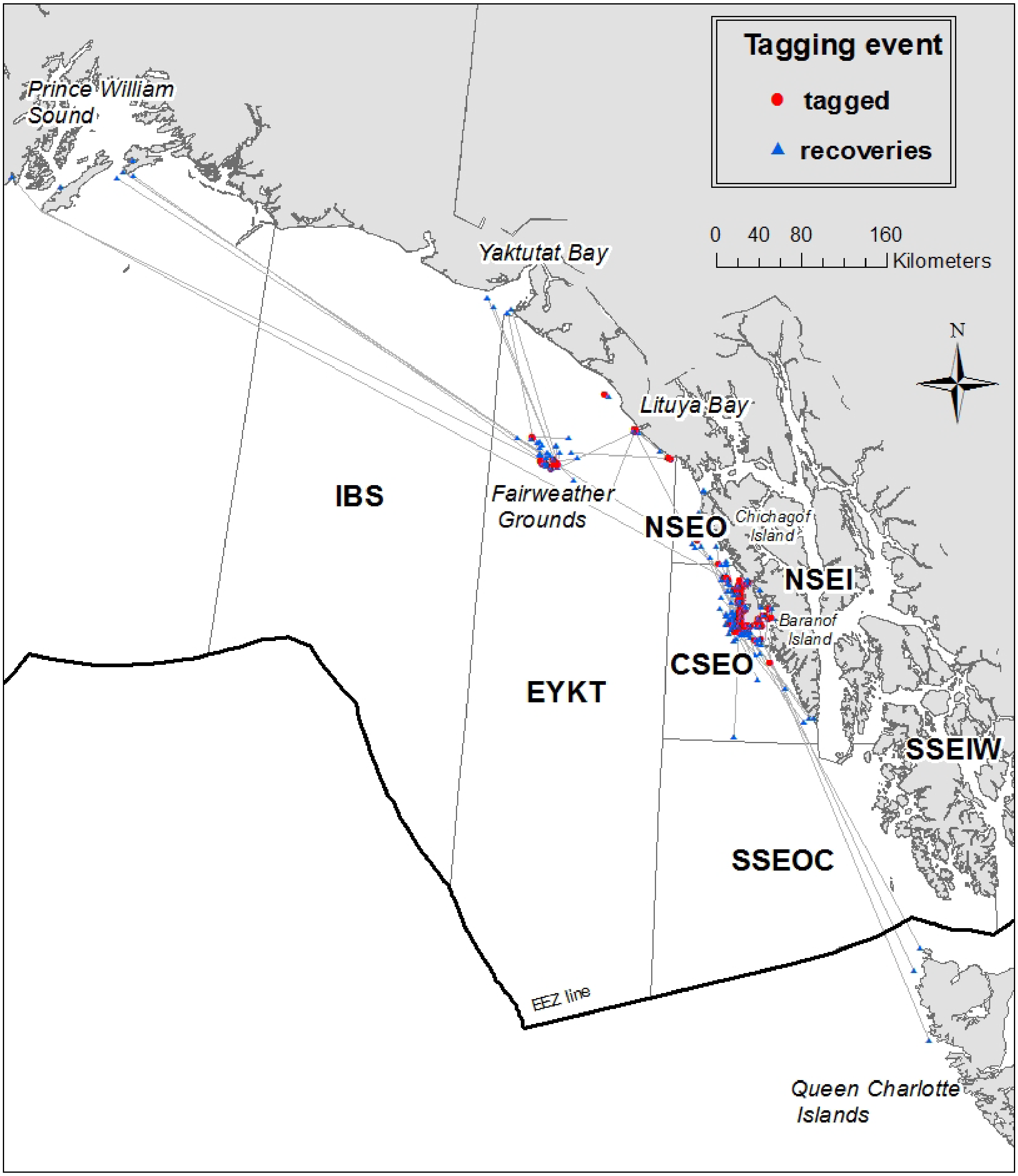

Figure 1.–Lingcod tag releases (1996–2009) and recoveries (1996–2011) by recovery event. Southeast Alaska Lingcod Management Areas are labeled as follows: Icy Bay Subdistrict (IBS), East Yakutat (EYKT), Northern Southeast Outside (NSEO), Central Southeast Outside (CSEO), Southern Southeast Outer Coast Sector (SSEOC), Southern Southeast Internal Waters (SSEIW), and Northern Southeast Inside (NSEI). The exclusive economic zone (EEZ) line for the US-Canada border is shown.

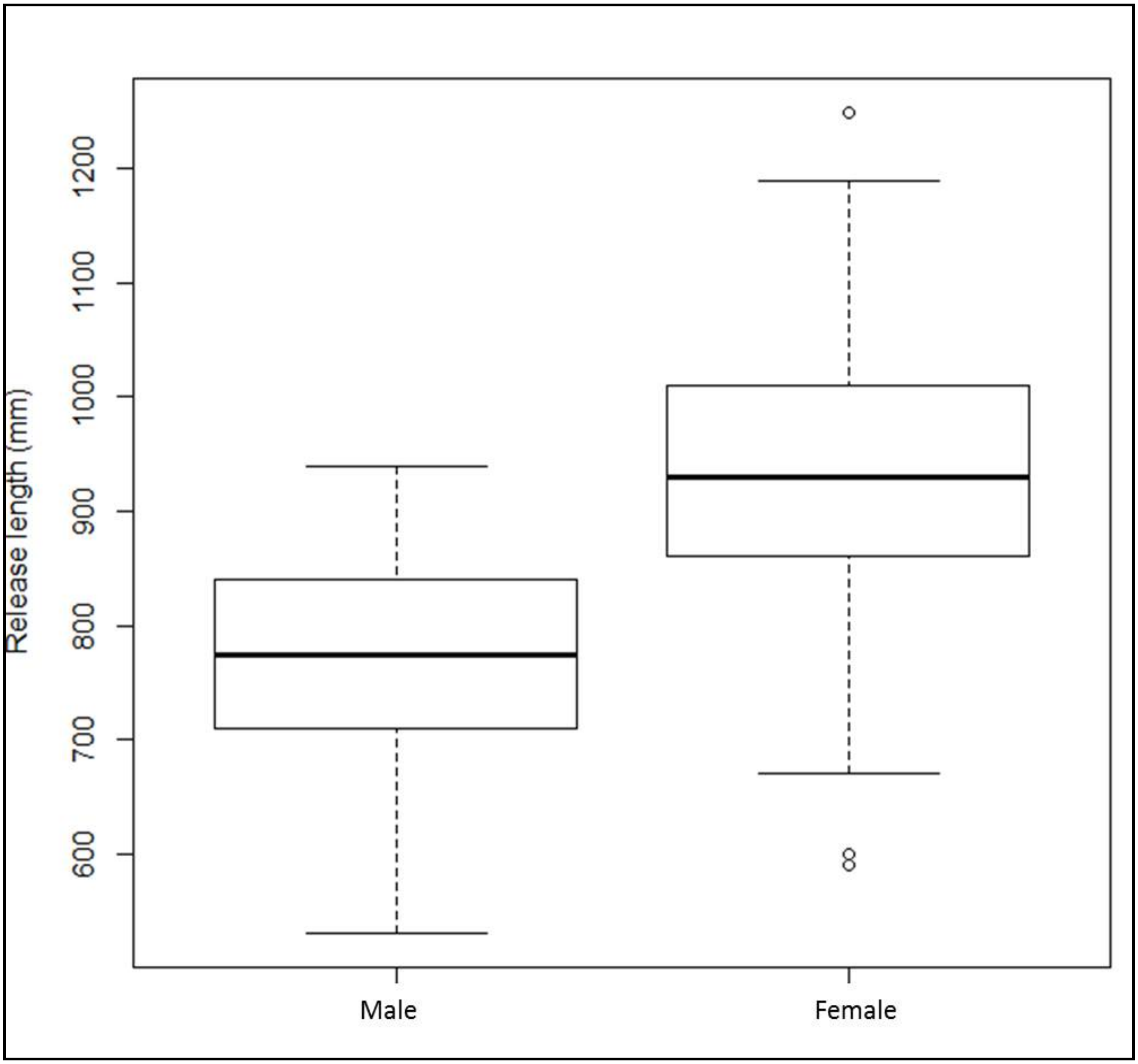

Figure 2.–Release lengths by sex for tagged lingcod recoveries.

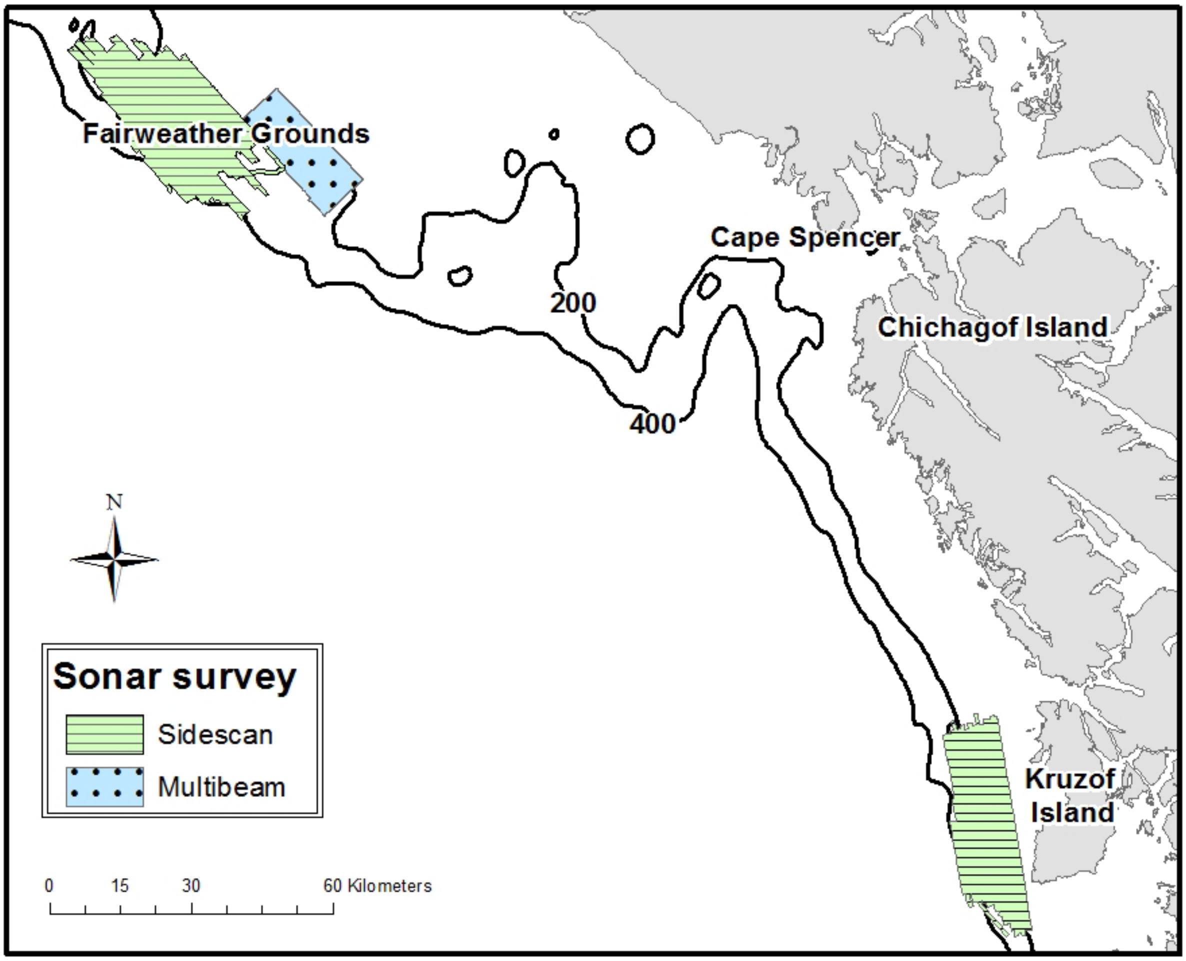

Figure 3.–Sonared areas that were examined with lingcod tag recoveries to assess associations with rocky habitat. Depth contours are in meters.

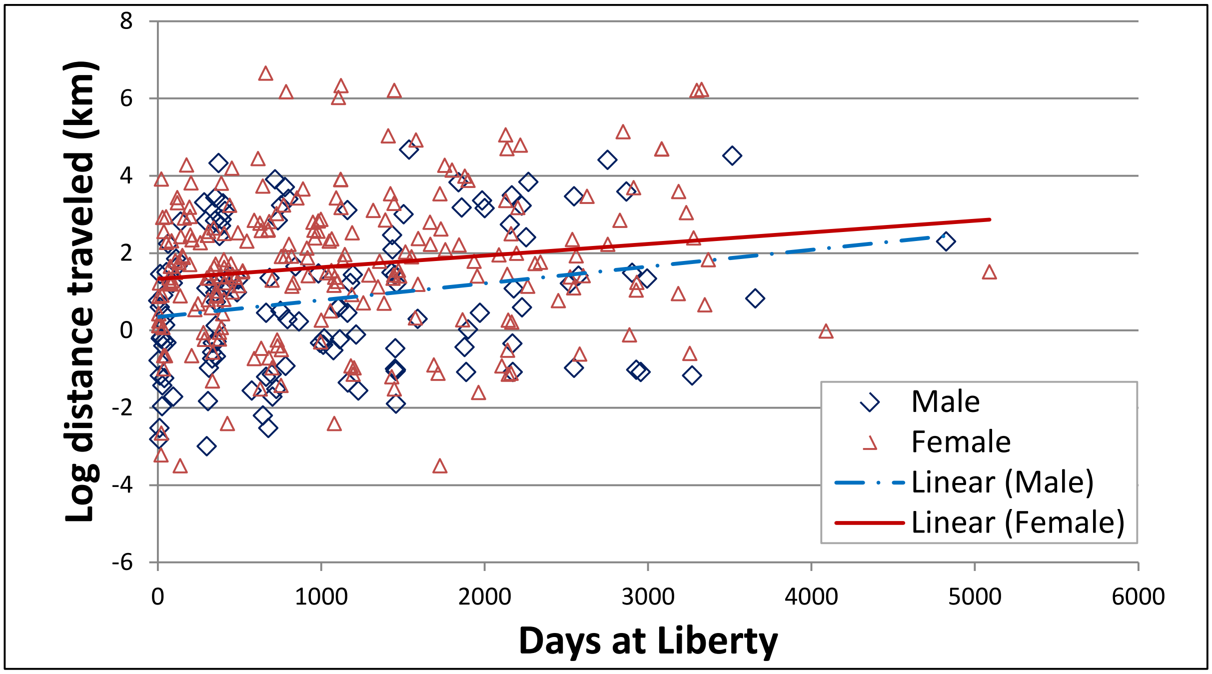

Figure 4.–Days at liberty for recovered lingcod versus distance traveled with linear trend lines.

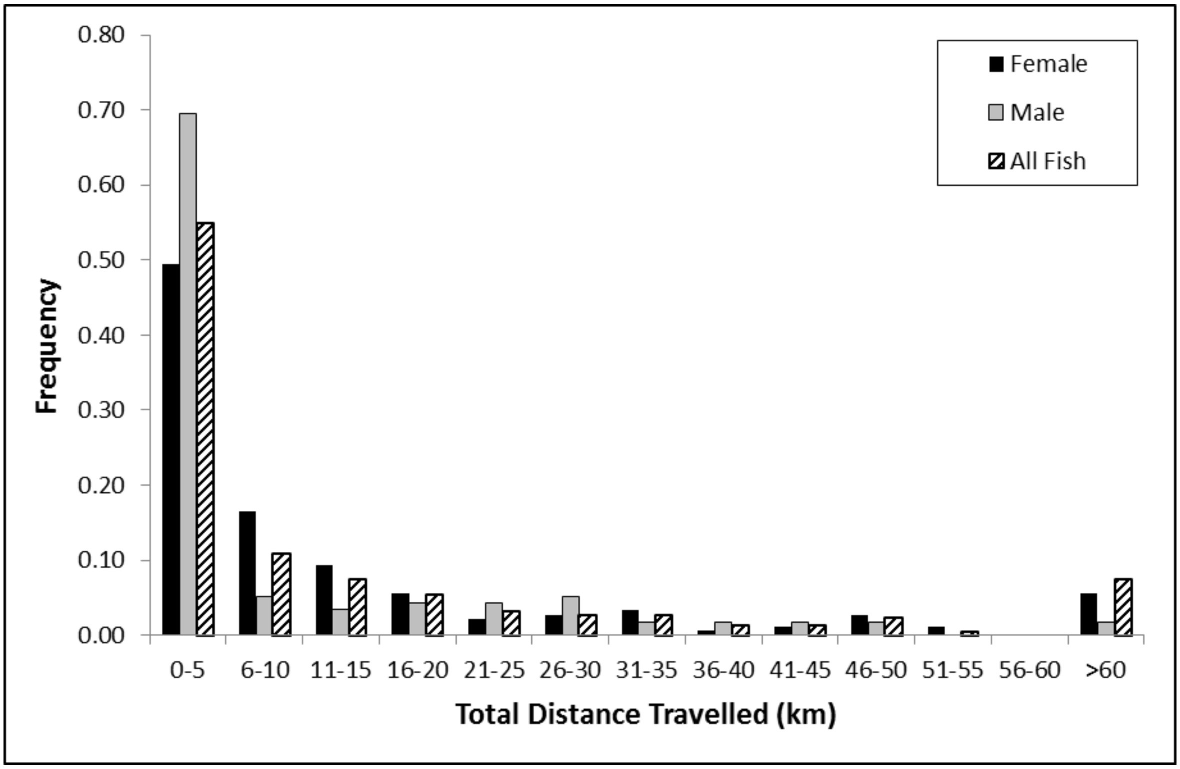

Figure 5.–Total distance traveled by recovered lingcod from release site by sex. Distance traveled for "all fish" includes data for all management areas and distance traveled for "males" or "females" includes data for CSEO management area only.

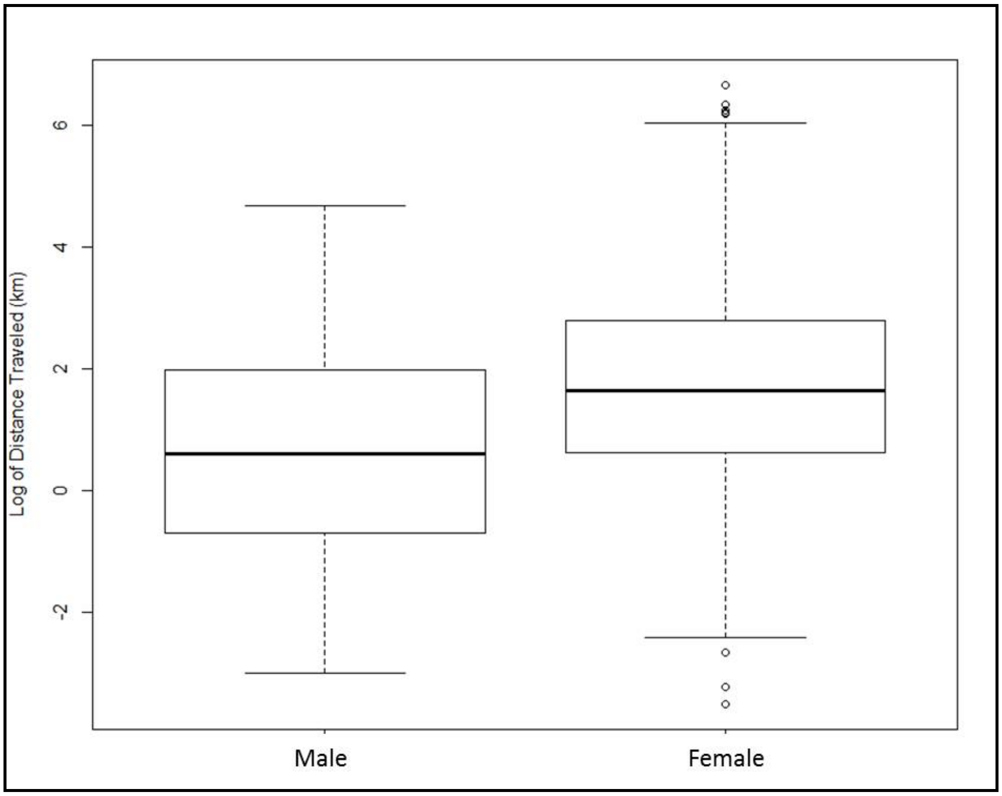

Figure 6.–Distribution of the log of total distance traveled by recovered lingcod from release site by sex.

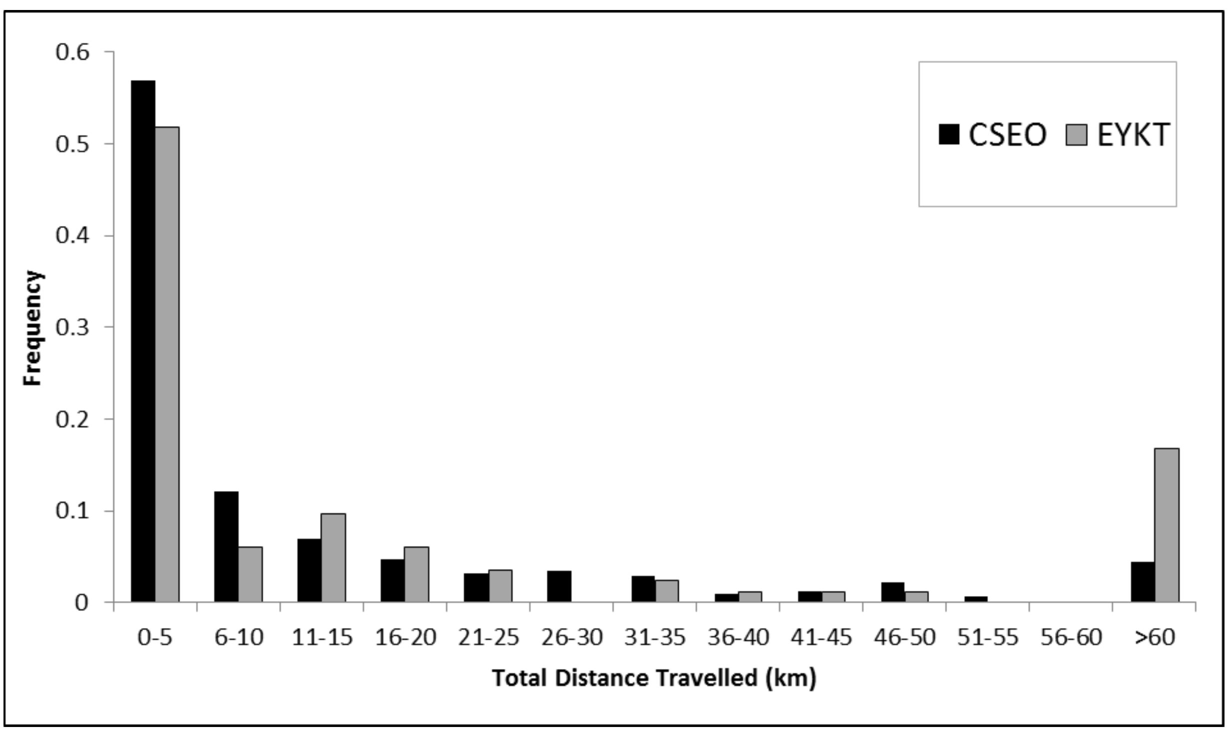

Figure 7.–Total distance traveled by recovered lingcod from release site by management area tagged.

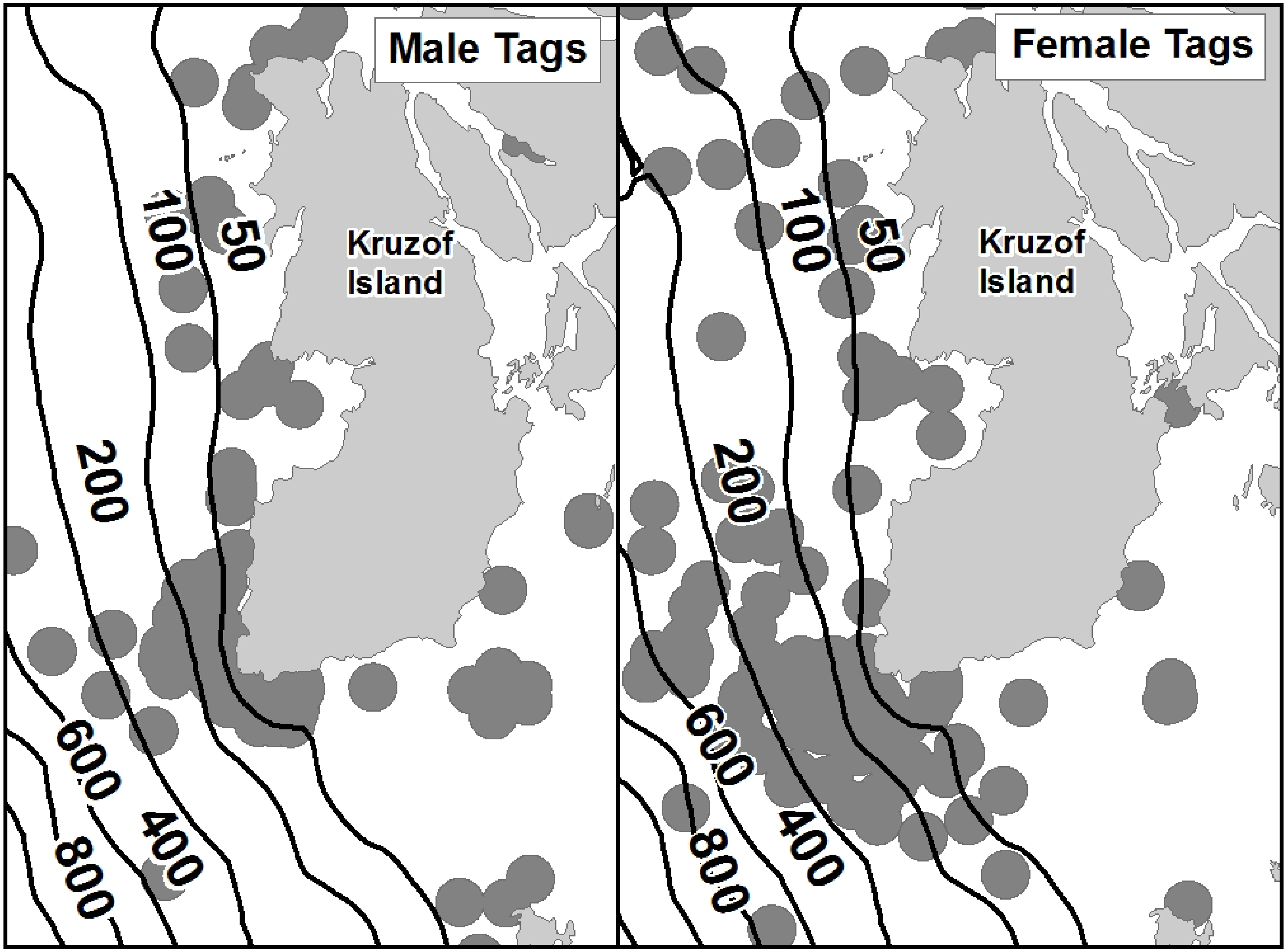

Figure 8.–Male and female tag recovery locations buffered by 1500 m (to preserve confidentiality) overlaid with bathymetric depth contours (m).

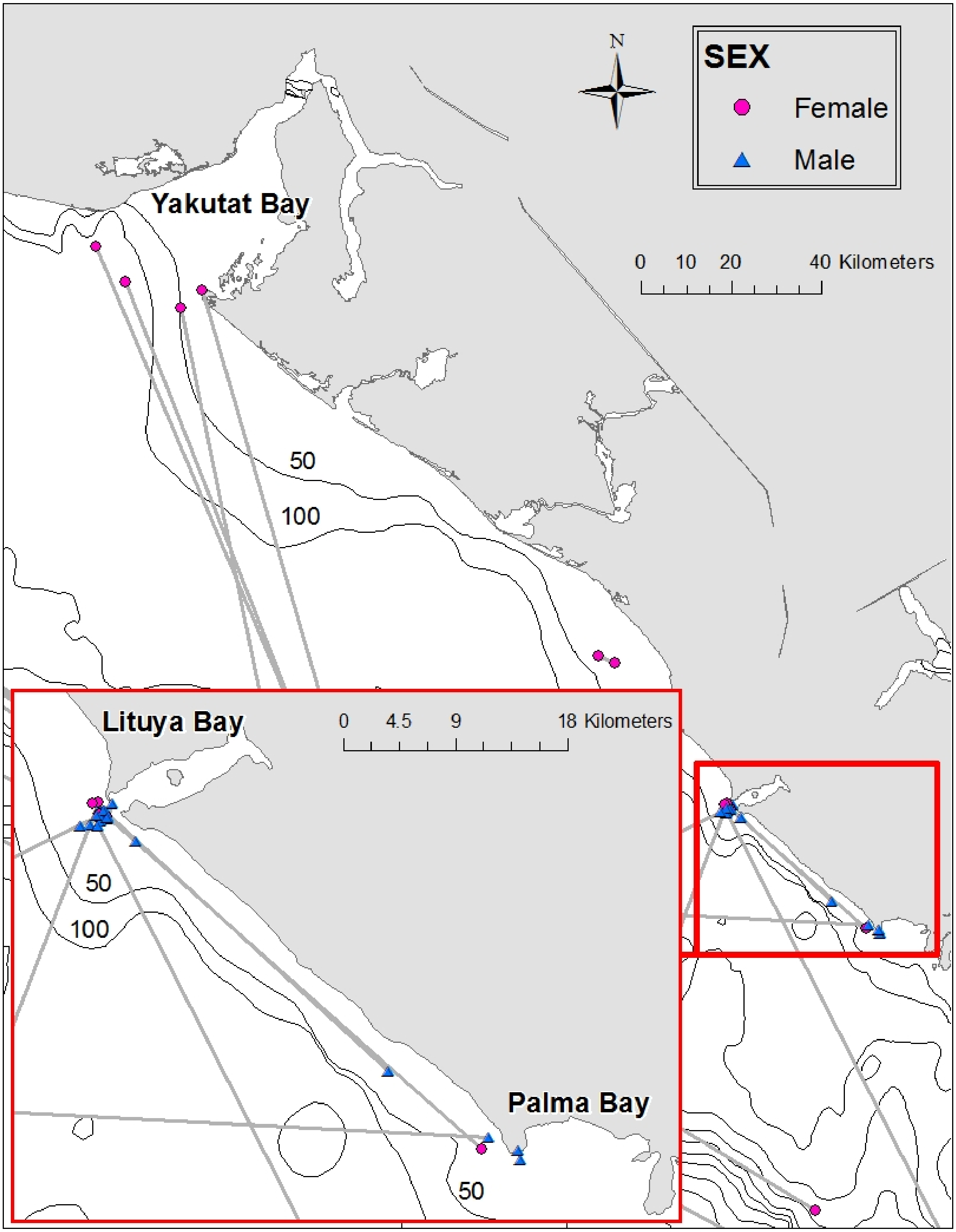

Figure 9.–Lingcod distribution around Yakutat, Lituya, and Palma Bays by depth (m) and sex.

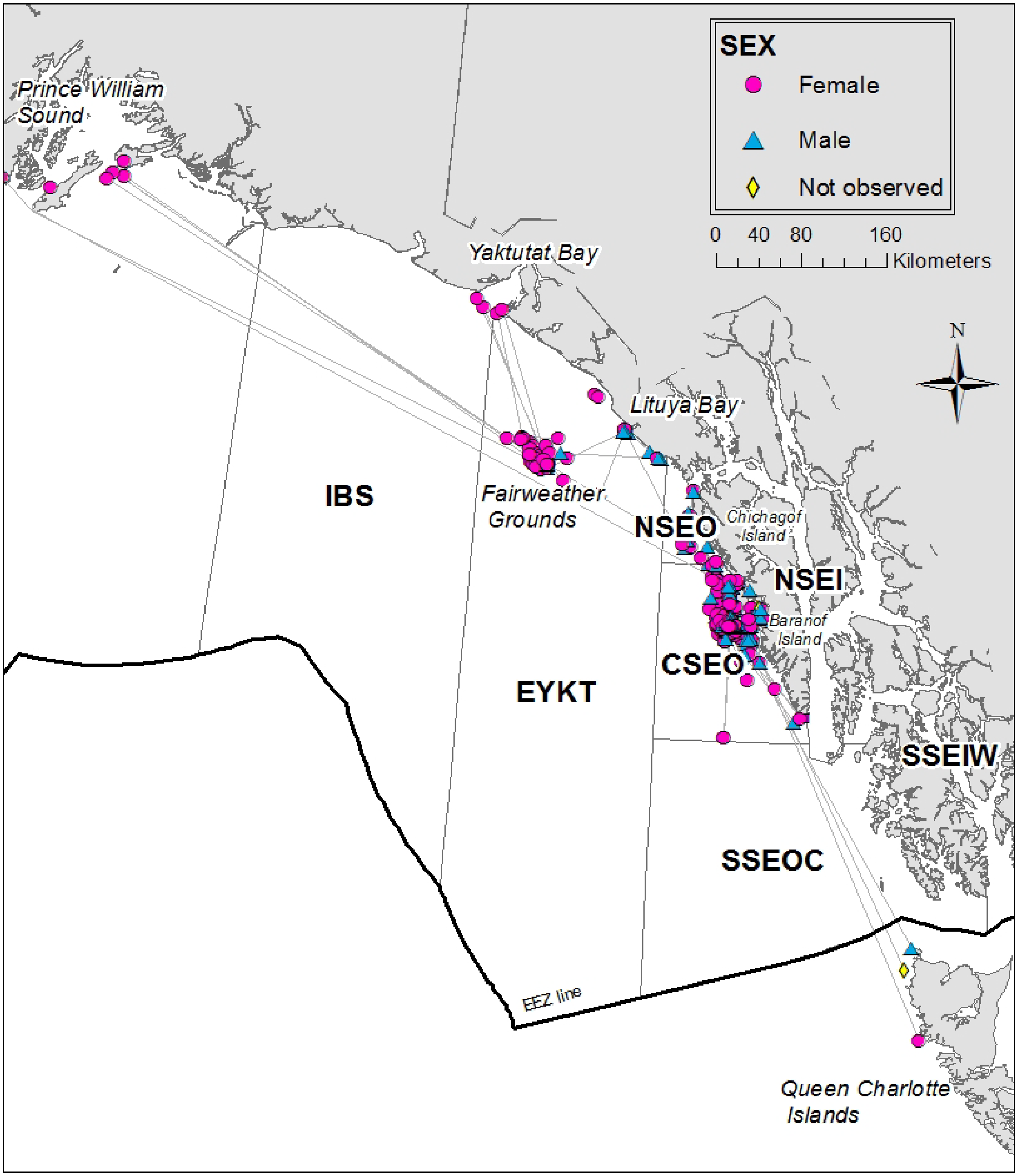

Figure 10.–Lingcod tag releases (1996–2009) and recoveries (1996–2011) by sex. Southeast Alaska Lingcod Management Areas are labeled as follows: Icy Bay (IBS), East Yakutat (EYKT), Northern Southeast Outside (NSEO), Central Southeast Outside (CSEO), Southern Southeast Outer Coast Sector (SSEOC), Southern Southeast Internal Waters (SSEIW), and Northern Southeast Inside. The exclusive economic zone (EEZ) line for the US-Canada border is shown.

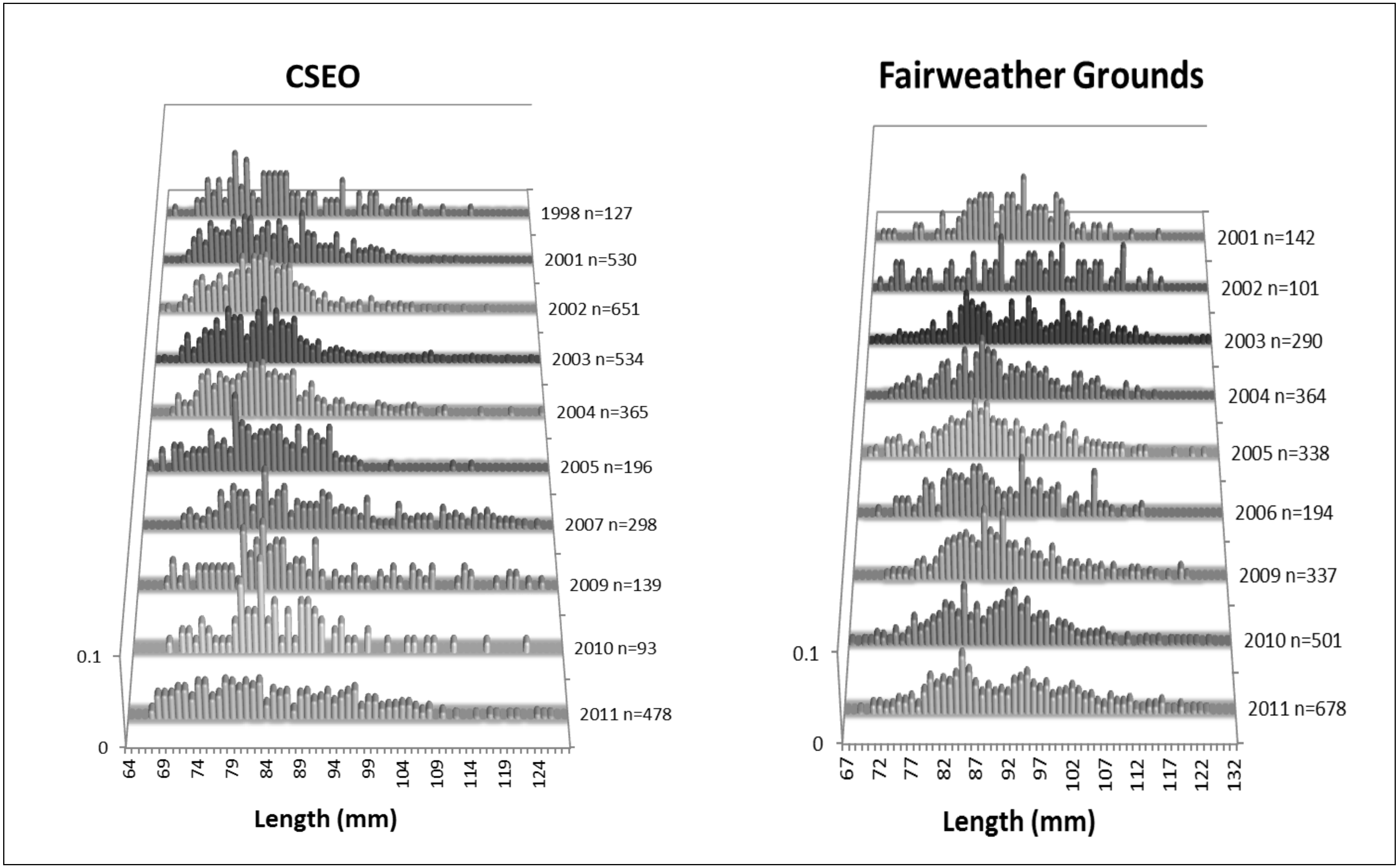

Figure 11.–Length distributions for lingcod caught in the directed commercial fishery in the Fairweather Grounds and CSEO management area.

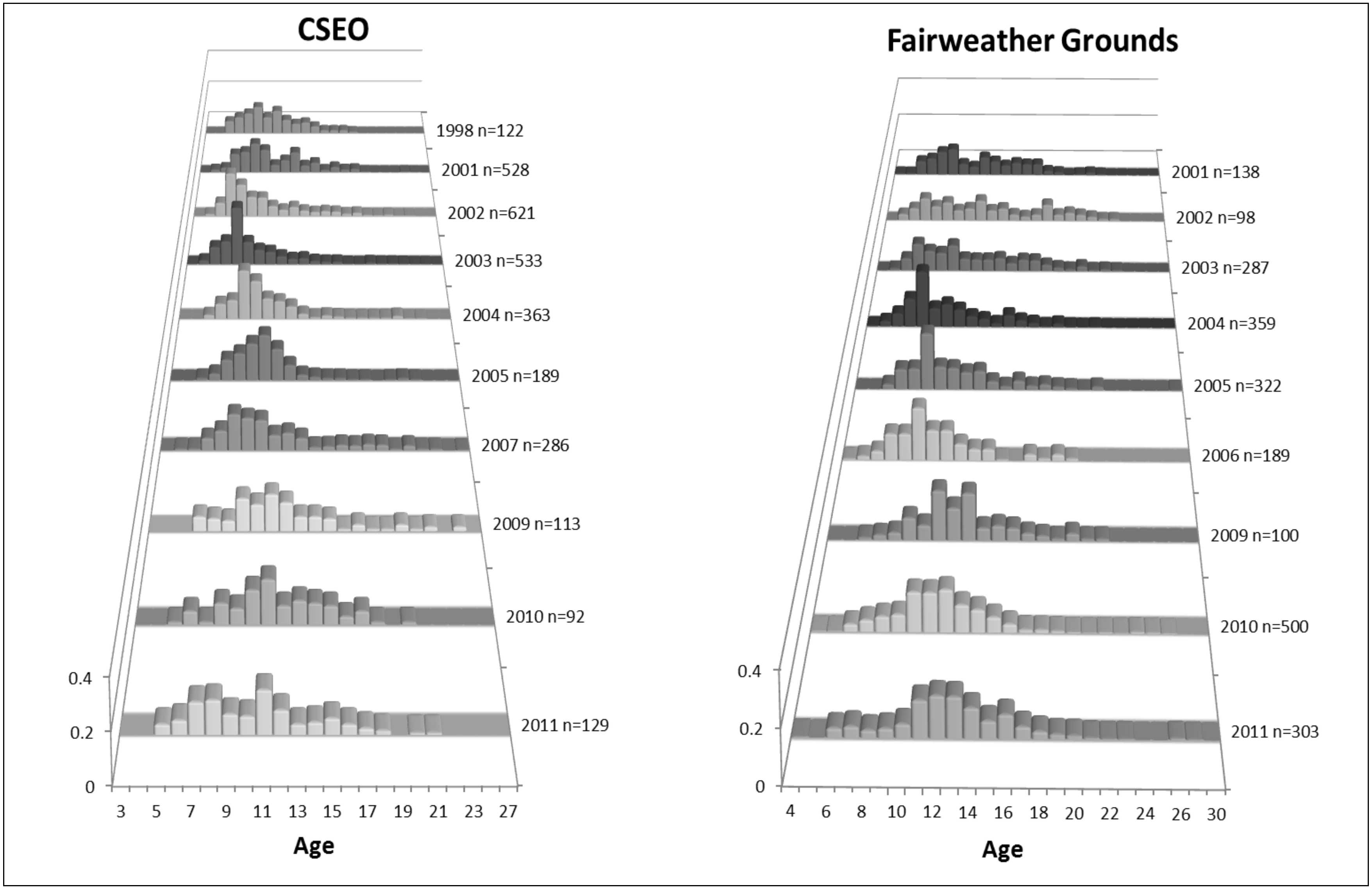

Figure 12.–Age distributions for lingcod caught in the directed commercial fishery in CSEO management area and the Fairweather Grounds.