Fishery Data Series No. YY-XX

DRAFT: A Bottom Trawl Survey for Tanner Crab in Kachemak Bay, 2017

by

Wyatt J. Rhea-Fournier,

Mike Byerly,

And

Carol Kerkvliet

A draft version of this report is being submitted for the March 8–11, 2020 Alaska Board of Fisheries meeting. The final report will be provided to the Board if it is published prior to the meeting start date.

Month Year

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

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. YY-XX

DRAFT: A BOTTOM TRAWL SURVEY FOR TANNER CRAB IN KACHEMAK BAY, 2017

by
Wyatt J. Rhea-Fournier and Mike Byerly
Alaska Department of Fish and Game, Division of Commercial Fisheries, Homer
and
Carol Kerkvliet
Alaska Department of Fish and Game, Division of Sport Fisheries, Homer

A draft version of this report is being submitted for the March 8–11, 2020 Alaska Board of Fisheries meeting. The final report will be provided to the Board if it is published prior to the meeting start date.

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

Month 2020

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

Wyatt J. Rhea-Fournier and Mike Byerly
Alaska Department of Fish and Game, Division of Commercial Fisheries,
3298 Douglas Place, Homer, AK 99603, USA,
and
Carol Kerkvliet
Alaska Department of Fish and Game, Division of Sport Fisheries,
3298 Douglas Place, Homer, AK 99603, USA

This document should be cited as follows:
Wyatt J. Rhea-Fournier, M. Byerly, and C. Kerkvliet. 2020. A Bottom Trawl Survey for Tanner Crab in Kachemak Bay, 2017. Alaska Department of Fish and Game, Fishery Data Series No. YY-XX, Anchorage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

A bottom trawl survey was conducted from August 29 to September 6, 2017 to estimate density and infer abundance of Tanner crab *Chionoecetes bairdi* in Kachemak Bay within the Southern District of the Cook Inlet Area. The survey was conducted aboard ADF&G's research vessel *Pandalus* using a 400-mesh Eastern otter trawl (large-mesh trawl). The survey caught 1,481 male Tanner crab of which 137 (9%) were of legal size (114 mm carapace width or greater) to produce a mean CPUE of 10.13 crab/nmi (CV = 0.52) and yielded an abundance estimate of 124,965 legal crab. Legal male Tanner crab were caught at 11 of the 38 stations with 90% of the total legal males caught at only 5 stations. The survey caught 1,350 female Tanner crab of which 348 (26%) were mature to produce a mean CPUE of 24.08 crab/nmi (CV = 0.50) and yielded an abundance estimate of 297,126 mature crab. Abundance estimates of legal male and mature female Tanner crab were well below the long-term average of the survey time series.

Key words: Tanner crab, trawl survey, Cook Inlet, Kachemak Bay, Southern District.

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) Division of Commercial Fisheries (DCF) and Division of Sport Fisheries (DSF) have the responsibility to sustainably manage Tanner crab *Chionoecetes bairdi* fisheries in the Cook Inlet Area (CIA). Tanner crab fisheries in the CIA are managed within 6 Districts of Registration Area H (Figure 1) and have historically been composed of commercial, subsistence, sport, and personal use fisheries. Commercial fishing for Tanner crab in the CIA began in 1968, with most of the harvest occurring in the Southern District (includes Kachemak Bay), Kamishak District, and Barren Islands District over the history of these fisheries (Rumble et al. 2014). Prior to 1989, the noncommercial Tanner crab fisheries were open all year. In 1989 and 1990, the commercial and noncommercial Tanner crab fisheries were closed in CIA for conservation reasons. The commercial fishery opened for the 1991–1994 seasons in the Southern District and for the 1991–1992 seasons in the Kamishak and Barren Islands districts with relatively low harvest. All commercial Tanner crab fisheries have been closed in CIA since 1995. Noncommercial fisheries in the CIA opened from 1991 to 2002, closed from 2003 to 2007, opened from 2008 to 2010, closed early in 2011 by Emergency Order (Kerkvliet et al. 2016) and reopened again in 2017.

Fishery-independent surveys have been the primary means to assess the population status of CIA Tanner crab. ADF&G conducted annual pot surveys for Tanner crab in Kachemak Bay and Kamishak Bay from 1974 to 1990 (Davis 1981; Kimker 1991a). These surveys provided an index of abundance (catch per unit effort (CPUE)) relative to that of the commercial fishery, were used to estimate the relative stock condition, and were used to set guideline harvest levels for commercial and noncommercial fisheries. In 1990, trawl surveys were initiated and conducted concurrent with the pot surveys (Kimker 1991b) and, since 1992, has been the sole survey method (Bechtol 1998; Goldman et al. 2018). The switch from pot to trawl surveys occurred because 1) abundance could be estimated with a trawl using area swept methods, 2) a trawl was considered less size selective than pots, and 3) a trawl is less susceptible to gear saturation (Bechtol et al. 2002). At the time of this method change, trawl surveys were also used by the National Marine Fisheries Service (NMFS) in the Bering Sea, and by ADF&G Westward Region, to determine stock abundance levels and annual harvests of Tanner crab (Jackson 1990). Data from CIA trawl surveys are used to develop Tanner crab abundance estimates, monitor population trends, and set guideline harvest levels for commercial and noncommercial fisheries under the current Tanner crab harvest strategy (5 AAC 35.408; Rumble et al. 2014).

DCF conducted a large-mesh bottom trawl survey in Kachemak Bay annually from 1990 to 2013, except in 2010, and in Kamishak Bay annually from 1990 to 2007, and in 2010 and 2012. The

DCF-funded bottom trawl survey in Kamishak Bay was discontinued after 2012 and the Kachemak Bay was discontinued after 2013 due to budgetary reasons. In 2017, after receiving funding through DSF, DSF and DCF jointly developed an operational plan (Goldman et al. 2017) to reestablish the large-mesh bottom trawl survey in Kachemak Bay.

The extents of the Kachemak Bay trawl survey area are based on the historical pot survey area. The survey design has evolved over time with modifications to the survey area extents, number of stations, station size, and trawl tow length occurring in 1992, 2008, and 2011 (Table 1; Goldman et al. 2018). Modifications were made after reviewing ADF&G staff feedback with the following objectives: 1) increasing sampling density, 2) maintaining spatial continuity with previous station design and tow locations, and 3) minimizing variation in station size. Untrawlable habitat areas were excluded due to subsea communication cable corridors and steep areas where the slope was calculated as greater than 5 degrees.

Management of Tanner crab commercial fisheries in the CIA, defined as Registration Area H (5 AAC 35.400), has changed significantly over time. In 1990, the Alaska Board of Fisheries (BOF) adopted, as findings, the *Policy on King and Tanner Crab Resource Management* and later incorporated into regulation as 5 AAC 35.080. This regulation requires an annual harvest strategy be established for every Tanner crab stock in Alaska, consistent with the policy. If adequate data are available, ADF&G shall establish a threshold level of abundance for each stock and may not allow commercial fishing on any stock that is below threshold. This regulation also states that Guideline Harvest Levels (GHLs) may be determined using data from estimates of exploitable biomass, recruitment, reproductive potential, and acceptable biological catch, as well as historical fishery performance and other considerations. Additionally, the regulation requires that ADF&G may not change established harvest strategies without BOF review. Noncommercial harvest was monitored using harvest estimates generated from the DSF Statewide Harvest Survey beginning in 1991 and then through a permit that was implemented in 1996.

In 2002, the BOF adopted 5 AAC 35.408, the *Registration Area H Tanner crab harvest strategy* that outlines the minimum abundance thresholds for the commercial and noncommercial fisheries based on trawl survey abundance estimates. The minimum abundance threshold of legal male Tanner crab was set at 500,000 crab for the commercial fishery to open in the Southern District of the CIA. This regulation stated that the combined commercial and noncommercial fisheries' GHL may not exceed 15 percent when the most recent abundance estimate was between 500,000 and 1,000,000 legal male Tanner crab. The combined GHL may not exceed 25 percent for the combined fisheries when the most recent abundance estimate is more than 1,000,000 legal male crab. In the absence of a commercial fishery, noncommercial fisheries in the Southern District are allowed if the recent 3-year average abundance estimate is at least 100,000 legal male Tanner crab. The GHL for the noncommercial fisheries is not to exceed 10 percent of the recent 3-year average legal male stock abundance and the noncommercial fisheries could not open in the CIA if the abundance estimate was below 50,000 legal crab in any given year. Implementation of the *Registration Area H Tanner crab harvest strategy* resulted in the continued closure of all commercial fisheries and periodic closures of noncommercial fisheries due to low abundance estimates of legal crab. With the discontinuation of the Kachemak Bay trawl survey after 2013, Southern District commercial and noncommercial fisheries were unable to open due to provisions in the harvest strategy that require an abundance estimate.

In addition to the Area H Tanner crab harvest strategy, the noncommercial fisheries for Tanner crab in the CIA have been managed through multiple regulations with similar language for the

subsistence (5 AAC 02.307 and 5 AAC 02.325), sport (5 AAC 58.022 and 5 AAC 58.035), and personal use fisheries (5 AAC 77.509 and 5 AAC 77.516). These regulations have been refined over time and currently state that when thresholds are met, Tanner crab may be harvested with a daily bag and possession limit of 5 legal sized male crab using no more than 2 pots per person and a maximum of 2 pots per vessel when abundances are above threshold.

Significant changes to the noncommercial regulations occurred at the March 2017 BOF meeting. The personal use fishery in the CIA was eliminated by repealing 5 AAC 77.516. Amendments to the Area H harvest strategy (detailed in 5 AAC 35.408(d)) allowed limited noncommercial fisheries to occur in the absence of a trawl survey or if abundance estimates are less than the thresholds in regulation. Noncommercial regulations were amended (5 AAC 02.325 and 5 AAC 58.022) to allow limited noncommercial fisheries when thresholds are not met or in the absence of a trawl survey, with a shortened season, a reduced bag and possession limit of 3 legal male Tanner crab, no more than 1 pot per person, and a maximum of 1 pot per vessel.

The minimum legal size for male Tanner crab was reduced to 4.5 in (114 mm) carapace width (CW) including spines from the previous legal size of 5.5 in (140 mm) at the 2017 BOF meeting (5 AAC 35.420). This was the first change to the legal size in the CIA since regulations were adopted at the 1976 BOF meeting (Donaldson and Donaldson 1992) as the previous minimum legal size of 140 mm had been aligned with the statewide size limit (5 AAC 35.060). Male Tanner crab were believed to be sexually mature at 110–115 mm CW and thus the legal size of 140 mm would allow males to be sexually mature and potentially reproduce for at least 1 year and up to 2 years before being available to harvest[1]. It was assumed that male Tanner crab exhibited indeterminate growth, growing via a succession of molts throughout their life, similar to other commercially important shellfish species such as Dungeness crab *Cancer magister* (Wainwright and Armstrong 1993) and red king crab *Paralithodes camtschaticus* (Zhou et al. 1998).

Maturity in members of the genus *Chionoecetes* often refers to crab in the "large-clawed" (LC) morphotype stage in contrast to crab in the "small-clawed" (SC) stage. The distinction between the LC and SC stage is based on the ratio of chela height (CH) to CW (Somerton 1980; Conan and Comeau 1986). Male Tanner crab utilize the LC for reproduction by selecting female partners and grasping them prior to copulating (Brown and Powell 1972). Studies have shown that SC Tanner crab have viable sperm (Stevens et al. 1993; Paul and Paul 1996) and thus the LC stage in Tanner crab represents functional or morphological maturity versus physiological maturity, which refers to the presence of spermatophores in the gonads (Brown and Powell 1972).

Another life history strategy of crab is that of determinate growth, where crab cease to molt after maturity, a stage that is referred to as the terminal molt (Conan and Comeau, 1986; Hartnoll et al. 1993). The occurrence of a terminal molt at morphological maturity in the genus *Chionoecetes* has been introduced and observed in laboratory studies (Conan and Comeau 1986), refuted in laboratory and field observations (Donaldson and Johnson 1988; Dawe et al. 1991; Paul and Paul 1995), and further debated (Conan et al. 1988). Conclusions refuting terminal molt were made following observations of molting after achievement of morphological maturity (LC) and modeling that indicated it was unlikely that the largest SC crab could grow into the largest LC crab in a single molt (Donaldson et al. 1981). Evidence of a terminal molt in Tanner crab at

[1] ADF&G (Alaska Department of Fish and Game). 1978. The establishment of a minimum size for the Tanner crab, *Chionoecetes bairdi* based on the growth per molt and reproductive biology to the Alaska Board of Fisheries. Division of Commercial Fisheries (unpublished report), Juneau.

morphological maturity (LC), as indicated by low levels of circulating molting hormones (Tamone et al. 2007), is now generally accepted, although observations from this pivotal study were on a small, secluded stock of crab and the authors acknowledged that a very small proportion of LC Tanner crab may molt again.

The acceptance of a terminal molt at the onset of morphological maturation and recent observations from Kachemak Bay trawl surveys suggested that currently, only a small proportion of male Tanner crab would reach the historical legal size of 140 mm in the CIA and thus a reduction of the legal size was proposed (ADF&G 2017). The new legal size was set at the size at which approximately 50% of the males had reached morphological maturity (CW_{50}) which was estimated through analysis of CH and CW from new shell male Tanner crab caught in the Kachemak bay trawl survey[2]. All available data (2007 to 2009 and 2011 to 2013) was pooled to estimate a CW_{50} at 112 mm (4.4 in). The legal size proposed to the 2017 BOF was rounded to 114 mm (4.5 in) for the entire CIA to ease in measuring and identifying legal crab for the public, provide consistency between districts, and aid enforcement in the noncommercial fishery.

Although there is a general acceptance by ADF&G of a terminal molt at morphological maturity for Tanner crab, the CIA is the only registration area in the state of Alaska that has a legal size at approximately the size of CW_{50}. In Southeast Alaska, mature males defined in stock assessments are 109 mm or greater and the legal size remains at 140 mm (5 AAC 35.113). The Kodiak, Chignik, South Peninsula, and Eastern Aleutian districts have a similar harvest strategy where the size for "mature male abundance" is 114 mm or greater but the legal size remains at 140 mm (5 AAC 35.507, 5 AAC 35.509). The Bering Sea District harvest strategy defines "mature male crab" as 112 mm and 102 mm (5 AAC 35.508) but does not allow harvest until crab reach a size of 4.8 in (122 mm) and 4.4 in (112 mm) as stated in 5 AAC 35.520. The reduction of the legal male size in the CIA to the size at morphological maturity represents a unique management strategy that is not implemented on any other Tanner crab stocks managed by ADF&G.

The large-mesh bottom trawl survey in Kachemak Bay has provided an assessment of Tanner crab abundance and maturity that directly informs DCF and DSF management. Survey results apply directly to regulations that open and close commercial and noncommercial fisheries in the Southern District. This report summarizes the 2017 trawl survey and is part of a series designed to assess the Tanner crab stock in Kachemak Bay from 2017–2019.

OBJECTIVES

The 2017 Kachemak Bay survey objectives were:

PRIMARY OBJECTIVE

1. Estimate the relative abundance of legal male, sublegal male, juvenile female, and mature female Tanner crab in the survey area.

SECONDARY OBJECTIVE

1. Estimate carapace width of male Tanner crab at 50% morphological maturity.

[2] Jie Zheng, ADF&G Fisheries Scientist, to Ken Goldman, ADF&G Fisheries Biologist dated November 17, 2016, unpublished (Analysis of Harvest Strategy and Legal Size for Cook Inlet Tanner Crab). Unpublished document obtained from Ken Goldman, ADF&G Fisheries Biologist, Homer.

METHODS

SURVEY DESIGN

The current survey design consists of 40 core stations spread across Kachemak Bay with respect to bathymetry and historical Tanner crab distribution (Figure 2). The trawl paths are selected within each grid station by the vessel skipper where it appears a successful tow can be made. Target tow length is 0.5 nmi with an average tow speed of 2.5 nmi per hour

The 2017 survey was conducted aboard the ADF&G research vessel *Pandalus* using a 400-mesh Eastern otter trawl with a 23.8 m headrope and a 29.9 m footrope. Mesh sizes were 10.2 cm in the wings and body, 8.9 cm in the intermediate, and 3.3 cm in the codend liner. The otter trawl was fished with 363 kg Nor'Eastern Astoria V trawl doors measuring 1.5 by 1.8 m. The net was equipped with a bottom contact sensor to measure time the net fished on bottom and Netmind Trawl Mensuration System sensors which provided real-time data on trawl performance. The vessel skipper monitored the sensors to determine how the net was performing so that adjustments could be made to ensure the trawl was fishing effectively and avoid net damage. In 2017, the trawl survey was conducted from August 29 to September 6, making it just the fourth time since the trawl survey began in 1990 that it has been conducted in September (Table 1).

TANNER CRAB CATEGORY DEFINITIONS

Tanner crab were grouped into categories of legal or sublegal males and juvenile or mature females and by shell condition. The regulations adopted by the BOF in 2017 define legally harvestable male Tanner crab as 4.5 in (114 mm) or larger CW including spines. Biological CW (excluding spines) is recorded on all ADF&G stock assessment surveys and thus male categories are based on CW measurements slightly different than those defined in regulations. For the 2017 survey, the legal male Tanner crab category was defined as 114 mm biological CW or greater and sublegal male Tanner crab category was defined as less than 114 mm biological CW. Prior to 2017, the legal size for male Tanner crab was 5.5 in (140 mm) CW, including spines. For historical survey results, prior to 2017, the legal male Tanner crab category was defined as 140 mm biological CW or greater and sublegal male Tanner crab category was defined as less than 140 mm biological CW. Prior to 2017, results were reported for male recruit categories (Table 2) but due to the acceptance of the terminal molt and uncertainty in growth-per-molt estimates, these categories were not included in this report.

Shell condition and female Tanner crab maturity was assessed in accordance with standardized data collection methods (Jadamec at al. 1999). Shell condition was assessed for all sampled Tanner crab; soft-shell and new-shell crab were pooled into a single new-shell category and old-shell and very old-shell crab were pooled into a single old-shell category.

CATCH SAMPLING

Upon retrieval of the trawl, the codend was weighed to the nearest 0.5 kg with a 5,000 kg capacity hanging electronic scale. The catch was emptied into a checker bin and the codend was reweighed. The catch weight was calculated by subtracting the weight of the empty codend from the initial codend weight.

The first tier of the catch sampling was to remove the primary target species (Appendix A1) which included all Tanner crab except for those less than 70 mm biological CW which are treated as

secondary target species (Goldman et al. 2018). All primary target crab species were sorted by sex and placed into baskets and weighed to the nearest 0.01 kg on a motion-compensated digital platform scale. Biological data was collected from a maximum of 2 baskets of Tanner crab for each sex, including biological CW measured to the nearest 0.1mm and shell condition. Male Tanner crab had CH measurement (excluding spines) recorded from the right claw. All female Tanner crab were assessed for maturity, clutch fullness, and egg fullness. If there were more than 2 baskets of Tanner crab for each sex, the remaining crab were counted by sex. Other primary target species were sorted, weighed, and counted; biological data were collected based on protocols for each species (Goldman et al. 2018).

Once primary target species are removed the remaining whole catch was completely processed if it was smaller than 2 fish baskets, otherwise, a subsample was taken (Appendix B1). If the remaining catch was very large (filled the checker bin above the first row), 3 fish baskets of catch were removed for a subsample; otherwise, a 2-basket subsample was taken.

The remaining catch or subsample was sorted to species, or to the lowest taxonomic group, and to sex for secondary target Tanner crab (<70 mm) and then weighed separately. If a sample was less than 5 kg, it was weighed to the nearest 0.001 kg using a motion compensated bench scale. Otherwise, the sample was weighed on a motion compensated digital platform scale to the nearest 0.01 kg. All secondary target Tanner crab were then counted, CW measured to the nearest 0.1mm, and shell condition recorded. All male Tanner crab greater than 50 mm CW had CH measurement recorded. All other species were counted, and additional biological data were collected on secondary target species (Appendix A1).

DATA ANALYSIS AND ABUNDANCE ESTIMATES

Methods for data analysis and abundance estimates are identical to those described in Goldman et al. 2017 and Goldman et al. 2018, although this report provides additional details on abundance estimate calculations that were not included in previous reports.

The catch (c) for crab category (g) in sample tow (i) was calculated by:

$$c_{gi}=tcm_{gi}+tcu_i\left(\frac{tcm_{gi}}{tcm_i}\right)+scm_{gi}+\frac{(tw_i-t_i-s_i)sc_i}{s_i}\left(\frac{scm_{gi}}{scm_i}\right). \quad (1)$$

Where

sc = the count of secondary target subsampled crab,

tw = the total weight of the catch,

t = the weight of the primary target crab,

s = the weight of the subsample,

tcm = the count of primary target sampled crab that were measured,

tcu = the count of primary target sampled crab that were unmeasured, and

scm = the count of secondary target subsampled crab that were measured.

The Tanner crab abundance estimates were area-swept calculations (Gunderson 1993; Rohlf and Sokal 1995). Mean catch per nautical mile ($\bar{c}$) by category groups (g) of Tanner crab, variance ($var(\bar{c}_g)$), and 95% confidence interval (CI) were calculated as follows:

$$\bar{c}_g = \frac{\sum_{i=1}^{n} c_{gi}}{n} \quad , \tag{2}$$

$$s^2_{\bar{c}_g} = \frac{1}{n\text{-}1} \sum_{i=1}^{n} \left(\frac{c_{gi}}{l_i} \text{-} \bar{c}_g \right)^2 , \tag{3}$$

$$var(\bar{c}_g) = \left(\frac{N\text{-}n}{N} \right) \frac{s^2_{\bar{c}_g}}{n} \quad , \tag{4}$$

and

$$\text{CI} = \bar{c}_g \pm t_{n\text{-}1} \sqrt{var(\bar{c}_g)} \quad . \tag{5}$$

Where

l = the distance towed in nautical miles,

n = the number of standardized 0.5 nmi tows, and

N = the number of total possible tows in the survey area (total survey area / area of a standardized tow [i.e. 0.5 nmi x (40'/6076')]).

An estimate of the surveyed population abundance ($\hat{P}$) for each group (g) was calculated by expanding $\bar{c}_g$ over the total expanded surveyed area as follows:

$$\hat{P}_g = \left(\frac{6{,}076}{40} \right) A \bar{c}_g \quad . \tag{6}$$

Where

6,076 = the length, in feet, of a nautical mile,

40 = the estimated width of the trawl opening in feet, and

A = standardized survey area (81.23 nmi^2).

The variance of the surveyed population was estimated as follows:

$$var(\hat{P}_g) = \left(\frac{6{,}076}{40} A \right)^2 var(\bar{c}_g) \quad . \tag{7}$$

At stations where all male Tanner crab were not measured CW frequencies were expanded to the total catch using equation 1 where group equals CW, following Bakkala and Wakabayashi (1985). The data were then aggregated into incremental 5 mm CW size bins and $\bar{c}_g$ was calculated for each size bin using equation 2. The binned $\bar{c}_g$ were then standardized to 1 nmi. and plotted for all surveys (1990 to 2017) to visualize recruitment strength and how cohorts have progressed through the population.

SIZE AT MORPHOLOGICAL MATURITY

CW_{50} was estimated for each year data was collected (2007 to 2009, 2011 to 2013, and 2017). The ratio of CW to CH was calculated for each sampled crab and filtered for outliers by removing crab with ratios outside of the 99th percentile. Crab were then preliminarily assigned to LC or SC class based on a CH/CW ratio = 0.18 (Tomone et al. 2007). Linear discriminant analysis was then used to predict claw size classes using log transformed CH and CW across all years (Venables and Ripley 2002). Due to large differences in sample sizes among years and tows within some years, the data were subsampled prior to the analysis to reduce the influence of oversampling. The data were grouped into 5 mm CW bins and a sample of 10 crab were randomly selected without replacement from each bin by year and tow similar to the methods in Siddon and Bednarski (2010). Separate logistic regressions were fit for each year to explore variability in the shape of the maturity functions and temporal trends in CW_{50}.

A binomial generalized linear model was used to estimate morphological maturity at size (McCallagh and Nelder 1989). For each year, assuming crab individuals are random samples from the population, the probability (π_i) of crab (i) being mature (M_i) was expressed as:

$$logit(\pi_i)=\alpha+\beta \mathrm{CW}_i \ ,$$
$$M_i \sim \mathrm{Bern}(\pi_i) \ . \quad (8)$$

With CW_{50} calculated as:

$$\mathrm{CW}_{50}=\frac{-\alpha}{\beta} \ . \quad (9)$$

The bootstrap method was used to estimate the CW_{50} 95% CI following Roa et al. (1999).

RESULTS

SURVEY STATIONS

The 2017 Kachemak Bay trawl survey conducted successful tows at 38 of the 40 core stations (Table 1). Station 113 and station 115 were not fished due to time constraints (Table 3). All tows were 0.5 nmi except for station 127, which was approximately 0.2 nmi in length due to the trawl net getting hung up.

TANNER CRAB ABUNDANCE ESTIMATES AND DISTRIBUTION

The survey caught 1,481 male Tanner crab of which 137 (9%) were of legal size (CW ≥ 114 mm) to produce a mean CPUE of 10.13 crab/nmi (CV = 0.52) and yielded an abundance estimate of 124,965 legal crab (Table 4). The 2017 legal male abundance estimate was well below the historical average of 203,823 crab although it was substantially larger than the abundance estimates from the most recent survey from 2011 to 2013 when the legal size was 140 mm (Figure 3). The 2017 abundance estimate of sublegal male Tanner crab was 1,010,978 crab (Table 4), which is well below the historical average of approximately 2.3 million and substantially lower than the most recent surveys (Figure 4). The total male crab abundance estimate for 2017 of 1,135,943 crab was well below the historical average of 2,484,408 crab and was the fourth lowest in the time series (Table 4).

Male Tanner crab CW size frequencies have varied over time in the Kachemak Bay trawl survey with the 2017 survey observations differing from the size frequencies observed in the early 1990s

when there appeared to be a higher proportion of larger crab in the population (Figure 5). The decrease in numbers of smaller crab in 2017 relative to the most recent surveys, and to the rest of the time series, directly contributed to the lower abundance estimate of sublegal and total male crab.

The survey caught 1,350 female Tanner crab of which 348 (26%) were mature to produce a mean CPUE of 24.08 crab/nmi (CV = 0.50) and yielded an abundance estimate of 297,126 mature crab (Table 5). The abundance estimate for mature female crab was well below the historical average of 651,213 crab and relatively low compared to the most recent surveys (Figure 3). The 2017 estimate for juvenile female crab was 839,202 (Table 5), which is well below the historical average of approximately 1.2 million crab and below the most recent surveys (Figure 4). The total female crab abundance estimate for 2017 of 1,136,328 was below the average for the time series of 1,880,460 crab.

Legal male Tanner crab distribution was patchy, with catches at only 11 stations and with 90% of the total legal males caught at only 5 stations (Table 3). Legal male crab density was the highest at stations associated with the deepwater trench (Figure 2) in the area near the Homer spit (Figure 6). Legal male Tanner crab were only caught at 1 station (125) in the inner bay inside of the Homer spit and there were only a few catches in the western area adjacent to Cook Inlet (stations 116–125 and 132–141). Sublegal male crab were more widely distributed throughout the survey area, including the inner bay (Figure 7). The highest densities of sublegal male crab were at the same stations as the highest densities of legal crab (Table 3) but were more widely distributed and were caught at 32 stations. New shell crab represented 80% of the legal male abundance and 99% of the sublegal abundance (Table 6).

Mature female crab distribution was also patchy, with catches at only 16 stations and with just under 80% of the total mature females caught at only 4 stations (Table 3). The highest density of mature female crabs was similar to that of male crabs at stations associated with the deepwater trench (Figure 8). Juvenile female Tanner crab catches were more widely distributed and captured at 33 stations (Table 3) and again had the highest densities at the same stations as mature female and male crab in the deepwater trench (Figure 9).

SIZE AT MORPHOLOGICAL MATURITY

CH and CW data collected from 10,368 new shell male Tanner crab (CW ≥ 50mm) were analyzed to model CW at morphological maturity. The linear discriminant analysis produced clear separation between the SC and LC male crab (Figure 10) with morphological maturity defined as the presence of LC. Estimated CW_{50} ranged from 120.27 mm (CI = 117.74 to 122.84 mm) in 2008 to 96.71 mm (CI = 95.34 to 98.18 mm) in 2012 (Table 7). The 2017 CW_{50} estimate was 100.48 (CI = 98.26 to 102.65) and was the second smallest CW estimate for the available data. CW_{50} estimates were larger than the current legal size in the earliest years and smaller than the legal size in later years though there was substantial intra- and inter-annual variability (Figure 11). Variability was also observed in the steepness and shape of the maturity curves for years where data was available (Figure 12). A multivariable binomial model with year and the interaction of CW and year, resulted in a significant ($p < 0.05$) year and interaction effect indicating morphological maturity varied by year and as a function of CW and year (Table 8).

DISCUSSION

Survey results from 2017 yielded abundance estimates for legal male crab that were well below the long-term average for the trawl survey time series even though the new, reduced legal size category includes additional, smaller size classes of crab. The trend in legal male Tanner crab abundance estimates from the Kachemak Bay trawl survey has been declining since the peak in 1992 with some interannual variability. It is important to note that CIA Tanner crab commercial harvest and associated abundance estimates prior to the initiation of the trawl survey also had a declining trend (Table 7 in Bechtol 2002; Zheng unpublished[2]) indicating a depressed stock and that that commercial and noncommercial fisheries were closed in 1989 and 1990 for conservation concerns. Sublegal and total male crab abundance estimates and mature, juvenile, and total female crab abundances estimates were also lower than the long-term average. The low abundance estimates of legal crab and the lack of larger crab in the Kachemak Bay trawl survey indicates that this stock has not fully recovered to a level observed in the early 1990s.

The acceptance that male Tanner crab have a terminal molt once morphological maturity is achieved is reason to change the reporting categories for abundance estimates generated by the Kachemak Bay trawl survey. Historically, male abundance estimates were categorized into a series of recruitment classes based on observed CW relative to the legal size of 140 mm to produce prerecruit, recruit, and postrecruit size classes. In accordance with the terminal molt theory, a prerecruit class would need to be defined as a crab with SC that is within 1 molt from achieving legal size. Any LC crab smaller than the legal size would never recruit to the fishery and thus morphological maturity would need to be incorporated into the categorization. If male Tanner crab do not continue to molt after morphological maturity, then the postrecruit category would not be relevant as previously defined. Postrecruit could be defined as crab that had achieved their molt to maturity the year prior and would need to be categorized as LC crab with very-old shell condition. The historical prerecruit categories were categorized using an equation from an older study (Paul and Paul 1996) which may need to be reassessed to consider its application to current Kachemak Bay Tanner crab survey catches. The CW growth per molt estimate from this study was developed by analyzing crab captured from 1980 to 1995. This older study that tracks growth and not age may not be suitable for describing current recruitment of Tanner crab when considering environmental changes over time that can influence growth. Without the inclusion of morphological maturity, very-old shell condition, and an updated growth-per-molt model, there is not enough information to accurately describe the historically reported recruitment classes. Going forward, the Kachemak Bay male Tanner crab abundances will be estimated for 2 categories (legal and sublegal) from historical and current surveys until a mechanism is established to define prerecruit and postrecruit classes.

There was a decrease in numbers of smaller sized male crab observed in 2017, compared to most recent surveys, yet sublegal crab that were observed near the legal size that could recruit into the fishery, at the new legal size of 114 mm, in 2018 (Figure 5). The trawl survey has observed cohorts through the years with the largest recruitment pulse recorded in 2011 and continuing through 2013 (Goldman et al. 2018). Observations of this cohort recruiting to legal, harvestable size is limited due to an absence of trawl surveys from 2014 to 2016 and thus it is unknown if this cohort would have reached the historical legal size of 140 mm like the cohort that recruited in 2006.

The historical trend for mature female crab has been highly variable but abundance estimates have been greater than legal male abundance estimates for all but 3 years in the time series. The

historical trends of legal male and mature female crab show very little correlation (Figure 3), unlike sublegal male and juvenile female crab that appear to have similar abundance trends including a more recent peak for both in 2012 (Figure 4). This may suggest similar ontogenetic movement patterns and habitat preferences across sexes at young age classes that diverge after the onset of maturity.

The highest density of legal male and female Tanner crab observed in the 2017 survey was from the deep trench within Kachemak Bay which was similar to previous surveys (Goldman et al. 2018). Current methodology calculates the average CPUE and extrapolates over the entire surveyed area, regardless of habitat depth, to produce an abundance estimate. The 2020 Regional Operation Plan for the Kachemak Bay trawl survey will outline methods for future Fisheries Data Series reports to delineate habitat by deep and shallow stratifications for abundance estimates.

Analysis of annual CW_{50} for new shell male Tanner crab indicated that earlier observations were larger than the current legal size and later observations smaller than the current legal size, though there was substantial annual variability. While there appears to be a decreasing trend within the available data, more observations are necessary to determine if this trend is significant. Variability in Tanner crab CW_{50} has been observed annually in the Bering Sea District (Zheng and Pengilly 2011) over a 16-year period that contained even larger swings in annual CW_{50} estimates. The new legal size of male Tanner crab in the CIA was based on a CW_{50} that was developed from all available data that was pooled for the analysis. To determine if this is an appropriate CW_{50} for the Kachemak Bay Tanner crab stock, the trawl survey will continue to collect maturity data to develop a CW_{50} model that incorporates annual variability. Maturity analysis was conducted on new shell crab only, and thus the annual CW_{50} estimate only applies to those crab that have recently molted, which means that the estimated annual CW_{50} reported does not apply to the entire population of Tanner crab in Kachemak Bay.

The decrease in larger size classes of male Tanner crab in the Kachemak Bay trawl survey was, in part, the justification for decreasing the legal size in order to provide additional opportunity for harvest. The size of the terminal molt at morphological maturity (CW_{50}) in the CIA is very similar to other Tanner stocks in the Gulf of Alaska, yet the CIA is the only area where the legal size has been reduced. The legal size in the CIA is now the smallest of any Gulf of Alaska stock and is the only stock in the state of Alaska where the legal size is set at approximately CW_{50}. Further justification for lowering the legal size was that a fishery on crab with 140 mm or greater CW (historical legal size for the CIA and current legal size in Southeast Alaska and Kodiak area) results in only the largest male crab being targeted in a fishery, which could potentially lower the overall yield and hurt the population genetically over the long-term (Zheng 2008). This may be a sustainable harvest strategy in districts where there is a substantial number of larger crab in the stock, such as in Kodiak and Southeast Alaska, where a harvestable surplus is available on crab 140 mm and larger. The reduced legal size in the CIA also has the potential to decrease discard mortality as smaller, previously sublegal crab are now retained. Finally, by distributing the legal harvest over more sizes of male crab, fishing mortality on the largest crab may be reduced which could keep more of the larger, mature crab on the grounds to participate in reproduction. Harvest strategies that include a legal size at approximately CW_{50} are recommended to include a mechanism to open and close the fishery based on the abundance estimate of crab that are larger than CW_{50} (Zheng unpublished[2]; Goldman et al. 2018)

The new legal size in the CIA at approximately CW_{50}, where the probability of a male crab reaching morphological maturity is 50%, allows harvest of male crab that have not yet copulated

due to the absence of a LC. This is the reason that Tanner crab stocks in the Gulf of Alaska have been historically harvested at a size that is at least 1 molt larger than the estimated CW_{50}. Due to harvest at approximately CW_{50} in the CIA, it is important for the annual trawl survey to continue analyzing maturity trends. If the trend in the size at maturity eventually increased it will be very important to continue annual fishery-independent survey observations of CW_{50} relative to the legal size to avoid recruitment overfishing and to monitor the proportion of SC male crab in the legally harvestable size range.

The Kachemak Bay trawl survey provides a continuous index of abundance, uses a consistent gear fished in a standardized manner and, as such, should effectively detect changes in the relative abundance of most cohorts of Tanner crab that reside within the survey area. ADF&G will conduct trawl surveys in 2018 and 2019 to monitor both male and female Tanner crab abundance with the resulting data supporting the prosecution and management of the current noncommercial fishery in a sustainable manner.

ACKNOWLEDGEMENTS

Thanks to Ted Jewell and boat officer David Knight of the research vessel *Pandalus* for being proficient and diligent in gear setting and retrieval. We also thank ADF&G staff for their help, ideas, and dedication to this work: Josh Mumm, Elisa Russ, Chris Russ, Jan Rumble, Michael Booz, and Joseph Loboy.

REFERENCES CITED

ADF&G (Alaska Department of Fish and Game). 2017. Staff comments on statewide (except Southeast and Yakutat) king and Tanner crab and supplemental issues. Alaska Department of Fish and Game, Regional Information Report 4K17-01, Kodiak.

Bakkala, R. G., and K. Wakabayashi. 1985. Results of cooperative U.S.-Japan groundfish investigations in the Bering Sea during May-August 1979. International North Pacific Fisheries Commission Bulletin 44.

Bechtol, W. R. 1998. A synopsis of life history and assessment of Cook Inlet rockfish. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A98-40, Anchorage.

Bechtol, W. R., C. E. Trowbridge, and N. Szarzi. 2002. Tanner and king crabs in the Cook Inlet Management Area: stock status and harvest strategies. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A02-07, Anchorage.

Brown, R. B., and G. C. Powell. 1972. Size at maturity in the male Alaskan Tanner crab, *Chionoecetes bairdi*, as determined by chela allometry, reproductive tract weights, and size of precopulatory males. Journal of the Fisheries Board of Canada 29(4): 423-427.

Conan, G. Y., and M. Comeau. 1986. Functional maturity and terminal molt of male snow crab, *Chionoecetes opilio*. Canadian Journal of Fisheries and Aquatic Sciences 43(9): 1710-1719.

Conan, G. Y., M. Comeau, M. Moriyasu, and R. Cormier. 1988. Reply to Donaldson and Johnson. Canadian Journal of Fisheries and Aquatic Sciences 45: 1501-1503.

Davis, A.S. 1981. King and Tanner Crab Studies, Cook Inlet. Commercial Fisheries Research and Development Act, Project No. 5-44-R-1. Alaska Department of Fish and Game, Juneau.

Dawe, E. G., D. M. Taylor, J. M. Hoenig, W. G. Warren, G. P. Ennis, R. G. Hooper, W. E. Donaldson, A. J. Paul, and J. M. Paul. 1991. A critical look at the idea of terminal molt in male snow crab (*Chionoecetes opilio*). Canadian Journal of Fisheries and Aquatic Sciences 48(11): 2266-2275.

Donaldson, W. E., R. T. Cooney, and J. R. Hilsinger. 1981. Growth, age and size at maturity of Tanner crab, *Chionoecetes bairdi* MJ Rathbun, in the northern Gulf of Alaska (Decapoda, Brachyura). Crustaceana 286-302.

Donaldson, W. E., and B. A. Johnson. 1988. Some remarks on "Functional maturity and terminal molt of male snow crab, *Chionoecetes opilio*. Canadian Journal of Fisheries and Aquatic Sciences 45: 1499-1501.

Donaldson, W. E., and W. K. Donaldson. 1992. A review of the history and justification for size limits in Alaskan king, Tanner, and snow crab fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries.

Goldman, K. J., C. Kerkvliet, M. Byerly, J. Mumm, X. Zhang, and S. Power. 2017. Operational plan: Bottom trawl surveys for Tanner crab and groundfishes for Kachemak Bay in the Southern District, 2017–2019. Alaska Department of Fish and Game, Regional Operation Plan ROP.CF.2A.2017.03, Anchorage.

Goldman, K. J., M. Byerly, J. Mumm, J. Rumble, and J. Zheng. 2018. Bottom Trawl Surveys for Tanner Crab in Lower Cook Inlet and Prince William Sound 1990–2015, with harvest strategy for Prince William Sound. Alaska Department of Fish and Game, Fishery Data Series No. Fishery Manuscript 18-02, Anchorage.

Gunderson, D. R. 1993. Surveys of fisheries resources. John Wiley & Sons, Inc., London.

Hartnoll, R. G., A. D. Bryant, and P. Gould. 1993. Size distribution in spider crab populations–spatial and temporal variation. Journal of Crustacean Biology 13(4): 647-655.

Jackson, D.R. 1990. A bottom trawl survey of crab and groundfish in the Kodiak Island and Alaska Peninsula Areas, June through September, 1989. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K90-22, Kodiak.

Jadamec, L. S., W. E. Donaldson, and P. Cullenberg. 1999. Biological field techniques for *Chionoecetes* crabs. University of Alaska Sea Grant College Program.

Kerkvliet, C. M., M. D. Booz, B. J. Failor, and T. Blackmon. 2016. Sport fisheries in the lower Cook Inlet management area, 2014-2016, with updates for 2013. Alaska Department of Fish and Game, Fishery Management Report No. 16-32, Anchorage.

Kimker, A. 1991a. A bottom trawl survey of crabs and groundfish in the Southern, Kamishak, and Barren Islands Districts of the Cook Inlet Management Area, July 6-17, 1990. Regional Information Report 2A90-13, Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.

Kimker, A. 1991b. Cook Inlet king and Tanner crab index of abundance survey, June 11-29, 1990. Regional Information Report 2A90-17, Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.

McCullagh, P., and J. A. Nelder. 1989. Generalized linear models. Chapman & Hall, London.

Paul, A. J., and J. M. Paul. 1995. Molting of functionally mature male *Chionoecetes bairdi* Rathbun (Decapoda: Majidae) and changes in carapace and chela measurements. Journal of Crustacean Biology, 15(4): 686-692.

Paul, A. J., and J. M. Paul. 1996. Male Tanner crab carapace widths at previous intermolt estimated from laboratory growth, Kachemak Bay, Alaska. Alaska Fishery Research Bulletin 3(2): 132-135.

Roa, R., B. Ernst, and F. Tapia. 1999. Estimation of size at sexual maturity: evaluation of analytical and resampling procedures. Fisheries. Bulletin. 97: 570-580.

Rohlf, F. J. and R. R. Sokal. 1995. Statistical tables. Macmillan.

Rumble, J., M. Wessel, E. Russ, K. J. Goldman, R. L. Gustafson, and C. Russ. 2014. Cook Inlet and Prince William Sound area management report for Tanner and king crab fisheries through 2013. Alaska Department of Fish and Game, Fishery Management Report No. 14-08, Anchorage.

Siddon, C.E. and J.A. Bednarski. 2010. Variation in size at maturity of Tanner crab in Southeastern Alaska, U.S.A. *In*: G.H. Kruse, G.L. Eckert, R.J. Foy, R.N. Lipcius, B. Sainte-Marie, D.L. Stram, and D. Woodby (eds.), Biology and Management of Exploited Crab Populations under Climate Change. Alaska Sea Grant, University of Alaska Fairbanks: 283-294.

Somerton, D.A. 1980. A computer technique for estimating the size of sexual maturity in crab. Canadian Journal of Fisheries and Aquatic Sciences 37(10): 1488-1494.

Stevens, B. G., W. E Donaldson, J. A. Haaga, and J. E. Munk. 1993. Morphometry and maturity of paired Tanner crab, *Chionoecetes bairdi*, from shallow-and deepwater environments. Canadian Journal of Fisheries and Aquatic Sciences 50(7): 1504-1516.

Tamone, S. L., S. J. Taggart, A. G. Andrews, J. Mondragon and J. K. Nielsen. 2007. The relationship between circulating ecdysteroids and chela allometry in male Tanner crab: Evidence for a terminal molt in the Genus *Chionoecetes*. Journal of Crustcea Biology 27: 635–642.

Venables, W. N. and B. D. Ripley. 2002. Modern Applied Statistics with S. Fourth edition. Springer, NY.

Wainwright, T.C. and D.A. Armstrong. 1993. Growth patterns in the Dungeness crab (*Cancer magister* Dana): synthesis of data and comparison of models. Journal of Crustacean Biology, 13(1): 36-50.

Zheng, J. 2008. Temporal changes in size at maturity and their implications for fisheries management for eastern Bering Sea Tanner crab. Journal of Northwest Atlantic Fishery Science 41: 137–149.

Zheng, J. and D. Pengilly. 2011. Overview of proposed harvest strategy and minimum size limits for Bering Sea district Tanner crab. Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services.

Zhou, S., T.C Shirley, and G.H Kruse. 1998. Feeding and growth of the red king crab *Paralithodes camtschaticus* under laboratory conditions. Journal of Crustacean Biology, 18(2): 337-345.

TABLES AND FIGURES

Table 1.–Chronology of the large-mesh, bottom trawl survey in Kachemak Bay, 1990–2017

Year	Dates	Research vessel	Headrope (ft)	Tow length (nmi)	Stations surveyed	
					Core	Total
1990	7/6 – 7/11	Pandalus	70	1	14	19
1991	7/17 – 7/31	Pandalus	70	1	15	20
1992	7/14 – 7/24	Pandalus	70	1	15	18
1993	7/6 – 7/14	Pandalus	70	1	16	20
1994	6/27 – 7/6	Pandalus	70	1	16	20
1995	7/5 – 7/10	Pandalus	70	1	16	20
1996	8/17 – 8/20	Pandalus	70	1	16	19
1997	6/26 – 7/1	Pandalus	70	1	16	23
1998	8/13 – 8/19	Pandalus	70	1	16	23
1999	7/19 – 7/23	Pandalus	70	1	16	20
2000	7/10 – 7/17	Pandalus	70 / 78	1	16	23
2001	5/29 – 6/4	Pandalus	70 / 78	1	16	22
2002	7/8 – 7/17	Pandalus	78	1	14	21
2003	7/1 – 7/9	Pandalus	78	1	16	23
2004	6/16 – 6/20	Pandalus	78	1	16	23
2005	6/27 – 7/1	Pandalus	78	1	15	22
2006	9/25 – 10/4	Pandalus	78	1	17	23
2007	9/10 – 9/17	Pandalus	78	1	16	23
2008	9/23 – 9/29	Pandalus	78	1	16	16
2009	5/18 – 5/22	Pandalus	78	1	15	16
2010	No survey					
2011	6/23 – 6/29	Solstice	78	0.5	37	37
2012	6/15 – 6/21	Solstice	78	0.5	37	37
2013	6/15 – 6/21	Solstice	78	0.5	37	38
2014	No survey					
2015	No survey					
2016	No survey					
2017	8/29 – 9/6	Pandalus	78	0.5	38	39

Table 2.–Male Tanner crab carapace width size categories by the current legal size and the historical legal size (recruit) for the Kachemak Bay trawl survey.

Current		Historical	
Size category	Carapace width (mm)	Size category	Carapace width (mm)
Sublegal	<114	Prerecruit 4	<70
Legal	≥114	Prerecruit 3	70 to <92
		Prerecruit 2	92 to <115
		Prerecruit 1	115 to <140
		Recruit	140 to <165
		Postrecruit	≥165

Note: Current = 2017 trawl survey. Historical = 1990–2013 trawl surveys.

Table 3.–Number of Tanner crab caught at each station in the 2017 Kachemak Bay trawl survey.

	Males			Females		
Station	Sublegal	Legal	Total	Juvenile	Mature	Total
101	59	0	59	31	1	32
102	107	0	107	22	0	22
103	20	0	20	4	0	4
104	2	0	2	3	0	3
105	5	0	5	5	0	5
106	8	0	8	2	0	2
107	28	0	28	13	2	15
108	6	0	6	12	0	12
109	10	0	10	5	0	5
110	8	0	8	4	0	4
111	8	0	8	5	3	8
112	4	0	4	0	1	1
113	ND	ND	ND	ND	ND	ND
114	2	0	2	2	1	3
115	ND	ND	ND	ND	ND	ND
116	12	0	12	6	7	13
117	6	2	8	4	1	5
118	3	0	3	2	0	2
119	166	1	167	99	5	104
120	21	0	21	23	0	23
121	2	0	2	2	1	3
122	7	0	7	8	0	8
123	0	0	0	0	0	0
124	4	7	11	0	10	10
125	234	33	267	111	17	128
126	60	1	61	65	72	137
127	143	38	180	192	76	268
128	329	21	350	290	123	413
129	27	0	27	30	0	30
130	24	22	46	24	17	41
131	16	0	16	16	0	16
132	11	1	12	11	0	11
133	0	1	1	1	0	1
134	0	0	0	0	6	6
135	4	0	4	5	0	5
136	4	11	15	0	4	4
137	3	0	3	4	0	4
138	1	0	1	1	0	1
140	0	0	0	0	0	0
141	0	0	0	1	0	1
Totals	1,344	137	1,481	1,003	347	1,350

Note: Legal males are defined as 114mm carapace width or greater. Stations 113 and 115 were not towed in 2017. ND = no data.

.

Table 4.–Male Tanner crab abundance estimates from Kachemak Bay trawl surveys, 1990–2017.

Year	Legal size (mm)	Sublegal		Legal		Total	
		Abundance	±CI	Abundance	±CI	Abundance	±CI
1990	140	2,326,212	940,070	388,422	403,617	2,714,634	1,145,882
1991	140	2,222,493	817,710	499,815	226,608	2,722,308	879,693
1992	140	1,719,710	621,618	1,055,855	734,287	2,775,565	1,097,301
1993	140	1,129,034	371,852	518,498	254,074	1,647,532	430,628
1994	140	813,905	437,350	193,199	106,304	1,007,104	451,486
1995	140	1,817,979	1,099,207	278,365	296,245	2,096,344	1,299,465
1996	140	1,355,042	1,144,620	101,322	69,836	1,456,364	1,174,485
1997	140	909,048	301,610	143,111	80,729	1,052,159	323,702
1998	140	565,279	261,034	205,808	190,004	771,087	373,615
1999	140	2,970,078	2,734,037	104,282	91,894	3,074,360	2,743,906
2000	140	1,738,494	768,749	82,374	72,974	1,820,868	754,144
2001	140	2,987,273	1,985,095	96,951	61,266	3,084,224	1,995,590
2002	140	4,013,716	2,093,524	88,010	69,895	4,101,726	2,098,934
2003	140	3,416,197	1,726,567	48,717	52,980	3,464,914	1,726,501
2004	140	3,512,354	1,821,768	110,930	75,834	3,623,284	1,875,763
2005	140	1,764,003	1,074,790	45,676	41,786	1,809,679	1,083,062
2006	140	1,642,729	1,761,725	214,520	278,492	1,857,249	1,827,892
2007	140	981,410	1,034,755	162,504	238,989	1,143,914	1,252,423
2008	140	1,160,697	726,507	103,535	130,587	1,264,232	784,561
2009	140	3,051,196	2,228,033	143,882	141,993	3,195,079	2,338,396
2010	140	ND	ND	ND	ND	ND	ND
2011	140	4,405,350	1,976,150	42,660	40,810	4,448,010	1,983,150
2012	140	4,810,302	1,792,101	21,408	20,993	4,831,710	1,795,663
2013	140	3,141,622	970,426	38,077	34,026	3,179,700	975,013
2014	140	ND	ND	ND	ND	ND	ND
2015	140	ND	ND	ND	ND	ND	ND
2016	140	ND	ND	ND	ND	ND	ND
2017	114	1,010,978	699,983	124,965	132,255	1,135,943	806,870

Note: CI is 95% confidence intervals. Trawl surveys were not conducted in 2010 and from 2014 to 2016. ND = no data.

Table 5.–Female Tanner crab abundance estimates from Kachemak Bay trawl surveys, 1990–2017.

	Juvenile		Mature		Total	
Year	Abundance	±CI	Abundance	±CI	Abundance	±CI
1990	986,132	435,566	437,762	471,302	1,423,894	597,299
1991	485,795	350,909	848,952	827,100	1,334,746	1,092,684
1992	287,743	188,991	748,755	908,911	1,036,498	914,538
1993	568,171	323,143	578,012	610,110	1,146,183	594,572
1994	643,345	524,200	384,757	329,104	1,028,103	697,829
1995	675,120	424,282	863,188	805,917	1,538,308	945,949
1996	223,512	145,814	506,237	533,304	729,750	589,474
1997	188,883	91,602	305,560	316,959	494,443	345,855
1998	399,268	303,830	78,481	155,168	477,749	320,493
1999	1,237,351	1,087,752	566,811	595,051	1,804,162	1,377,638
2000	692,520	549,354	250,751	301,589	943,271	592,957
2001	2,161,815	2,321,558	447,251	437,516	2,609,066	2,353,086
2002	2,750,107	1,524,651	435,209	410,903	3,185,316	1,718,798
2003	1,315,229	976,196	244,512	134,582	1,559,741	1,081,698
2004	1,244,052	618,088	1,888,886	2,164,265	3,132,939	2,526,689
2005	985,618	829,221	224,362	356,513	1,209,980	840,474
2006	937,529	1,319,050	29,068	36,427	966,597	1,325,638
2007	603,481	604,255	1,509,612	3,184,135	2,113,093	3,767,243
2008	567,254	339,559	229,603	310,934	796,856	403,518
2009	1,416,060	1,161,372	1,530,501	1,167,925	2,946,561	2,007,361
2010	ND	ND	ND	ND	ND	ND
2011	4,089,772	2,235,923	248,923	177,514	4,338,695	2,231,119
2012	4,638,687	2,187,999	662,728	451,871	5,301,416	2,526,810
2013	1,175,307	465,649	1,957,902	1,353,766	3,133,209	1,541,356
2014	ND	ND	ND	ND	ND	ND
2015	ND	ND	ND	ND	ND	ND
2016	ND	ND	ND	ND	ND	ND
2017	839,202	727,415	297,126	302,289	1,136,328	1,019,282

Note: CI is 95% confidence intervals. Trawl surveys were not conducted in 2010 and from 2014 to 2016. ND = no data.

Table 6.–Male Tanner crab new and old shell abundance estimates from Kachemak Bay trawl surveys, 1990–2017.

		Sublegal				Legal			
	Legal size	New shell		Old shell		New shell		Old shell	
Year	(mm)	Abundance	± CI	Abundance	± CI	Abundance	± CI	Abundance	± CI
1990	140	2,275,063	930,936	51,148	26,709	157,488	94,858	230,934	356,735
1991	140	2,080,141	796,190	142,352	102,986	304,971	189,754	194,843	163,297
1992	140	1,482,177	644,934	237,533	245,829	896,392	671,854	159,463	201,791
1993	140	1,010,361	393,502	118,673	94,360	319,292	152,317	199,206	212,542
1994	140	742,204	430,191	71,701	48,418	74,294	49,703	118,904	104,674
1995	140	1,759,364	1,096,564	58,615	39,202	195,452	237,350	82,914	101,790
1996	140	1,020,184	1,033,657	334,858	261,476	52,123	35,944	49,199	41,444
1997	140	862,395	305,630	46,654	25,208	131,800	77,920	11,311	8,333
1998	140	485,878	248,088	79,401	87,594	135,038	107,915	70,770	119,967
1999	140	2,802,746	2,694,985	167,332	136,862	60,913	63,256	43,369	63,390
2000	140	1,708,977	762,976	29,517	16,111	72,355	62,342	10,019	10,848
2001	140	2,862,611	2,017,072	124,662	135,690	71,087	58,767	25,863	31,649
2002	140	3,967,500	2,078,204	46,216	34,363	86,220	69,943	1,790	2,626
2003	140	3,358,128	1,717,516	58,068	34,831	37,338	38,073	11,379	15,764
2004	140	3,310,854	1,838,298	201,500	227,601	85,104	72,951	25,826	39,565
2005	140	1,500,340	1,023,234	263,663	384,960	27,582	13,707	18,094	33,534
2006	140	1,556,758	1,755,096	85,971	89,261	201,015	264,191	13,505	19,804
2007	140	858,764	845,244	122,646	196,891	46,819	70,282	115,685	191,090
2008	140	1,002,170	641,284	158,527	253,509	63,485	60,786	40,049	73,508
2009	140	2,864,734	2,280,116	186,462	184,117	106,865	141,846	37,017	49,983
2010	140	ND	ND	ND	ND	ND	ND	ND	ND
2011	140	4,294,759	1,989,017	110,590	92,015	12,548	21,626	30,112	35,746
2012	140	4,739,388	1,770,784	70,914	47,630	0	0	21,408	20,993
2013	140	2,984,787	953,981	156,835	127,922	1,892	2,680	36,186	34,150
2014	140	ND	ND	ND	ND	ND	ND	ND	ND
2015	140	ND	ND	ND	ND	ND	ND	ND	ND
2016	140	ND	ND	ND	ND	ND	ND	ND	ND
2017	114	999,200	691,215	11,778	11,293	104,259	112,345	20,706	22,607

Note: CI is 95% confidence intervals. Trawl surveys were not conducted in 2010 and from 2014 to 2016. ND = no data.

Table 7.–Estimated CW_{50} for male Tanner crab.

Year	CW_{50}	Lower CI	Upper CI
2007	115.71	112.85	118.90
2008	120.27	117.74	122.84
2009	119.23	117.33	121.19
2011	107.04	100.94	112.57
2012	96.71	95.34	98.18
2013	107.96	106.79	109.13
2017	100.48	98.26	102.65

Note: CI is 95% confidence intervals.

Table 8.–Generalized linear model results for testing the effects of carapace width (CW), survey year, and their interaction on the maturity of male Tanner crab.

Term	df	Deviance	AIC	$\chi 2$	*P-value*
		2,984.2	3,012.2		
CW	1	3,237.7	3,263.7	253.5	< 0.001
Year	6	2,997.2	3,013.2	13.0	0.042
CW:Year	6	3,004.3	3,020.3	20.2	0.003

Note: AIC is Akaike's Information Criterion.

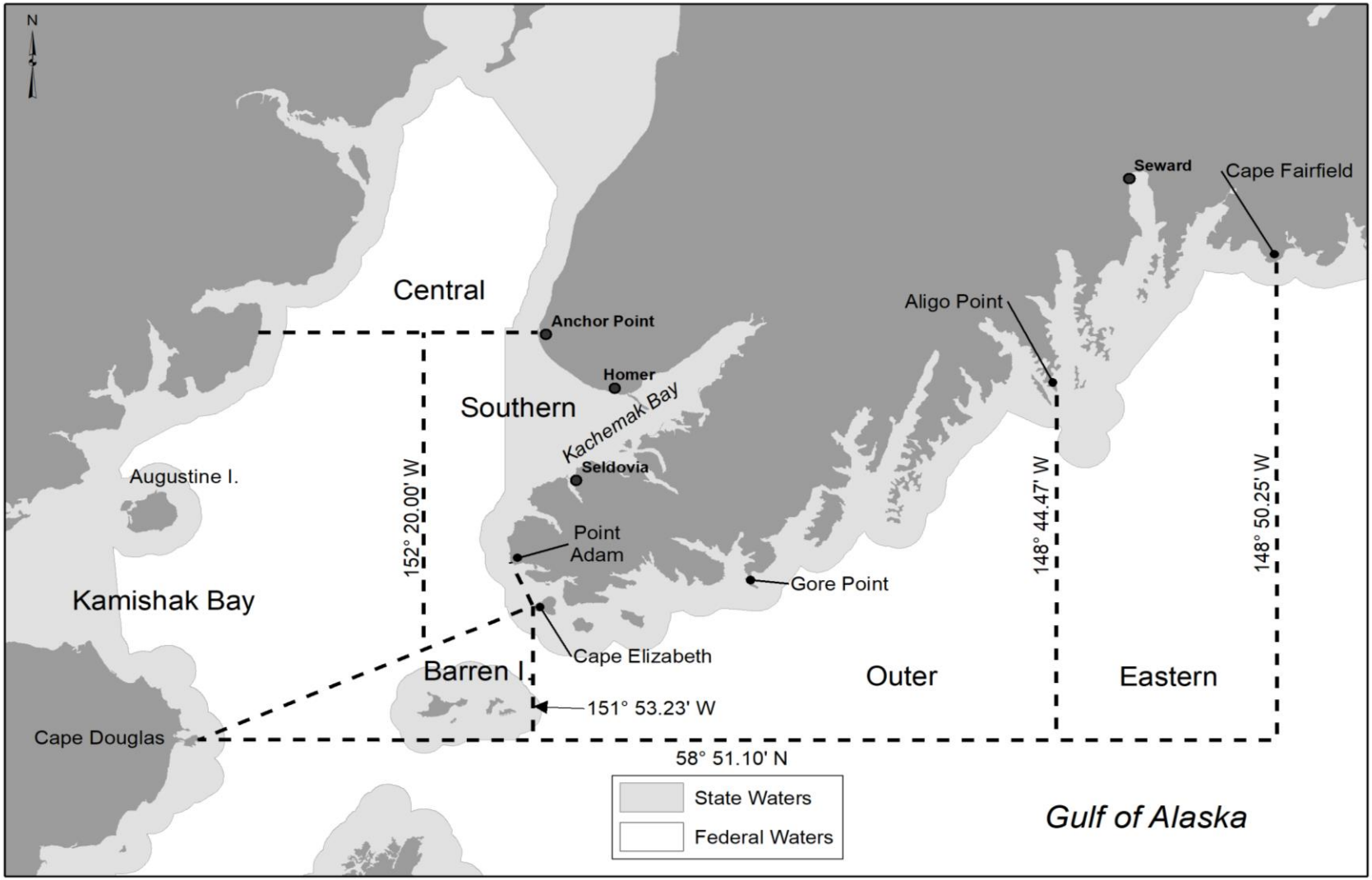

Figure 1.–Cook Inlet Area (Registration Area H) commercial crab fishing districts.

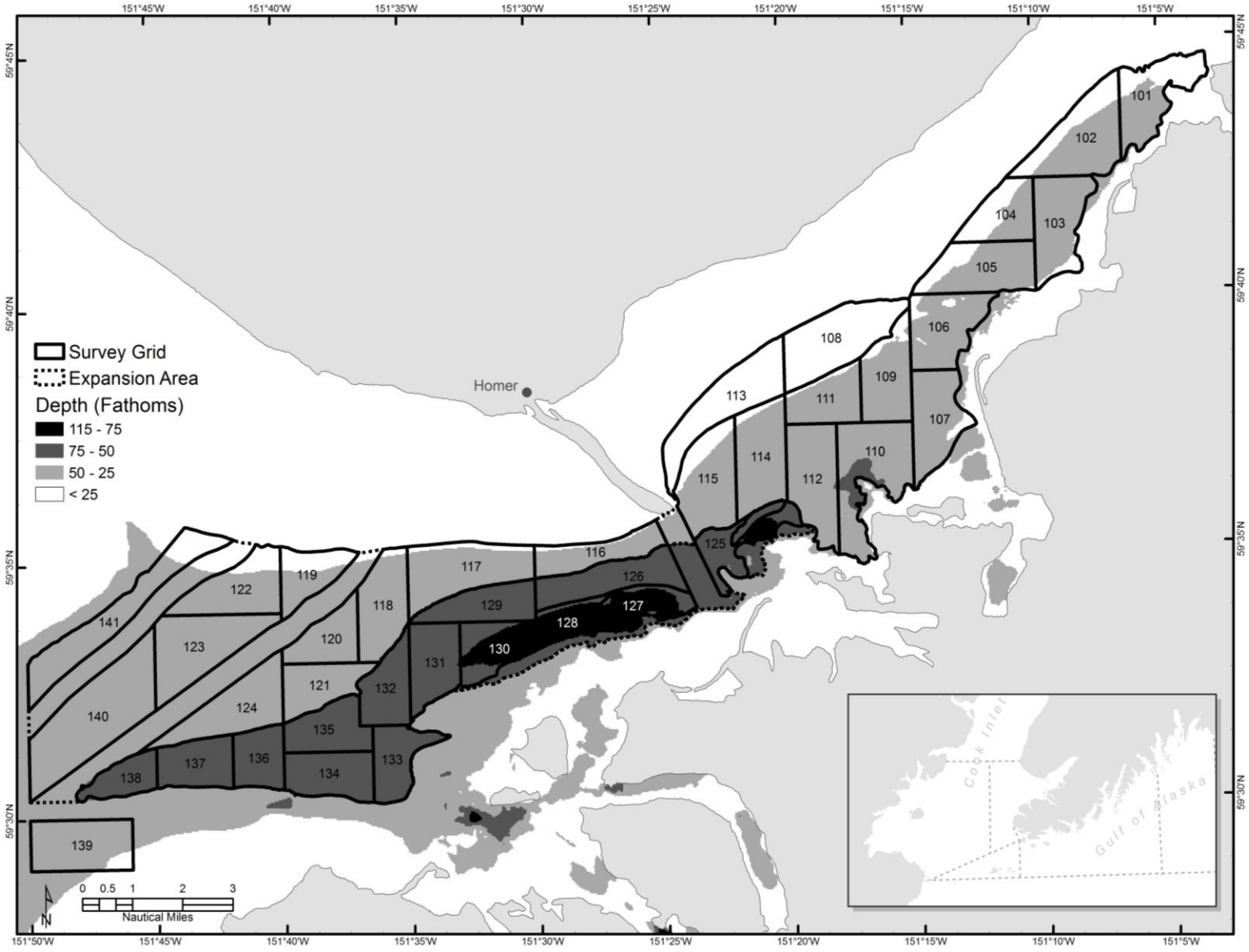

Figure 2.–Kachemak Bay large-mesh bottom trawl survey grid

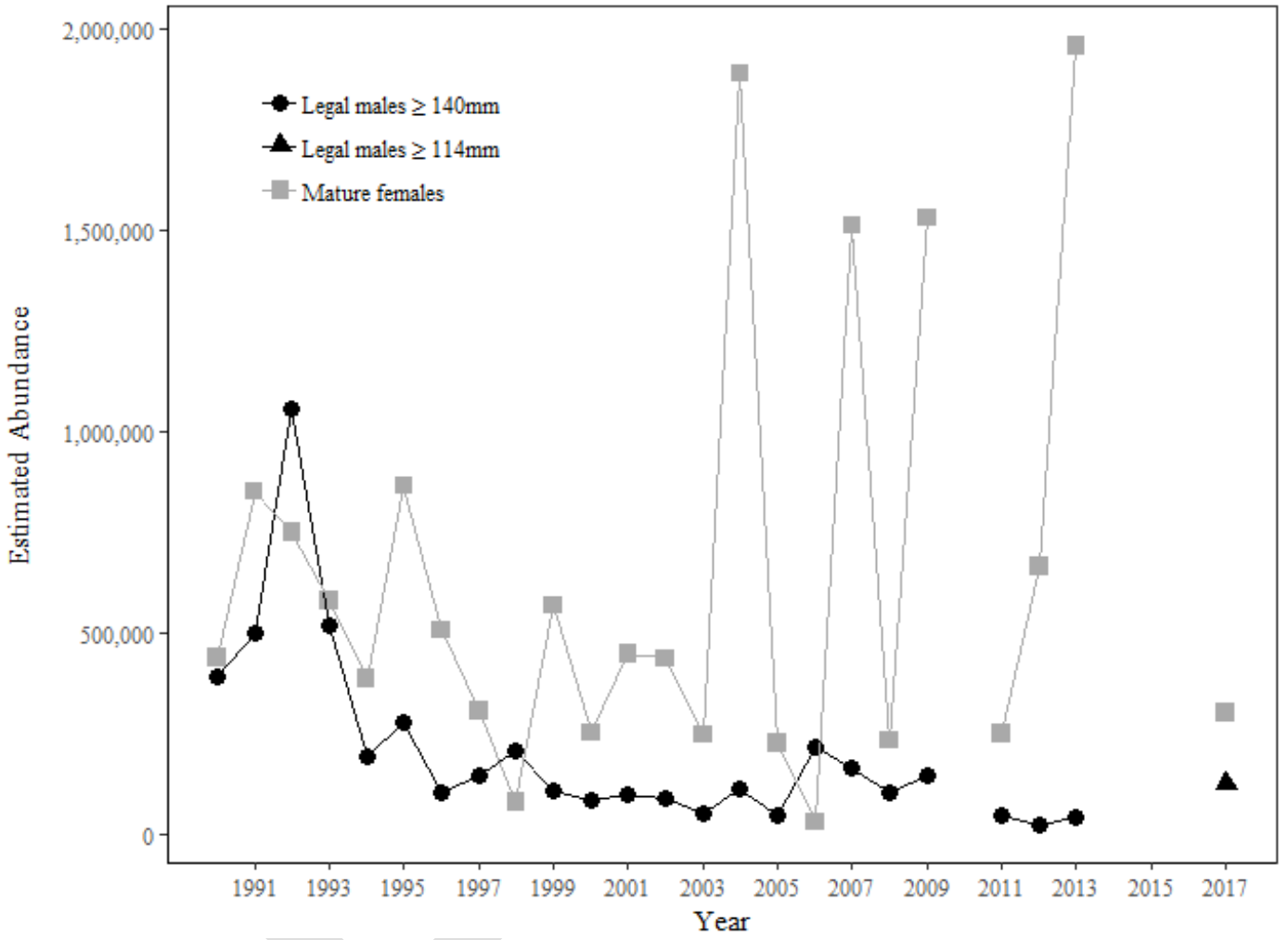

Figure 3.–Estimated abundance of legal male and mature female Tanner crabs from the Kachemak Bay trawl survey, 1990–2017.

Note: Legal males are ≥ 140mm carapace width for 1990–2013 and ≥ 114mm carapace for 2017. Surveys were not conducted in 2010 and 2014–2016.

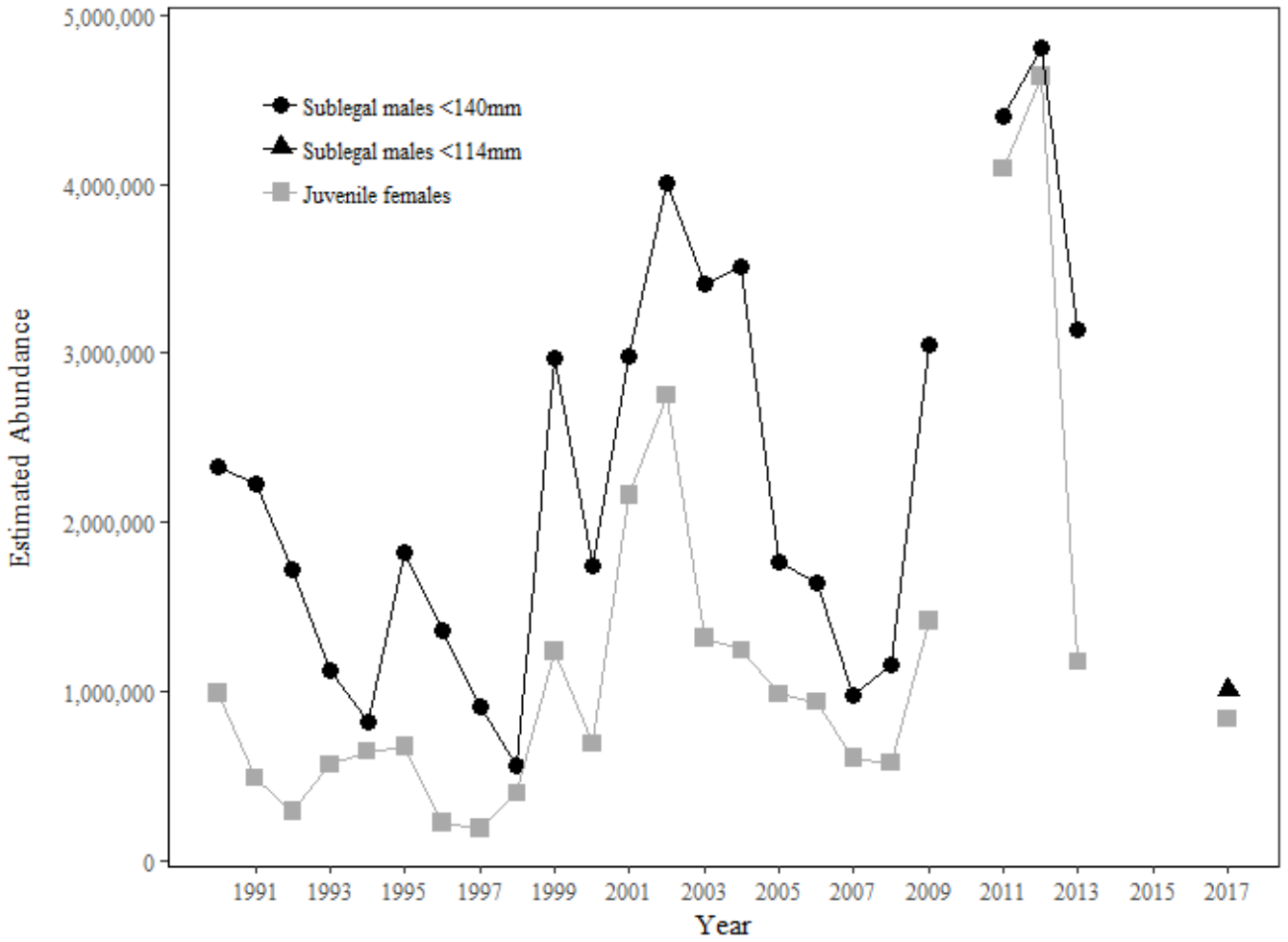

Figure 4.–Estimated abundance of sublegal male and juvenile female Tanner crabs from the Kachemak Bay trawl survey, 1990–2017.

Note: Sublegal males are < 140mm carapace width for 1990–2013 and < 114mm carapace width for 2017. Surveys were not conducted in 2010 and 2014–2016.

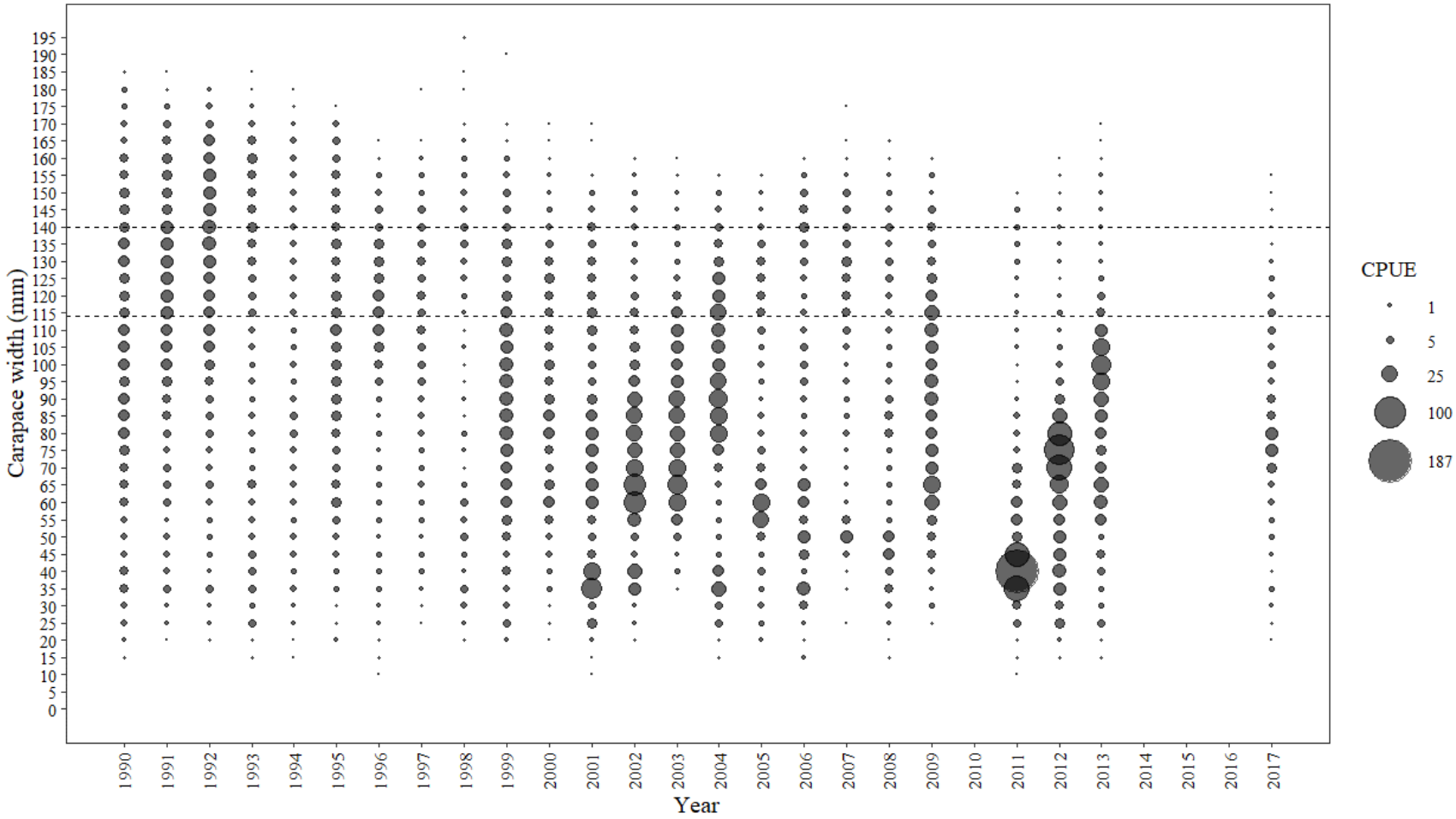

Figure 5.–Mean standardized CPUE by 5 mm size bins of male Tanner crab collected from the Kachemak Bay trawl survey, 1990–2017.

Note: Dashed lines are the historical legal size (140mm) and the new legal size (114mm) established in regulations in 2017. Surveys were not conducted in 2010 and 2014–2016.

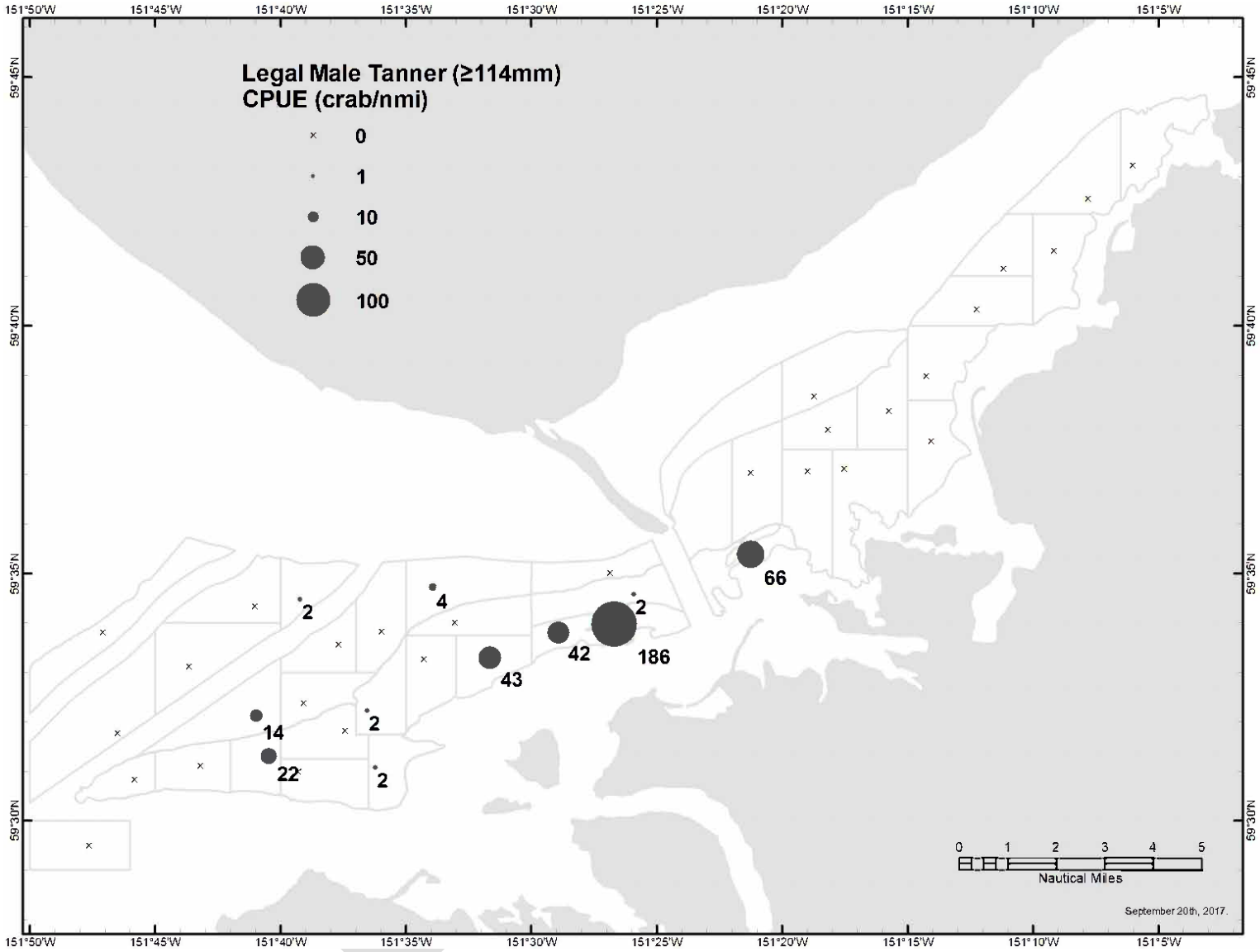

Figure 6.–Location of legal male Tanner crab caught in the 2017 Kachemak Bay trawl survey.

Note: CPUE is standardized to catch/nmi.

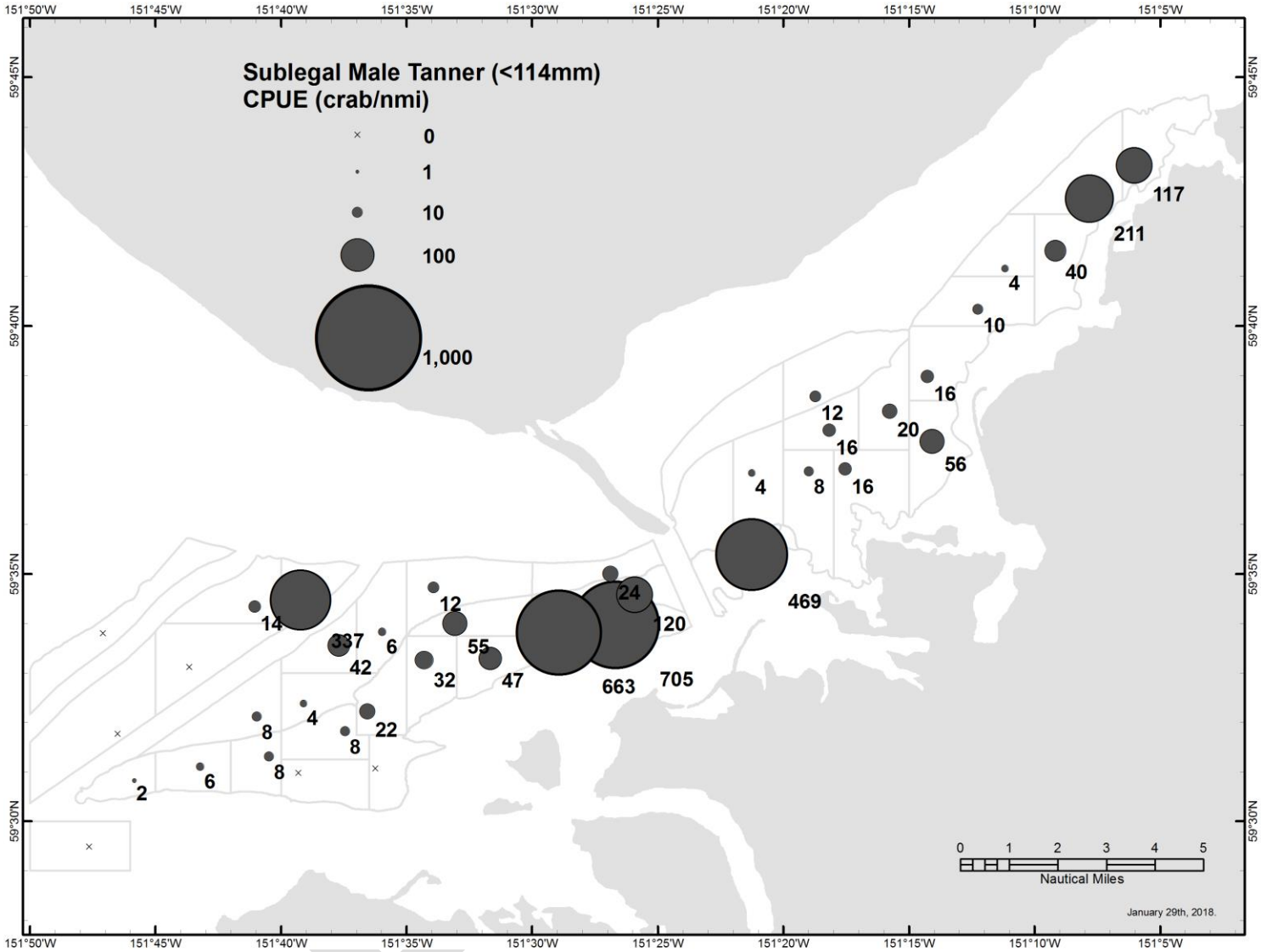

Figure 7.–Location of sublegal male Tanner crab caught in the 2017 Kachemak Bay trawl survey.

Note: CPUE is standardized to catch/nmi.

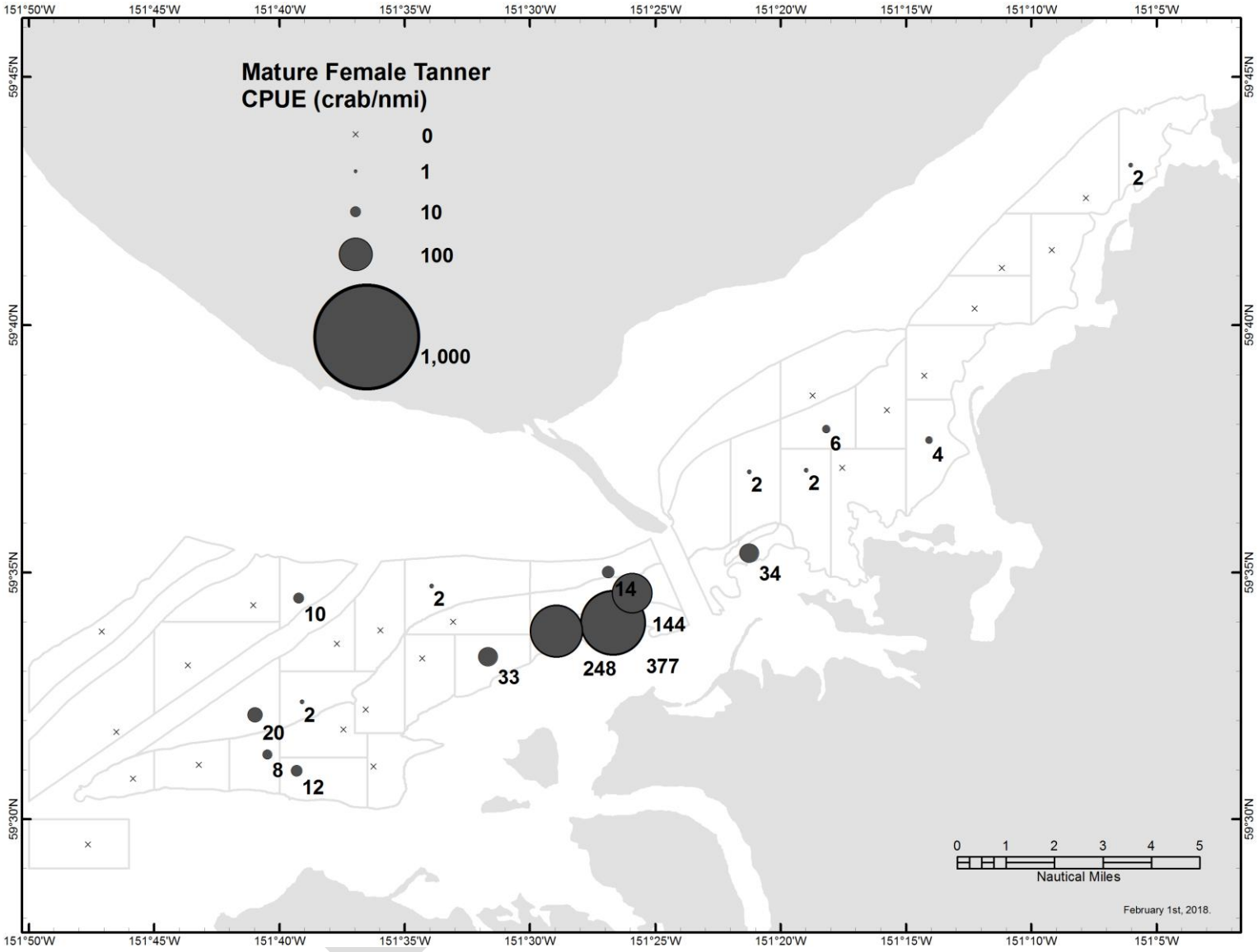

Figure 8.–Location of mature female Tanner crab caught in the 2017 Kachemak Bay trawl survey.

Note: CPUE is standardized to catch/nmi.

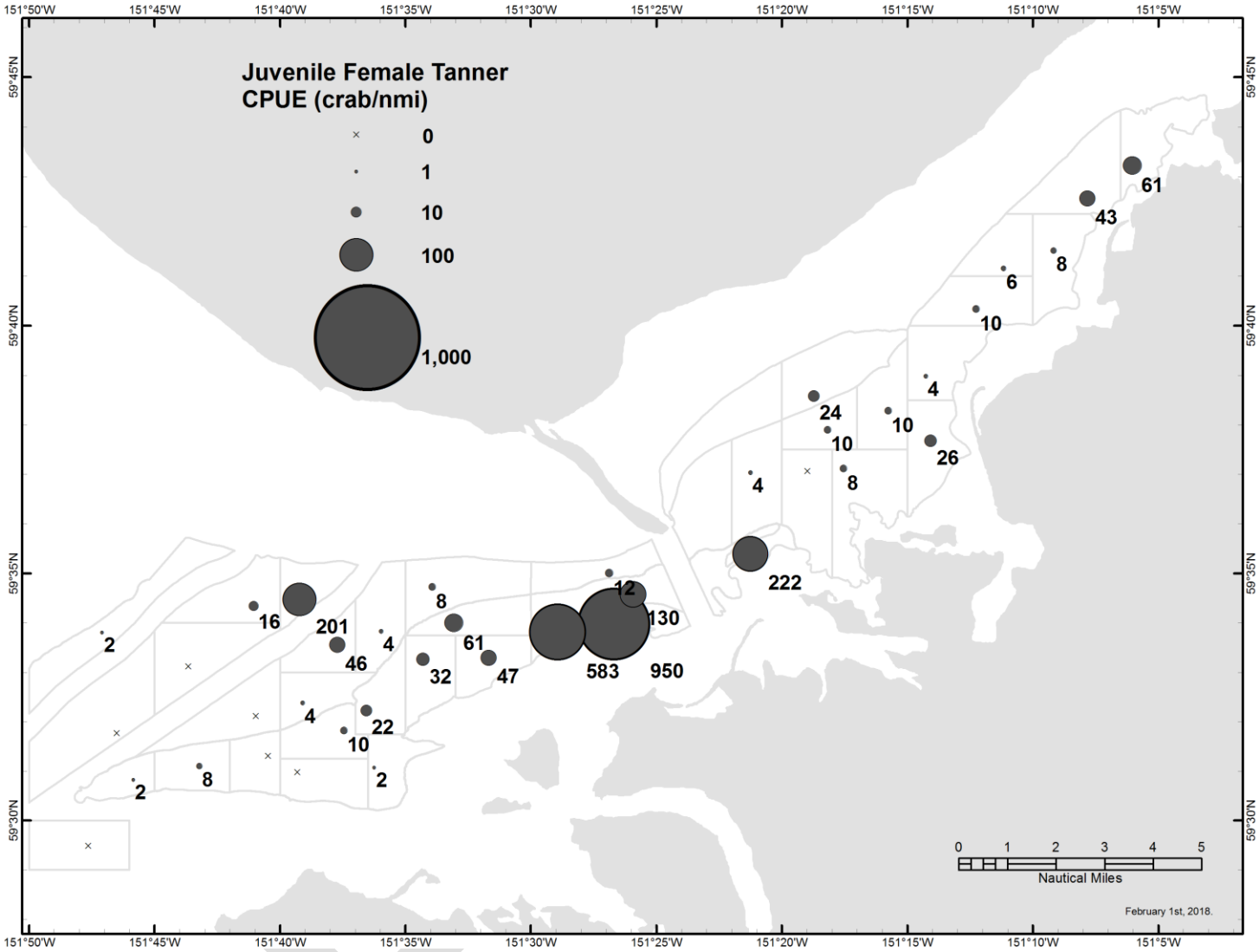

Figure 9.–Location of juvenile female Tanner crab caught in the 2017 Kachemak Bay trawl survey.

Note: CPUE is standardized to catch/nmi.

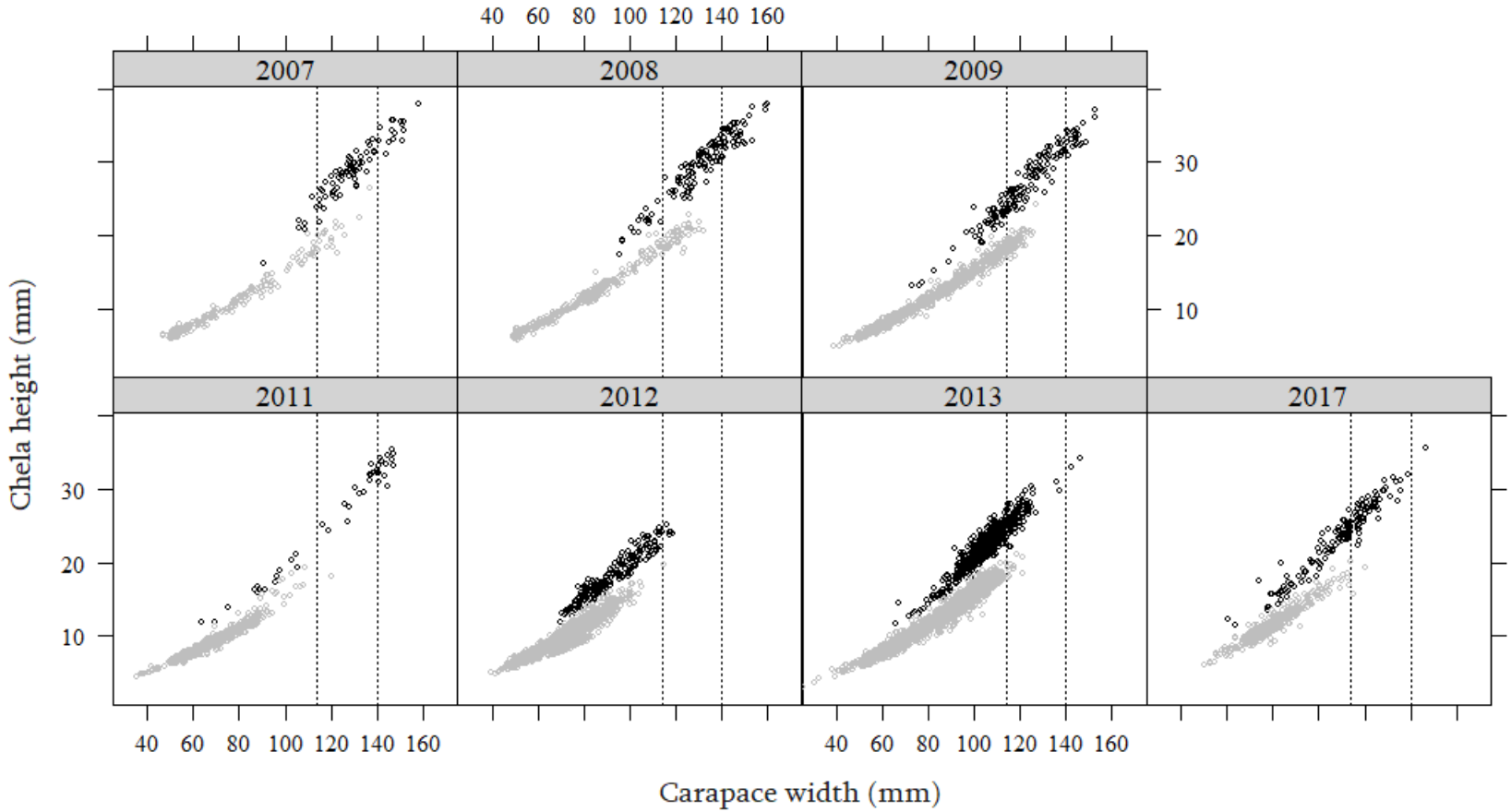

Figure 10.–New shell male Tanner crab carapace width and chela height data from the Kachemak trawl surveys.

Note: Large claw are black circles and small claw are gray circles. Vertical dashed lines are the historical legal size (140mm) and the new legal size (114mm) established in regulations in 2017. Surveys were not conducted in 2010 and 2014–2016.

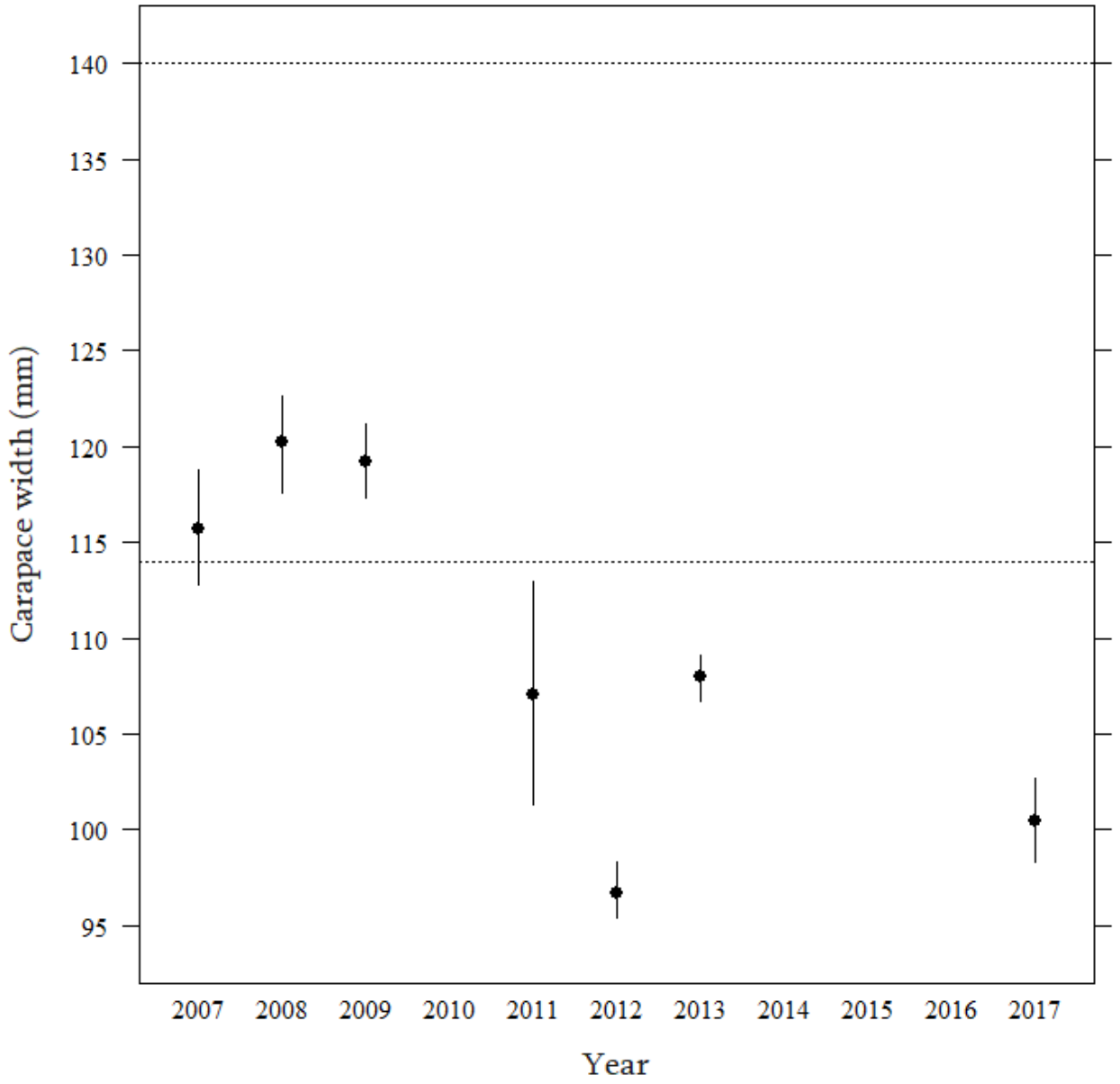

Figure 11.–Estimated size at 50% maturity for new shell male Tanner crab from the Kachemak Bay trawl survey.

Note: Vertical lines are 95% confidence intervals. Horizontal dashed lines are the historical legal size (140mm) and the new legal size (114mm) established in regulations in 2017. Surveys were not conducted in 2010 and 2014–2016.

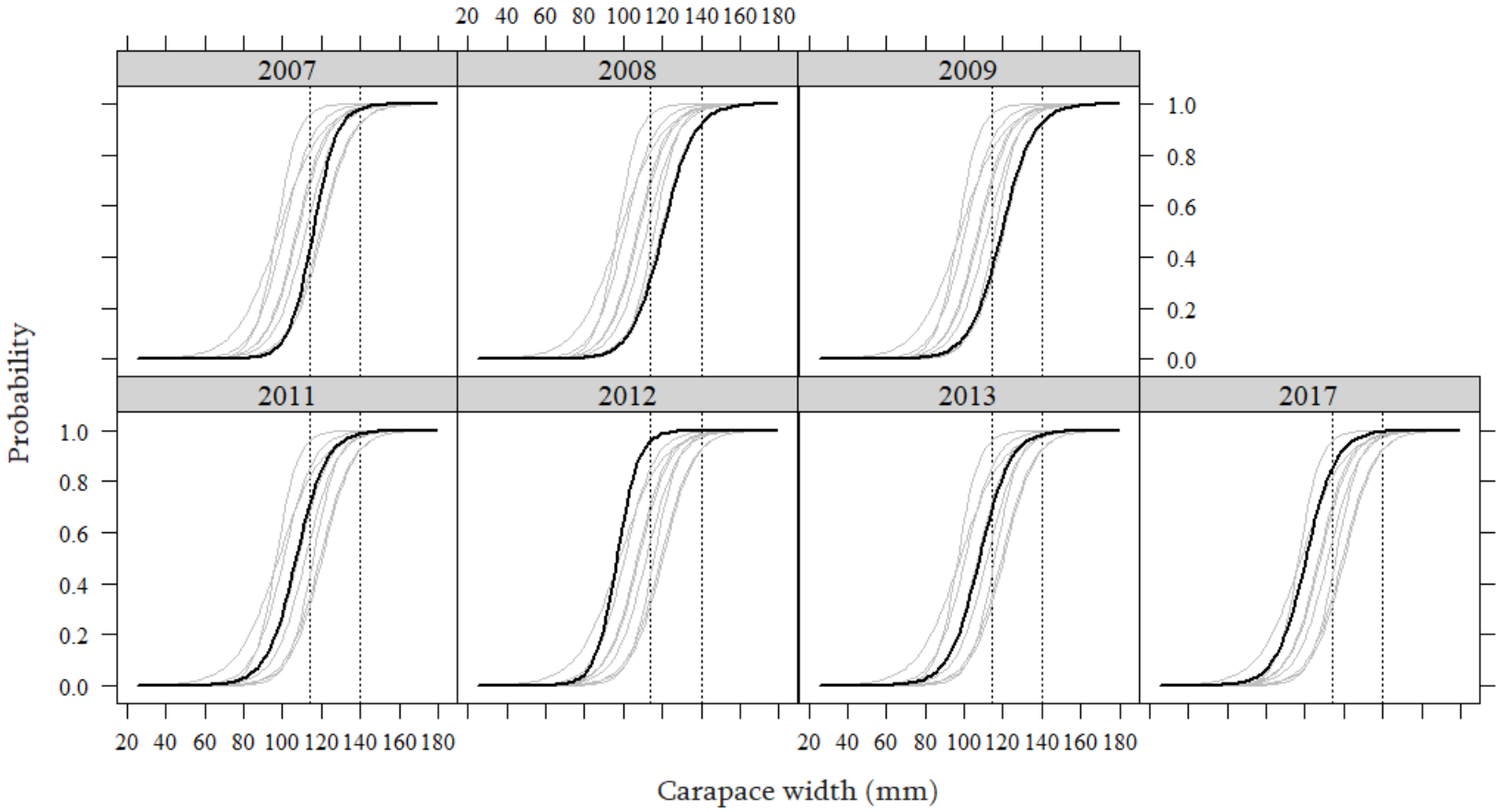

Figure 12.–Maturity curves for new shell male Tanner crab from the Kachemak Bay trawl survey.

Note: Vertical dashed lines are the historical legal size (140mm) and the new legal size (114mm) established in regulations in 2017. Surveys were not conducted in 2010 and 2014 to 2016.

APPENDIX A: TARGET SPECIES SAMPLING

Appendix A1.–Target sampling category for species, groups and types of biological samples collected for the 2017 trawl survey in Kachemak Bay, Southern District, Cook Inlet Area.

Target category	Common name	Scientific name	Biological sampling[a] Size[b] (mm)	Weight (kg)	Sex	Age structure
Primary	Dungeness crab	*Cancer magister*	CW[c]	N	Y	N
	golden king crab	*Lithodes aequispina*	CL	N	Y	N
	red king crab	*Paralithodes camtschaticus*	CL	N	Y	N
	Tanner crab[d]	*Chionoecetes bairdi*	CW[e]	N	Y	N
	box crab	*Lopholithodes foraminatus*	N	N	N	N
	north Pacific octopus	*Enteroctopus dofleini*	N	N	N	N
	majestic squid	*Berryteuthis magister*	N	N	N	N
	sunflower seastar	*Pycnopodia helianthoides*	N	N	N	N
	weathervane scallop	*Patinopecten caurinus*	SH	N	N	N
	all rockfish species	*Scorpaenidae*	FL	Y	Y	Y
	all salmon species	*Oncorhynchus*	FL	N	N	N
	all skate egg case[f]	*Rajidae*	N	N	N	N
	all skate species	*Rajidae*	TL	N	Y	N
	Atka mackerel	*Pleurogrammus monopterygius*	FL	N	N	N
	giant wrymouth	*Cryptacanthodes giganteus*	N	N	N	N
	lingcod	*Ophiodon elongatus*	FL	Y	Y	Y
	Pacific cod	*Gadus macrocephalus*	FL	N	N	N
	Pacific halibut	*Hippoglossus stenolepis*	FL[g]	N	N	N
	Pacific sleeper shark	*Somniosus pacificus*	FL	N	Y	N
	sablefish	*Anoplopoma fimbria*	FL	Y	Y	Y
	salmon shark	*Lamna ditropis*	FL	N	Y	N
	spiny dogfish	*Squalus suckleyi*	FL	N	Y	N
	Walleye Pollock	*Theragra chalcogramma*	FL	N	N	N
	wolfeel	*Anarrhichthys ocellatus*	N	N	N	N
	wolffish	*Anarhichas orientalis*	N	N	N	N
Secondary	Tanner crab[a]	*Chionoecetes bairdi*	CW	N	Y	N
	Alaska plaice	*Pleuronectes quadrituberculatus*	TL	N	N	N
	arrowtooth flounder	*Reinhardtius stomias*	FL	N	N	N
	butter sole	*Isopsetta isolepis*	TL	N	N	N
	Dover sole	*Microstomus pacificus*	TL	N	N	N
	English sole	*Paraphrys vetulus*	TL	N	N	N
	flathead sole	*Hippoglossoides elassodon*	TL	N	N	N
	petrale sole	*Psettichthys melanostictus*	TL	N	N	N
	rex sole	*Glyptocephalus zachirus*	TL	N	N	N
	rock sole	*Paraplagusia bilineata*	TL	N	N	N
	sand sole	*Eopsetta jordani*	TL	N	N	N
	slender sole	*Lyopsetta exilis*	TL	N	N	N
	starry flounder	*Platichthys stellatus*	TL	N	N	N
	yellowfin sole	*Limanda aspera*	TL	N	N	N

[a] N = not collected and Y = collected

[b] SH = shell height, FL = fork length, TL = total length

[c] CW = carapace width including spines

[d] Tanner crab in Primary ≥ 70 mm CW and in Secondary < 70 mm CW

[e] CW = carapace width excluding spines

[f] Recorded whether live or dead (empty)

[g] Length taken if too large to weigh

APPENDIX B: ONBOARD SAMPLING PROCESS

Appendix B1.–Details of onboard catch sampling process for the 2017 large-mesh trawl survey in Kachemak Bay, Southern District, Cook Inlet Area.