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Red king crab movement, growth, and size composition within eastern Norton Sound, Alaska, 2012–2014

by

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

Symbols and Abbreviations

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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)

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

FISHERY DATA SERIES NO. 16-37

RED KING CRAB MOVEMENT, GROWTH, AND SIZE COMPOSITION WITHIN EASTERN NORTON SOUND, ALASKA, 2012–2014

by

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ABSTRACT

The Alaska Department of Fish and Game (ADF&G) examined spring/summer size composition and growth, reproductive condition, movement, potential critical locations, and handling of Norton Sound red king crab (RKC) *Paralithodes camtschaticus* from 2012 through 2014. RKC were captured in pots in Norton Sound and all crab 71 mm carapace length (CL) and greater were tagged. Tagged RKC were recaptured during subsequent commercial and subsistence fisheries. Observers placed on commercial fishing vessels monitored capture and handling of non-target RKC (sublegal and female) and other species. A total of 19,495 RKC were tagged during the project and 1,395 crab have been recaptured. Growth increment was different between sublegal and legal RKC; molting frequency and probability were also variable depending on CL and shell condition. The majority of females had full clutches in all years of the project. Potential critical locations for juvenile crab were identified in waters around Cape Nome and west of Golovnin Bay suggesting possible rearing areas. Movement of tagged RKC was generally southwest offshore and recapture of crab tagged on the most nearshore transect was lower, suggesting heterogeneous movement behavior within the population. Handling information collected by observers in the commercial fishery identified 2 commercial fishery locations where the handling of sublegal crab was high; catches in all other fishing areas were predominantly target crab. Basic biological and life history information provided by this study will enhance fishery management decision-making for Norton Sound RKC, which are locally valuable in both subsistence and commercial fisheries.

Key words: Red king crab, *Paralithodes camtschaticus*, legal red king crab, sublegal red king crab, growth increment, molting probability, movement, handling, growth, Norton Sound.

INTRODUCTION

Norton Sound has the northernmost red king crab (RKC) *Paralithodes camtschaticus* population supporting a viable commercial fishery. The commercial fishery for RKC began in 1977 as a large vessel (predominantly >100 feet in length) fishery, but became a small boat fishery with the introduction of new pot limits and the designation of the fishery as super-exclusive in the mid-1990s. Since the super-exclusive designation, Norton Sound RKC harvest has averaged 310,591 pounds annually (1994–2014). Historically, the majority of RKC harvest originated in statistical harvest areas west of Topkok Head (64°33.036 N, 163°58.719 W). However, beginning in the mid-1990s, a significant amount of commercial harvest pressure was refocused toward statistical areas east of Topkok Head[1] (Figure 1). Explanations postulated for this abrupt shift in harvest location included the newly adopted exclusivity of the fishery and use of smaller vessels (Bue et al. 1996a); eastern Norton Sound village residents comprising a majority of permit holders (Bue et al. 1996a, b; 1997; Brennan et al. 1998); relative proximity of the Golovnin Bay area to the nearshore closure line in the 1990s (Bue et al. 1996b, 1997; Brennan et al. 1998, 1999); and targeted closure line relaxations in eastern Norton Sound that provided additional harvest opportunity in waters normally closed to commercial fishing (Brennan et al. 1998, 1999).

Despite its commercial importance, several aspects of the life history of Norton Sound RKC are poorly understood. Tagging studies were conducted from 1980 to 1985 mainly in western Norton Sound where the majority of the fishing occurred (Powell et al. 1983; Brannian 1987; Figure 2). Those studies revealed that adult Norton Sound RKC exhibit migration patterns similar to RKC in Bristol Bay, with a late winter-spring migration from deeper to shallower water termed the spawning migration and an early summer-fall migration from shallower water back to deeper water termed the feeding/molting migration (Bright 1967; Powell and Reynolds 1965). This migration pattern has also been re-validated in recent years (2008–2012) with RKC tagged during the winter and recaptured offshore in the commercial fishery the following summer (data

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[1] Historical information can be found in the *Annual management report Norton Sound–Port Clarence Area and Arctic-Kotzebue* series by year (e.g. Menard et al. 2015).

on file with the Arctic Research Group, ADF&G, Division of Commercial Fisheries, Nome). Given this linkage between nearshore RKC and offshore commercial fisheries and an eastward shift in commercial harvest, it is crucial to gain an understanding of RKC in nearshore waters adjacent to commercial fisheries. Winter pot surveys historically conducted close to Nome were not far reaching because of difficulty in accessing remote areas during winter months. Consequently there is little information about RKC in nearshore waters of Norton Sound beyond waters off of Nome (Figure 2).

Current knowledge gaps of nearshore Norton Sound RKC include several population level characteristics. Specifically, there is limited understanding concerning the extent and timing of RKC mixing throughout waters of Norton Sound and how this may affect availability of crabs to the commercial fishery. Further, it is assumed female and juvenile RKC utilize habitats in predominantly nearshore waters, yet there has been limited work conducted to determine location and breadth of potential critical areas. Finally, there has been no evaluation of the discard of non-target size classes of RKC and enumeration of other species caught in commercial crab pots. Bycatch is part of every RKC fishery and has been examined in other fisheries (e.g., Bristol Bay RKC, Barnard and Pengilly 2006) to address concerns about handling mortality (NPFMC 2005). However, it may not be appropriate to draw comparisons between large boat fisheries occurring mainly in winter months and the small boat fishery occurring throughout the summer in Norton Sound. Currently, the Norton Sound RKC commercial fishery is prosecuted offshore to help minimize bycatch and handling of non-target crab size classes and to minimize conflicts between the summer commercial fishery and winter through-the-ice nearshore fisheries. There are no data to fully support the assertion that bycatch and handling of non-target RKC are minimized in offshore waters, thereby highlighting the need to gather information about non-target crab composition in nearshore and offshore waters.

This project attempts to address 4 knowledge gaps in basic biology, life history, behavior, and fishery impacts to Norton Sound RKC. In this study the Alaska Department of Fish and Game (ADF&G) conducted an intensive spring tagging program to assess RKC movement, growth, and size composition within nearshore waters of Norton Sound (Figure 2). Additionally, observers were deployed on commercial fishing vessels to gather information about catch composition and the abundance of other species captured in the summer commercial fishery.

OBJECTIVES

1) Determine size composition, reproductive condition, and growth increments of eastern Norton Sound RKC.
2) Identify possible critical locations in eastern Norton Sound used by juvenile and breeding female RKC.
3) Determine offshore movement patterns of eastern Norton Sound RKC.
4) Estimate discard ratio of non-target Norton Sound RKC captured in commercial crab pots configured with different escape mechanisms and with variable soak times.

METHODS

BIOLOGICAL MEASUREMENTS

Following methods outlined in the *Shellfish observer manual* (ADF&G 2003) all RKC were measured and classified according to length class/gender and shell condition. Length class/gender were divided into 3 categories by carapace length: female (F) all lengths, sublegal male (SL) less than 103 mm, and legal male (L) 103–115 mm.

To best define length class of SL and L crab, carapace lengths between 100 mm and 110 mm were also measured for carapace width (CW) using a 4.75 inch legal stick. This is the same instrument used by commercial fishermen to identify sublegal and legal crab according to Norton Sound RKC fishery regulations (5 AAC 34.920(d) (1)). Carapace width less than 4.75 inches was considered SL and CW greater than 4.75 inches was L. For this report, juvenile crab were equated with SL crab because reproductive development was not evaluated in male crabs. Shell condition was evaluated using criteria from the *Shellfish observer manual* (ADF&G 2003):

> **New**—A new shell is brightly colored and often iridescent dorsally. The coxa and ventral surface of the exoskeleton are dull in king crabs. The ventral surface is not translucent and may have slight discoloration with limited scratching. Carapace and chelae cannot be indented by thumb pressure. The crab usually appears clean with few barnacles or other epibionts; leech cocoons are often present. Spines and dactyls are sharp but may show slight wear, and the meri are not easily compressed by pinching and will crack if bent. Meat fill is moderate to full.
>
> **Old**—The dorsal surface is no longer bright and shows significant scratching, wear, and abrasions. Carapace and chelae are hard and cannot be indented by thumb pressure. Barnacles and other epibionts are usually present. The types and severity of epibiotic encrustation vary with geographic area and depth. Dactyls are worn and dull and spines show wear with rounded tips. Meat fill is at maximum.
>
> **Very old**—The carapace is typically hard, but can become soft and spongy due to decay. Epibionts are usually present in larger numbers than with old shell crabs, typically with a covering of barnacles, bryozoans, worm casings, and hydroids. Spines and dactyls are heavily worn. Meat fill is maximum to medium.

Egg clutch fullness (no eggs, up to one-eighth full, one-quarter full, one-half full, three-quarters full, and full), egg color, and egg development (uneyed or eyed) were noted for female RKC.

RED KING CRAB TAGGING

RKC were captured each spring (June 2012, June and July 2013, and June 2014) in pots deployed along 2 parallel transects 5 and 10 miles from shore from Cape Nome to Elim (Figure 3). Along each transect 45 pots were spaced every 2 nautical miles for a total of 90 pots. All pots were collapsible with dimensions 1.5 m x 1.2 m x 0.6 m and webbing of 8.9 cm stretched mesh to retain crab greater than 70 mm carapace length (CL). Unlike commercial fishing pots, pots used did not have escape mechanisms in order to retain smaller crab. All pots were baited with approximately 3 lb of Pacific herring *Clupea pallasii* in bait jars and bags. Location, depth, date, and time of deployment were recorded. Pots were deployed over a 2–3 week period with 2 (2012) or 3 (2013, 2014) pot checks (tagging events); all pots were soaked for a minimum of 48 hours.

All RKC in the pots were measured (following the methods described above) and RKC 71 mm CL and greater were tagged with individually numbered spaghetti tags attached to hogs rings secured through the isthmus muscle (Figure 4; Gray 1965; Powell at al. 1983). For all RKC under 71 mm CL only gender and CL were recorded. All other species captured in crab pots were identified and enumerated. All animals were returned immediately to the water. There was a total of 702 pot pulls: 170 in 2012, 263 in 2013, and 269 in 2014. In 2012, all pots had RKC, in 2013 10 pots had no crab, and in 2014 36 pots had no crab. A total of 19,495 RKC were tagged over the 3-year project; 4,579 were tagged in 2012, 9,072 were tagged in 2013, and 5,844 were tagged in 2014 (Table 1).

Conductivity, temperature, depth, and dissolved oxygen (CTD) were collected in years 2 and 3 of the project in order to examine salinity and temperature gradients along tagging transects. A CTD cast was completed at every fifth station as weather allowed. Data were downloaded after each complete tagging event.

TAG RECOVERY AND OBSERVERS

There were 3 fishery observers aboard commercial fishing vessels during each Norton Sound summer commercial RKC fishery from 2012 to 2014. Commercial vessel participation in the observer program was voluntary and observers followed observer protocols outlined in the *Shellfish observer manual* (ADF&G 2003). Observers were required to check all pots for tag recoveries. When a tagged crab was encountered, the observer recorded location, soak time, and type of escape mechanism on the pot. Recorded biological information from each tagged crab included sex, CL, length class/gender, shell condition, and tag number; all tagged crab were returned to the fisherman or the ocean. In addition to examining commercial pots for tagged RKC, fishery observers randomly selected 5 crab pots per trip and recorded location, type of escape mechanism, depth, soak time, and contents of each pot. Data collected included CL, length class/gender, and shell condition for all RKC (including non-tagged crab). For females, reproductive condition (clutch fullness, egg development, and egg color) was also recorded. Biological measurement collected by observers used the same methods as described above. Finally, all other species in the pot were identified and enumerated.

In addition to the observer program, a tag reward program was initiated to provide incentive for commercial fishermen to participate in tag recovery if no observer was on board their vessel. When a tagged crab was recaptured by a commercial fisherman, only coordinates and tag number were recorded at time of capture and biological information was collected (according to methods described above) at the processing plant by an ADF&G commercial harvest monitor. Tagged crab were also turned into the processing plant by commercial fishermen without specific capture location. In most cases, only the capture statistical area was known and biological information was collected by an ADF&G harvest monitor. Finally, in a few cases, tags were recaptured in winter commercial and subsistence fisheries from individual harvesters. This final method of recovery resulted in non-specific capture locations (e.g., 1 mile offshore of Cape Nome) with limited biological data.

DATA ANALYSIS

To address Objective 1, analysis of variance (ANOVA) was used to evaluate differences between average CL of tagged RKC by year. Prior to running the ANOVA, proportional data were transformed using the arcsin function to meet assumptions of normality. Contingency table analysis was used to test independence between the proportion of tagged and recaptured crab by shell condition (Zar 1999). To determine the relationship between growth increment and CL, full and reduced linear regression models were tested to determine the feasibility of pooling shell condition. The full model allowed for different slopes for each shell condition (Equation 1) and the reduced model assumed the slopes were consistent between shell conditions and were offset by some amount (Equation 2).

$$MoltInc = \beta_0 + \beta_1 * CL + \beta_2 * SC + \beta_3 * CL * SC + \varepsilon\,, \tag{1}$$

$$MoltInc = \beta_0 + \beta_1 * CL + \varepsilon\,, \tag{2}$$

where

CL = carapace length,

SC = shell condition, and

$\varepsilon \sim N(0, \sigma^2)$.

Model fit was evaluated using an F-test (Neter et al. 1990). Finally, a logistic regression was used to evaluate probability of molting (Zar 1999).

To address Objective 2, linear regression was used to examine the relationship between salinity and length class catch per unit effort (CPUE) and temperature and length class CPUE. CPUE was defined as the number of crab in a pot per hour soaked. ANOVA was used to evaluate abundance patterns of SL and F crab along transects (Zar 1999).

To address Objective 3, RKC directional movement was calculated by converting each start and end point latitude and longitude into Cartesian coordinates then to polar coordinates and representing it as polar azimuth (i.e., 0° is due east and angles are stated as positive from 0°). Contingency table analysis was used to test independence between the proportion of recaptured RKC and tagging transect (Zar 1999).

To address Objective 4, linear regression models were used to determine the relationship between soak time and non-target crab CPUE. CPUE is defined as the number of non-target crab per pot per day soaked. Full and reduced linear regression models were tested to determine the feasibility of pooling location. The full model allowed for different slopes for location (Equation 3) and the reduced model assumed the slopes were consistent between locations and were offset by some amount (Equation 4).

$$CPUE = \beta_0 + \beta_1 * st + \beta_2 * EM + \beta_3 * Loc + \beta_4 * EM * Loc + \varepsilon\,, \tag{3}$$

$$CPUE = \beta_0 + \beta_1 * st + \beta_2 * EM + \varepsilon\,, \tag{4}$$

where

st = soak time,

EM = escape mechanism,

Loc = location, and

$\varepsilon \sim N(0, \sigma^2)$.

Model fit was evaluated using an F-test (Neter et al. 1990).

RESULTS

SIZE COMPOSITION, REPRODUCTIVE CONDITION, AND GROWTH INCREMENTS OF EASTERN NORTON SOUND RED KING CRAB

During the 2012–2014 period, size composition shifted from older to younger crab (ANOVA: $F = 603.9$, $P < 0.0001$; Table 2) evidenced by a decline in average CL from 106.8 mm (SD = 16.8) in 2012 to 96.3 mm (SD = 19.7) in 2013 and 96.1 mm (SD = 14.6) in 2014 (Figure 5). Also, there was an increase in the proportion of SL from 37% in 2012 to 62% in 2013 and 2014. Within the commercial fisheries the majority of recaptured crabs were legal and the increased proportions of tagged SL were detected by increased proportions of recaptured SL over the years: sublegal crab made up 4.6% of recaptured crabs in 2012 and 9.3% in 2013. The proportion of recaptured SL crab jumped to 19% in 2014 despite tagged SL proportions being similar in 2013 and 2014 (Table 1).

More than 65% of the female crab had full clutches and females with no clutch contributed less than 6% except in 2013 when no-clutch individuals made up 27% of the females (Figure 6). Length frequency distribution was similar in all years (Figure 7) and smaller (<80 mm CL) and larger (>98 mm) females tended to have more individuals with no clutches than other sizes (Figure 8).

RKC were included in growth increment analysis if they were at liberty for greater than a year, but not more than 2 years, and had a change in CL between 5 mm and 20 mm. Changes in CL outside this range were considered sampling errors. Crabs were at liberty for an average of 397 days (SD = 34). Younger crab grew faster than older crab and new shell crab grew bigger than old shell crab within each growth increment. Sublegal crab had an average change in CL of 14 mm (SD = 2) and older crab had an average change in CL of 11 mm (SD = 2). Additionally, L new shell when tagged crabs had an average change in CL of 13 mm (SD = 2) and L old shell when tagged crabs had an average change in CL of 11 mm (SD = 2).

Molting crab came from L and SL tagged crab in equal proportions (Tables 3 and 4). The full model was the most appropriate to explain the length of growth increment ($P = 0.002$; Tables 5 and 6; Figure 9) indicating CL and shell condition when tagged were important contributors to the size of the growth increment.

Molting frequency was evaluated from 382 recaptured RKC; 315 were at liberty for just over 1 year and 67 crab were at liberty for over 2 years (Table 4). Younger crab tended to molt every year whereas older crab had a biennial molt. For example, nearly all (101, 87%) SL crab molted before recapture regardless of shell condition when tagged. However, L old shell crab molted more frequently than new shell crab after 1 year at liberty (Table 4).

Further evidence of biennial molting in older crab is given with the growth increment of crabs at liberty for greater than 2 years. Legal crab had an estimated growth increment of 11 mm (SD = 3) indicating 1 molting event over 2 years and SL crab had an average change in CL of 27 mm (SD = 7) signifying 2 molting events over 2 years. Molting probability analysis indicates the switch to biennial molting happens near CL of 110 mm (Figure 10).

POSSIBLE CRITICAL LOCATIONS IN EASTERN NORTON SOUND USED BY JUVENILE AND BREEDING FEMALE RKC

Average salinity was relatively consistent among transects and years varying between 24.9 and 36.6 PSU. Generally, bottom water became less saline moving eastward along both transects and nearshore stations tended be less saline than offshore stations (Figure 11). There was no obvious relationship between salinity and CPUE of L or SL crab sampled (Figures 12 and13). The relationship between salinity and female CPUE was not evaluated because of the small number of times female crab occurred in pots where a CTD cast was conducted.

Average bottom temperatures were cooler and more variable in 2013 than in 2014. In 2013 average bottom temperature ranged from 0.03°C to 10.3°C and in 2014 average bottom temperature varied from 5.4°C to 9.5°C (Figure 14). There was no obvious relationship between temperature and CPUE of L or SL crab sampled (Figures 15 and 16). The relationship between temperature and female CPUE was not evaluated because of the small number of times female crab occurred in pots where a CTD cast was conducted.

Small RKC were more abundant than large crab in nearshore waters (Figure 17). Specifically, waters off Cape Nome may be a possible critical location for juvenile crab because the first 10 pots of both transects at the western end of the study contained higher proportions of SL crab then the other pots along the transects (ANOVA: $F = 9.7$, $P = 0.002$; Table 7; Appendix A1). Additionally, there was an indication of higher concentration of SL crab in pots 25–30, in waters just west of Golovnin Bay. Possible critical locations for female crab were not as obvious as SL crab. The majority of the female crab were captured in 2014 and tended to be more abundant in pots along the 10 mile transect (Figure 18; Appendix A1).

OFFSHORE MOVEMENT PATTERNS OF EASTERN NORTON SOUND RKC

During the 2012–2014 period a total of 1,395 tagged RKC were recaptured. Of those, 618 crab were tagged in 2012, 545 crab were tagged in 2013, 215 crab were tagged in 2014, and 17 tagged crab were recaptured but the initial tagging year could not be determined (Table 1). A total of 8 fishing vessels took observers in 2012, 13 in 2013, and 10 in 2014 and 5 captains collected crab information in 2012, 6 collected in 2013, and 8 captains participated in 2014. RKC recaptured in the commercial fishery immediately after tagging were at liberty for a little over a month (average = 33 days, SD = 14), and traveled an average of 52 km (SD = 32; straight line distance between where crab was tagged and where it was recaptured) at an average speed of 2 km day^{-1} (SD = 1).

Tagged RKC moved beyond the longitudinal boundaries of their initial tagging statistical area (Table 8) and dispersed throughout the offshore area. The majority of recaptures came during the summer commercial fisheries (Table 9), and the distribution of recaptured tagged crab within the commercial fishery was similar to the distribution of the commercial harvest (Table 10; Figures 19 and 20). Overall movement was typically directed west southwest (216.2°; Figure 21).

RKC tagged in nearshore waters did not mix equally in offshore waters immediately after tagging. A higher proportion of crab tagged along the 10 mile transect were recaptured in the commercial fisheries immediately following tagging events when compared to those caught along the 5 mile transect (chi square test: $\chi^2 = 32$, $df = 1$, $P < 0.0001$). Nearshore RKC did eventually mix equally in offshore waters because the proportion of recaptured tagged crab by transect was similar in the commercial fisheries 1 and 2 years beyond the tagging events (Table 11).

Estimate Discard Ratio of Non-target Norton Sound RKC Captured in Commercial Crab Pots Configured With Different Escape Mechanisms and Variable Soak Times

Observers collected catch composition data from 461 commercial crab pots throughout Norton Sound over the 3 year project: 124 pots in 2012, 190 pots in 2013, and 147 pots in 2014 (Figure 22). RKC were the majority of the catch and SL crab were the most numerous of the sampled crab. A total of 12,771 crab sampled included 5,680 (44.5%) retained L crab, 780 (6.1%) not-retained L crab, 5,899 (46.2%) SL crab, and 412 (3.2%) female crab. The average number of L crab per pot was 12.3 (SD = 10.2) whereas not-retained L crab had an average of 1.7 (SD = 2.8) crab per pots, females had an average of 0.9 (SD = 2.6) per pot, and SL crab had an average of 12.8 (SD = 15.7) crab per pot. The average number of discards (i.e., not-retained L, SL, and female crab) per pot was 15.4. Non-target (i.e., SL and female) crab were the predominant proportion of the catch in commercial shellfish statistical areas 646401 and 646330 and L crab were the majority in all other statistical areas (Figure 23).

The full model was selected to explain CPUE of non-target crab in observer pots ($P < 0.0001$) indicating soak time and location were factors influencing the composition of commercial crab pots. In all locations, fewer non-target crab were handled as soak time increased (Figure 24) and the number of non-target crab handled depended on the location of the pots (Tables 12, 13, and 14).

Species composition of commercial RKC pots was consistent in all years. There were 33 different species (including RKC) and purple orange sea stars *Asterias amurensis* were the second most numerous (4,629) behind RKC; of the remaining species, none made up greater than 0.6% of the total (Table 15).

DISCUSSION

Size Composition, Reproductive Condition, and Growth Increments of Eastern Norton Sound Red King Crab

Size composition data collected in this study are being used for management of the Norton Sound RKC commercial fishery. For example the frequency of L male crab by size class has been incorporated into the most recent update of the Norton Sound RKC *Stock assessment and fishery evaluation (SAFE) biomass projection model* (NPFMC 2015). The size composition of tagged crab may indicate a 3–4 year lag between abundant year classes available to the fishery because the peak of pre-recruit 3 sized crab (74–83 mm CL) in 2013 reappeared as pre-recruit 2 (84–93 mm CL) and 1 (94–103 mm CL) crab in 2014. However, as that year class was progressing there was no clear presence of another, younger, abundant year class coming behind it. Continuing to collect size composition in nearshore waters in the spring may help elucidate this potential pattern of recruitment. Effort should also focus on defining possible relationships between nearshore and offshore crab abundance such that this type of sampling can inform fisheries management decisions.

The majority of female crab had full clutches in all years and the increase in empty clutches in 2013 could be because of the large number of pre-recruit 3 sized males (74–83 mm CL) found in nearshore waters in 2013 (Figure 5). Although physiological maturity of male crab in Norton Sound may be attained in crab as small as 50 mm CL (Paul et al. 1991) there is probably a physical barrier to successful breeding. When grasping pairs for mating were examined, there were very few instances when the female was larger than the male crab (Powell and Nickerson 1965) suggesting size at functional maturity of male crab is probably attained at a greater CL. Female crab of 70–80 mm CL were the most abundant size class in 2013 (Figure 7) therefore the abundance of pre-recruit 3 males may have had an effect on the spawning success of females.

This study was not designed to evaluate size at maturity of female RKC because clutch fullness was not noted for female crab less than 71 mm CL. Female RKC captured in trawl surveys conducted throughout Norton Sound had an estimated size at which 50% of the females were sexually mature (SM50) range of 65.7 mm in 1976 to 73.9 mm in 1985 (Otto et al. 1989). Further, in pot surveys conducted in western Norton Sound (Figure 2) the SM50 was estimated to be 68 mm CL (Powell et al. 1983). The proportion of partial clutches detected in this project (Figures 6 and 8) is similar to what was found by Powell et al. (1983) and lower than identified by Brannian (1987) who found 17% and 38% females with partial clutches respectively. Female crab with partial clutches were not examined for sexual development, therefore drawing conclusions about the causes of partial clutches are limited. Future research should look to enhance earlier investigations (e.g., Otto et al. 1989) conducted in Norton Sound to provide more resolution on female size at maturity and reproductive contributions.

Differences detected in growth increment were some of the more intriguing results of this study. This work suggests growth is greater in SL crab than in L crab and that new shell crab have a larger growth increment than old shell crab. The notion that SL growth increment may be larger than L growth increment and new shell crab may have a larger growth increment than old shell crab was hinted at in early work in Norton Sound but interpretation was not confirmed, possibly due to small sample sizes (Powell et al. 1983). The current study found that L old shell crab did have a smaller growth increment than L new shell crab. However, there was no difference in growth increment for old shell and new shell SL crab (Figure 9). This result may have useful application for updating the Norton Sound RKC SAFE biomass projection model (NPFMC 2015). One possible explanation for the notable differences in size of SL and L growth increments and L old shell and L new shell growth increments is the energetic trade-off between molting and mating. In general SL crab are not involved in mating, thus resource allocation would be similar between new shell and old shell SL crab. For L crab, there is a potential tradeoff between mating and molting and the energetic costs of mating may be greater than the energetic costs of molting.

Examining molting frequency and probability reveals an increase in the chances of biennial molting with increasing CL. These finding are consistent with results from early work in Norton Sound. Powell et al. (1983) detected 100% molting in recaptured SL new shell crab and only 54% in L new shell crab at liberty for a year. Brannian (1987) found 100% molting of SL crab and only 23% of L crab greater than 130 mm molted after 1 year. In the present study, similar patterns were found: the majority of SL crab recaptured after at least 1 year at liberty molted (Table 4) and those SL crab recaptured after greater than 2 years at liberty had an average growth of 27 mm, suggesting they molted 2 times between tagging and recapture. Conversely, the majority of L new shell crab did not molt after 1 year at liberty (Table 4) and those L crab at large for over 2 years had an average molt increment similar to 1 molt cycle suggesting an every other year molt pattern.

Tagged crab will be recaptured throughout the next several years, therefore additional information will be available to aid in understanding molting in subsequent years. Ongoing research is examining the molting hormone levels in crab at different times throughout the year to help refine our understanding of molt timing. Additional work needs to be done to understand how molting and its timing drive the movement between nearshore and offshore areas.

POSSIBLE CRITICAL LOCATIONS IN EASTERN NORTON SOUND USED BY JUVENILE AND BREEDING FEMALE RKC

Waters historically closed to summer commercial RKC fishing since the early 1980s for allocative reasons (Kent and Bell 2014) have also been hypothesized to protect sublegal and female crab from handling stress associated with capture in commercial fisheries. Data collected during this project support this hypothesis, evidenced by high incidences of SL crab in waters off Cape Nome and potentially in a smaller area just west of Golovnin Bay during spring tagging (Figure 17). Although these areas are within closed waters and are inherently protected from the commercial fishery, observer data has also shown waters typically open to commercial fishing in statistical areas 646401 and 646330 have higher proportions of SL crab in commercial crab pots (Figure 23). Fishery managers could increase the protection of non-target crab by utilizing this information to determine areas opened or closed to commercial fishing.

Salinity and temperature were collected along each transect over all tagging events when practical. We detected average salinities between 25 and 36 PSU (Figure 11) and average temperatures between 0.03°C and 10.3 °C (Figure 14), which are within known limits for RKC (Rodin 1989; Thomas and Rice 1992; Ilyushchenko and Zenzerov 2012). There was no relationship between salinity (Figures 12 and 13) or temperature (Figures 15 and 16) and CPUE of L and SL crab along the transects. The presence or absence of RKC may be a balance between environmental characteristics and biological needs that are more difficult to discern than simple salinity and temperature metrics. Additional work should focus on evaluating the area around Cape Nome to determine the reason SL crab appear more abundant in that location.

OFFSHORE MOVEMENT PATTERNS OF EASTERN NORTON SOUND RKC

Recapture events in this study were fishery dependent and, consequently, results should be interpreted cautiously. Recovery data from the commercial fishery is affected by 1) the number of tagged RKC released; 2) movement patterns of tagged RKC; 3) effort and distribution of commercial crab fishermen; and 4) commercial crab catch efficiency and harvest biases. The original hypothesis for this project was tagged crab captured in the commercial fishery in each statistical area would originate from the nearest nearshore tagging location. Tags were recaptured beyond the longitudinal boundaries of tagging (e.g., RKC tagged in a statistical area beginning with 646 were recaptured outside those statistical areas; Table 8). Further, in this study, tags recaptured in the fishery immediately after tagging were in proportions similar to proportions of harvest by statistical area (Table 10; Figures 19 and 20) indicating dispersal of nearshore crab to all areas of the offshore commercial fishery. These findings support an alternative hypothesis: RKC mix throughout Norton Sound and crab harvested in each statistical area may originate from several nearshore locations. Directional movement offshore, as determined by recaptured crabs with specific recapture locations (Figure 21) may be biased because of unequal distribution of those crab within the commercial fishery due to voluntary participation in the tag recovery program. For such a broad geographical region, it would have been costly and impractical to facilitate a systematic fishery-independent recapture event to evaluate directional movement.

A previous study indicated Norton Sound L male crab migrate offshore in the spring/summer and back to nearshore waters in the late winter/spring (Powell et al. 1983). This general inshore-offshore seasonal movement pattern has been documented for RKC populations in other areas of Alaska, e.g., in Southeast Alaska (Stone et al. 1992; Taggert et al. 2008), in Bristol Bay (Simpson and Shippen 1968; Rodin 1989; Takeshita et al. 1989), Alaska Peninsula (Hayes and Montgomery 1963), and Kodiak Island-Cook Inlet (Powell and Reynolds 1965). Conclusions from this project reaffirm movement offshore in the spring/summer for Norton Sound RKC (Figures 5 and 21). Results from this study also found crab located in nearshore waters in the spring do not have an equal probability of capture in the offshore commercial fishery (Table 11) and may indicate not all components of the population exhibit the same migratory pattern each year. A 1981 tagging study near Nome provided some initial evidence that portions of the RKC stock utilized by nearshore fisheries and portions of the RKC stock exposed to the offshore commercial fishery "freely intermixed," but that this level of exchange occurred over an extended period of time (Ron Regnart, Commercial Fisheries Biologist, ADF&G; 1982 internal memo archived at Nome ADF&G office). The difference in recapture rates between crabs tagged on the 5 mile transect and those tagged on the 10 mile transect (Table 11) in fisheries occurring within months of tagging suggests complete mixing does not occur during the short time frame between our spring tagging and the subsequent summer fishery. Data imply all RKC eventually mix and are recovered in equal proportions by the following year's summer commercial fishery (e.g., those RKC tagged in 2012 and recovered in 2013, Table 11). What cannot be inferred from this study is at what time during the year complete mixing takes place. Additional years of tagging and recovery are needed to further elucidate the life history or demographic characteristics of crab that may influence the differential recapture seen in this study.

ESTIMATE DISCARD RATIO OF NON-TARGET NORTON SOUND RKC CAPTURED IN COMMERCIAL CRAB POTS CONFIGURED WITH DIFFERENT ESCAPE MECHANISMS AND VARIABLE SOAK TIMES

Bycatch is a potentially crucial element of managing any fishery and has not been thoroughly examined in the Norton Sound RKC commercial fishery. RKC were the predominant species in the majority of pots sampled by observers. Purple orange sea stars were the next most abundant species. There were very few fish species captured in pots, which is probably due to the relatively low abundance of demersal fish such as Pacific halibut (*Hippoglossus stenolepis*) and Pacific cod (*Gadus macrocephalus*) in the region (Soong and Hamazaki 2015; Table 14).

The effects of handling RKC have been examined in the laboratory by simulating conditions crab encounter in large-vessel fisheries conducted in Bristol Bay and Kodiak, Alaska (Zhou and Shirley 1996). Results from that work indicate RKC may be robust to typical handling. Despite this, efforts should be made to minimize the capture of non-target crab. The average number of discard crab in the Norton Sound summer commercial fishery, based on observer data, was 15.4 crab per pot, or 56 % of handled crab, which is lower than other RKC fisheries with similar soak times. For example, bycatch averaged 49.8 crab per pot, or 68% of handled crab, in the 2005/2006 Bristol Bay RKC commercial fishery (Barnard and Pengilly 2006). In both fisheries, SL crab were the predominant size class in the bycatch, indicating escape mechanisms may not be enough to minimize handling of non-target crab.

Results from the present study suggest a negative relationship between soak time and the number of SL crab in pots. Similar results were found in a study conducted in Bristol Bay, Alaska where increased soak time decreased the ratio between SL and L crab in commercial pots (Pengilly and Tracy 1998). The pattern of non-target crab handled and soak time observed in this study is primarily driven by a few long soak times that are atypical for Norton Sound fishermen. Generally pots are soaked for 48–60 hours, which may not allow enough time for non-target crab to escape as evidenced by the high number of non-target crab handled in certain areas of Norton Sound (e.g., statistical areas 646401, and 646330; Figure 23) under typical soak times. In the presence of high numbers of non-target crab, longer soak times may be needed to effectively minimize the handling of non-target crab.

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TABLES AND FIGURES

Table 1.–Summary of red king crab tagging and recaptures by year.

	2012	2013	2014	Total	Percent recaptures
Annual tagging					
F	102	246	556	904	
SL	1,717	5,573	3,702	10,992	
L	2,760	3,253	1,586	7,599	
Total	4,579	9,072	5,844	19,495	
Annual recaptures					
F	3	1	2	6	0.66%
SL	26	46	40	112	1.02%
L	531	447	173	1,151	15.15%
Unknown length class	58	51	0	109	
Total	618	545	215	1,378	
Percent recaptures	13.50%	6.01%	3.68%	7.07%	

Note: 17 recaptured tags do not have initial tag year. Female (F) all lengths, sublegal male (SL) less than 103 mm, and legal male (L) 103–115 mm.

Table 2.–Analysis of variance results for carapace length by year.

Source	*DF*	Sum of squares	Mean square	*F* value	*Pr* > *F*
Model	2	378307.922	189153.961	603.920	<0.0001
Error	18,555	5811657.167	313.212		
Corrected total	18,557	6189965.089			

R-Square	Coeff var	Root MSE	CL mean
0.061	17.920	17.698	98.758

Source	*DF*	Type I *SS*	Mean square	*F* value	*Pr* > *F*
Year	2	378307.922	189153.961	603.920	<0.0001

Source	*DF*	Type III *SS*	Mean square	*F* value	*Pr* > *F*
Year	2	378307.922	189153.961	603.920	<0.0001

Table 3.–Number of recaptured male red king crab 1 year after tagging by legal size and shell condition compared to number of red king crab tagged by legal size and shell condition.

Shell condition when tagged		Sublegal when tagged		Legal when tagged		All crab	
		Number tagged	Recaptured	Number tagged	Recaptured	Number tagged	Recaptured
	New shell	10,308	102(92)	4,352	87(19)	14,662	189
	Old shell	684	14(14)	3,247	112(88)	3,930	126
	Proportion of new shell recaptured		0.010		0.020		0.013
	Proportion of old shell recaptured		0.020		0.035		0.032

Note: Values in parentheses indicate the number of crab used in molt increment size analysis. Boxed areas indicate differences between the proportion of new and old shell recapture.

Table 4.–Number of red king crab that molted by shell condition, legal size, and time at liberty.

Legal size	Shell condition when tagged	Molted?	1 year at liberty	2 years at liberty
SL	new	no	1	0
SL	new	yes	101	22
SL	old	no	0	0
SL	old	yes	14	6
L	new	no	67	0
L	new	yes	20	22
L	old	no	18	2
L	old	yes	46	11
L	very old	no	4	1
L	very old	yes	44	3

Note: Crab with a change in carapace length of greater than 20 mm were not included in growth increment analysis; however, they are counted as molted crab. Sublegal male (SL) less than 103 mm and legal male (L) 103–115 mm.

Table 5.–Results of analysis of variance for the full model examining factors effecting growth increment.

Regression statistics	
Multiple R^2	0.383
Adjusted R^2	0.374
Residual Std. Error	2.061
Observations	211

ANOVA

	df	*SS*	*MS*	*F*	Significance *F*
CL	1	498.200	498.200	117.273	<0.001
Shell	1	33.390	33.390	7.861	0.006
CL: Shell	1	19.740	19.740	4.646	0.032
Residual	209	887.870	4.250		

Coefficients	Estimate	Std. Error	*t*-value	*Pr(>|t|)*
Intercept	19.811	1.890	10.478	<0.0001
CL	-0.062	0.020	-3.191	0.002
Shell	6.129	3.380	1.813	0.071
CL: Shell	-0.068	0.031	-2.155	0.032

Table 6.–Results of analysis of variance for the reduced model examining factors effecting growth increment.

Regression statistics	
Multiple R^2	0.346
Adjusted R^2	0.343
Residual Std. Error	2.112
Observations	211

ANOVA

	df	*SS*	*MS*	*F*	Significance *F*
CL	1	498.200	498.200	111.700	<0.001
Residual	211	941.000	4.460		

Coefficients	Estimate	Std. Error	*t*-value	*Pr(>|t|)*
Intercept	24.942	1.184	21.060	<0.001
CL	-0.119	0.011	-10.570	<0.001

Table 7.–Results of analysis of variance for the proportion of sublegal red king crab in waters off Cape Nome.

Source	*DF*	Sum of squares	Mean square	*F* value	*Pr* > *F*
Model	1	1.174	1.174	9.660	0.002
Error	663	80.547	0.121		
Corrected total	664	81.721			

R-Square	Coeff Var	Root MSE	TpaSL mean
0.014	52.843	0.349	0.660

Source	*DF*	Type I *SS*	Mean square	*F* value	*Pr* > *F*
Capenome	1	1.174	1.174	9.660	0.002

Source	*DF*	Type III *SS*	Mean square	*F* value	*Pr* > *F*
Capenome	1	1.174	1.174	9.660	0.002

Table 8.–Red king crab recapture statistical area by original tagging statistical area, Norton Sound, AK.

	Recaptured statistical area					
Tagged statistical area	616	626	636	646	656	666
626	4	146	73	23	33	8
636	2	45	105	80	80	19
646	1	20	33	92	235	79
656		1	2	1	24	3

Note: The first 3 digits of the statistical area represent longitudinal boundaries.

Table 9.–Distribution of recaptured tagged red king crab by event.

	2012	2013	2014
Spring pot survey		20	19
Summer commercial fishery	287	399	594
Fall pot survey		6	1
Winter commercial fishery		28	8

Note: A total of 21 tags were returned with no information about recovery.

Table 10.–Distribution of commercial harvest and recaptured red king crab in the commercial fishery by statistical area.

Statistical area	Number of crab harvested	Percent of harvest	Number of recaptured crab	Percent of recaptures
616331	1,763	0.4%	0	0.0%
616401	4,278	1.0%	2	0.3%
626331	230	0.1%	0	0.0%
626401	74,669	17.7%	135	22.1%
636330	7,189	1.7%	4	0.7%
636401	87,718	20.8%	119	19.5%
646330	3,657	0.9%	1	0.2%
646401	65,948	15.7%	93	15.2%
646402	1,803	0.4%	11	1.8%
656330	5,387	1.3%	5	0.8%
656401	118,624	28.2%	121	19.8%
656402	12,623	3.0%	56	9.2%
666330	331	0.1%	1	0.2%
666401	28,618	6.8%	39	6.4%
666402	6,786	1.6%	22	3.6%
666431	1,749	0.4%	2	0.3%

Table 11.–Proportion of recovered tagged red king crab by transect in all years.

	Tagged in 2012				Tagged in 2013			Tagged in 2014			All tags combined	
		Recaptured in				Recaptured in			Recaptured in			
	Number tagged	2012	2013	2014	Number tagged	2013	2014	Number tagged	2014	2015	Number tagged	Recaptured[a]
5 mile L	1,367	100	75	60	1721	88	141	716	65		3,804	253
10 mile L	1,393	169	78	48	1533	131	127	869	102		3,795	402
Proportion recaptured from 5 mile		0.07	0.06	0.05		0.05	0.09		0.09			0.07
Proportion recaptured from 10 mile		0.12	0.06	0.04		0.09	0.09		0.12			0.11

Note: Boxed values indicate significance at $P < 0.001$.

[a] These are only the tags recaptured in the summer commercial fishery immediately after tagging.

Table 12.–Results of analysis of variance for the full model examining factors effecting number of non-target crab in crab pots.

Regression statistics	
Multiple R^2	0.2677
Adjusted R^2	0.2603
Residual Std. Error	7.795
Observations	399

ANOVA

	df	*SS*	*MS*	*F*	Significance *F*
st	1	3902.000	3902.00	64.227	<0.001
Location	1	3938.400	3938.40	64.825	<0.001
Esc mech	1	118.900	118.90	1.956	0.163
Location: esc mech	1	813.000	813.00	13.381	<0.001
Residual	395	23997.900	60.800		

Coefficients	Estimate	Std. error	*t*-value	*Pr(>|t|)*
Intercept	8.6802	1.047	8.291	<0.001
st	-1.808	0.309	-5.862	<0.001
Location	7.4773	0.919	8.139	<0.001
Esc mech	0.4092	1.053	0.388	0.697
Location: esc mech	-8.4738	2.3165	-3.658	<0.001

Table 13.–Results of analysis of variance for the reduced model examining factors effecting number of non-target crab in crab pots.

Regression statistics	
Multiple R^2	0.1446
Adjusted R^2	0.1402
Residual Std. Error	8.403
Observations	399

ANOVA

	df	*SS*	*MS*	*F*	Significance *F*
st	1	3902.000	3902.000	55.260	<0.001
Esc mech	1	834.900	834.900	11.824	<0.001
Residual	397	28033.200	70.600		

Coefficients	Estimate	Std. error	*t*-value	*Pr(>|t|)*
Intercept	13.483	0.933	14.451	<0.001
st	-2.226	0.328	-6.791	<0.001
Esc mech	-3.336	0.970	-3.439	<0.001

Table 14.–Non-target red king crab catch per unit effort and standard deviations (SD) for different types of escape mechanisms (rings, large mesh) and within different locations.

	Statistical areas 646401 and 646331				All other statistical areas			
Soak time	Rings	SD	Large	SD	Rings	SD	Large	SD
<24	0.7	1.2	–	–	0.0	0.0	–	–
24–47	17.6	15.3	0.8	–	10.5	8.2	7.0	5.2
48–71	13.2	10.5	–	–	3.0	3.4	4.8	5.2
72–96	5.2	6.2	2.5	2.4	3.6	0.4	2.8	3.2
>97	0.6	0.4	–	–	0.5	0.4	0.5	0.6

Table 15.–Species and number found in all observer pots during the 2012–2014 summer commercial fisheries, Norton Sound, AK.

Common Name	Species	Number
Red king crab	*Paralithodes camtschaticus*	12,771
Flatbottom sea star	*Asterias amurensis*	4,629
Tanner crab	*Chionoecetes opilio*	110
Circumboreal toad crab	*Hyas coarctatus*	88
Helmet crab	*Telmessus cheiragonus*	62
Hermit crab	*Pagurus* spp.	36
Pacific halibut	*Hippoglossus stenolepis*	29
Starry flounder	*Platichthys stellatus*	28
Basket star	*Gorgonocephalus caryi*	25
Neptune whelks	*Neptunea* spp.	25
Pacific cod	*Gadus macrocephalus*	23
Leptasterias sea star	*Leptasterias* spp.	21
Yellowfin sole	*Limanda aspera*	10
Green sea urchin	*Strongylocentratus droebachiensis*	8
Sculpin	*Enophrys* spp. / *Myoxocephalus* spp.	3
Jellyfish		3
Blue king crab	*Paralithodes platypus*	1
Spiny king crab	*Paralithodes brevipes*	2
Misc. invertebrates		6
Misc. sea star		5
Misc. fish		3

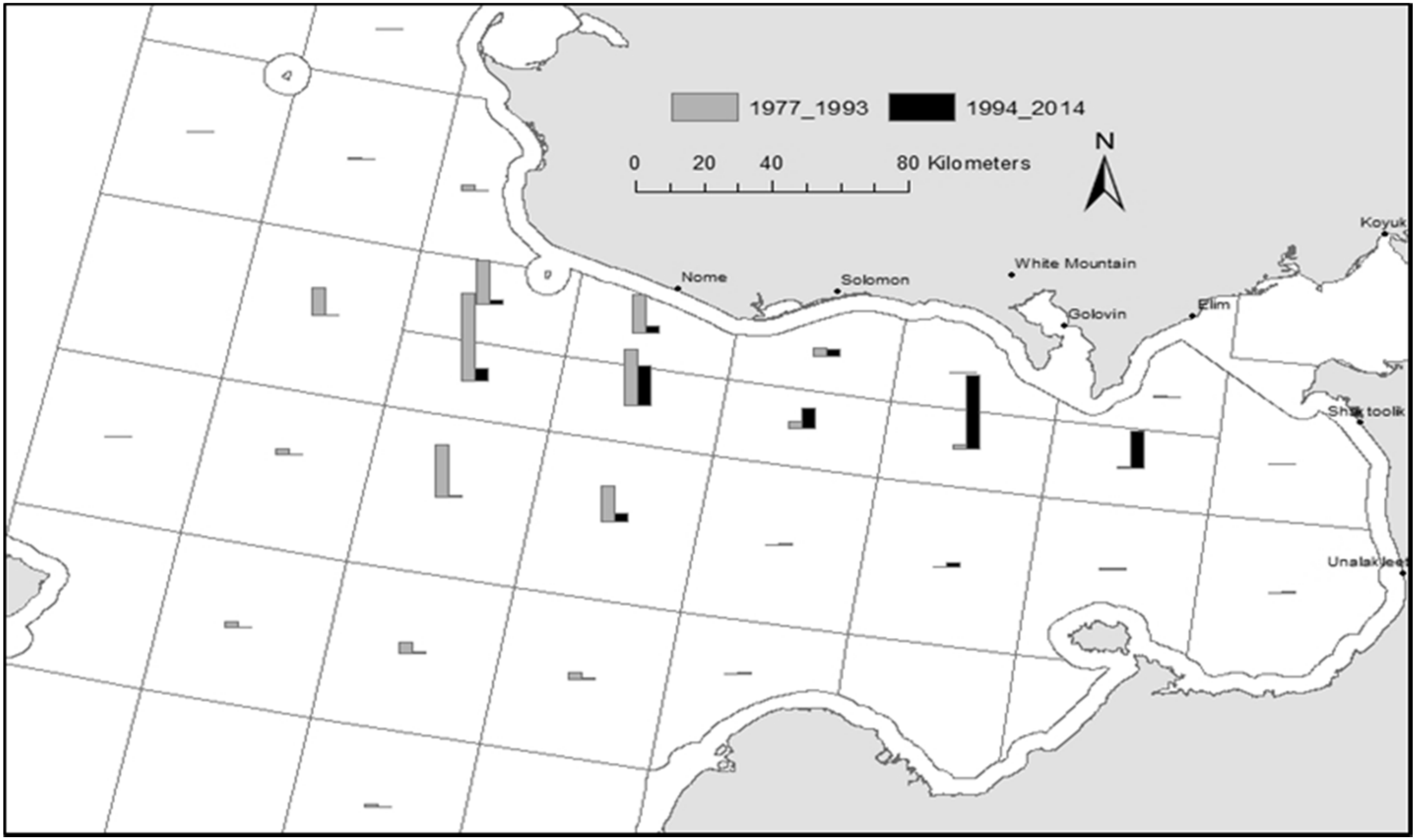

Figure 1.–Norton Sound red king crab summer commercial fishery harvest (in lb) by statistical area, 1977–1993 and 1994–2014.

Note: The black line perpendicular to shore separates western and eastern portions of Norton Sound as defined in this study.

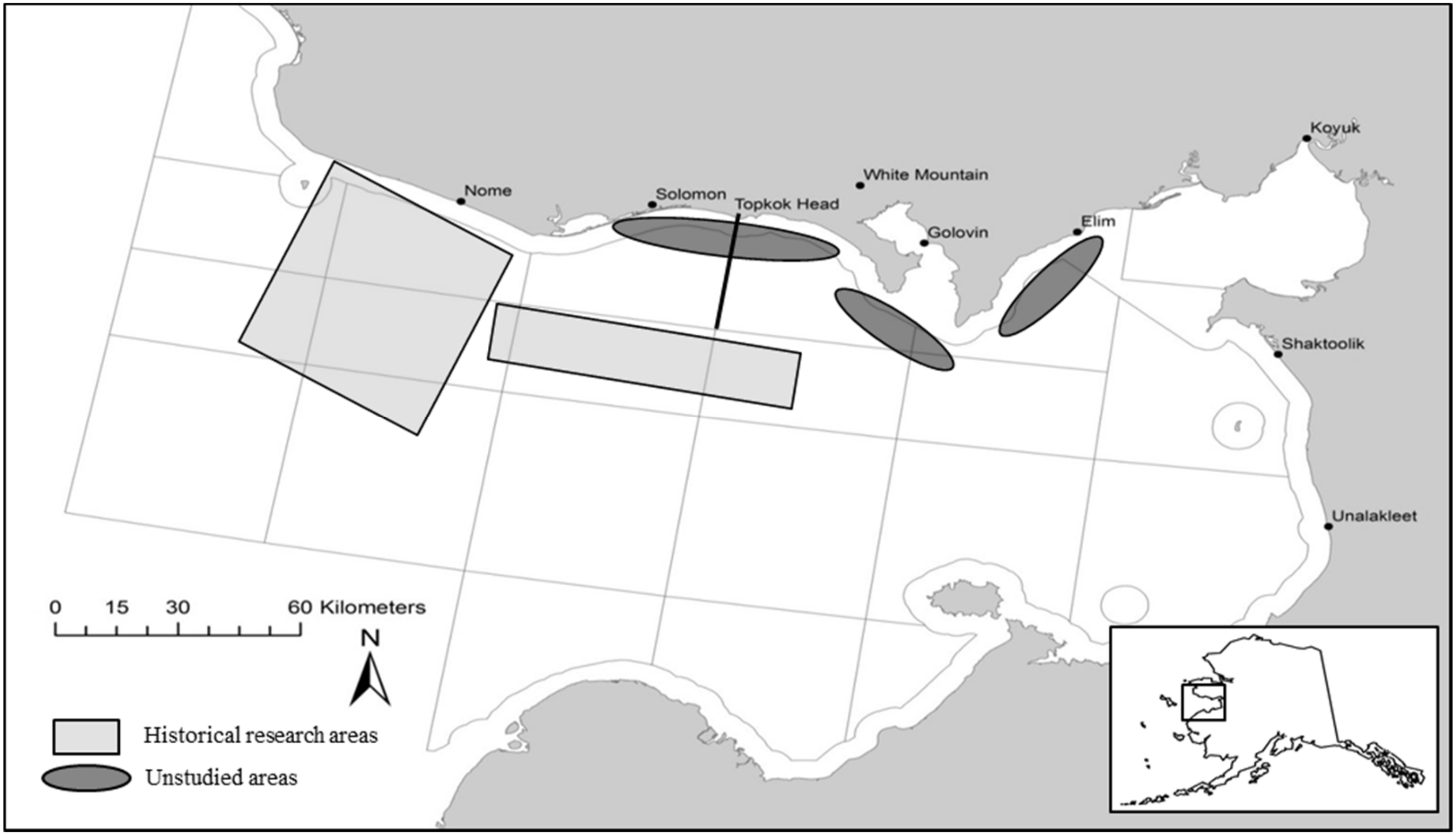

Figure 2.–Historical research and current areas of interest in Norton Sound, AK.

Note: The black line perpendicular to shore separates western and eastern portions of Norton Sound as defined in this study.

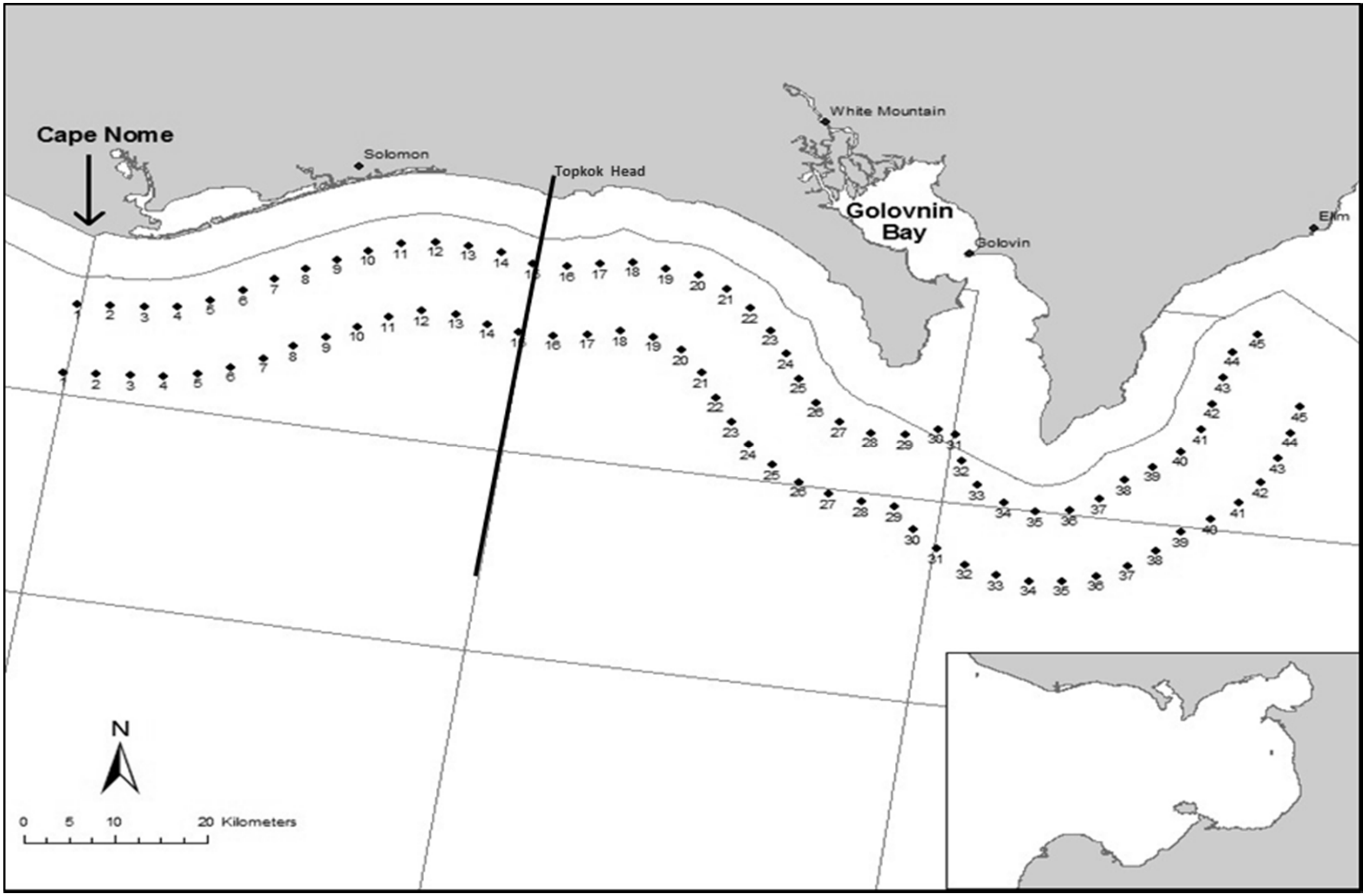

Figure 3.–Location of red king crab pots along 5 and 10 mile transects, Norton Sound, AK.

Note: The black line perpendicular to shore separates western and eastern portions of Norton Sound as defined in this study.

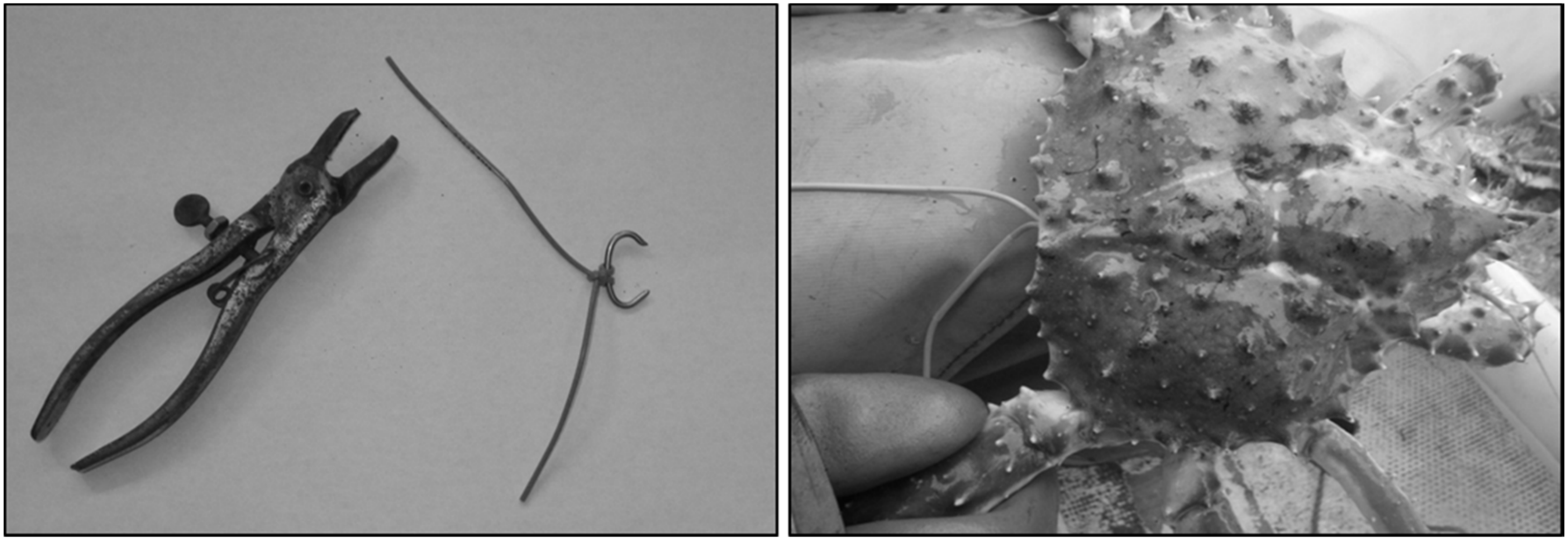

Figure 4.–Crimpers and spaghetti tag tied to a hog ring (left) and placement of the tag through the isthmus muscle of the crab (right).

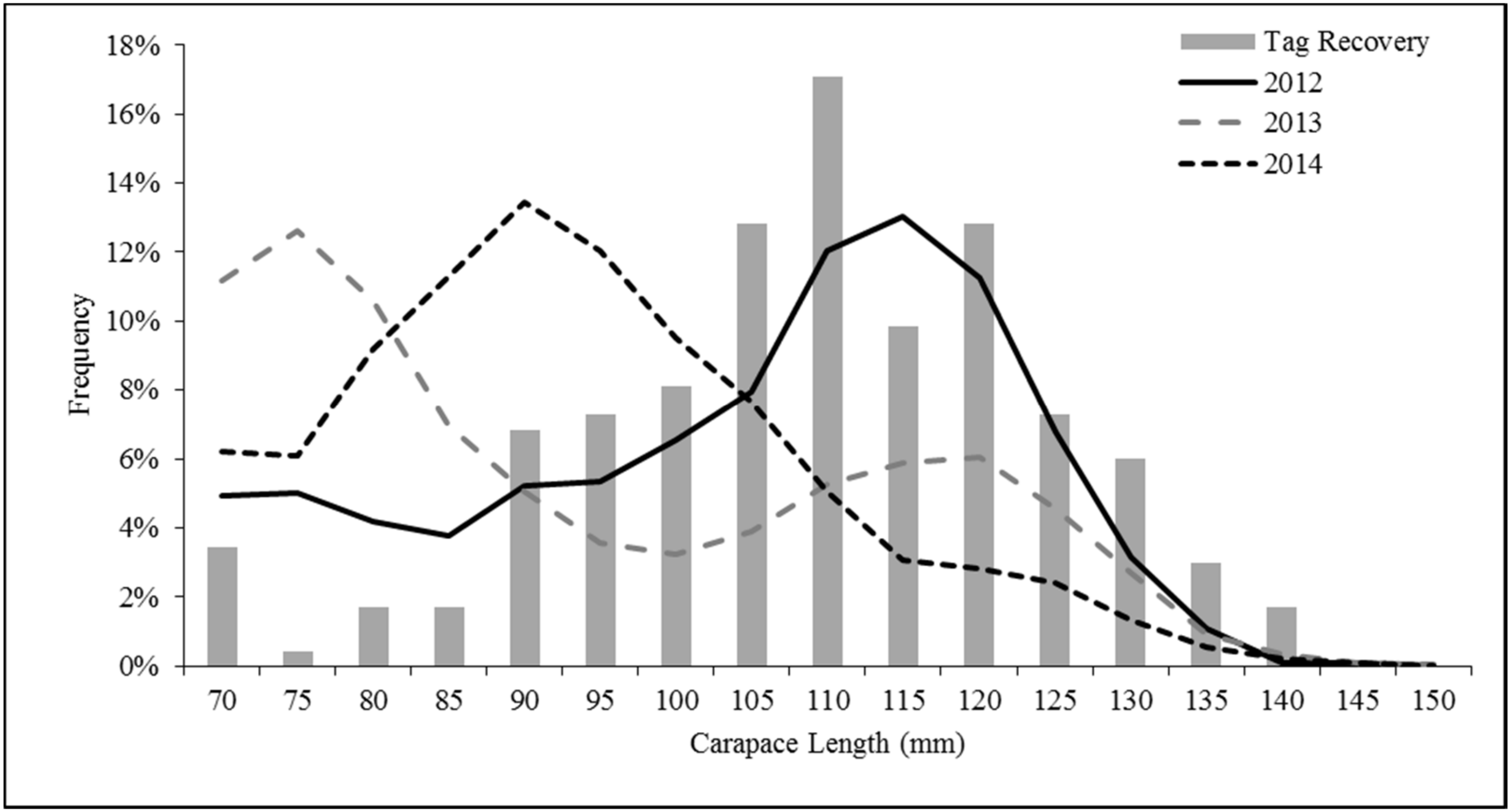

Figure 5.–Length frequency distribution of tagged red king crab (by year; lines) and recaptured red king crab (all years combined; bars).

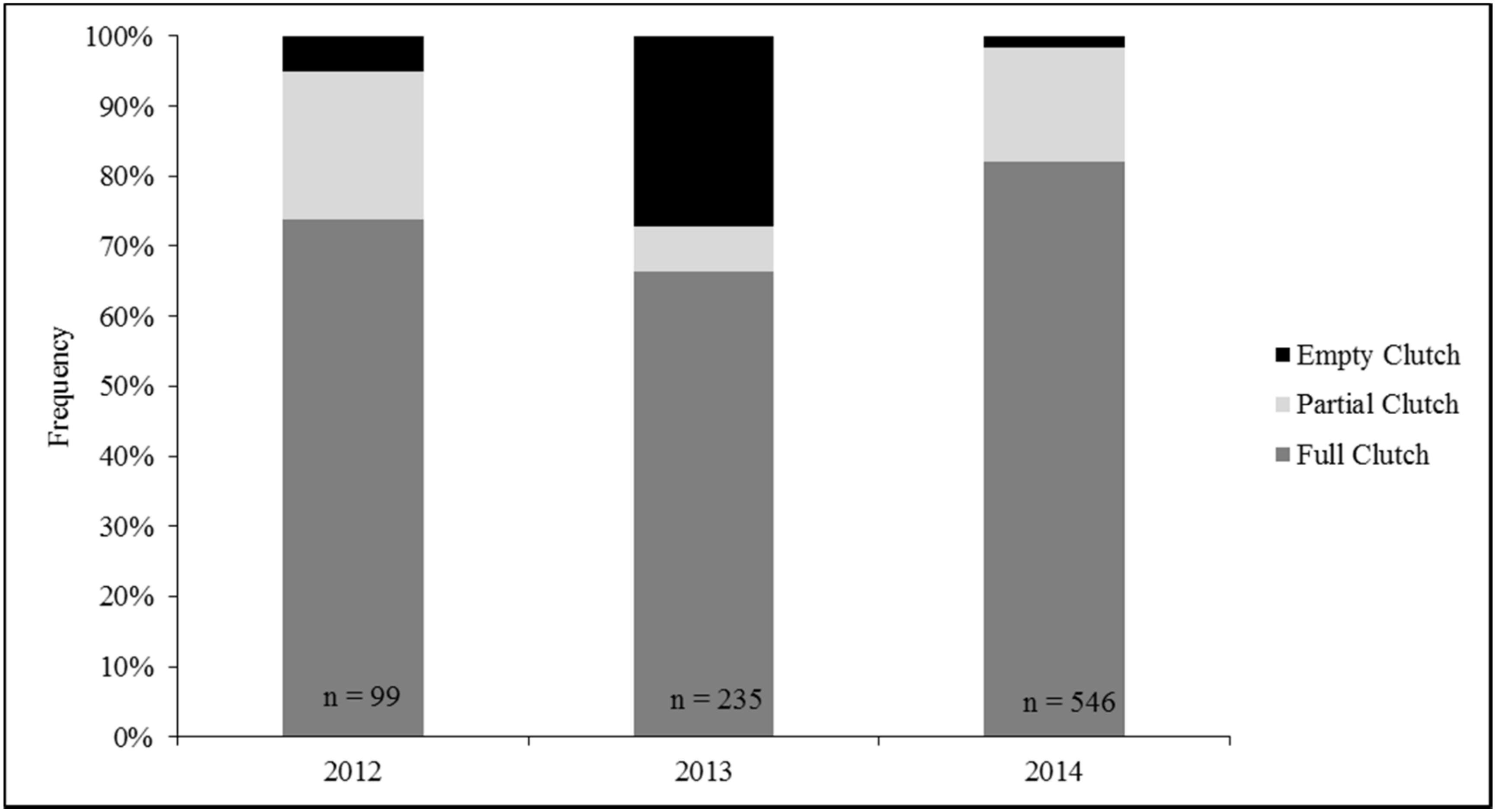

Figure 6.–Reproductive condition of female red king crab captured during tagging.

Note: *n* is the sample size.

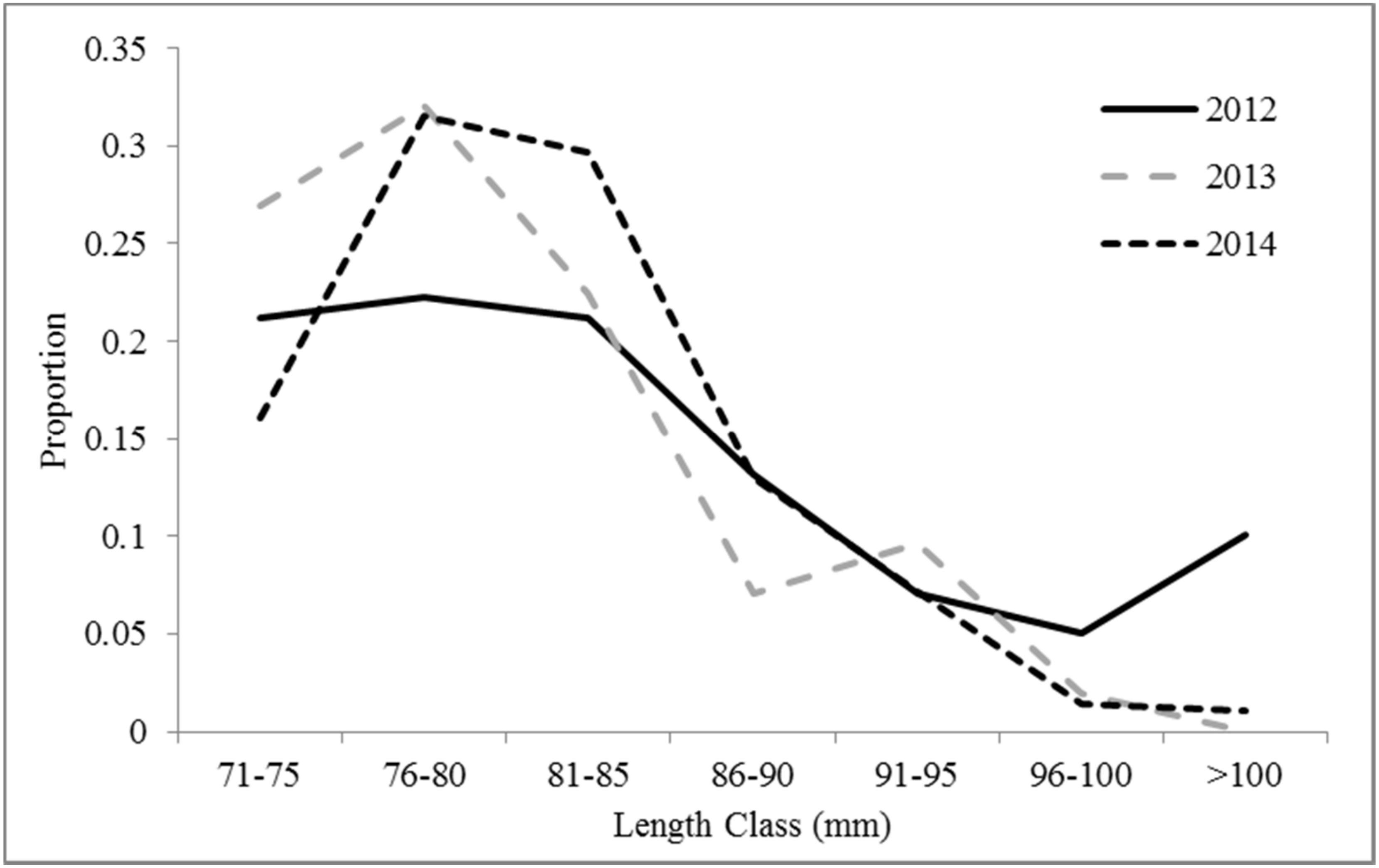

Figure 7.–Length frequency distribution of female red king crab captured in pots during spring tagging, 2012–2014.

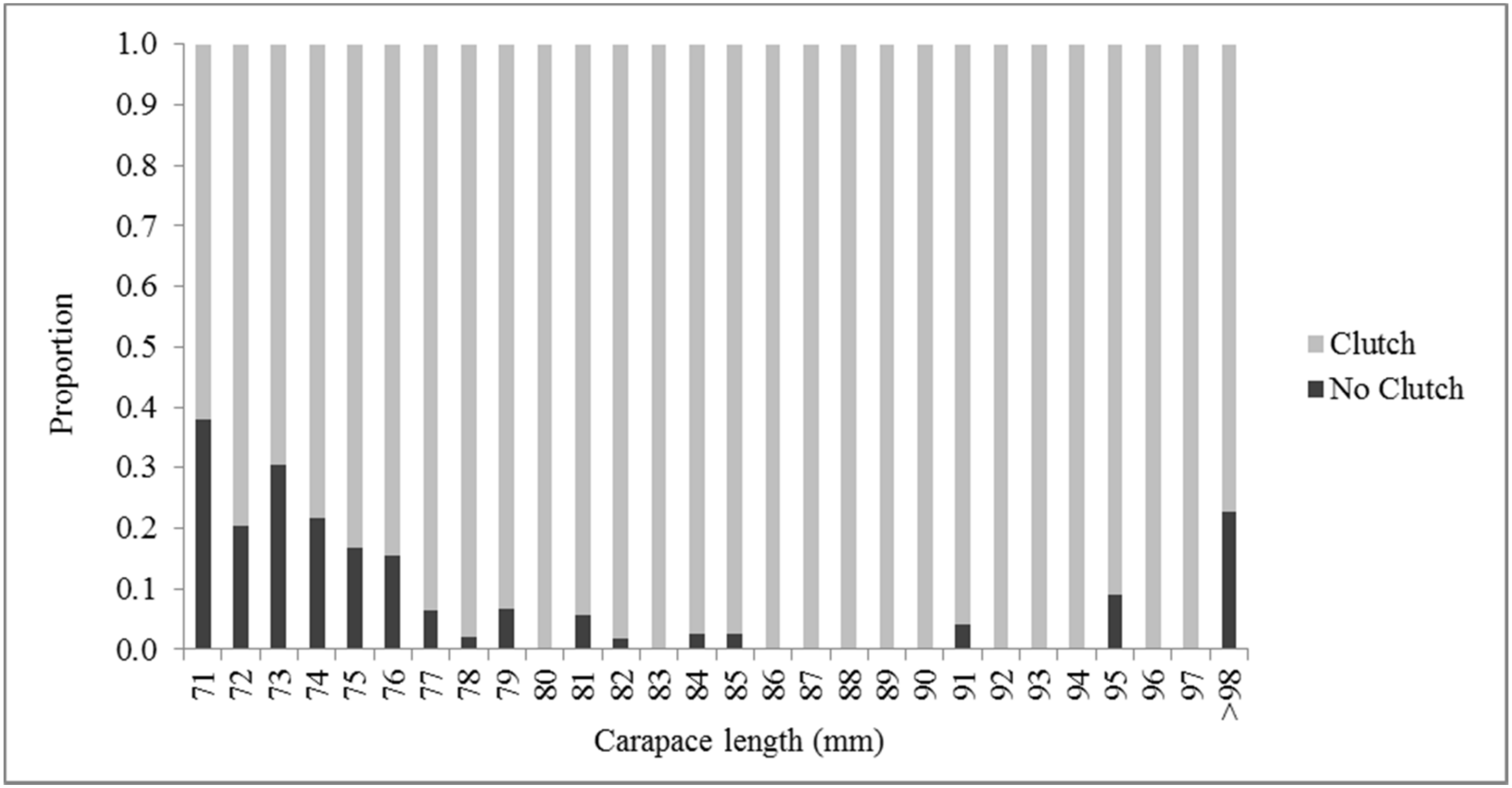

Figure 8.–Proportion of female red king crab with clutches and no clutches by carapace length.

Note: Minimum sample size exceeds n = 4 at all carapace lengths.

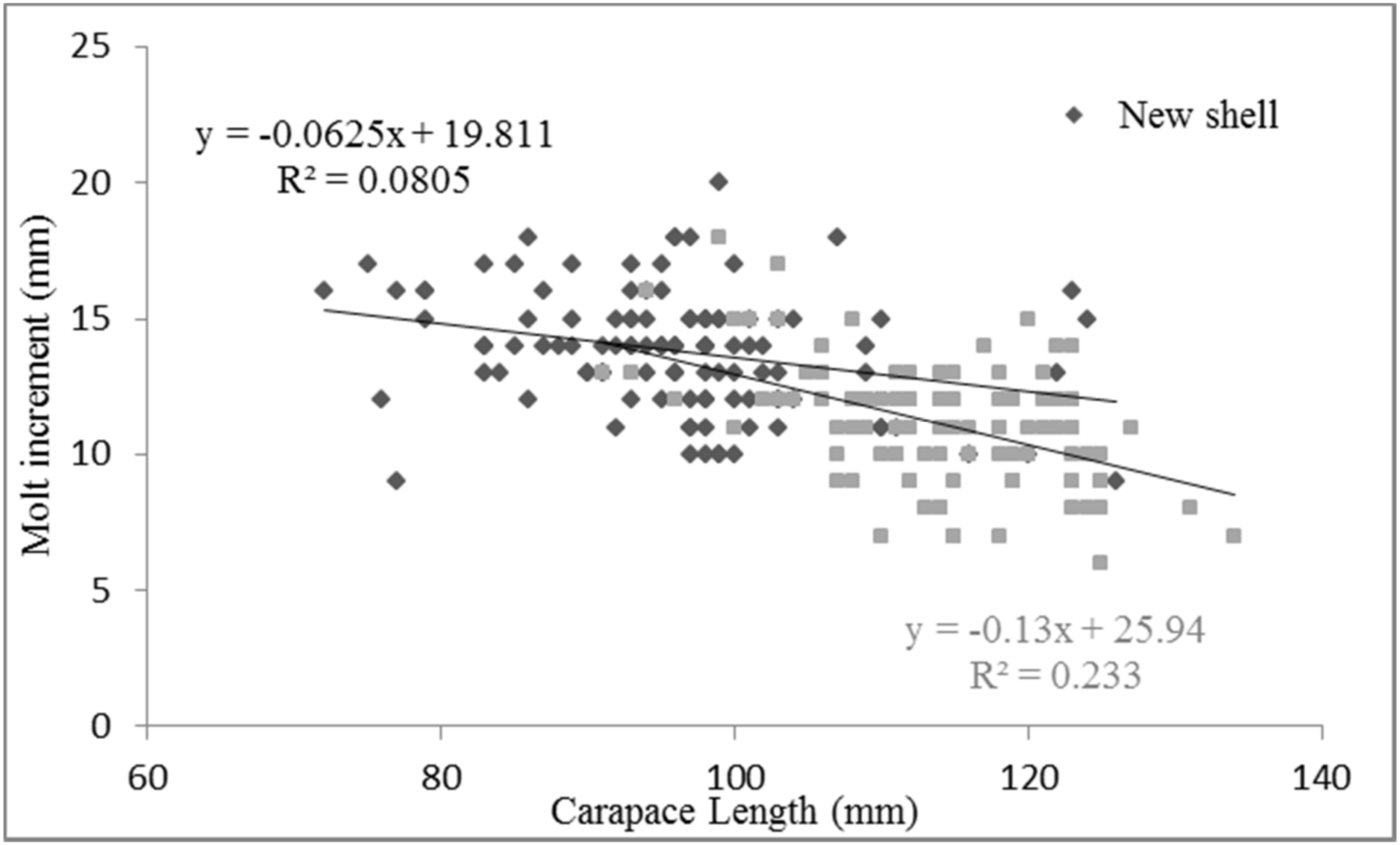

Figure 9.–Red king crab molt increment by carapace length and shell condition (at time of tagging).

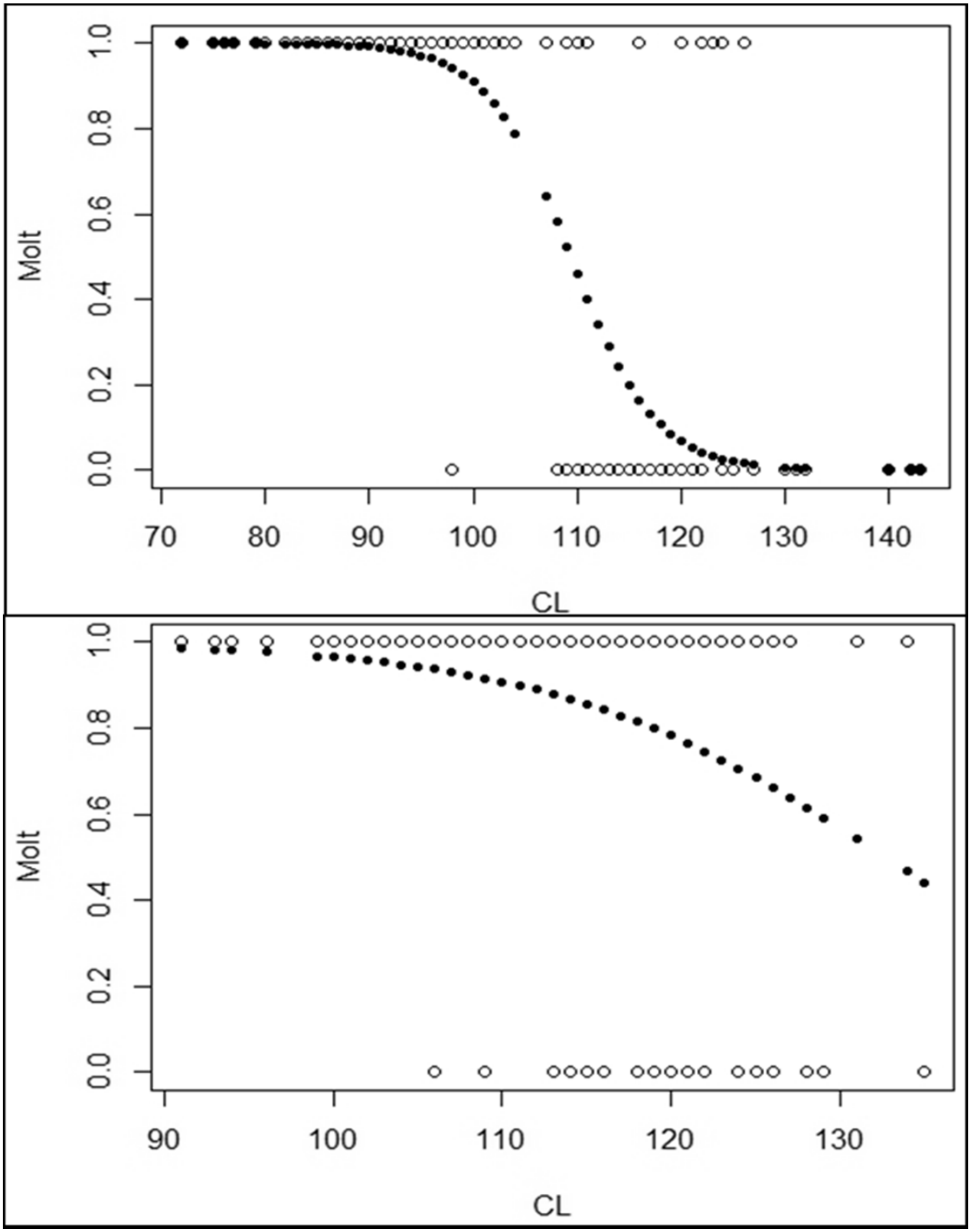

Figure 10.–Molting probability of new shell (top) and old shell (bottom) red king crab by carapace length (CL).

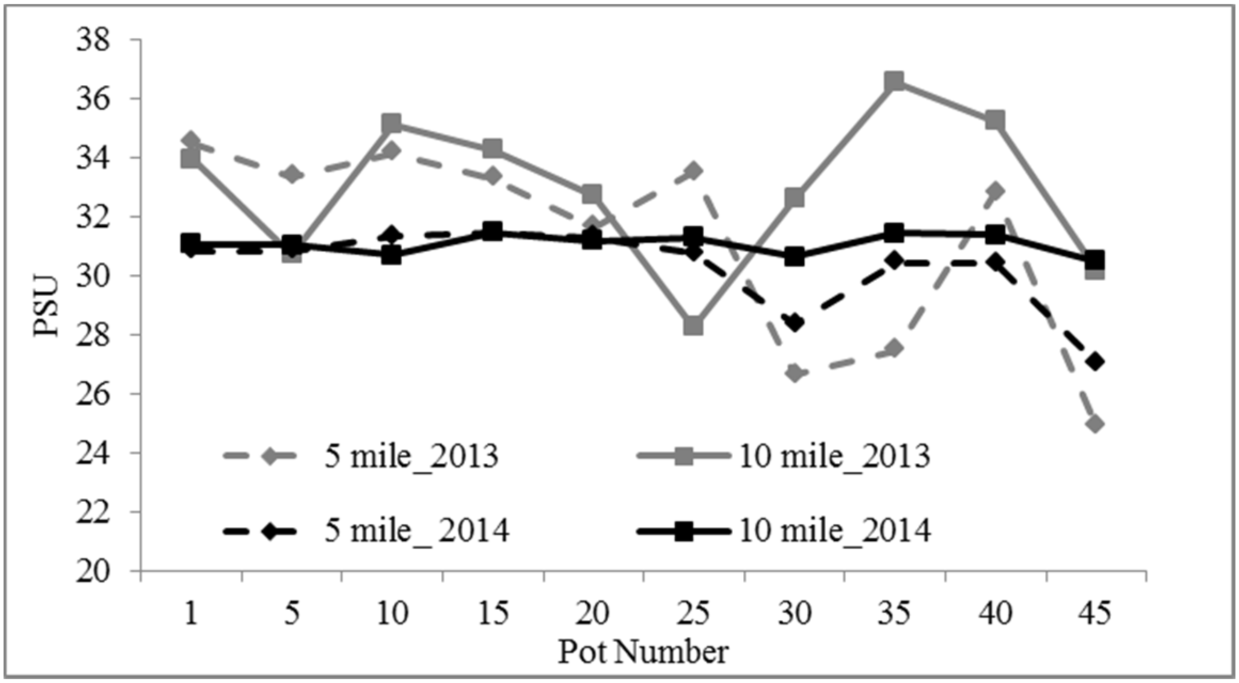

Figure 11.–Average bottom salinity (PSU) along the 5 and 10 mile transects.

Note: Pot number 1 is at the western end of the transect.

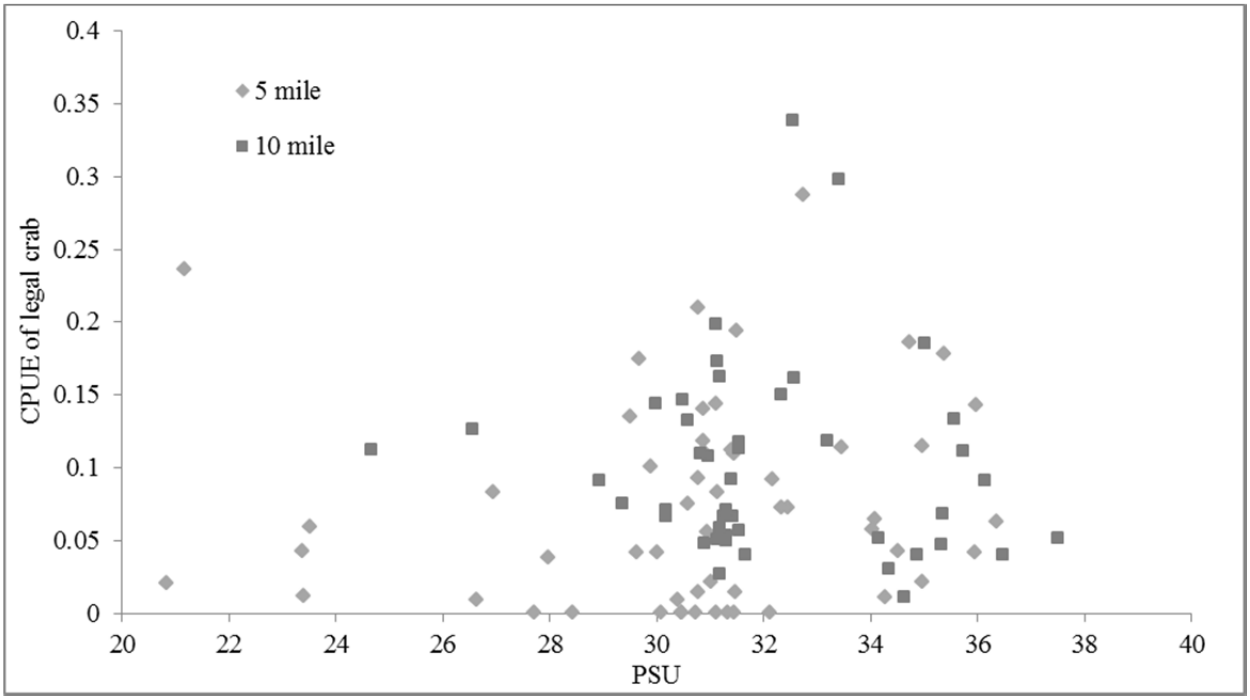

Figure 12.–Relationship between salinity (PSU) and catch per unit effort (CPUE) of legal red king crab by transect, Norton Sound, AK.

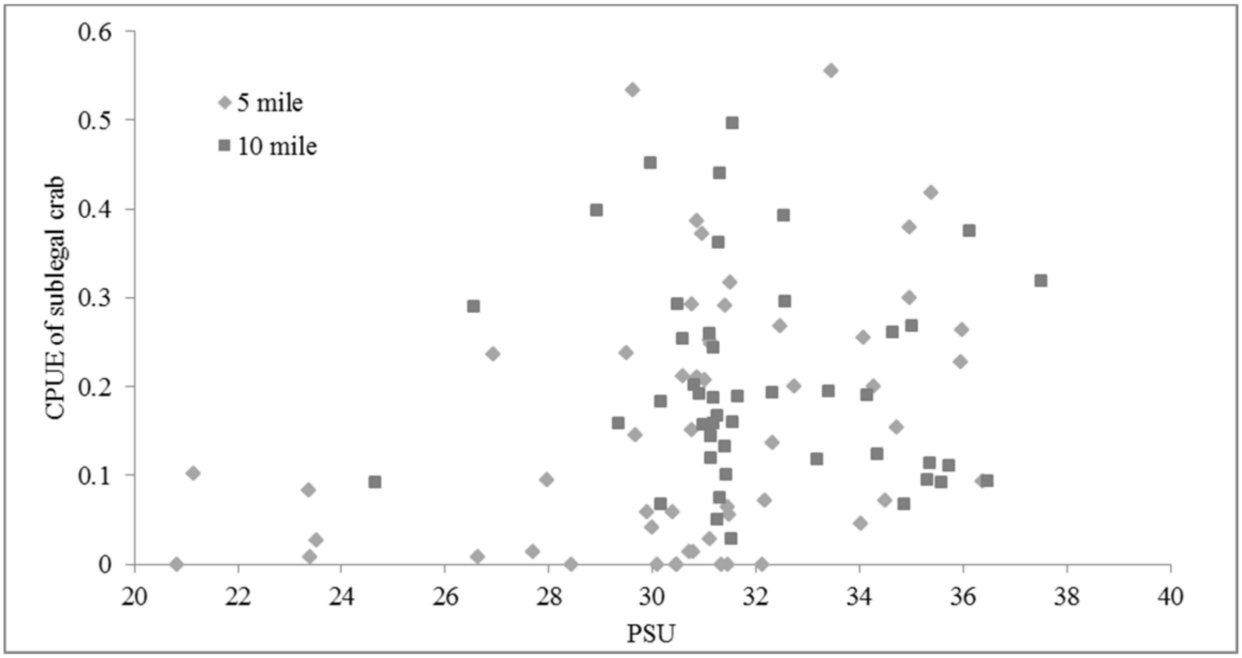

Figure 13.–Relationship between salinity (PSU) and catch per unit effort (CPUE) of sublegal red king crab by transect, Norton Sound, AK.

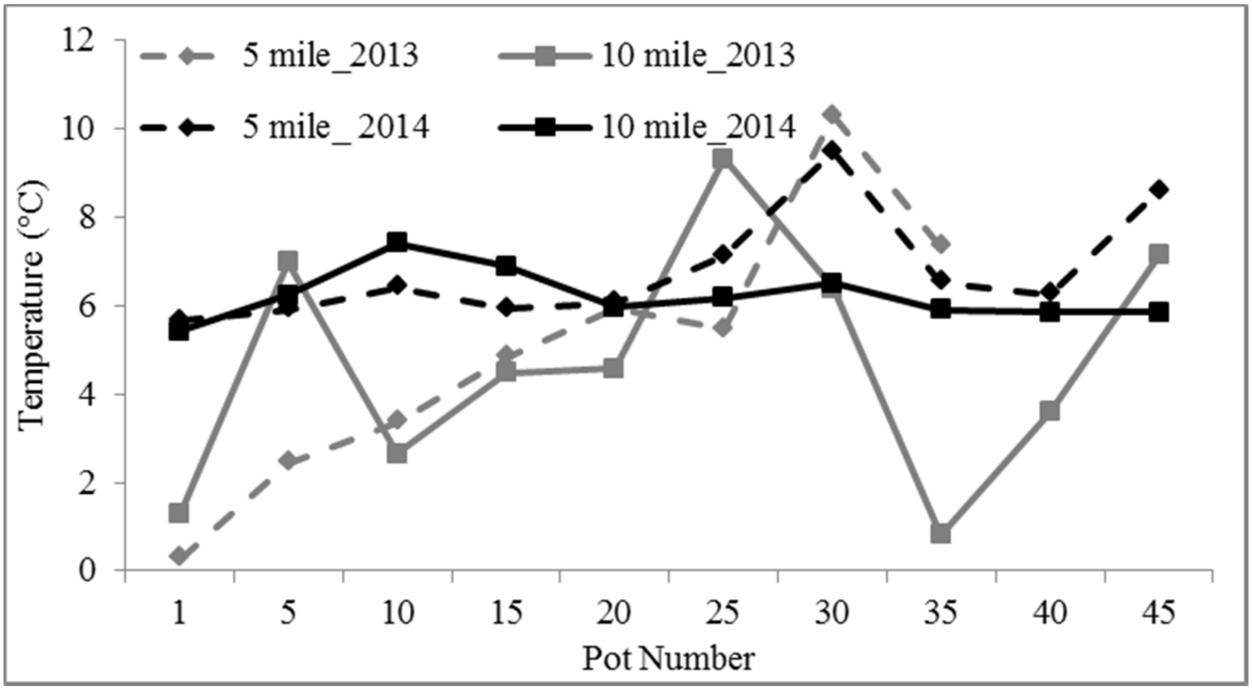

Figure 14.–Average temperature along the 5 and 10 mile transects, Norton Sound, AK.

Note: Pot number 1 is at the western end of the transect.

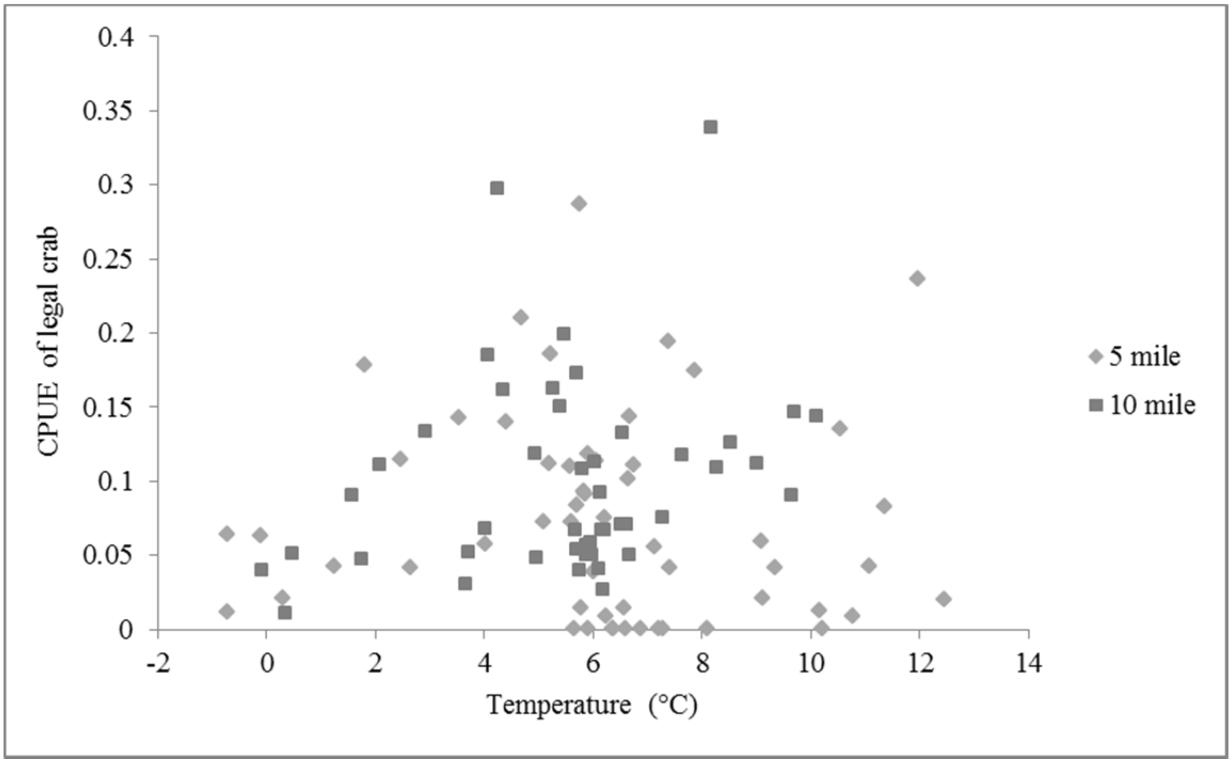

Figure 15.–Relationship between bottom temperature and catch per unit effort (CPUE) of legal red king crab by transect, Norton Sound, AK.

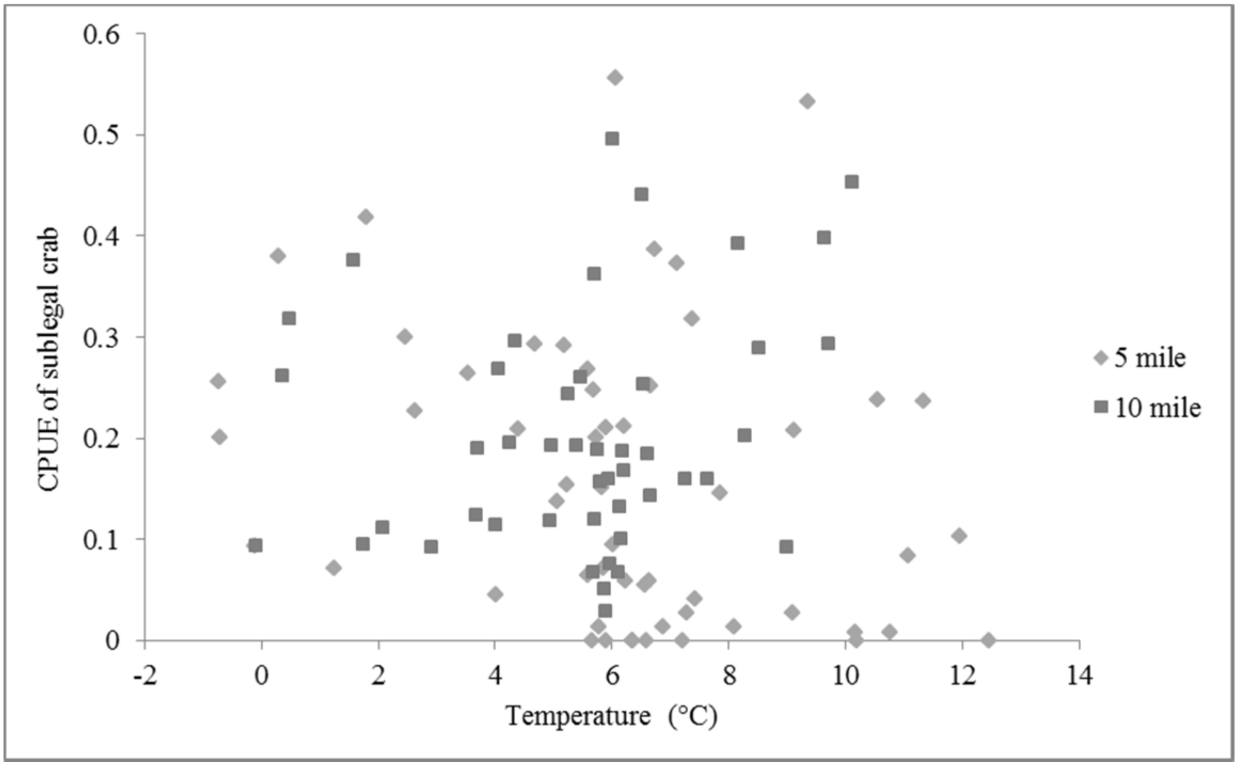

Figure 16.–Relationship between bottom temperature and catch per unit effort (CPUE) of sublegal red king crab by transect, Norton Sound, AK.

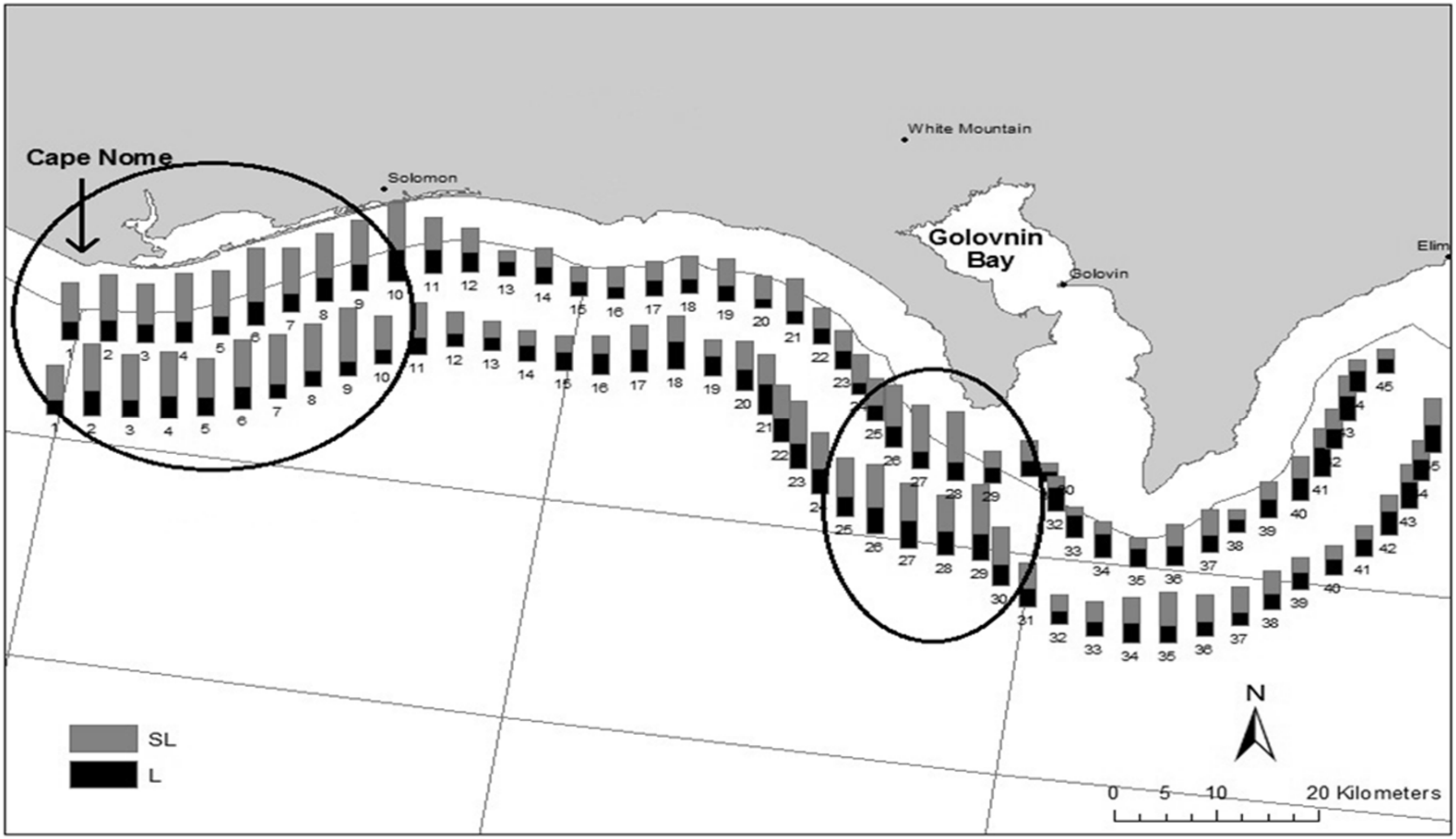

Figure 17.–Abundance of legal (L) and sublegal (SL) male red king crab for all years at each tagging location, Norton Sound, AK.

Note: Circles indicate possible critical locations for SL red king crab. Sample size indicated by bar length.

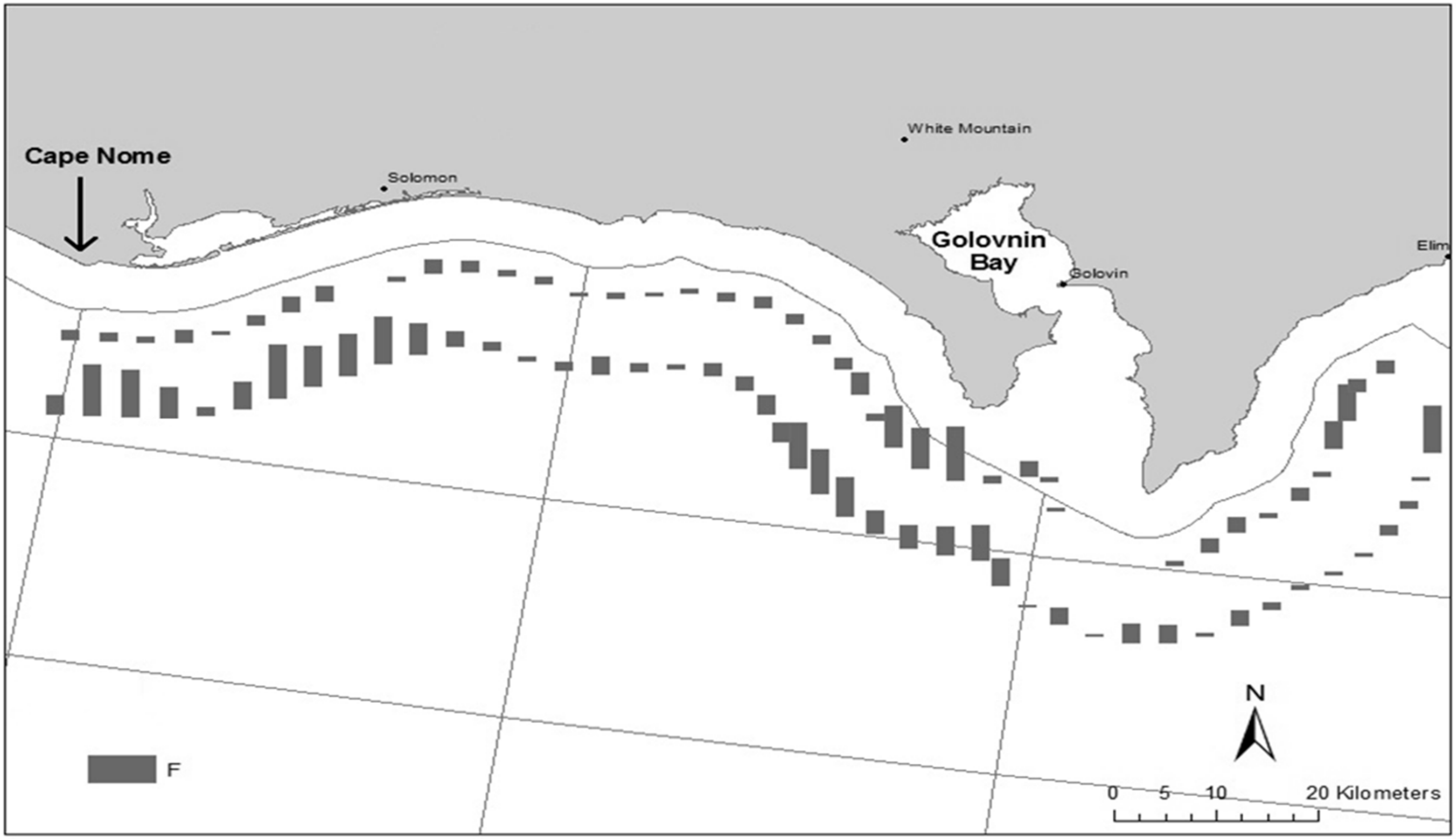

Figure 18.–Abundance of female (F) red king crab for all years at each tagging station, Norton Sound, AK.

Note: Sample size indicated by bar length.

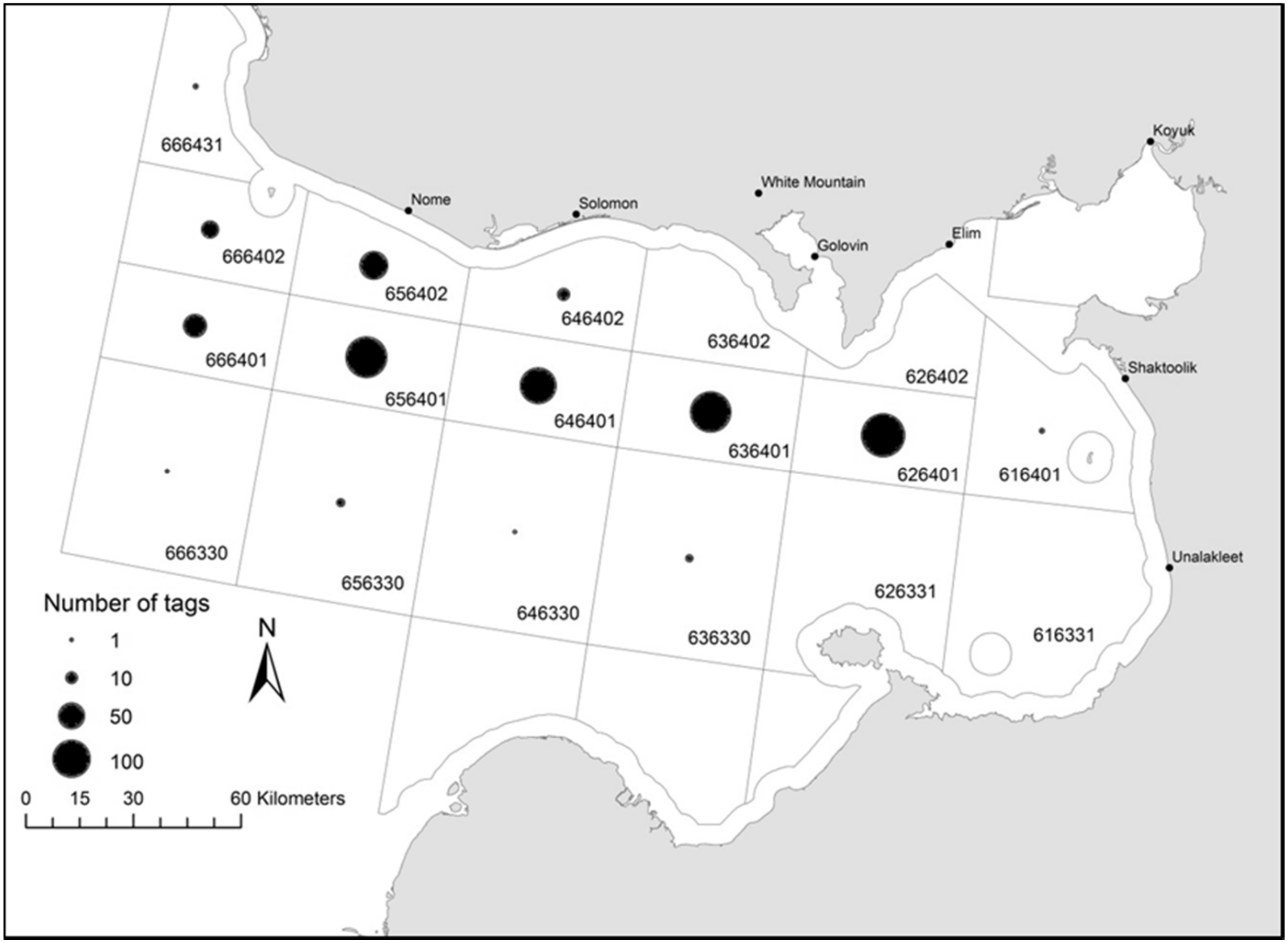

Figure 19.–Distribution of recaptured red king crab in the summer commercial fisheries, 2012–2014 by statistical area, Norton Sound, AK.

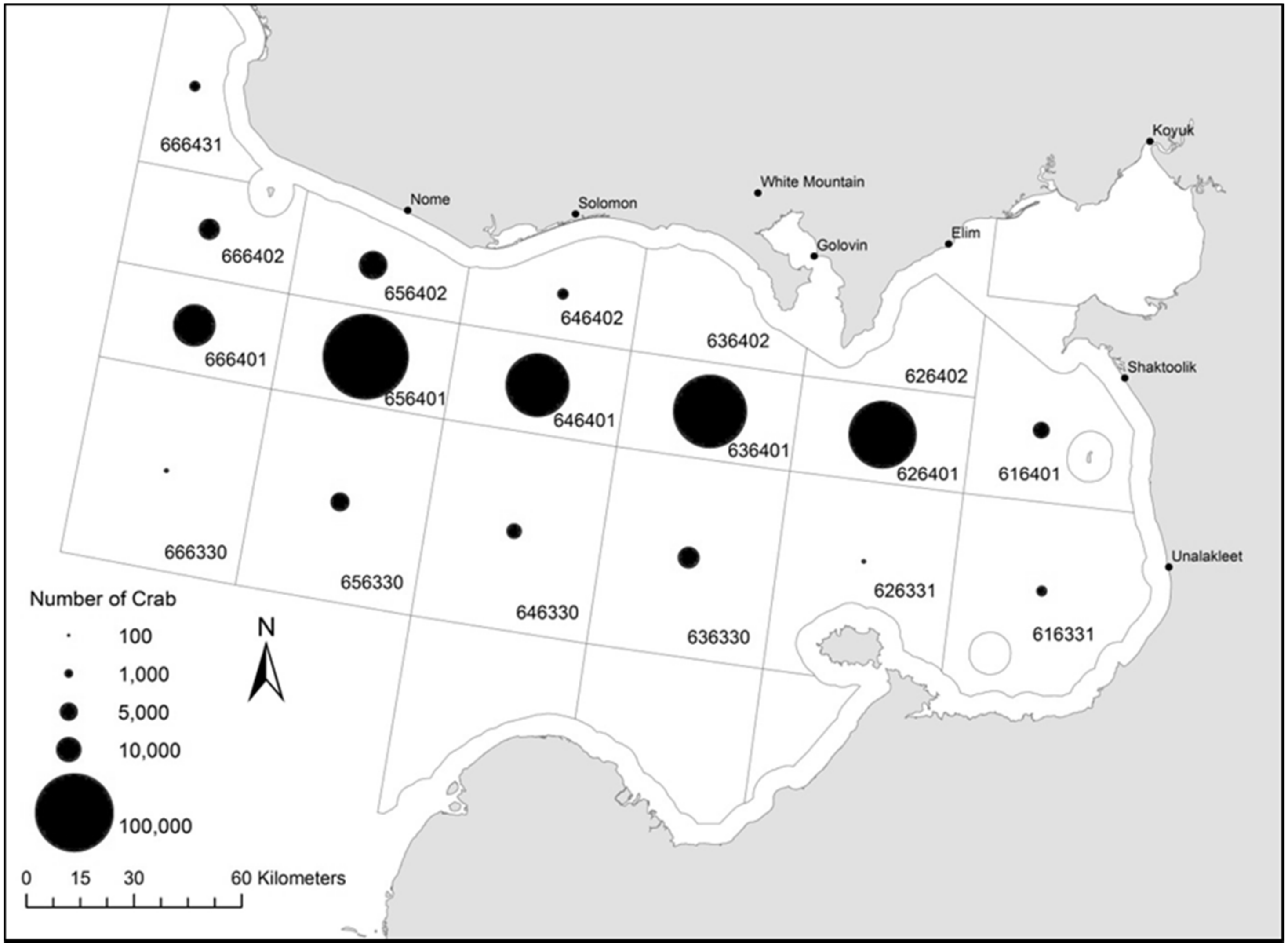

Figure 20.–Distribution of red king crab harvested in the commercial fisheries, 2012–2014 by statistical area, Norton Sound, AK.

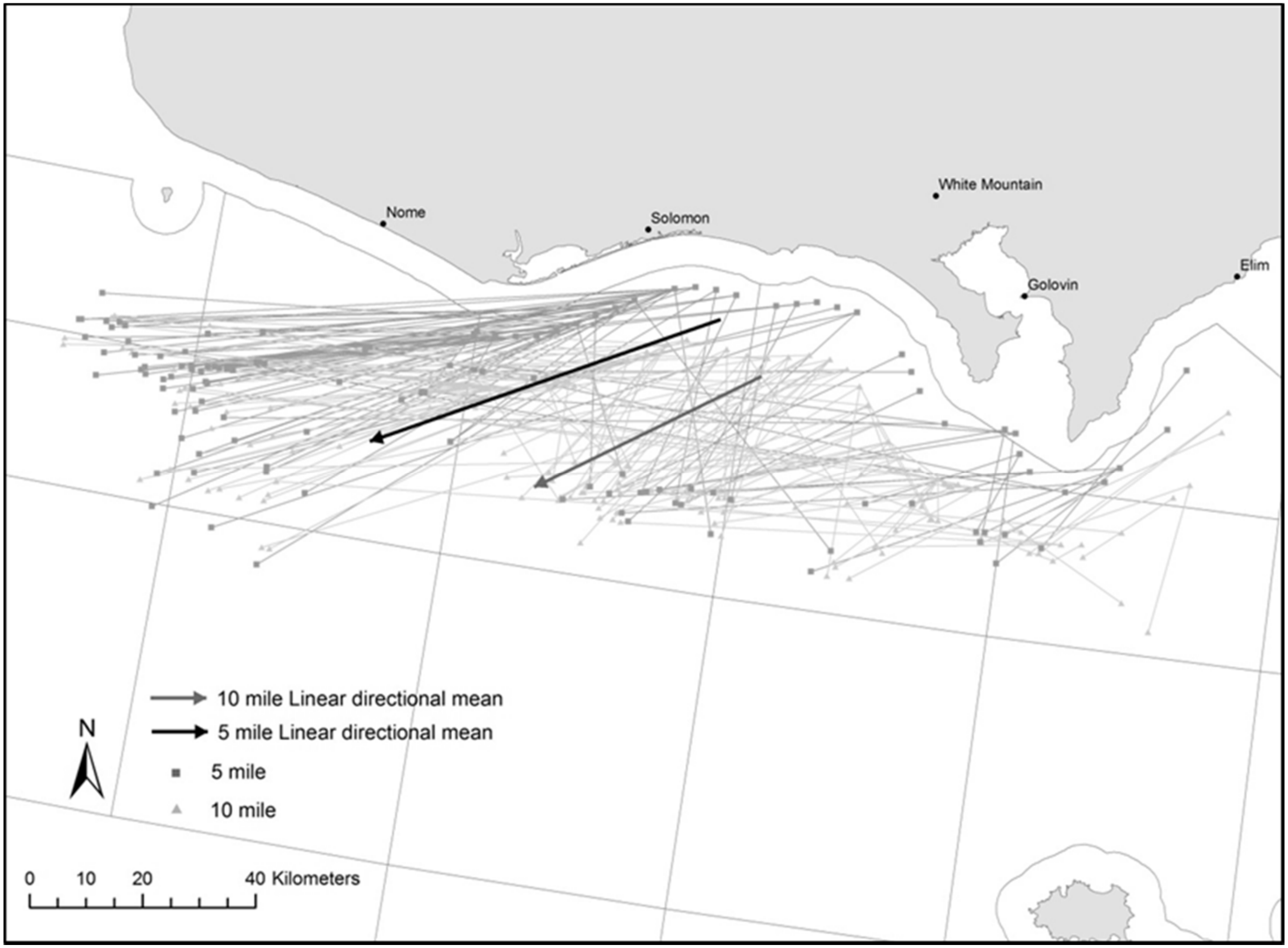

Figure 21.–Straight line direction of red king crab tagged and recaptured by transect, Norton Sound, AK.

Note: Heavy arrows represent linear directional mean by transect.

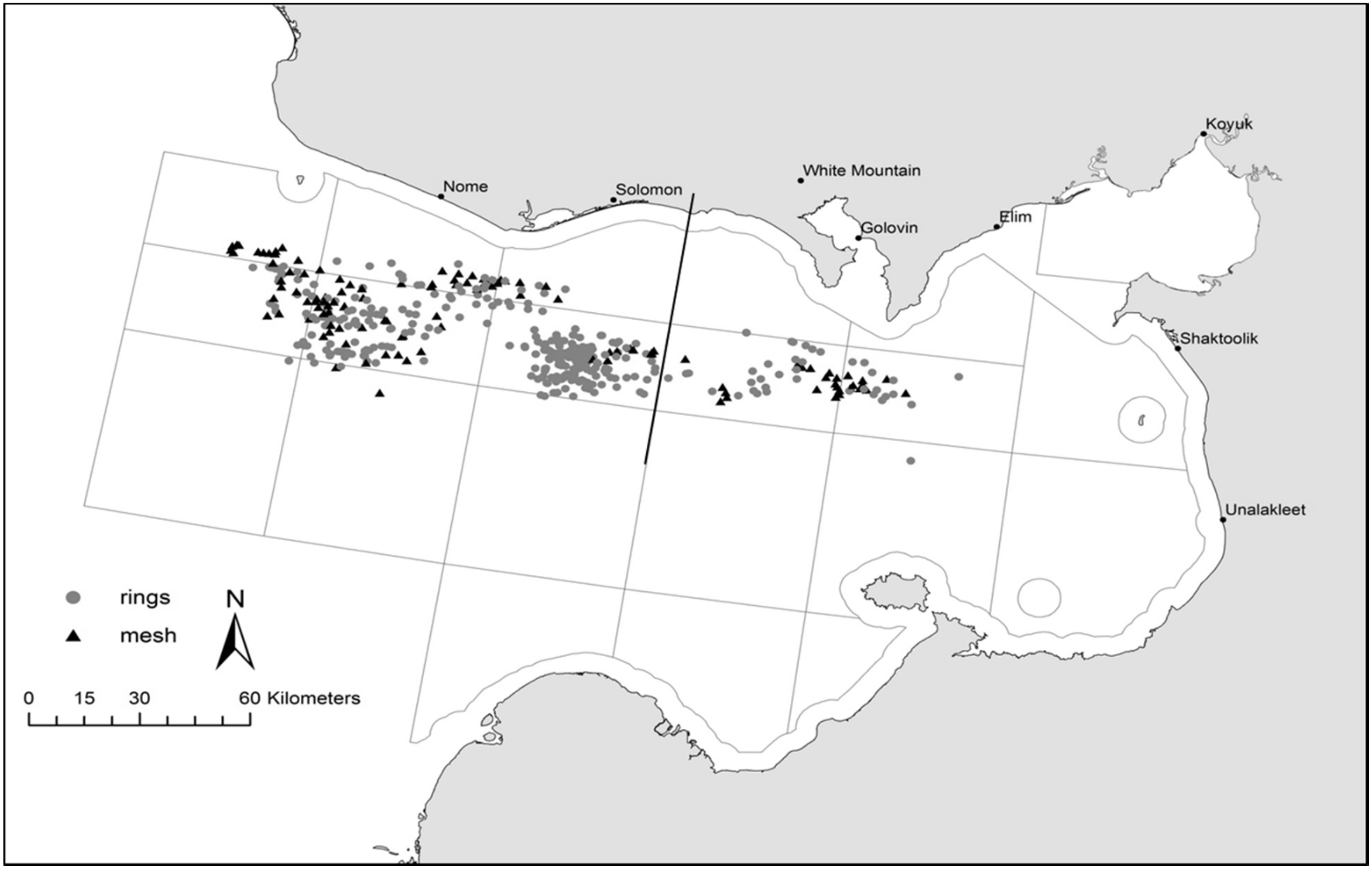

Figure 22.–Observer pot locations by escape mechanism, Norton Sound, AK.

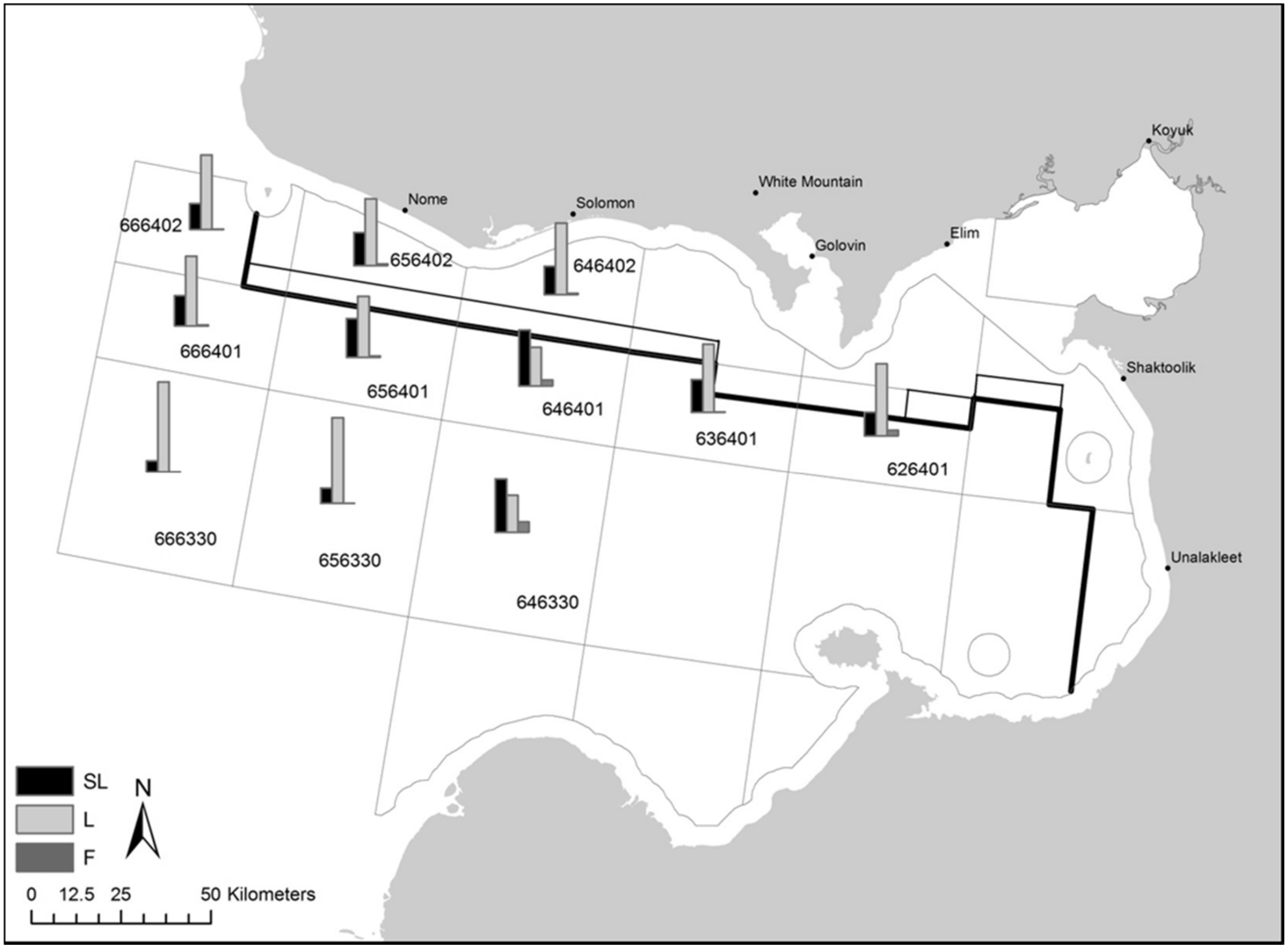

Figure 23.–Proportion by length class of red king crab captured in observer pots in each statistical area, Norton Sound, AK.

Note: Sublegal (SL), legal (L), and female (F). Also the heavy black line is the existing closure line whereas the thinner black line is a reduced closure area in 2013; harvest within statistical areas 656402 and 646402 came from that small portion in each statistical area opened during the 2013 season.

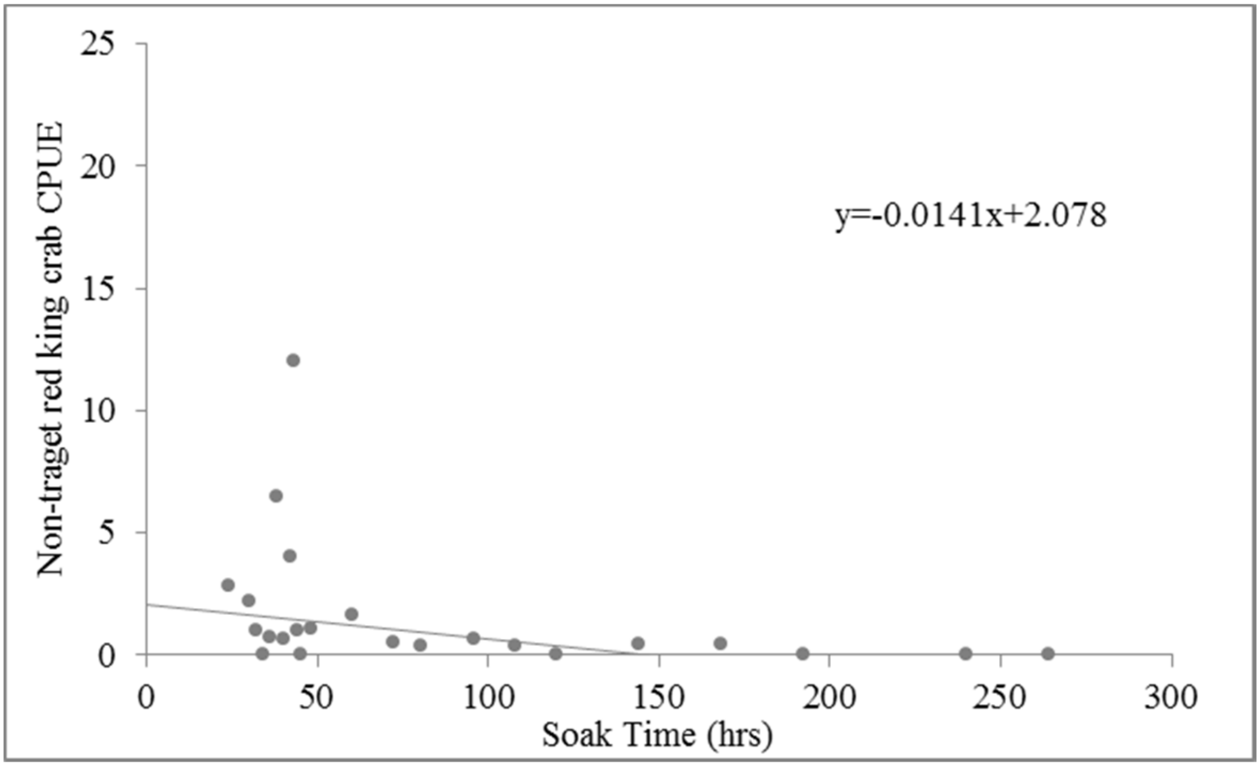

Figure 24.–Relationship between soak time and catch per unit effort (CPUE) of sublegal red king crab, Norton Sound, AK.

APPENDIX

Appendix A1.–Summary of red king crab composition by length class in pots along the 5 and 10 mile transects.

	5 mile transect			10 mile transect		
Pot #	Legal	Sublegal	Female	Legal	Sublegal	Female
1	83	174	6	62	144	11
2	97	202	5	108	195	31
3	86	176	4	76	191	28
4	93	217	8	95	186	18
5	87	200	2	81	162	5
6	106	240	6	94	192	16
7	89	200	10	65	203	32
8	111	197	10	65	201	24
9	119	201	0	65	225	25
10	143	209	2	61	144	28
11	111	141	9	73	144	18
12	87	109	7	60	88	9
13	65	51	3	57	67	5
14	74	83	4	67	65	3
15	65	66	2	76	67	5
16	56	87	4	88	77	10
17	70	88	2	96	103	5
18	69	102	3	119	106	3
19	71	119	5	84	68	7
20	44	100	7	89	117	8
21	61	141	6	127	124	11
22	74	91	6	100	139	11
23	82	91	7	107	176	27
24	53	123	14	103	156	26
25	74	120	5	81	162	23
26	96	182	28	116	178	14
27	77	207	27	113	156	13
28	81	228	36	101	156	17
29	68	74	4	115	209	21
30	72	89	10	90	161	16
31	49	40	3	81	110	1
32	108	50	2	56	73	10
33	101	40	0	62	87	1
34	104	60	0	81	105	11
35	84	51	0	70	141	10
36	88	94	2	65	110	2
37	78	114	9	57	103	9
38	56	50	10	64	98	4
39	83	79	3	70	65	2
40	102	96	8	66	62	2
41	132	84	3	75	56	2
42	87	90	18	97	70	5
43	110	89	24	114	73	4
44	97	50	8	88	83	2
45	61	43	8	116	114	28