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Pot Survey for Spot Shrimp in the Prince William Sound Area, 1992–2023

by

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and

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February 2025

Alaska Department of Fish and Game **Division of Commercial Fisheries**

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

The Alaska Department of Fish and Game Division of Commercial Fisheries has conducted an annual pot survey for spot shrimp *Pandalus platyceros* in the Prince William Sound Area (PWSA; Registration Area E) since 1992. Throughout the time series, 6–9 sites, spanning the northwestern and northern PWSA, were each surveyed annually with 44 pots set on sloped shrimp habitat and in depths ranging from 52–220 m. The biomass per unit effort (BPUE) of marketable-size (>32 mm) spot shrimp along with total harvest from fisheries and surveys are inputs into a surplus production model to estimate maximum sustainable yield and calculate total allowable harvest (TAH) for PWSA pot shrimp fisheries. Since the commercial fishery re-opened in 2010, the outputs from the surplus production model and the resulting TAH have been relatively stable. The BPUE and shrimp count per unit effort (CPUE) from the PWSA pot survey have been decreasing in recent years and are approaching time series minimums that were observed in the mid-1990s. The carapace length (CL) at which there is a 50% probability that a PWSA spot shrimp has transitioning to female (CL_{50}) was estimated at approximately 40 mm which is estimated to be approximately 6-years old. A univariate model, with a p-value <0.005 and an R2 value of 0.654, indicated a significant negative correlation between CL_{50} and the annual CPUE of males 3-years prior. Results from the annual pot survey informed fishery managers, both commercial and non-commercial, of trends in PWSA shrimp populations and provided insight into whether a fishery in the coming year was viable.

Keywords: spot shrimp, *Pandalus platyceros*, Prince William Sound, Registration Area E, pot survey, pot fishery

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) Division of Commercial Fisheries has the responsibility to assess spot shrimp *Pandalus platyceros* and collaborate with ADF&G Division of Sport Fisheries to sustainably manage shrimp pot fisheries in the Prince William Sound Area (PWSA; Registration Area E). The PWSA is relatively large and encompasses both the inside waters of Prince William Sound and waters in the Gulf of Alaska between the longitudes of 148°50.25′ W and 144°00′ W and south to the border of the U.S Exclusive Economic Zone, which extends 200 nautical miles off Alaska's coastline. Despite the large size of the PWSA, both historic and current pot fisheries for shrimp have occurred exclusively in the inside waters of Prince William Sound.

POT FISHERIES

Prior to the ADF&G reporting of shrimp harvest in PWSA, the U.S. Department of Commerce, Bureau of Commercial Fisheries documented harvest beginning in 1935 although annual total harvest was not documented until 1950 (Pirtle 1976). ADF&G first reported shrimp harvest in the PWSA in 1960 and described it as a family operation from a small packing company in northern Prince William Sound (Pirtle 1961) with pots being identified as the gear type (Pirtle and Baxter 1963). For the PWSA shrimp pot fishery, ADF&G has reported the number of vessels and landings starting in 1978 and began reporting species specific harvest in 1980 (Trowbridge 1992).

The PWSA shrimp pot fishery increased rapidly in both participation and harvest from 1978–1982 prompting ADF&G to establish fishing seasons to avoid egg bearing periods and a guideline harvest range based on historical harvest (Donaldson 1988). At the 1984 Alaska Board of Fisheries (BOF) meeting, 3 areas with management plans were established. These areas were: Traditional Harvest Area, Montague Straight Experimental Harvest Area (MSEHA) and the Eastern Harvest Area (Figure 1). After continuous fishing in the MSEHA from 1985–1988, ADF&G closed the area due to stock conservation concerns and at the 1990 BOF meeting it was combined into the Traditional Harvest Area (Donaldson 1991). Historically, the majority of shrimp were harvested in the northern and western portions of the Traditional Harvest Area with the Eastern District

having very low harvest, which led to an ADF&G Commissioner's permit being required to allow accurate monitoring of effort and catch (Trowbridge 1992a).

Starting in 1950, PWSA shrimp harvest was recorded as round (whole) weight and thus required a conversion factor when landings were reported as weight of tails with heads removed. From 1960–1990, harvest was converted from tail weight to whole weight using a conversion factor of 1.67 (Trowbridge 1992a). Starting in 1991, the conversion factor was changed to 2.0 and all historical annual harvests were updated in ADF&G reports (Trowbridge 1993).

Total shrimp pot commercial harvest in PWSA increased substantially starting in 1981 and peaked in 1986 with a harvest of 290,632 lb. Annual total shrimp pot harvests from 1981–1988 averaged ~230,000 lb while annual harvest from 1960–1980 averaged ~13,000 lb. After the peak annual harvests from 1981–1988, annual average harvest decreased to less than 30,000 lb from 1989–1991 and ADF&G closed the pot shrimp fishing in the Traditional Harvest Area in 1992 (Trowbridge 1993). From 1980–1991, spot shrimp were 96.4% of the PWSA shrimp pot fishery harvest.

From 1992–2009, it was determined that the PWSA shrimp population was not healthy enough to prosecute a commercial fishery, although the Alaska Board of Fisheries (BOF) allowed a noncommercial fishery at historical harvest levels (Blaine-Roth et al. 2021). After 18 years, the PWSA shrimp pot sport fishery harvest indicated a healthy population and commercial fishery regulations were adopted at the 2009 BOF meeting (Wessel et al. 2012). At the 2009 BOF meeting, (5 AAC 31.210) was adopted into regulations to define the shrimp pot fishing area as waters of the Inside District from Middle Point at 60° 20.00' N lat, 147° W long, north to a point at 60° 40.00' N lat, 147° W long, then northeast to the Coast Guard marker light on Goose Island at 60° 42.78' N lat, 146° 43.63' W long, to a point on Knowles Head at 60° 41.00' N lat, 146° 37.50' W long (Figure 2). This regulation also states that fishing will be rotated on a triennial basis, within the allowable waters of the Inside District, between the following areas: (Area 1) the waters north of 60° 40.00' N lat and east of 148° W long; (Area 2) the waters south of Area 1 and north and west of a line from 60° 30.00' N lat, 147° 57.70' W long, to 147° W long, including those waters south of 60° 30.00' N lat, in Kings Bay and Port Nellie Juan; (Area 3) the waters south of 60° 30.00' N lat, excluding those waters in Kings Bay and Port Nellie Juan. In all other waters of PWSA, shrimp may be taken by pots only under the authority and conditions of a permit issued by the commissioner. Also, at the 2009 BOF meeting, (5 AAC 31.214) was adopted into regulations to define the minimum total allowable harvest (TAH) to open a commercial fishery, within the waters described in (5 AAC 31.210), as 110,000 lb of spot shrimp. This regulation also defined the commercial guideline harvest level (GHL) for the commercial pot gear fishery as 40% of the TAH and stated that ADF&G will manage the fishery to allow no more than 50% of the GHL to be taken from any 1 statistical area. The remaining 60% of the PWSA TAH is allocated to noncommercial fisheries following the Prince William Sound noncommercial fishery management plan (5 AAC 55.055).

Since the commercial fishery re-opened, the shrimp pot TAH has ranged from 117,653 lb in 2016 to 175,000 lb in 2021 (Table 1). The shrimp pot commercial harvest has ranged from 21,561 lb in Area 3 in 2012 to 70,169 lb in Area 3 in 2021. Spot shrimp have been the predominant species harvested in the PWSA shrimp pot fishery with coonstripe shrimp *P. hypsinotus* averaging 3.2% of the harvest and a maximum of 6% of the harvest in 2014.

Although noncommercial fisheries have occurred in the PWSA historically, accurate harvest reporting has occurred only when the permitting process was being implemented from 2002–2005 and 2009–present. Total reported and published harvests reconstructed since 1960 from commercial and noncommercial fisheries indicate that the recent PWSA shrimp pot fisheries have reached similar harvests levels to those observed in the 1980s (Figure 3).

POT SURVEY

In 1989 a pot survey study began to investigate the effects of the Exxon Valdez Oil Spill on the PWSA spot shrimp population (Trowbridge 1992b). In 1992, ADF&G restructured the survey as an assessment tool to provide spot shrimp stock status information to management biologists (Trowbridge 1994). There is an ontogenetic change in the habitat of spot shrimp with juveniles utilizing shallow-water eelgrass and *Laminarium* or *Agarum* spp. kelp habitats until they grow to approximately 20 mm in carapace length (CL), at which point they migrate to rocky habitats including reefs, glass sponge reefs, and corals (Chew et al. 1974; Marliave and Roth 1995). Adult spot shrimp are benthic scavengers as well as predators and undergo diurnal feeding migrations, moving shoreward along the bottom into shallower waters at night and back to deeper waters during the day (Butler 1980). The PWSA spot shrimp survey design targets shrimp habitat that encompass a depth range expected to be occupied by adult shrimp.

Spot shrimp aggregations are likely best described as metapopulations (Smith 2020). Although adults are relatively sedentary, with tagged adults observed within a mile or 2 of their release location in PWSA (Kimker et al. 1996), larvae are planktonic and may be widely transported by ocean currents. Thus, area of localized depletion could have immigration recruitment from another area in the PWSA with more productive or healthy habitat. The pot survey has been designed to assess spot shrimp in areas of commercial fishery effort with the goal of providing information about the PWSA metapopulations. The survey uses a fixed site and station sampling design (sites with multiple stations within each site). Though there have been changes to the sites and stations and biological collections throughout the time series, the survey area has remained spatially consistent and currently provides valuable information to open, close, and manage spot shrimp harvest and pot shrimp fisheries in PWSA.

SURVEY MANAGEMENT APPLICATIONS

At the March 2009 Alaska Board of Fisheries (BOF) meeting, (5 AAC 31.214) was adopted into regulation that set the requirement of a minimum Total Allowable Harvest (TAH) of 110,000 lb of spot shrimp to open the commercial pot fishery. This regulation also set the guideline harvest level (GHL) for the commercial pot fishery at 40% of the TAH. The remaining 60% of the TAH is allocated to a noncommercial fishery GHL (5 AAC 55.055), although there is no threshold of harvestable surplus that must be met for the noncommercial shrimp fisheries to open (Blaine-Roth et al. 2021). The annual TAH and the GHLs are for all shrimp in all waters open to shrimp pot fishing in the Registration Area E (PWSA) Inside District (5 AAC 31.210)

The ADF&G spot shrimp pot survey currently generates a biomass per unit effort (BPUE), where unit effort equals 1 pot haul, of marketable-size spot shrimp (≥32 mm CL) for an input into a Schaefer surplus production model (Haddon 2011). The other input to the model is total fishery removals from all shrimp pot fisheries and surveys but does not include any fishery CPUE. The model calculates a maximum sustainable yield (MSY) for PWSA shrimp. The lower 90% CI from the annually calculated MSY has served as the annual TAH for the PWSA shrimp pot fisheries

(Rumble et al. 2022), except in 2019 and 2020 when the point estimate of MSY was used for the TAH.

All sites (except the ancillary site in Port Valdez that is not included in this report) and all stations that were surveyed in each year, are included in the calculation of BPUE for marketable-size spot shrimp for input into the surplus production model. Since the inception of the ADF&G survey in 1992, some sites and stations have been removed and added. In 2015, the boundary between Area 2 and 3 was moved to the north and thus Area 3 increased in size while Area 2 decreased. In the current area and pot survey site configuration, there are 3 survey sites in Area 1, 2 survey sites in Area 2, and 4 survey sites in Area 3 (Figure 2). Much of the non-commercial fishery is located near the ports of Whittier and Valdez where there are permanent closures for the commercial fishery (Blaine-Roth et al. 2021). There are no sites in the PWSA spot shrimp survey in these locations. Thus, the PWSA BPUE estimate of marketable-size spot shrimp from the pot survey does not include observations from areas with the highest noncommercial harvest.

INDEX SITES AND STATIONS

The PWSA spot shrimp pot survey has had considerable changes to both the fixed site/station design and to the biological collection methods since it began in 1992. To observe temporal trends, from consistent observations throughout the time series of the survey, index sites and index stations were defined as those that were sampled every year of the survey. Only catches from these index sites and index stations were used to construct a time series to observe population trends over the entirety of the survey. The surplus production model for management applications utilizes a BPUE, yet neither individual biomass nor aggregate biomass by size-class were recorded during the first half of the survey, as opposed to counts of all shrimp caught in every pot which have been recorded since the beginning of the survey. Size and sex have been recorded from all pots or in sub-sampled pots with sex and size proportions extrapolated to the site when sub-sampled. Annual counts per unit effort (CPUE), where unit effort equals 1 pot haul, of male, female, marketable-size, and total shrimp were calculated for the entire survey timeseries from index sites/stations to observe temporal trends and variability.

SIZE, AGE, GROWTH, AND TRANSITION TO FEMALE

Spot shrimp are protandric hermaphrodites transitioning to being females after approximately 3–5 years as males (Kruse and Murphy 1989). In Alaska, females may live for another 3–5 years and reproduce annually (Trowbridge 1992b; Love and Bishop 2005). Tagging studies in PWSA suggest a maximum age range of 7 to 10 years (Kimker et al. 1996; Donaldson 1991), substantially older than the faster growing populations in the warmer waters of British Columbia, Washington and California (Butler 1964; Lowry 2007) where the maximum age is estimated to be 6 years. Growth and maturity development of Pandalid shrimp populations may be related to water temperatures, with egg extrusion timing delays and decreases of gravid female abundance associated with temperatures (Nunes 1984). Increased water temperatures may decrease average mature, female size, and population fecundity and thus result in a decline in recruitment (Koeller et al. 2003). This report will conduct an analysis on annual pot survey data from index sites and stations to determine the annual and average CL at which there is a 50% probability of being a female spot shrimp (CL_{50}).

To obtain life history information, ADF&G conducted a series of spot shrimp tagging projects in the PWSA using streamer tags beginning in 1982 near Green Island (Kimker 1986). In 1983, the

tagging project was moved to Unakwik Inet to examine spot shrimp growth and longevity (Kimker et al. 1996). This tagging project used size and time at large to produce a growth model and this report will use those growth curve parameters to estimate the age of marketable-size shrimp, average size of males, and CL_{50}.

OBJECTIVES

1. Describe the survey site, station, and biological collection design.
2. Describe survey data used to generate BPUE of marketable-size spot shrimp for input into a surplus production model.
3. Report annual exploitable biomass and index of relative abundance from the most recent run of the Schaefer surplus production model.
4. Define survey index sites and stations and produce a time series of CPUE for marketable-size, male, female, and total spot shrimp.
5. Estimate the size (CL) at which there is a 50% probability of being female (CL_{50}).
6. Estimate the age of shrimp at marketable-size, average size of males, and at transition to female (CL_{50}).
7. Explore the time series of index site and station CPUE and CL_{50} data for significant correlations

METHODS

SURVEY DESIGN

The ADF&G PWSA pot survey for spot shrimp is a fixed site and station sampling design with sites distributed across the inside western and northern waters of Prince William Sound. The survey design is geographically scaled, with pots nested within a station (11 pots to a station) and stations nested within a site (4 stations to a site) with 7 sites distributed throughout the survey area. Stations of longlined research shrimp pots are distributed within each site. Since 1992, the general distribution of sites has not changed and survey timing has been consistent with all surveys in the time series conducted in October except for in 1995 and 1996 when it was conducted in early mid-November (Table 2). Sites and stations have been added and removed, and biological collection methods have changed to address management and research objectives.

Sites

The PWSA pot survey was designed with sites spatially distributed in suitable habitat within PWSA waters open by regulation to commercial pot shrimp fishing (Figure 2). The target depth range was 37–146 m, following an initial study where it was observed spot shrimp catch rates dropped precipitously at depths greater than 146 m (Trowbridge 1994). Site selection was based in part on early logbook data from previous commercial pot shrimp fisheries in PWSA as well as anecdotal information provided by fishermen.

In the PWSA spot shrimp pot survey, there have been a total of 10 sites that have been surveyed and used to calculate the BPUE of marketable-size spot shrimp for an input to the surplus production model (Table 3). From 1992–2007, 8 sites were surveyed annually: Site 1 (Unakwik), Site 2 (Golden), Site 3 (Culross), Site 4 (Herring Bay), Site 5 (Junction Island), Site 6 (Green Island), Site 7 (Chenega), and Site 8 (Prince of Wales). In 2008, Site 6 (Green Island) was removed due to regular gear loss from the strong currents in Montague Strait and the following year Site 9 (Long Bay) was added to replace it. In 2012, Site 10 (Bald Head Chris) was added to the northern

waters of PWSA. From 2012–2021, annual BPUE has been calculated from the same 9 sites: Site 1 (Unakwik), Site 2 (Golden), Site 3 (Culross), Site 4 (Herring Bay), Site 5 (Junction Island), Site 7 (Chenega), Site 8 (Prince of Wales), Site 9 (Long Bay), and Site 10 (Bald Head Chris) (Figure 2).

An ancillary site in Valdez was developed in 2012 but due to its location, could only be surveyed if time and weather permitted. This site was also in waters closed to commercial shrimp pot fishing and due to inconsistencies of site observations, it was not included in the surplus production model nor as an Index site.

Index sites were consistently sampled throughout the entirety of the survey and were used to construct a time series of CPUE. These sites include: Site 1 (Unakwik), Site 2 (Golden), Site 3 (Culross), Site 4 (Herring Bay), Site 5 (Junction Island), Site 7 (Chenega), and Site 8 (Prince of Wales) (Figure 2; Table 3). Each Index Site was surveyed every year except in 1992, when Site 5 (Junction Island) was not surveyed and in 1998, when Site 8 (Prince of Wales) was not surveyed.

Stations

Stations consisting of longlined pots were distributed along decreasing depth profiles within each site. A number of factors were considered in the development of stations within each site: maximize the range of depths each string of pots can successfully fish, limit exposure to bottom structure where gear hangups were likely and avoid areas of strong currents where gear loss may occur. Originally, 4 stations were established for each site (A, B, C and D) with 11 pots spread equidistantly on a longline. The location of these 4 original stations has remained constant throughout the survey time series. Station placement varies across sites with stations at Site 2 (Golden), Site 3 (Culross), and Site 4 (Herring Bay) placed in parallel and equal distance apart every 250–300 m. However, stations at Site 1 (Unakwik), Site 5 (Junction Island), Site 7 (Chenega), Site 8 (Prince of Wales), Site 9 (Long Bay), and Site 10 (Bald Head Chris) were placed much further apart at variable distance from each other in an effort to achieve adequate spatial distribution across available habitat within those sites.

In 1994, station O (consisting of 6 pots) was added to the Prince of Wales site and the catches were included in the calculation of annual BPUE for the surplus production model. This station was abandoned the following year.

The survey design was modified in 2016 and 2017, when 4 additional stations (W, X, Y, and Z) were added to each site along with the standard A, B, C and D stations (Table 3). The catch from all 8 stations at each site were included in the calculation of annual BPUE for the surplus production model. The number of pots for all 8 stations (longlined string) was decreased to 5 in 2016 and 2017 due to limited number of research pots. In 2018, the survey method reverted to the original 4 stations (A, B, C, and D) per site with each station consisting of 11 pots.

Only stations A, B, C, and D were consistently sampled through the entirety of the survey and are considered Index Stations. These stations were fished every year at every site except in 1993 when station C of Prince of Wales was not fished, and in 1998 when the Prince of Wales site was not surveyed.

Gear Configuration and Deployment

Each station consisted of 1 long-lined string of pots, buoyed at both ends. Anchors were added to both ends starting in 2009. Pot placement was every 18.2 m on 219 m of groundline in all years of

the survey, except for 2016 and 2017 when the number of stations increased and the number of pots per station decreased. In these years pot placement was at every even numbered attachment point, or every 36.5 m.

Rectangular pots measuring 16” x 16” x 36” were used and were covered with black fabric except for the 2 tunnels on opposing ends. The tunnels were made of 1/2” web and had 2.5” openings. These pots did not fit the commercial pot specifications (5AAC 31.223) as they were designed to catch shrimp of all sizes.

Each pot was baited with a 2.5-quart perforated plastic jar containing chopped herring. Pots were set in the morning or early afternoon and retrieved the following morning with typical soak times from 20–22 hours and at target depths of 37–146 m. Catches from damaged pots and those with doors open were not included in the analysis, while lost pots were excluded from effort totals (Trowbridge 1994).

BIOLOGICAL COLLECTIONS

Biological data collected has varied since the inception of the spot shrimp pot survey, but certain observations have been recorded consistently throughout the time series. Since 1992, as each pot was retrieved and disconnected from the longline, the entire contents were separated by species and counted. Aggregate biomass (weights) for each species from each pot was recorded to the gram. All pots were visually inspected as they came on board to see if any had been compromised (i.e., open door, predator [e.g. octopus] present) and pots that had been compromised were noted on the sampling form and subsequently excluded from the analysis.

From 1992–2004, all spot shrimp from every pot were retained for biological data collection of sex, CL, and egg development. However, in 1996 all biological data were lost and in 1995 and 1997 the presence of eggs on female shrimp was not recorded. During this time period, the weight of individual shrimp was not recorded. Spot shrimp CL was measured from the front of the carapace directly behind 1 of the eyes (socket) to the terminal end of the carapace to the nearest 0.1 mm using electronic calipers, while sex was determined by examination of endopod morphology (Figure 5), using methods described by Butler (1980). From 1992–2004, nonovigerous females were identified by the presence or absence of breeding dress (Trowbridge 1994). Additional observations of ovigerous females included egg condition (eyed or uneyed), egg color, and number of dead eggs.

In 2005, only half of the males had CL measured from all pots although all females were measured. The following year, significant changes were made to biological collections by implementing a sub-sampling procedure and eliminating the protocol to collect biological information from all spot shrimp. From 2006–2023, biological data were collected from 1 randomly selected pot at each station instead of all pots as had been done previously (Rumble et al. 2022). Catch in all pots were still speciated, counted, and total weight (kg) of spot shrimp was recorded. The subsample pot was used to collect biological data on CL, sex, and egg development as was collected in prior years for all pots. Beginning in 2006, the individual weight (g) of spot shrimp was collected from the subsampled pot. The change from measuring CL for all shrimp to just the shrimp in the sub-sampled pots resulted in a substantial decrease in the proportion of the shrimp measured (Figure 4).

Sex of a spot shrimp was determined by the examination of the inner part of the second pleopod and its 2 appendages, the appendix masculine and the appendix interna, which vary in size

depending on the sexual stage as shown in the visual guide (Lowry 2007)(Figure 5). Beginning in 2012, since spot shrimp are protandric, those observed to be in metamorphosis from male to female were assigned a transitional sex code.

To construct a time series of CPUE for male and female spot shrimp using consistent information from index sites and stations, all shrimp not identified as female were assigned the male sex for this analysis.

BIOMASS AND COUNTS OF SPOT SHRIMP PER POT

The annual BPUE and CPUE for spot shrimp is calculated from the PWSA pot survey from 1992–present. The same equations estimate both BPUE and CPUE with slightly different inputs.

The annual survey-wide BPUE was calculated from all sites surveyed that year. The annual Area BPUE estimates are derived from those sites within each Area using the current Area boundaries established in 2015. The A, B, C, and D stations were surveyed at all sites in all years except in 1993 when station D was skipped at Site 6 (Green Island) and station C was skipped at Site 8 (Prince of Wales). In 1994, station O was added to Site 8 (Prince of Wales) and in 2016 and 2017, the W, X, Y, and Z stations were added to all sites to calculate BPUE (Table 3). The total spot shrimp weight for every pot in the survey has been recorded for the entire survey time series for a simple calculation of total spot shrimp BPUE. Prior to 2006, all shrimp had CL recorded (except for in 2005 when only half the males had CL recorded) but neither individual weights nor marketable-size aggregated weights were recorded. To estimate the individual weights of marketable-size shrimp prior to 2006, a length-weight relationship, developed from shrimp caught in the survey from 2006–2010 (Figure 6), was applied to the individual CLs:

$$w = e^{-7.004} * l^{2.864} \quad (1)$$

where w = whole weight in grams, and l = carapace length in mm.

From 2006–present, the proportion of marketable-size shrimp weight in the sub-sampled pot from each station was expanded for a within-site estimate of marketable-size shrimp BPUE.

The annual survey CPUE is calculated from the index stations at the index sites except in 1993 when station D was skipped at Site 6 (Green Island) and station C was skipped at Site 8 (Prince of Wales). The total spot shrimp count for every pot in the survey has been recorded for the entire survey time series for a simple calculation of total spot shrimp CPUE. From 2006–present, the proportion of each shrimp group (male, female, and marketable-size) counts in the sub-sampled pot from each station was expanded for a within-site estimate of marketable-size shrimp CPUE.

Total Shrimp Catch

The total catch of spot shrimp (c_{all}) was the sum of weights or counts in individual pots:

$$c_{all} = \sum_{i=1}^{N} c_{all_i} \quad (2)$$

where c_{all_i} is the catch in pot i, and N is the number of pots successfully fished.

The BPUE or CPUE ($\bar{c}_{all}$) of total shrimp was calculated by dividing the total catch by the total number of pots successfully fished:

$$\bar{c}_{all} = \frac{c_{all}}{N} \tag{3}$$

with variance calculated as

$$\text{var}(\bar{c}_{all}) = \frac{\sum_{i=1}^{N} \left(\bar{c}_{all_i} - c_{all} \right)^2}{N(N\text{-}1)} \tag{4}$$

Marketable-size, Male, and Female Catch

The catch of each group (g) of male, female, and marketable-size spot shrimp was calculated using a ratio estimator based on the proportion of each group's weight or counts in the sub-sampled pots, stratified by site.

Within-site

Within each site, the catch of each shrimp group (c_{g_h}) was estimated from the catch of all shrimp and proportion of each group:

$$\hat{c}_{g_h} = r_h c_{all_h} \tag{5}$$

where c_{all_h} is catch of all shrimp at site h, and
r_h is the proportion of each group measured at site h.

The proportion of each group was calculated from the measured shrimp pooled by site:

$$r_h = \frac{\sum_{i=1}^{n_h} S_{g_i}}{\sum_{i=1}^{n_h} S_{all_i}} \tag{6}$$

where S_{g_i} is the weight or count of the shrimp group measured in sample pot i, and
S_{all_i} is the weight or count of all shrimp measured in sample pot i.

The variance of the proportion of each group was estimated as:

$$\hat{\text{var}}(r_h) = \left(\frac{N_h\text{-}n_h}{N_h} \right) \left(\frac{s_h^2}{\hat{\mu}_{all_h}^2 n_h} \right) \tag{7}$$

Where

$$\hat{\mu}_{all_h} = \frac{1}{n_h} \sum_{i=1}^{n_h} S_{all_i} \tag{8}$$

$$s_h^2 = \sum_{i=1}^{n_h} \frac{\left(\hat{c}_{g_i} - r_h c_{all_i} \right)^2}{n_h - 1} \tag{9}$$

μ_{all_h} is the average count or weight of groups per pot at site h,

$$\frac{1}{N_h} \sum_{i=1}^{N_h} S_{all_i} \text{ ;} \tag{10}$$

n_h is the number of sub-sampled pots at site h; and
N_h is the total number of pots at site h.

The variance for BPUE of marketable-size shrimp and CPUE of marketable-size, male, and female spot shrimp was estimated as:

$$\hat{\text{var}}(\hat{c}_{lrg_h}) = \hat{\text{var}}\left(c_{all_h}\, r_h\right) \approx \left(c_{all_h}\right)^2 \hat{var}(r_h) + (r_h)^2 \text{var}\left(c_{all_h}\right) - \hat{\text{var}}(r_h)\text{var}\left(c_{all_h}\right) \quad (11)$$

where

$$\text{var}\left(c_{all_h}\right) = \sum_{i=1}^{N_h} \frac{\left(c_{all_i} - \bar{c}_{all_i}\right)^2}{N_h - 1} \quad (12)$$

Area and Survey-wide

The Area and survey-wide catch of each shrimp group (c_g) was estimated by summing the estimated weight or count of each group within each site:

$$\hat{c}_g = \sum_{h=1}^{L} \hat{c}_{g_h} \quad (13)$$

where L is the number of sites in each area or in the survey.

BPUE of marketable-size or CPUE of each group ($\bar{c}_g$) was estimated as

$$\bar{c}_g = \frac{c_g}{N} \quad (14)$$

with variance estimated from the sum of the estimated variances of each group's catch within each site:

$$\hat{\text{var}}(\bar{c}_g) = \frac{\sum_{h=1}^{L} \hat{\text{var}}(c_{g_h})}{N^2} \quad (15)$$

SURPLUS PRODUCTION MODEL

The Schaefer surplus production model is run every year with the most recent inputs to re-calculate model parameters, the annual exploitable biomass, index of relative abundance, and MSY (with upper and lower confidence intervals) for PWSA spot shrimp. The annual exploitable biomass equation is written as follows:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t \quad (16)$$

where r is an intrinsic rate of population growth, K is a parameter that corresponds to the unfished equilibrium population size, B_{t+1} is the exploitable biomass at the end of year t or the beginning of year t+1, B_t is the exploitable biomass at the start of year t, and C_t is the biomass caught during year t.

Also, an index of relative abundance is generated from the equation:

$$\hat{I}_t = q\frac{\hat{B}_{t+1} + \hat{B}_t}{2} \tag{17}$$

where $\hat{I}_t$ is an estimated index of relative abundance for year t and q is the catchability coefficient, proportion of the total stock taken by 1 unit of effort ($I = qB$). Since the stock biomass changes within the year (t) due to the stock growth and death (including catches) in that year, the equation uses the average biomass at the start (B_t) and end of year t (B_{t+1}) so that the catches or catchability coefficient, q, relates to the biomass more realistically. The input data to the model are catches (C_t) and BPUE (observed I_t) from 1981–present. The BPUE data are from 2 sources: 1 is the commercial fisheries (1981–1988); the other is the survey (1989–present) which includes survey data from before the ADF&G standardized survey began in 1992. The BPUE from commercial fisheries is adjusted to the level of the survey BPUE using the ratio of the average BPUE from 1989 and 1990 to the average BPUE from 1987 and 1988. The catch data is the total catch weight, which is summation of catches from the survey, the commercial and non-commercial fisheries.

The parameters r, K, initial biomass B_0, and q are estimated by minimizing the sum of squares error $\sum (I_t - \hat{I}_t)^2$. The maximum sustainable yield (MSY) is obtained from the equation

$$MSY = \frac{rK}{4}. \tag{18}$$

To determine the uncertainty in the estimate of MSY, a bootstrap analysis is conducted by resampling the residuals between estimated BPUE ($\hat{I}_t$) and observed BPUE (I_t). Ninety percent confidence intervals are constructed using at least 1,000 bootstrapping samples. The lower confidence interval (CI) bound is used instead of MSY as the harvestable surplus biomass in order to capture some of the uncertainty of MSY and set more conservative, sustainable harvest levels.

SIZE AT TRANSITION TO FEMALE

Sex and CL data collected from 10,368 spot shrimp from 1992 to 2023 were used to analyze the relationship between CL and sexual transition from male to female.

The survey design includes pots nested within a station (11 pots to a station), stations nested within a site (4 stations to a site), and 7 sites spatially distributed throughout the survey area. To take the survey design into account, stations nested within site were included as a grouping parameter and modeled as a random effect. Also of interest is the overall "average" effect of size of shrimp transitioning to female across all years of the survey. To account for annual variability in female transition, survey year was included as a random effect. Shrimp were measured in every pot from 1992 to 2005, but beginning in 2006, 1 pot was randomly sampled for biological data from each station. This made it difficult to account for the second level of nesting (pot within a station) in the analysis, so for practical purposes this grouping effect is ignored. Generalized linear mixed-effects modeling was used for this analysis (Zuur et al. 2009). Mixed effects models allow grouping parameters to vary randomly while estimating population level parameters for the fixed effects. It is acknowledged that temporal and spatial autocorrelation may exist within the data, but these were not modeled in the interest of simplifying the analysis.

A binomial generalized linear model was used to estimate morphological maturity at size (McCallagh and Nelder 1989). For each year (s), site (j), and station (k), female transition (u) of shrimp (i) can be treated as following a Bernoulli distribution with probability (π) according to:

$$logit(\pi_{sijk}) = \alpha + \beta cl_{sijk} + a_i + b_i cl_{sijk} + c_{ij} + d_{ij} cl_{sijk} + e_{ijk} + f_{ijk} cl_{sijk} + \varepsilon_{sijk} \quad , \tag{19}$$

$$u_{sijk} \sim \text{Bern}(\pi_{sijk}) \; . \tag{20}$$

Where:

$$a_i \sim N(0, \sigma_a^2);\; b_i \sim N(0, \sigma_b^2);\; c_{ij} \sim N(0, \sigma_c^2);\; d_{ij} \sim N(0, \sigma_d^2);\; \square ijk \sim N0, \sigma e2;\; fijk \sim N0, \sigma f2;\; \varepsilon sijk \sim N0, \sigma 2, \tag{21}$$

having random intercepts year (a), site within year (c), and station within site within year (e), and random slopes year (b), site within year (d), and station within site within year (f). The fixed effect intercept is represented by α and the fixed effect slope by β. The error term is represented by ε.

With the CL_{50} calculated as:

$$CL_{50} = \frac{-\alpha}{\beta} \tag{22}$$

For mixed effects models, this would be considered the CL_{50} for an "average" year. Survey year CL_{50} was calculated similarly but including the yearly deviations from the random intercepts and slopes. Following the sampling design, a pairwise bootstrap procedure drawing 1000 random samples was used to estimate CL_{50} 95% CI (Roa et al. 1999).

AGE ESTIMATES

Age at marketable-size (32 mm), age at CL_{50}, and age of the average size of males caught in the survey were estimated using a von Bertalanffy growth model (VBGM) and parameters estimated from a PWSA spot shrimp mark-recapture study conducted in the mid-1980s in Unakwik Inlet (Kimker et al. 1996). Using a mark-recapture parametrization of the VBGM the estimated growth parameters from that study were $L_\infty = 49.2$, $K = 0.26$. The authors fixed t_0 at values of -10, 0 and 10 and found little effect on the overall results so for this report and analysis, $t_0 = 0$ was used. Age estimates in this study are considered approximate since there are a number of factors that contribute to the uncertainty and possible bias in the estimates. These include the use of parameters from the mark-recapture parametrization of the typical VBGM equation, there was no uncertainty in parameter estimates reported in the original study, and possible temporal variation in growth.

SURVEY DATA CORRELATIONS WITH SIZE AT TRANSITION TO FEMALE

Annual observations from the PWSA shrimp pot survey were tested to see if there were significant correlations with annual CL_{50} estimates using univariate linear regression models. Annual survey observations included: average male shrimp CL, proportion of females in total CPUE, and marketable-size, male, female, and total shrimp CPUE. The annual CL_{50} estimates were tested against survey observations from the same year and against survey observations from 1–6 years prior. Statistical analysis to determine the best-fit regression model included SE, Akaike information criterion (AIC), p-value, and R^2.

RESULTS

BIOMASS PER POT OF MARKETABLE-SIZE AND TOTAL SHRIMP

From 1992 to 2023, survey-wide BPUE of marketable-size (≥ 32 mm) shrimp has been calculated with as few as 6 sites and as many as 9 sites (Table 3). The survey-wide BPUE of marketable-size shrimp has ranged from a low of 0.07 kg in 1998 to a high of 1.05 kg in 2020, with a survey average of 0.45 kg (Table 4). Since the peak in 2020, BPUE of marketable-size shrimp has been declining (Figure 7) with the last 2-years below the survey average at 0.40 kg in 2022 and 0.24 in 2023. Survey-wide marketable-size and total shrimp BPUE were low in the 1990s, had a general increase up to 2008 and 2009 followed by a slight decrease until the peak years from 2016–2020 which led to 3-years of decreasing values (Figure 7).

Area 1 BPUE of marketable-size shrimp was only calculated from Site 1 (Unakwik) until Site 9 (Long Bay) was added in 2009 and Site 10 (Bald Head Chris) was added in 2012 (Table 3). Area 1 BPUE of marketable-size shrimp has ranged from a low of 0.06 kg in 1999 to a high of 1.67 kg in 2020, with a survey average of 0.72 kg (Table 5). Area 1 marketable-size and total shrimp BPUE were low during the first 10-years of the survey, followed by relatively high inter-annual variability that led to the peak in 2020 followed by 3-years of decreasing values (Figure 8).

Area 2 BPUE of marketable-size shrimp has been calculated from Site 2 (Golden) and Site 3 (Culross) for the entire time series (Table 3). Area 2 BPUE of marketable-size shrimp has ranged from a low of 0.07 kg in 1998 to a high of 1.05 kg in 2016, with a survey average of 0.47 kg (Table 6). Area 2 marketable-size and total shrimp BPUE were low during the first 10-years of the survey, followed by relatively high in 2008 and 2009, then a slight decrease that led to the peak in 2016 followed by 7-years of mostly diminishing values (Figure 9).

Area 3 BPUE of marketable-size shrimp has been calculated from 3, 4, and 5 sites during the entire time series (Table 3). Area 3 BPUE of marketable-size shrimp has ranged from a low of 0.05 kg in 1998 to a high of 0.67 kg in 2018, with a survey average of 0.26 kg (Table 7). Area 3 marketable-size and total shrimp BPUE were low during the first 10-years of the survey, followed by relatively high in 2008 and 2009, then a slight decrease that led to the peak in 2018 followed by 5-years of mostly decreasing values (Figure 10).

Spot shrimp CL bins weighted by BPUE indicates there was strong recruitment that led to the peak in abundance from 2017–2020, although there does not appear to be any recent strong recruitment cohorts (Figure 11).

SURPLUS PRODUCTION MODEL

The surplus production model is run annually with the most recent total removals and survey BPUE and re-estimates annual exploitable biomass and index of relative abundance. The results after the 2023 survey indicate that both the exploitable biomass and index of relative abundance were substantially higher than the survey time series average and slightly below the 2010–2022 average (Table 8). Due to the dependence of the index of relative abundance on the exploitable biomass calculations, relative temporal trends in these 2 model output time series are the same. Both model outputs capture the substantial decrease in the PWSA spot shrimp stock status from the beginning of the time series to the lowest values in 1991 (Table 8, Figure 12). Both outputs indicate that the stock status has been stable during the last 10 years relative to the beginning of the time series.

COUNT PER POT AT INDEX SITES/STATIONS

The annual average total number of successful pot lifts at index stations from index sites was 292 with an average of 42 pot lifts per site. (Table 9).

The index sites' annual CPUE of marketable-size spot shrimp ranged from a low of 2.16 shrimp in 1998 to a high of 32.98 shrimp in 2020, with a survey average of 15.70 shrimp for the entire survey time series. The average marketable-size spot shrimp CPUE from 2010–2022 was more than double the average from 1992–2009 (Table 10). The time series for marketable-size shrimp CPUE was at its minimum in the 1990s, reached its peak in 2020, and has been declining since with the last 3 years below the 2010–2022 average and 2023 below the 1992–2009 average (Figure 13).

The index sites' annual CPUE of male spot shrimp ranged from a low of 6.42 shrimp in 1993 to a high of 123.19 shrimp in 2017, with a survey average of 40.69 shrimp for the entire survey time series. The average male spot shrimp CPUE from 2010–2022 was more than double the average from 1992–2009 (Table 10). The time series for male shrimp CPUE was at its minimum in the 1990s and in 2010 and reached its peak in 2017 and has been declining since with the last 2 years below the 2010–2022 average and 2023 below the 1992–2009 average (Figure 14).

The index sites' annual CPUE of female spot shrimp ranged from a low of 0.46 shrimp in 1998 to a high of 13.62 shrimp in 2020, with a survey average of 4.38 shrimp for the entire survey time series. The average female spot shrimp CPUE from 2010–2022 was more than double the average from 1992–2009 (Table 10). Annual CPUE for female shrimp was at its minimum in the 1990s, was low again in 2015, reached its peak in 2020, and has since followed a declining trend. Annual CPUE for female shrimp in 2022 and 2023 fell below the 2010–2022 average (Figure 15).

The index sites' annual CPUE of total spot shrimp ranged from a low of 8.01 shrimp in 1993 to a high of 130.64 shrimp in 2017, with a survey average of 44.09 shrimp for the entire survey time series. The average total spot shrimp CPUE from 2010–2022 was more than double the average from 1992–2009 (Table 10). The time series for total shrimp annual CPUE was at its minimum in the 1990s, was low again in 2010 and reached its peak in 2017. Since then, the annual CPUE for total shrimp has been declining, with the last 2 years below the 2010–2022 average and 2023 below the 1992–2009 average (Figure 16). For the years of the time series when sex information was recorded (all years except 1996) female spot shrimp average CPUE was 9.7% and male spot shrimp was 90.3% of the total spot shrimp average CPUE with the highest proportions of females occurring from 2009–2013 (Figure 17).

BIOLOGICAL COLLECTIONS

Biological collections of length and weight have varied since the beginning of the PWSA spot shrimp survey with a total of 127,155 CL recorded from shrimp identified as male, female, and transitional from all sites and stations. Observed CLs from all sites and stations was 7.8–49.8 mm for males, 24.4–49.7 mm for transitional, and 25.5–56.6 mm for females (Figure 18).

Index Sites and Stations

The number of pots sampled for biological information from index sites and stations has also varied over time with a significant decrease starting in 2006 (Table 11). The number of female spot shrimp measured was 9% and the number of male shrimp measured was 91% of the total spot shrimp measured for the time series.

Male spot shrimp (males and those not identified as females) had a time series average CL of 29.1 mm with a SD of 4.9 mm while female spot shrimp had an average CL of 42.6 with a SD of 2.8 mm (Table 11). Annual average CLs of the sexes had no apparent trends in the time series (Figure 19) from the shrimp measured in the sampled pots. Most of the female shrimp measured were egg bearing, resulting in a series average of 94% of the females being gravid with 2006–2010 being consecutive years of below the time series average (Figure 20).

SIZE AT TRANSITION TO FEMALE

Annual CL_{50} estimates for spot shrimp collected in the PWSA pot survey fitted with a logistic regression varied by year (Figure 21) with a time series low from 2007–2010 and again during the last 4 years of the survey, which had the smallest CL_{50} observations (Figure 22). The time series had a max CL_{50} in 2003 of 42.4 mm and a minimum in 2022 of 37.4 mm (Table 12). The mixed effects model (Table 13) estimated mean CL_{50} at 39.9 mm with a lower 95% CI of 37.6 mm and an upper 95% CI of 42.2 mm (Table 12).

AGE ESTIMATES

The VBGM produced from the PWSA tagging study estimated the age of male shrimp with an average carapace length from index stations at index sites of (29.1 mm) as 3.1 years old. Marketable-size (32mm) shrimp were estimated as 3.6 years old and the age at CL_{50} was estimated as 5.8 years old (Figure 23). As a result of the age estimates, the average males caught in the survey at index sites and stations have approximately 3-years before transitioning to female.

SURVEY DATA CORRELATIONS WITH SIZE AT TRANSITION TO FEMALE

The best univariate model (lowest AIC) for the dataset to predict CL_{50} from index site and station biological and CPUE survey metrics was male CPUE lagged 3-years from the annual CL_{50} estimate (Table 14). The highly significant model (p-value <0.005) with 25 degrees of freedom, had an R^2 value of 0.654 and indicated a negative correlation between male CPUE and the size of transition to female 3-years later (Figure 24).

DISCUSSION

The PWSA pot survey for spot shrimp has provided information for management decisions since it began in 1992. Although there have been slight modifications to the survey design, the overall spatial extent, survey timing, and fishing gear used has been consistent. This is the first report to completely summarize the survey and officially document the locations of each individual station to ensure consistency going forward.

The current PWSA pot survey design doesn't include waters that are typically of high noncommercial harvest near the ports of Whittier and Valdez. To more accurately capture trends in shrimp abundance in areas of high noncommercial harvest and provide survey BPUE for the inputs to the surplus production model from these areas of high noncommercial harvest ADF&G will need to add additional sites to the survey.

Spot shrimp first begin to be captured in the pot survey at ~20mm which corresponds to approximately 2-years of age. This is consistent with previous research that indicates this is the age at which spot shrimp move from shallower waters with vegetation protection into rockier adult habitat. The approximation of aging spot shrimp at marketable size of ~3–4 years old will provide

insight into the timing of recruitment processes for future management decisions as will the estimate of transition to female at ~5–6 years old.

Biological collections on the survey indicate the PWSA spot shrimp may be some of the oldest of the species as the largest CLs don't appear to fit on the current growth curve. Kimker et al. (1996), found that the maximum age of spot shrimp in PWSA exceeded 7 years of age and Smith (2020) used 8 as the maximum age for management in Southeast Alaska. Another tagging study is recommended to be conducted in multiple areas of the PWSA to generate a new, current growth model and to reassess maximum age in areas where growth potential may vary.

The negative correlation between male CPUE and the size at transition to female 3-years later may be the result of density dependence factors that are not fully understood. A relatively large population of males may promote faster development and sexual transition and thus females are present in the population at a smaller size 3-years later. An alternative interpretation may be that the growth curve used from the previous study is not necessarily applicable to all growing conditions and population structures. This may indicate that when the male population is relatively large that growth is faster and transition to females occurs at a younger age 3-years later.

The trends in both the survey BPUE and CPUE time series indicate that PWSA spot shrimp metapopulation abundance was relatively depressed in the 1990s. The survey results suggest PWSA spot shrimp abundance began to increase in the early 2000s, with only non-commercial fisheries harvesting occurring, which may indicate a re-building of the metapopulation. With the onset of commercial fisheries in 2010, there appears to be a decrease in the survey abundance indices followed by an increase in interannual variability. This was followed by an increase in the BPUE and CPUE time series that led to the relative time series maximum survey catches from 2016–2020 for all data sets. During these years of survey catch maximum, commercial and non-commercial harvest was also at its largest (Figure 3). Since 2020, all survey results indicate that the spot shrimp abundance in the PWSA is decreasing and is approaching abundance levels similar to the 1990s.

The trends in the outputs from the surplus production model, which estimates MSY and exploitable biomass, follow the trends in BPUE or CPUE from the pot survey in recent years. The dynamics of a surplus production model show how population sizes change in response to fishing over time. When fishing pressure is high, the population decreases; when fishing pressure is low, the population increases. If other non-fishing factors, such as process error, mainly cause changes in the population, the model might not match the fishery or survey data, or the population might not be responding as expected to fishing pressure. Another key point of the model is that CPUE data should reliably indicate the population size over time, yet this isn't always true. The model relies on the parameter q, the catchability coefficient, which may not hold constant through years. This value might change if survey methods and locations change over the years. Understanding these assumptions and limitations is crucial for effectively using the model's results in fishery management.

Potential adjustments to the PWSA shrimp assessment include developing a random effects model for the index station CPUE for an input to the surplus production model. It could also be beneficial to generate a standardized CPUE from the commercial and noncommercial fisheries as either an input to the surplus production model or to compare to the trends from the survey CPUE. ADF&G is also considering a change from the Schaefer surplus production model to a Pella-Tomlinson approach and using a likelihood or Bayesian method instead of sums of squares.

Historical harvest records indicate that a PWSA shrimp pot fishery with a commercial and non-commercial combined harvest over 200,000 lb is not likely sustainable. Recent PWSA harvest once again exceeded 200,000 lb and the following years' survey results indicated a decrease in the spot shrimp population. This may provide context to evaluate the maximum harvest that the PWSA pot shrimp fishery can sustain and thus offer another tool for ADF&G to sustainably manage this resource.

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TABLES AND FIGURES

Table 1.–Total Allowable Harvest (TAH), Guideline Harvest Level (GHL), and commercial harvest for the Prince William Sound Area shrimp pot fishery.

						Harvest (lb)			
Year	TAH (lb)	GHL (lb)	Area	Vessels (*n*)	Pot lifts	Spot	Coonstripe	Other	Total
2010	137,500	55,000	1	75	18,025	45,076	263	10	45,349
2011	131,900	52,760	2	45	29,580	51,302	1,204	44	52,550
2012	128,100	51,240	3	35	19,644	18,097	3,428	36	21,561
2013	165,750	66,300	1	45	34,804	59,376	2,266	2	61,644
2014	166,500	66,600	2	32	41,670	64,220	4,085	158	68,464
2015	167,000	67,000	3	30	20,004	21,193	1,934	11	23,138
2016	117,653	47,061	1	57	27,360	47,822	580	21	48,423
2017	167,000	67,000	2	54	45,261	66,555	783	83	67,421
2018	168,000	68,000	3	45	41,351	65,101	2,268	5	67,375
2019	170,200	68,100	1	72	34,094	68,700	245	2	68,947
2020	170,209	68,100	2	73	32,679	69,777	120	1	69,898
2021	175,000	70,000	3	71	44,281	69,488	677	4	70,169
2022	167,250	66,900	1	64	34,222	64,661	512	3	65,176
2023	157,750	63,100	2	73	37,726	61,950	308	2	62,260

Table 2.–Prince Willaim Sound Area spot shrimp pot survey dates.

Year	Vessel	Start Date	End Date	Survey days
1992	*Montague*	10/7/1992	10/15/1992	8
1993	*Montague*	10/20/1993	10/28/1993	8
1994	*Montague*	10/21/1994	10/29/1994	8
1995	*Montague*	10/25/1995	11/2/1995	8
1996	*Montague*	11/6/1996	11/14/1996	8
1997	*Montague*	10/16/1997	10/24/1997	8
1998	*Montague*	10/14/1998	10/21/1998	7
1999	*Montague*	10/5/1999	10/13/1999	8
2000	*Montague*	10/10/2000	10/19/2000	9
2001	*Montague*	10/11/2001	10/19/2001	8
2002	*Montague*	10/10/2002	10/17/2002	7
2003	*Solstice*	10/9/2003	10/17/2003	8
2004	*Solstice*	10/6/2004	10/14/2004	8
2005	*Solstice*	10/2/2005	10/10/2005	8
2006	*Solstice*	10/11/2006	10/19/2006	8
2007	*Pandalus*	10/15/2007	10/24/2007	9
2008	*Solstice*	10/8/2008	10/16/2008	8
2009	*Solstice*	10/13/2009	10/21/2009	8
2010	*Solstice*	10/15/2010	10/23/2010	8
2011	*Solstice*	10/12/2011	10/20/2011	8
2012	*Solstice*	10/18/2012	10/27/2012	9
2013	*Solstice*	10/13/2013	10/23/2013	10
2014	*Solstice*	10/13/2014	10/23/2014	10
2015	*Solstice*	10/13/2015	10/23/2015	10
2016	*Solstice*	10/13/2016	10/22/2016	9
2017	*Solstice*	10/13/2017	10/23/2017	10
2018	*Solstice*	10/14/2018	10/24/2018	10
2019	*Solstice*	10/13/2019	10/22/2019	9
2020	*Solstice*	10/15/2020	10/24/2020	9
2021	*Solstice*	10/13/2021	10/23/2021	10
2022	*Solstice*	10/14/2022	10/23/2022	9
2023	*Solstice*	10/13/2023	10/22/2023	9

Table 3.–All stations surveyed in the Prince William Sound Area spot shrimp pot survey.

	Area 1			Area 2			Area 3			
	Sites									
	1*	9	10	2*	3*	4*	5*	6	7*	8*
Year	Unakwik	Long Bay	Bald Head Chris	Golden	Culross	Herring Bay	Junction Island	Green Island	Chenega	Prince of Wales
1992	ABCD	ND	ND	ABCD	ABCD	ABCD	ND	ABCD	ABCD	ABCD
1993	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABC	ABCD	ABD
1994	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCDO
1995	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
1996	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
1997	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
1998	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ND
1999	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
2000	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
2001	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
2002	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2003	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
2004	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
2005	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
2006	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
2007	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD
2008	ABCD	ND	ND	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2009	ABCD	ABCD	ND	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2010	ABCD	ABCD	ND	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2011	ABCD	ABCD	ND	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2012	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2013	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2014	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2015	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD		ABCD	ABCD
2016	WXYZ	WXYZ	WXYZ	WXYZ	WXYZ	WXYZ	WXYZ	ND	WXYZ	WXYZ
	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD		ABCD	ABCD
2017	WXYZ	WXYZ	WXYZ	WXYZ	WXYZ	WXYZ	WXYZ	ND	WXYZ	WXYZ
2018	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2019	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2020	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2021	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2022	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD
2023	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ABCD	ND	ABCD	ABCD

Note: ND = no data (sites not surveyed). * = Index site.

Table 4.–Annual biomass per unit effort (BPUE) of spot shrimp from all sites and stations in the Prince William Sound Area spot shrimp pot survey.

					Marketable-size		Total	
Year	Sites (*n*)	Stations (*n*)	Pots set (*n*)	Pots sampled (*n*)	BPUE (kg/pot)	Var	BPUE (kg/pot)	Var
1992	8	32	349	349	0.25	0.002	0.32	0.018
1993	8	30	325	324	0.12	0.001	0.17	0.012
1994	8	33	355	353	0.08	0.001	0.19	0.013
1995	8	32	350	350	0.15	0.001	0.27	0.015
1996	8	32	350	ND	ND	ND	0.24	0.015
1997	8	32	345	342	0.10	0.001	0.19	0.014
1998	6	24	264	264	0.07	0.001	0.13	0.011
1999	8	32	346	332	0.10	0.002	0.22	0.015
2000	8	32	349	349	0.18	0.002	0.32	0.020
2001	8	32	351	350	0.29	0.002	0.43	0.023
2002	7	28	304	298	0.37	0.003	0.56	0.034
2003	8	32	352	352	0.36	0.003	0.51	0.033
2004	8	32	352	352	0.38	0.002	0.65	0.038
2005	8	32	349	349	0.28	0.002	0.65	0.035
2006	8	32	346	32	0.37	0.025	0.72	0.038
2007	8	32	349	32	0.48	0.033	1.09	0.052
2008	8	28	348	32	0.50	0.020	1.16	0.058
2009	8	32	351	32	0.67	0.032	1.07	0.052
2010	8	32	350	32	0.50	0.017	0.62	0.036
2011	8	32	350	30	0.76	0.029	0.89	0.060
2012	9	36	392	50	0.72	0.016	0.96	0.052
2013	9	36	392	36	0.62	0.013	0.86	0.043
2014	9	36	393	36	0.63	0.021	0.87	0.043
2015	9	32	395	36	0.46	0.018	0.72	0.036
2016	9	72	359	72	0.90	0.026	1.25	0.063
2017	9	72	359	71	0.87	0.049	1.78	0.077
2018	9	36	392	36	0.85	0.054	1.73	0.053
2019	9	36	393	36	0.67	0.042	1.50	0.058
2020	9	36	386	36	1.05	0.035	1.77	0.062
2021	9	36	385	36	0.62	0.023	1.10	0.055
2022	9	36	372	36	0.40	0.011	0.74	0.044
2023	9	36	376	36	0.24	0.012	0.41	0.031
Survey avg	8	35	357	164	0.45	0.016	0.75	0.038

Note: ND= no data. Marketable-size spot shrimp are ≥ 32 mm carapace length. Var = annual variance.

Table 5.–Annual biomass per unit effort (BPUE) of spot shrimp from all Area 1 sites and stations in the Prince William Sound Area spot shrimp pot survey.

					Marketable-size		Total	
Year	Sites (*n*)	Stations (*n*)	Pots set (*n*)	Pots sampled (*n*)	BPUE (kg/pot)	Var	BPUE (kg/pot)	Var
1992	1	4	43	43	0.38	0.009	0.39	0.059
1993	1	4	43	43	0.30	0.007	0.31	0.045
1994	1	4	44	44	0.13	0.003	0.18	0.031
1995	1	4	44	44	0.21	0.004	0.30	0.041
1996	1	4	44	ND	ND	ND	0.26	0.048
1997	1	4	44	43	0.20	0.007	0.23	0.048
1998	1	4	44	44	0.08	0.003	0.10	0.024
1999	1	4	44	44	0.06	0.003	0.10	0.031
2000	1	4	44	44	0.14	0.003	0.18	0.025
2001	1	4	44	44	0.45	0.008	0.52	0.063
2002	1	4	44	38	0.24	0.007	0.35	0.051
2003	1	4	44	44	0.18	0.005	0.28	0.051
2004	1	4	44	44	0.95	0.013	1.41	0.129
2005	1	4	44	44	0.57	0.009	0.76	0.085
2006	1	4	42	4	1.08	0.027	1.29	0.095
2007	1	4	43	4	1.26	0.117	1.62	0.116
2008	1	4	44	4	1.26	0.050	1.57	0.127
2009	2	8	87	8	0.99	0.064	1.26	0.125
2010	2	8	88	8	0.75	0.059	0.85	0.078
2011	2	8	87	8	1.51	0.107	1.65	0.162
2012	3	12	132	12	1.21	0.018	1.33	0.123
2013	3	12	130	12	0.71	0.022	0.81	0.084
2014	3	12	131	12	0.78	0.025	0.90	0.082
2015	3	12	132	12	0.66	0.038	0.83	0.070
2016	3	24	120	24	1.27	0.042	1.53	0.128
2017	3	24	120	24	1.11	0.074	1.76	0.128
2018	3	12	132	12	1.14	0.106	1.69	0.104
2019	3	12	130	12	0.90	0.102	1.78	0.112
2020	3	12	125	12	1.67	0.052	2.32	0.113
2021	3	12	130	12	0.92	0.040	1.38	0.096
2022	3	12	124	12	0.76	0.022	1.16	0.097
2023	3	12	127	12	0.44	0.023	0.61	0.065
Survey avg	2	8	79	25	0.72	0.034	0.93	0.082

Note: ND= no data. Marketable-size spot shrimp are ≥ 32 mm carapace length. Var = annual variance.

Table 6.–Annual biomass per unit effort (BPUE) of spot shrimp from all Area 2 sites and stations in the Prince William Sound Area spot shrimp pot survey.

					Marketable-size		Total	
Year	Sites (*n*)	Stations (*n*)	Pots set (*n*)	Pots sampled (*n*)	BPUE (kg/pot)	Var	BPUE (kg/pot)	Var
1992	2	8	131	131	0.19	0.002	0.28	0.023
1993	2	8	130	129	0.14	0.002	0.22	0.021
1994	2	8	132	130	0.08	0.001	0.19	0.018
1995	2	8	130	130	0.14	0.001	0.28	0.021
1996	2	8	131	ND	ND	ND	0.24	0.026
1997	2	8	128	127	0.08	0.001	0.18	0.020
1998	2	8	132	132	0.07	0.001	0.17	0.020
1999	2	8	130	116	0.15	0.005	0.33	0.030
2000	2	8	130	130	0.19	0.003	0.35	0.032
2001	2	8	131	130	0.38	0.004	0.54	0.044
2002	2	8	129	129	0.58	0.005	0.90	0.061
2003	2	8	132	132	0.57	0.007	0.79	0.068
2004	2	8	132	132	0.44	0.004	0.83	0.064
2005	2	8	132	132	0.33	0.003	0.90	0.065
2006	2	8	132	12	0.38	0.036	0.84	0.063
2007	2	8	131	12	0.38	0.066	1.46	0.094
2008	2	8	132	12	0.41	0.046	1.44	0.092
2009	2	8	132	12	0.65	0.070	1.21	0.084
2010	2	8	130	12	0.58	0.023	0.74	0.060
2011	2	8	131	12	0.80	0.024	0.99	0.082
2012	2	8	129	15	0.66	0.036	1.05	0.063
2013	2	8	131	12	0.67	0.029	1.16	0.072
2014	2	8	131	12	0.73	0.057	1.24	0.073
2015	2	8	131	12	0.57	0.039	1.13	0.055
2016	2	16	119	24	1.05	0.063	1.64	0.099
2017	2	16	119	24	0.95	0.118	2.53	0.140
2018	2	8	132	12	0.75	0.084	2.04	0.078
2019	2	8	132	12	0.71	0.061	1.81	0.086
2020	2	8	129	12	0.92	0.064	2.06	0.084
2021	2	8	130	12	0.72	0.041	1.32	0.097
2022	2	8	119	12	0.32	0.016	0.63	0.057
2023	2	8	122	12	0.13	0.019	0.38	0.053
Survey avg	2	9	129	62	0.47	0.030	0.93	0.061

Note: ND= no data. Marketable-size spot shrimp are ≥ 32 mm carapace length. Var = annual variance.

Table 7.–Annual biomass per unit effort (BPUE) of spot shrimp from all Area 3 sites and stations in the Prince William Sound Area spot shrimp pot survey.

					Marketable-size		Total	
Year	Sites (*n*)	Stations (*n*)	Pots set (*n*)	Pots sampled (*n*)	BPUE (kg/pot)	Var	BPUE (kg/pot)	Var
1992	4	16	175	175	0.26	0.003	0.34	0.027
1993	5	19	152	152	0.06	0.001	0.09	0.010
1994	5	20	179	179	0.08	0.001	0.19	0.021
1995	5	20	176	176	0.15	0.002	0.25	0.023
1996	5	20	175	ND	ND	ND	0.23	0.018
1997	5	20	173	172	0.08	0.001	0.18	0.019
1998	3	12	88	88	0.05	0.001	0.09	0.011
1999	5	20	172	172	0.07	0.001	0.16	0.016
2000	5	20	175	175	0.18	0.002	0.33	0.030
2001	5	20	176	176	0.18	0.002	0.32	0.027
2002	4	16	131	131	0.21	0.003	0.30	0.027
2003	5	20	176	176	0.24	0.003	0.36	0.030
2004	5	20	176	176	0.19	0.002	0.32	0.028
2005	5	20	173	173	0.19	0.002	0.43	0.039
2006	5	20	172	16	0.20	0.040	0.49	0.046
2007	5	20	175	16	0.36	0.031	0.68	0.055
2008	4	16	172	16	0.37	0.017	0.85	0.082
2009	4	16	132	12	0.48	0.022	0.79	0.067
2010	4	16	132	12	0.27	0.010	0.35	0.043
2011	4	16	132	10	0.22	0.017	0.28	0.035
2012	4	16	131	23	0.29	0.027	0.51	0.049
2013	4	16	131	12	0.48	0.017	0.61	0.056
2014	4	16	131	12	0.39	0.015	0.47	0.046
2015	4	16	132	12	0.15	0.008	0.21	0.024
2016	4	32	120	24	0.37	0.026	0.57	0.063
2017	4	32	120	23	0.54	0.050	1.06	0.090
2018	4	16	128	12	0.67	0.086	1.45	0.084
2019	4	16	131	12	0.39	0.045	0.92	0.085
2020	4	16	132	12	0.59	0.066	0.97	0.086
2021	4	16	125	12	0.20	0.038	0.59	0.074
2022	4	16	129	12	0.13	0.021	0.44	0.050
2023	4	16	127	12	0.15	0.018	0.24	0.034
Survey avg	4	18	148	77	0.26	0.019	0.47	0.044

Note: ND = no data. Marketable-size spot shrimp are ≥ 32 mm carapace length. Var = annual variance.

Table 8.–Annual outputs and time series averages of exploitable biomass and index of relative abundance from the Prince William Sound Area shrimp surplus production model.

Year	Exploitable Biomass (lb)	Index of Relative Abundance
1982	772,420	0.78
1983	773,369	0.78
1984	721,675	0.73
1985	671,935	0.68
1986	543,398	0.55
1987	383,034	0.39
1988	214,561	0.22
1989	82,459	0.08
1990	77,913	0.08
1991	64,401	0.07
1992	66,088	0.07
1993	85,549	0.09
1994	110,708	0.11
1995	135,099	0.14
1996	164,789	0.17
1997	204,741	0.21
1998	254,299	0.26
1999	318,333	0.32
2000	394,823	0.40
2001	486,821	0.49
2002	588,064	0.59
2003	705,033	0.71
2004	829,190	0.84
2005	945,736	0.96
2006	1,059,036	1.07
2007	1,165,654	1.18
2008	1,250,800	1.26
2009	1,329,182	1.34
2010	1,398,728	1.41
2011	1,367,184	1.38
2012	1,376,940	1.39
2013	1,425,533	1.44
2014	1,433,208	1.45
2015	1,432,152	1.45
2016	1,471,429	1.49
2017	1,469,114	1.48
2018	1,458,838	1.47
2019	1,413,954	1.43
2020	1,395,858	1.41
2021	1,340,452	1.35
2022	1,344,533	1.36
2023	1,354,876	1.37
Averages		
2010–2022	1,409,840	1.42
1982–2023	811,474	0.82

Table 9.–Successful pot lifts from index stations at index sites and in the Prince William Sound Area spot shrimp pot survey.

	Sites								
	1	2	3	4	5	7	8		
Year	Unakwik	Golden	Culross	Herring Bay	Junction Island	Chenega	Prince of Wales	Total	Annual average
1992	43	44	43	44	43	44	44	305	44
1993	43	43	44	43	44	43	32	292	42
1994	44	44	44	44	44	43	43	306	44
1995	44	44	44	42	44	44	44	306	44
1996	44	44	44	43	44	43	44	306	44
1997	44	42	44	42	44	44	43	303	43
1998	44	44	44	44	44	44	ND	264	44
1999	44	43	44	43	44	44	41	303	43
2000	44	44	42	44	43	44	44	305	44
2001	44	44	43	44	44	44	44	307	44
2002	44	44	42	43	44	44	43	304	43
2003	44	44	44	44	44	44	44	308	44
2004	44	44	44	44	44	44	44	308	44
2005	44	44	44	44	44	44	42	306	44
2006	42	44	44	44	44	44	42	304	43
2007	43	43	44	44	44	44	44	306	44
2008	44	44	44	44	44	44	43	307	44
2009	44	44	44	44	44	44	44	308	44
2010	44	44	43	43	44	44	44	306	44
2011	43	44	44	43	44	44	44	306	44
2012	44	44	43	42	44	44	43	304	43
2013	43	43	44	44	43	44	44	305	44
2014	44	44	43	44	44	43	44	306	44
2015	44	44	44	43	44	44	44	307	44
2016	20	20	20	20	20	20	20	140	20
2017	20	20	19	20	20	20	20	139	20
2018	44	44	44	44	44	43	41	304	43
2019	43	44	44	44	44	43	44	306	44
2020	40	44	41	44	44	44	44	301	43
2021	43	44	44	42	43	41	41	298	43
2022	40	39	40	40	44	44	41	288	41
2023	41	42	37	43	43	42	42	290	41
Survey avg	42	42	42	42	42	42	41	292	42

Note: ND= no data

Table 10.–Annual index site CPUE (counts per pot) of spot shrimp from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

	Marketable-size		Male		Female		Total	
Year	CPUE	Var	CPUE	Var	CPUE	Var	CPUE	Var
1992	9.14	0.08	12.23	0.11	1.94	0.02	14.17	0.82
1993	3.36	0.04	6.42	0.08	1.59	0.02	8.01	0.62
1994	2.85	0.03	11.09	0.11	0.52	0.01	11.60	0.80
1995	5.92	0.05	14.58	0.13	0.69	0.01	15.27	0.92
1996	ND	0.00	ND	0.00	ND	0.00	12.44	0.89
1997	3.33	0.05	9.38	0.12	0.70	0.01	10.09	0.88
1998	2.16	0.03	8.07	0.11	0.46	0.01	8.53	0.86
1999	3.41	0.08	12.47	0.14	0.79	0.03	13.25	1.06
2000	6.50	0.06	17.77	0.17	0.89	0.01	18.66	1.22
2001	10.49	0.08	17.65	0.14	1.54	0.01	19.20	1.09
2002	10.76	0.09	26.30	0.22	2.63	0.03	28.93	1.86
2003	12.35	0.10	23.69	0.20	2.19	0.02	25.88	1.64
2004	13.02	0.09	34.99	0.25	3.36	0.02	38.35	2.26
2005	11.21	0.07	43.34	0.28	2.26	0.02	45.59	2.71
2006	13.81	1.19	41.49	0.67	3.48	0.61	44.97	2.28
2007	19.07	1.94	73.05	0.76	4.35	0.66	77.40	3.76
2008	19.49	1.00	68.86	0.83	5.08	0.72	73.94	3.64
2009	24.69	1.79	48.26	0.88	8.09	0.85	56.34	2.64
2010	18.14	1.11	21.82	0.40	4.95	0.37	26.76	1.66
2011	24.58	1.45	27.38	0.80	9.04	0.78	36.42	2.42
2012	25.11	0.93	37.52	0.82	8.71	0.78	46.23	2.34
2013	22.37	0.73	37.02	0.83	7.37	0.80	44.39	2.11
2014	24.78	1.48	41.72	0.73	4.55	0.68	46.27	2.60
2015	14.65	0.93	34.82	0.42	2.91	0.36	37.73	2.26
2016	29.67	1.98	60.55	1.46	8.24	1.31	68.79	4.93
2017	23.37	2.89	123.19	1.82	7.45	1.42	130.64	9.67
2018	32.72	2.85	109.76	0.77	6.14	0.58	115.90	3.89
2019	23.47	1.56	88.97	1.28	6.63	1.20	95.59	4.14
2020	32.98	2.33	83.64	1.44	13.62	1.40	97.27	3.63
2021	20.68	1.42	60.63	0.84	7.58	0.73	68.21	3.77
2022	13.74	0.48	41.13	0.55	4.83	0.49	45.97	2.78
2023	8.92	0.73	23.60	0.34	3.22	0.26	26.84	2.11
Averages								
1992–2009	10.09	0.38	27.63	0.29	2.39	0.17	29.03	1.66
2010–2022	23.56	1.55	59.09	0.94	7.08	0.84	66.17	3.55
Survey	15.70	0.86	40.69	0.55	4.38	0.44	44.05	2.44

Note: ND= no data. Marketable-size spot shrimp are ≥ 32 mm carapace length. Var = annual variance.

Table 11.–Carapace length (CL) of spot shrimp from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

		Male			Female			
Year	Pots sampled (*n*)	Shrimp measured (*n*)	Average CL (mm)	CL SD	Shrimp measured (*n*)	Average CL (mm)	CL SD	% Gravid
1992	271	3,574	32.2	5.0	536	42.1	2.5	96.6
1993	236	1,874	28.0	6.1	464	42.6	2.1	97.8
1994	257	3,360	27.7	4.5	157	43.8	2.1	97.5
1995	290	4,462	29.3	5.1	211	43.5	2.6	ND
1996	ND	ND	ND	ND	ND	ND	ND	ND
1997	240	2,840	28.6	4.9	215	42.3	2.2	ND
1998	197	2,131	27.7	4.9	121	43.9	2.5	99.2
1999	240	3,347	28.1	4.6	216	43.2	2.3	97.7
2000	272	5,419	28.7	5.0	272	44.3	2.5	97.4
2001	268	5,420	31.1	4.9	474	44.0	2.5	99.6
2002	275	7,828	28.5	5.7	776	44.1	2.5	98.2
2003	274	7,297	29.8	5.9	674	45.6	2.4	99.6
2004	281	10,776	28.8	5.2	1,035	44.5	3.1	97.4
2005	275	6,637	28.1	4.7	691	43.8	3.5	95.2
2006	27	1,076	28.1	5.4	98	41.1	3.4	89.8
2007	28	2,076	28.2	4.1	125	41.3	3.1	83.2
2008	28	2,206	29.2	3.6	157	41.4	3.2	80.9
2009	27	1,495	30.3	3.8	238	41.5	2.9	88.2
2010	27	773	31.9	4.2	169	41.0	2.6	92.9
2011	23	947	31.4	6.1	311	41.7	3.0	99.0
2012	42	1,318	30.1	5.5	239	42.5	2.6	90.4
2013	28	1,053	29.9	4.9	179	43.6	2.6	88.3
2014	28	1,235	31.4	4.9	131	43.6	3.2	85.5
2015	27	1,028	29.6	5.5	87	44.1	2.6	97.7
2016	27	1,866	29.6	5.0	250	44.2	2.5	98.4
2017	28	3,309	27.6	4.1	223	44.3	2.7	98.7
2018	28	2,802	28.5	4.6	161	42.9	3.1	93.8
2019	28	2,656	28.4	4.2	190	41.6	3.3	96.3
2020	28	2,564	28.1	4.6	387	40.2	2.7	94.8
2021	28	2,630	27.3	4.6	275	39.6	2.7	93.8
2022	28	1,768	27.9	4.6	196	39.7	2.4	84.7
2023	28	697	28.3	6.6	94	40.0	6.6	84.0
Survey avg	125	3,112	29.1	4.9	302	42.6	2.8	93.7

Note: ND = no data.

Table 12.–Estimated carapace length (CL) at transition to female (CL_{50}) with associated CIs and predicted age for spot shrimp from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

Year	Male (*n*)	Female (*n*)	CL_{50} (mm)	Lower 95% CI[a]	Upper 95% CI[a]	Predicted age
1992	3,574	536	40.22	39.95	40.43	5.9
1993	1,874	464	39.79	39.58	40.03	5.7
1994	3,351	157	40.55	40.15	40.99	6.0
1995	4,462	211	40.36	39.97	40.63	5.9
1996	ND	ND	ND	ND	ND	ND
1997	2,836	213	39.65	39.29	39.95	5.7
1998	2,131	121	41.20	40.68	41.44	6.3
1999	3,347	216	40.00	39.70	40.42	5.8
2000	5,419	272	40.90	40.51	41.19	6.1
2001	5,420	474	40.71	40.41	40.98	6.1
2002	7,825	776	40.80	40.54	41.02	6.1
2003	7,297	674	42.37	42.01	42.64	6.8
2004	10,776	1,035	41.18	40.85	41.36	6.3
2005	6,637	691	40.78	40.39	41.04	6.1
2006	1,076	98	39.80	39.10	40.35	5.7
2007	2,076	125	39.18	38.78	39.73	5.5
2008	2,206	157	38.95	38.55	39.35	5.4
2009	1,495	238	38.47	38.09	38.85	5.3
2010	773	169	38.67	38.37	39.08	5.3
2011	947	311	39.55	39.25	39.92	5.6
2012	1,318	239	40.35	39.84	40.62	5.9
2013	1,053	179	40.40	39.96	40.80	5.9
2014	1,235	131	41.12	40.60	41.38	6.2
2015	1,028	87	40.88	40.34	41.22	6.1
2016	1,866	250	40.70	40.14	40.96	6.1
2017	3,309	223	41.00	40.40	41.27	6.2
2018	2,802	161	40.23	39.67	40.66	5.9
2019	2,656	190	39.11	38.73	39.47	5.5
2020	2,563	387	37.67	37.42	38.21	5.0
2021	2,630	275	37.84	37.66	38.46	5.1
2022	1,768	196	37.43	37.13	38.05	4.9
2023	697	94	38.19	37.75	38.75	5.2
Survey avg	3,111	302	39.94	37.63	42.19	5.8

Note: ND = no data.

[a] Mixed effects model was used to calculate CL_{50} and associated confidence intervals.

Table 13.–Mixed effects model statistics to estimate size of spot shrimp at transition to female (CL50) from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

Parameter	Estimate	SE	P -value
Intercept	-53.109	1.629	<0.005
Carapace Length	1.329	0.039	<0.005

Table 14.–Linear model statistics to predict spot shrimp size (mm) at transition to female (CL50) from male shrimp CPUE, lagged 3-years, from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

Parameter	Estimate	SE	P -value
Intercept	41.279	0.248	<0.005
Male CPUE	-0.033	0.004	<0.005

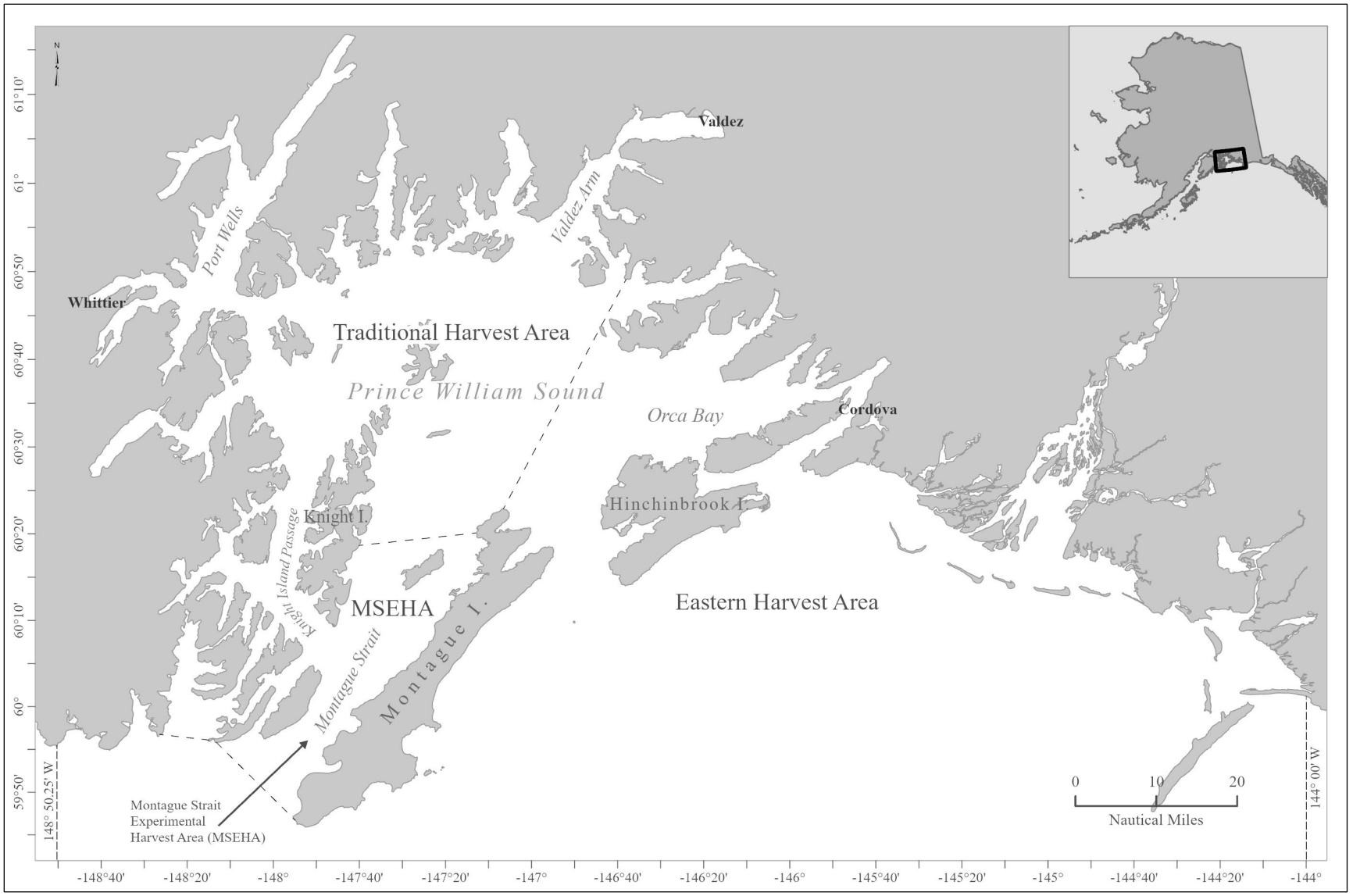

Figure 1.–Historical Prince William Sound Area shrimp pot fishery areas.

Figure 2.–Prince William Sound Area spot shrimp pot survey sites and shrimp pot commercial fishery area boundaries.

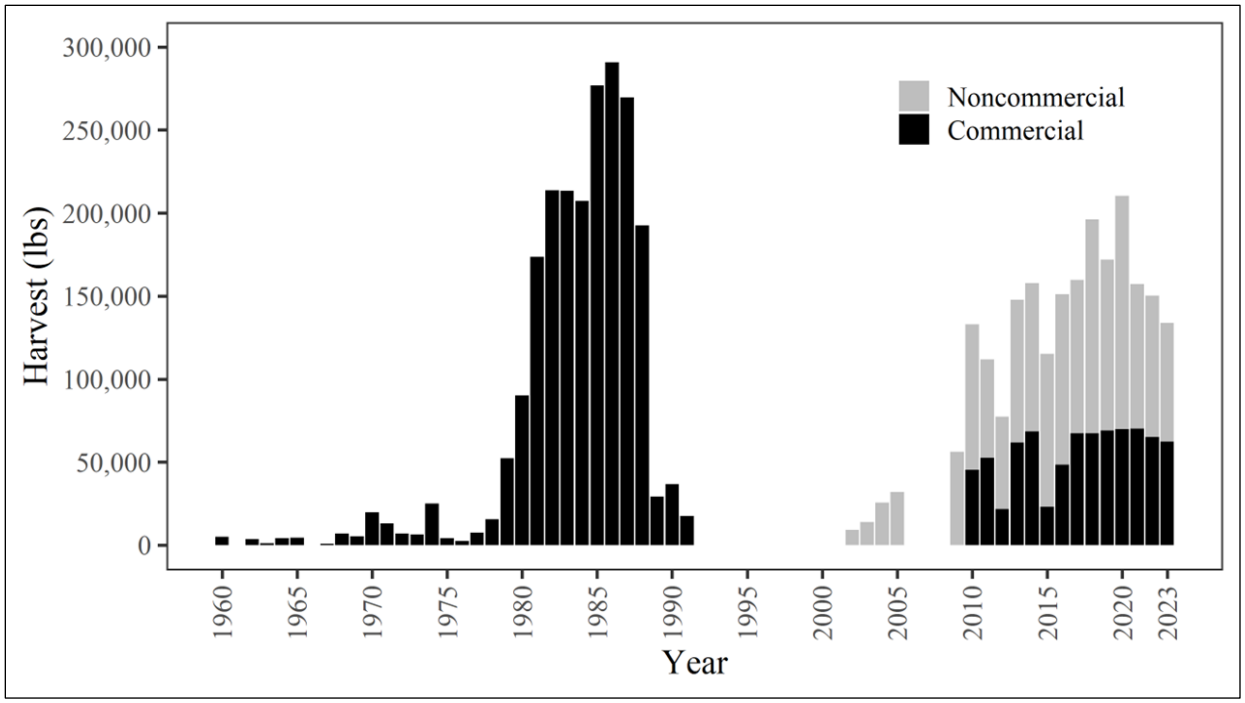

Figure 3.–Shrimp pot fishery harvests in the Prince William Sound Area.

Notes: 1960–1991 commercial harvest data from Trowbridge (1993).
2002–2019 noncommercial harvest data from Blaine-Roth et al. (2021).
2020 noncommercial harvest data from Rumble et al. (2022).
2021–2022 noncommercial harvest data converted using 3.89 lb/gal from Arthur et al. (2024).

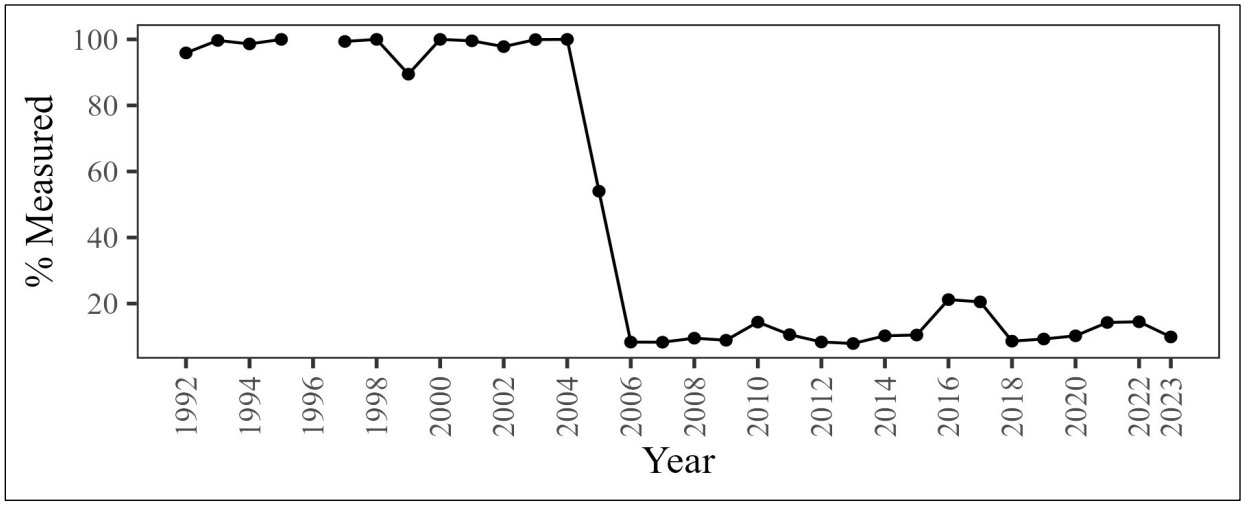

Figure 4.–Percentage of spot shrimp measured from all sites and stations in the Prince William Sound Area spot shrimp pot survey.

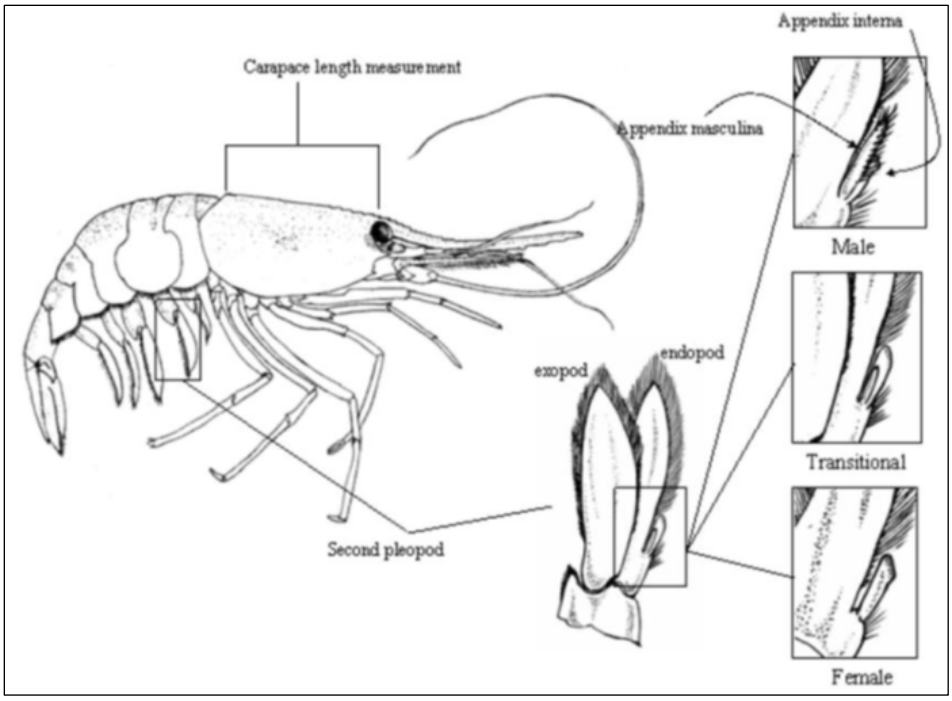

Figure 5.–Diagram of spot shrimp pleopod morphology to determine sex on the Prince Willaim Sound Area spot shrimp pot survey.

Note: From Lowry (2007).

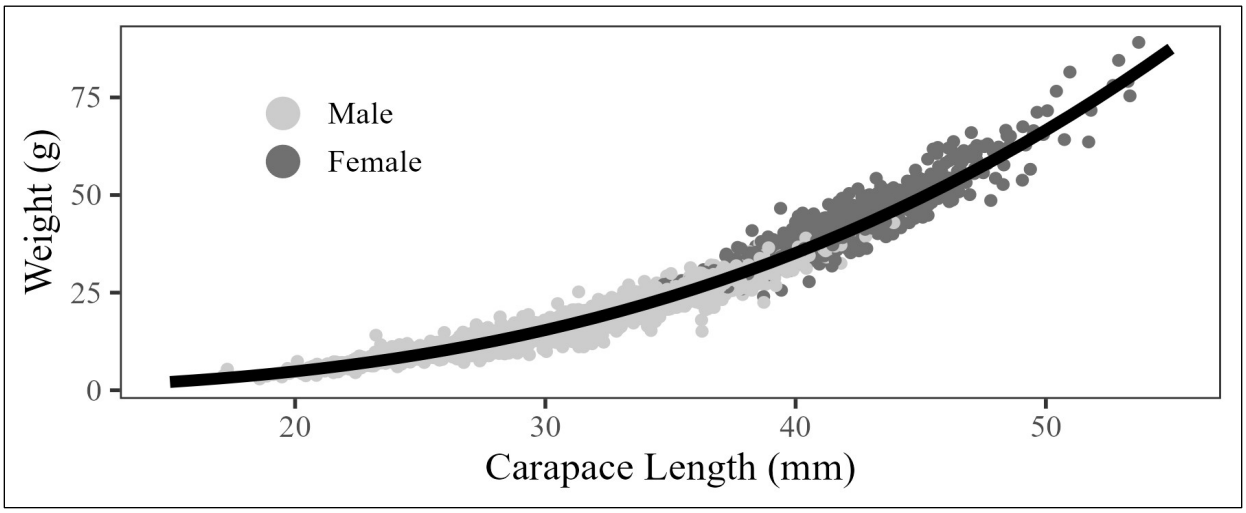

Figure 6.–Carapace length and weight relationship of spot shrimp caught from 2006–2010 in the Prince William Sound Area spot shrimp pot survey.

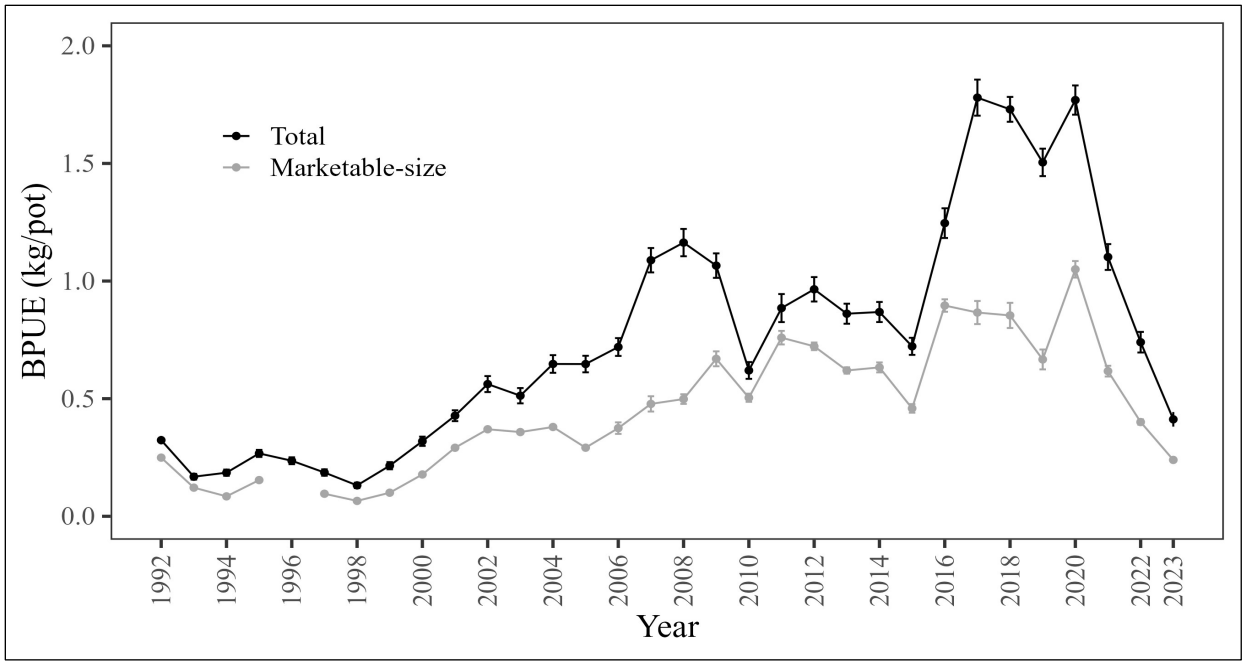

Figure 7.–Biomass per unit effort (BPUE) of spot shrimp from all sites and stations in the Prince William Sounds Area spot shrimp pot survey.

Note: Vertical lines are standard error.

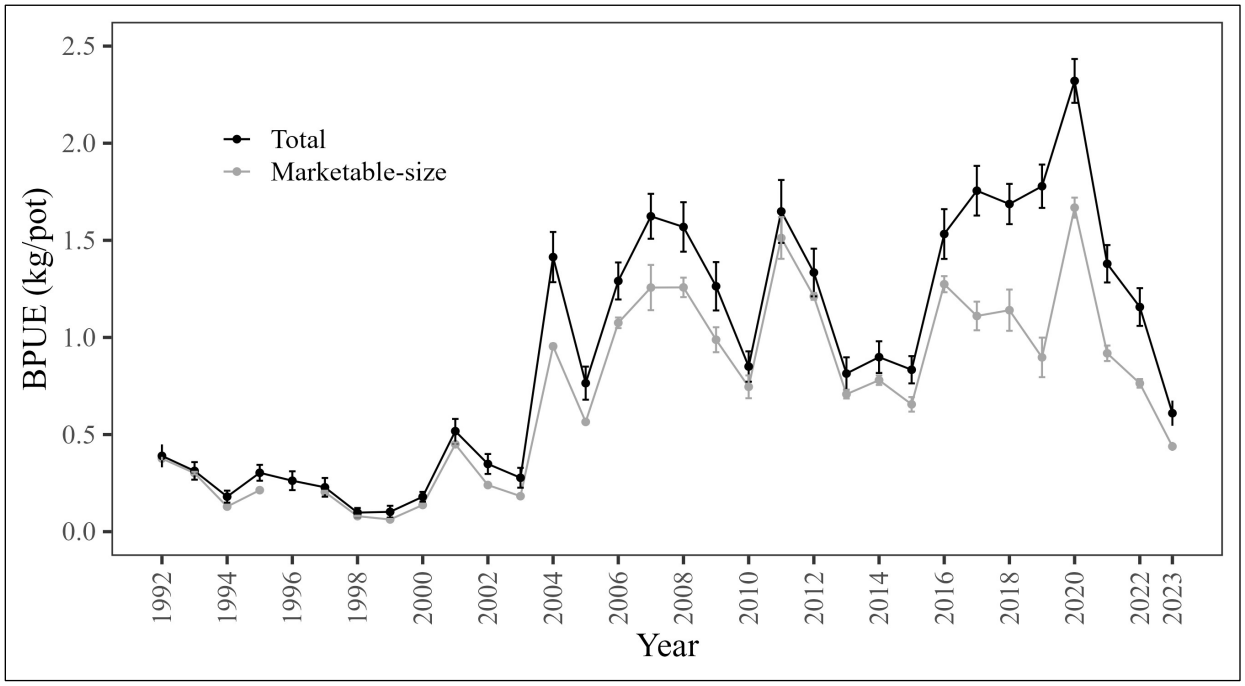

Figure 8.–Biomass per unit effort (BPUE) of spot shrimp from all Area 1 sites and stations in the Prince William Sounds Area spot shrimp pot survey.

Note: Vertical lines are standard error.

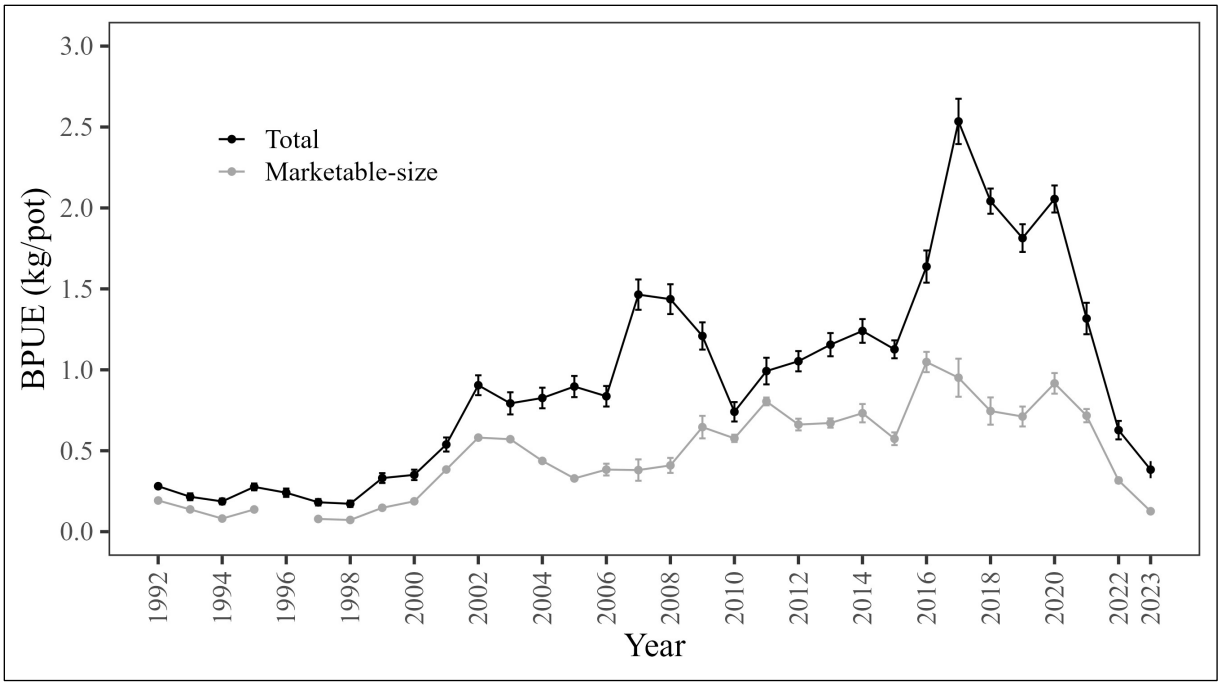

Figure 9.–Biomass per unit effort (BPUE) of spot shrimp from all Area 2 sites and stations in the Prince William Sounds Area spot shrimp pot survey.

Note: Vertical lines are standard error.

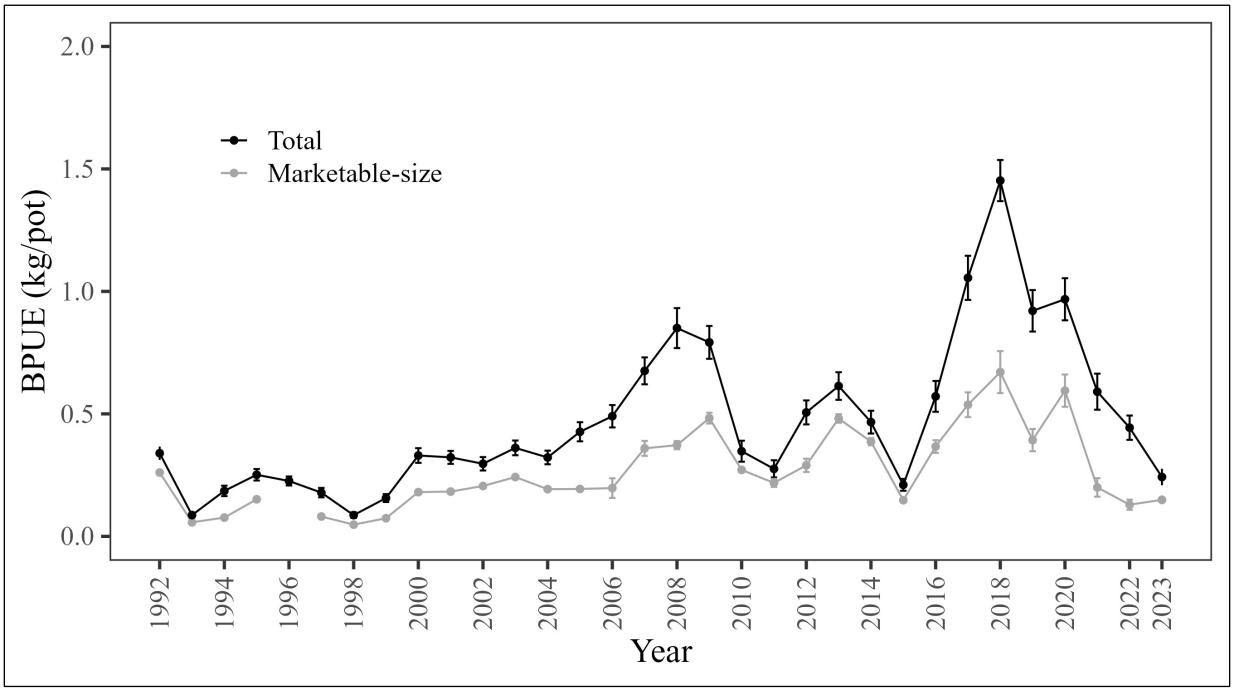

Figure 10.–Biomass per unit effort (BPUE) of spot shrimp from all Area 3 sites and stations in the Prince William Sounds Area spot shrimp pot survey.

Note: Vertical lines are standard error.

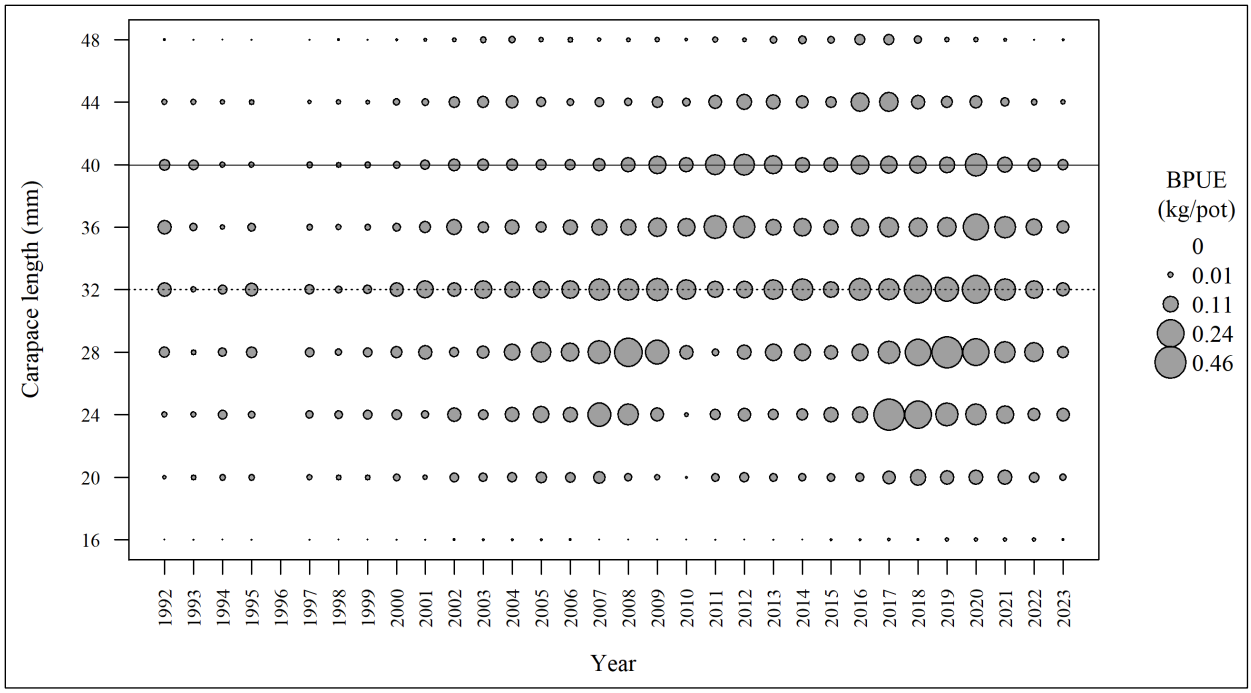

Figure 11.–Size binned biomass per unit effort (BPUE) of spot shrimp at all sites and stations in the Prince William Sound Area spot shrimp pot survey.

Note: Solid horizontal line is size at transition to female (CL50) = 39.95 mm. Dashed horizontal line is marketable-size = 32 mm.

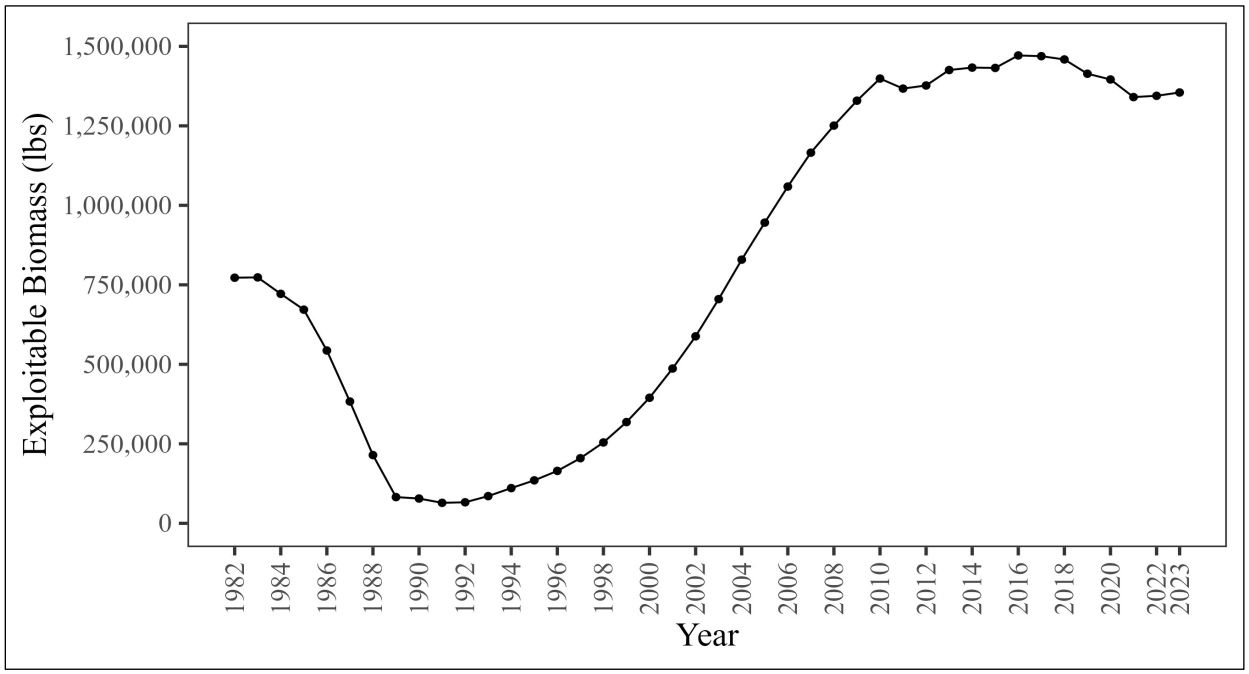

Figure 12.–Annual exploitable biomass output from a surplus production model for Prince William Sound Area shrimp pot fisheries.

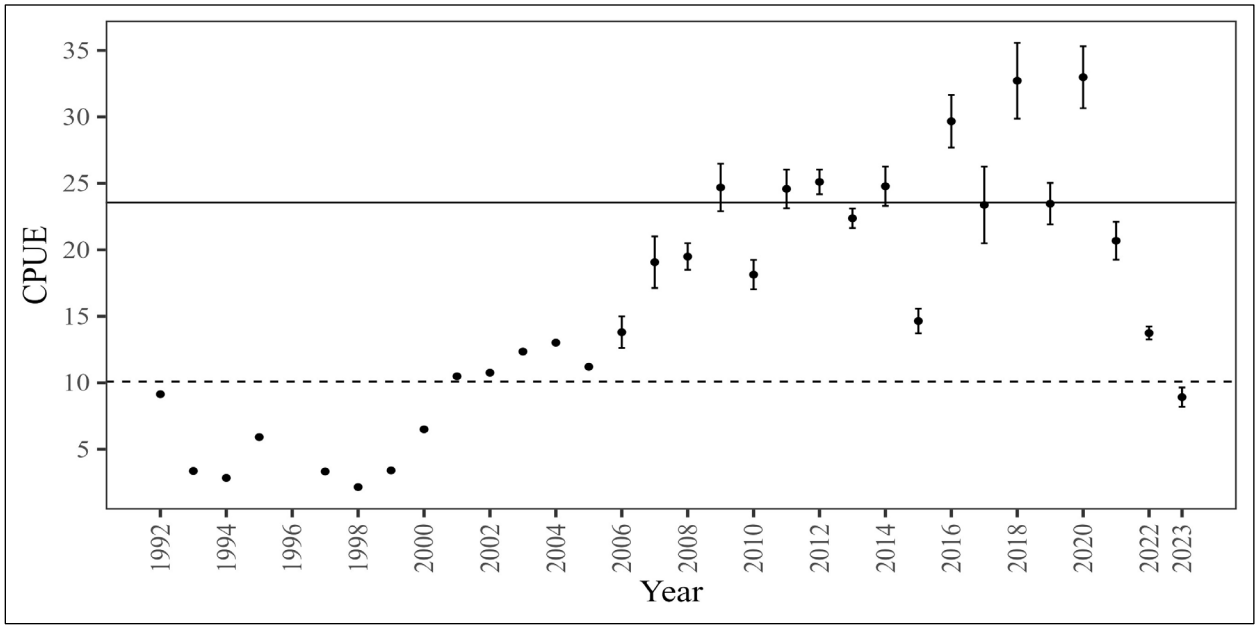

Figure 13.–Index sites' annual CPUE (counts per pot) of marketable-size (≥32 mm) spot shrimp in the Prince William Sound Area spot shrimp pot survey.

Note: Dashed horizontal line is 1992–2009 average. Solid horizontal line is 2010–2022 average. Vertical lines are standard deviation.

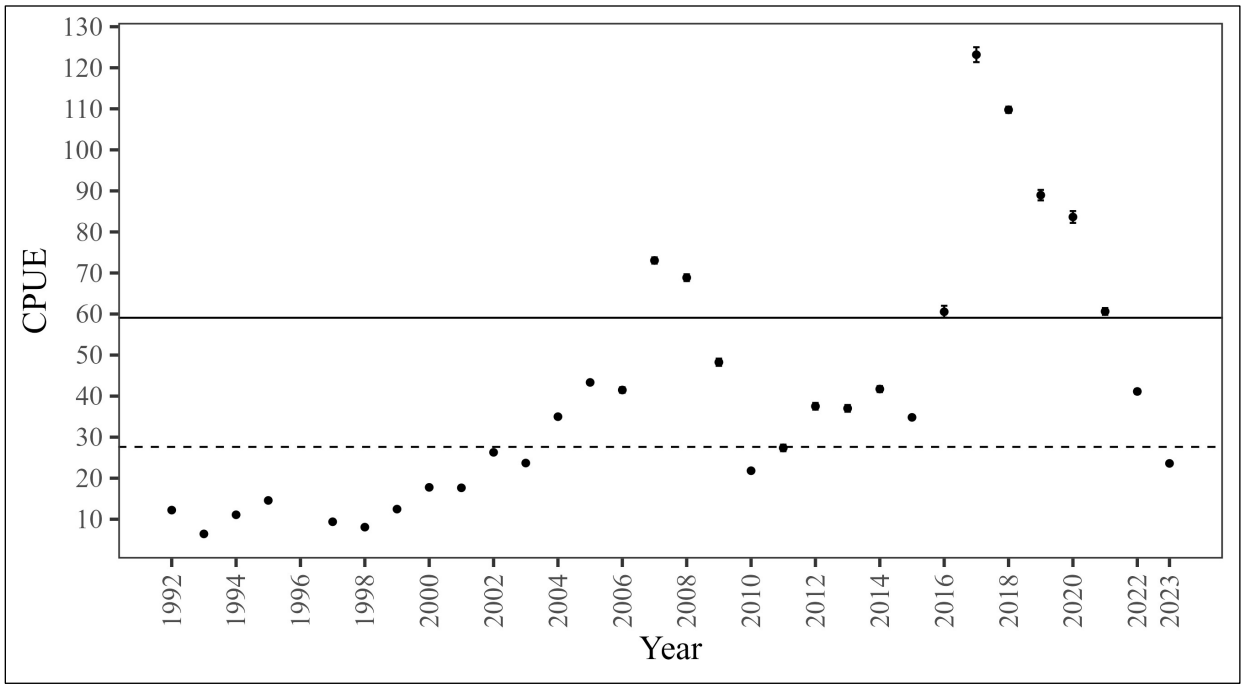

Figure 14.–Index sites' annual CPUE (counts per pot) of male spot shrimp in the Prince William Sound Area spot shrimp pot survey.

Note: Dashed horizontal line is 1992–2009 average. Solid horizontal line is 2010–2022 average. Vertical lines are annual variance

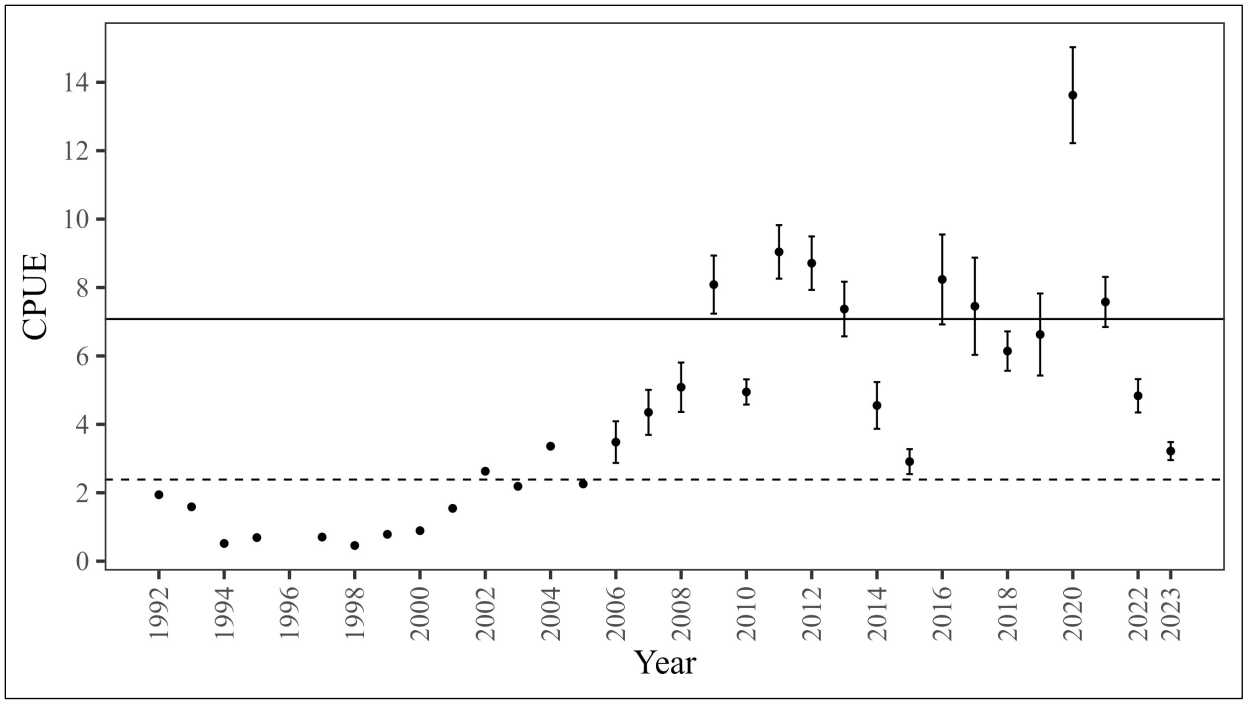

Figure 15.–Index sites' annual CPUE (counts per pot) of female spot shrimp in the Prince William Sound Area spot shrimp pot survey.

Note: Dashed horizontal line is 1992–2009 average. Solid horizontal line is 2010–2022 average. Vertical lines are annual variance.

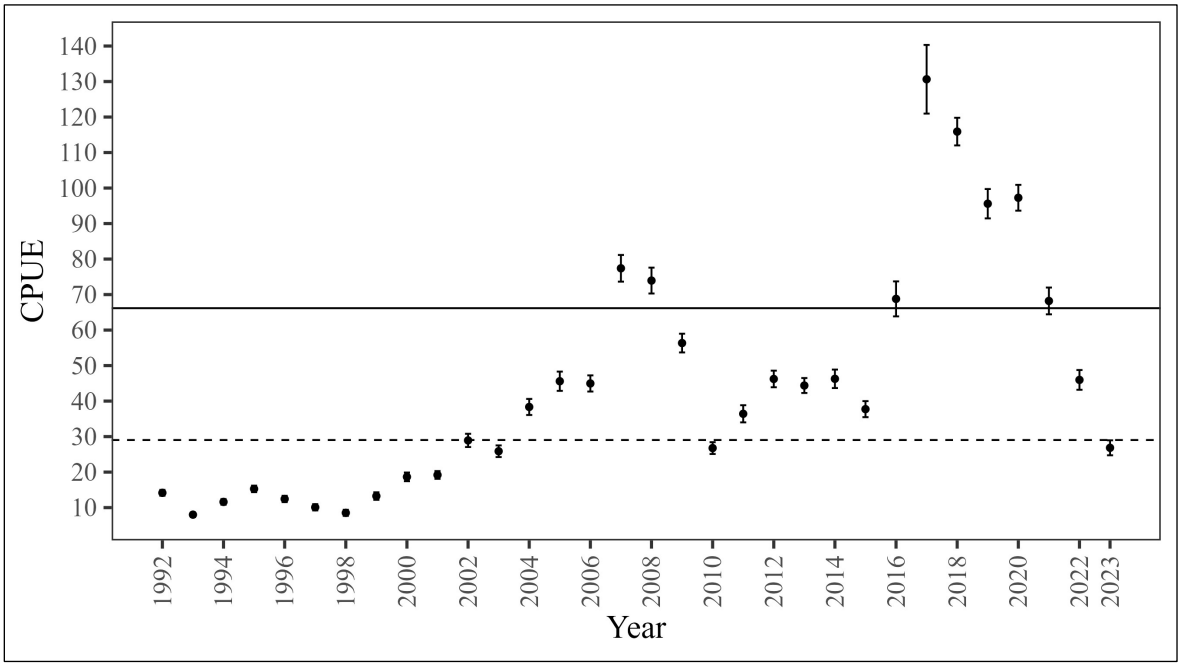

Figure 16.–Index sites' annual CPUE (counts per pot) of total spot shrimp in the Prince William Sound Area spot shrimp pot survey.

Note: Dashed horizontal line is 1992–2009 average. Solid horizontal line is 2010–2022 average. Vertical lines are annual variance.

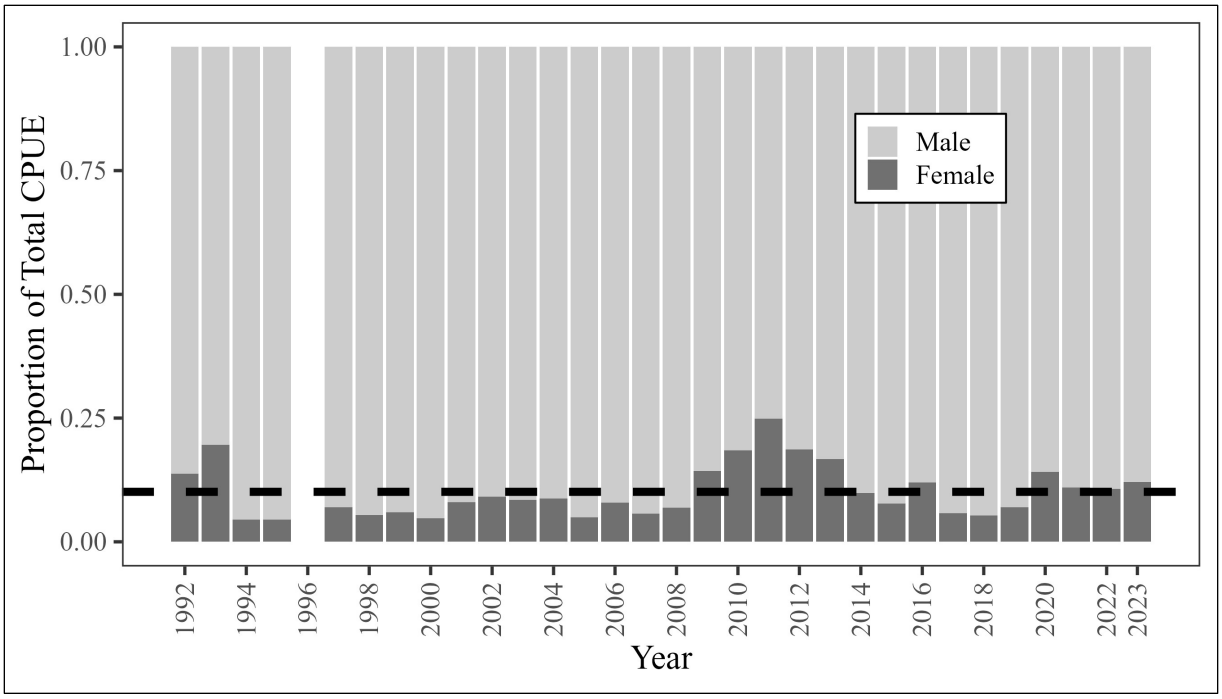

Figure 17.–Sex ratio of CPUE (counts per pot) of spot shrimp from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

Note: Dashed horizontal line is survey average for females.

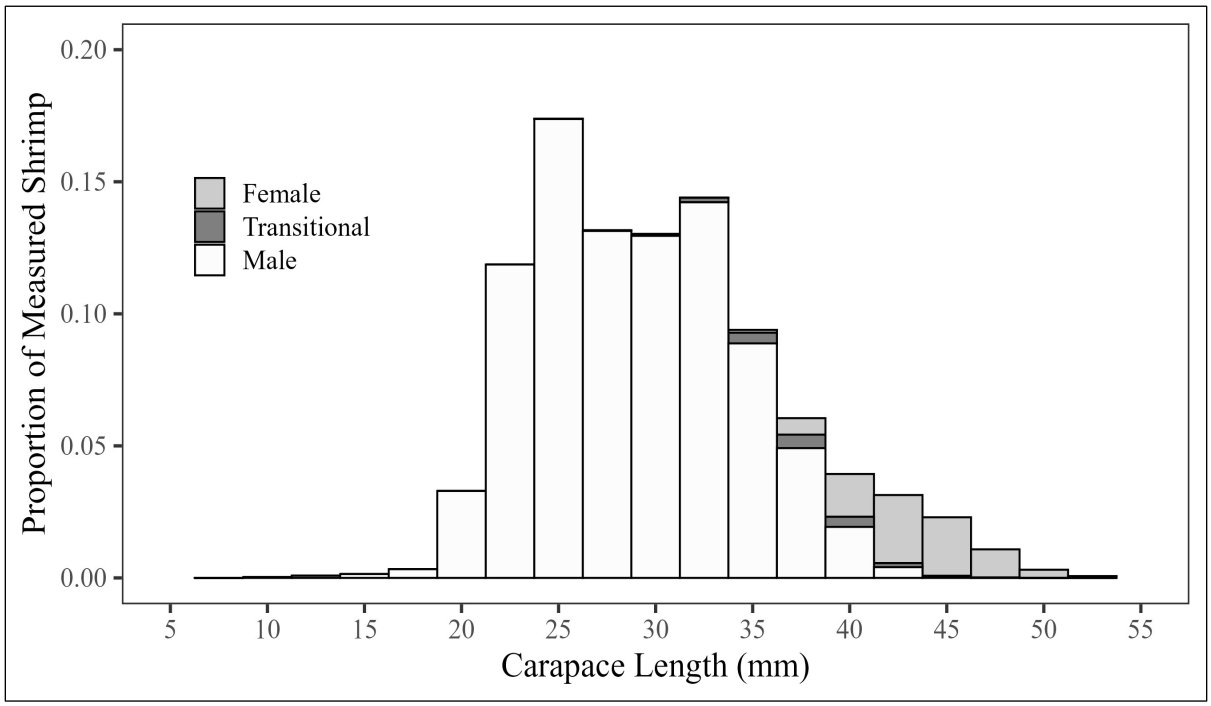

Figure 18.–Sex and carapace length of spot shrimp measured at all sites and stations in the Prince William Sound Area spot shrimp pot survey.

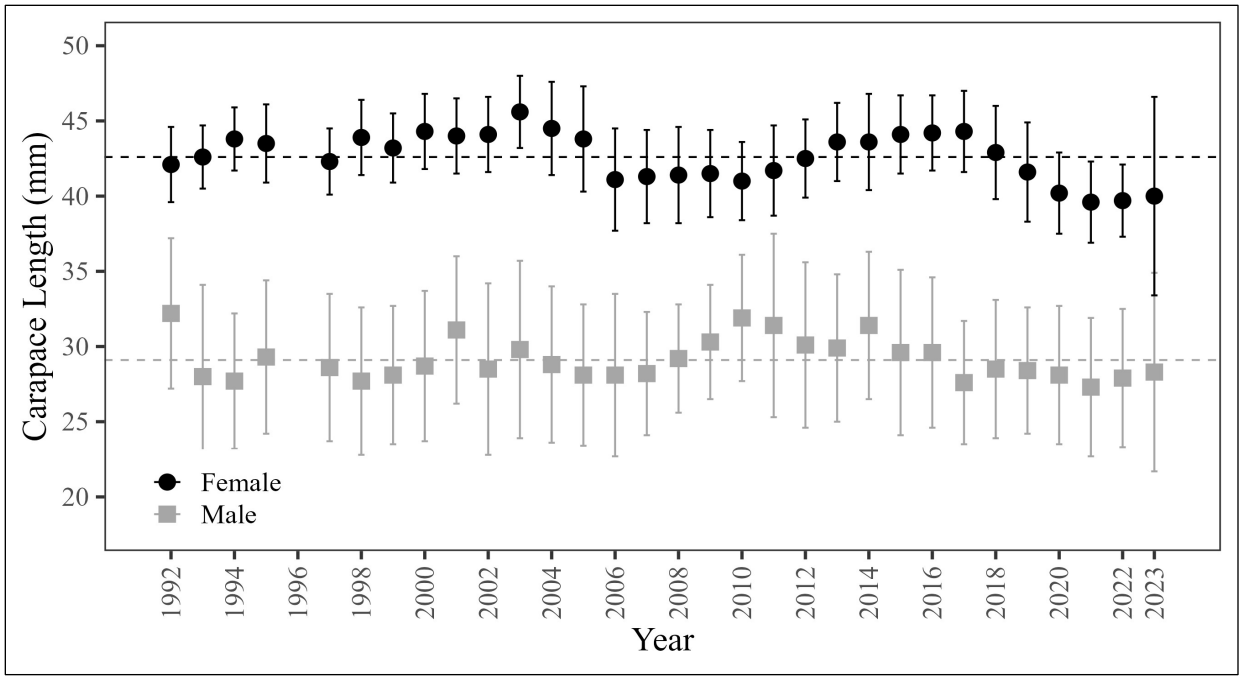

Figure 19.–Annual average carapace length of spot shrimp from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

Note: Dashed horizontal line is survey average for each sex. Vertical lines are +/- annual SD.

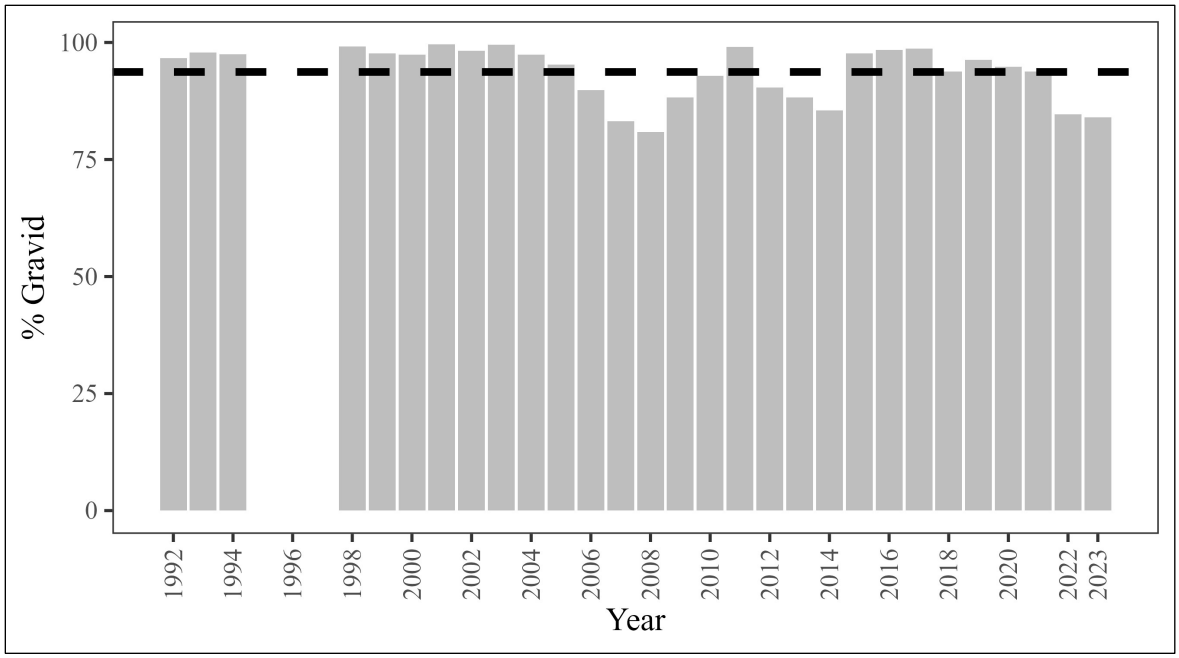

Figure 20.–Proportion of female spot shrimp with eggs from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

Note: Dashed horizontal line is survey average.

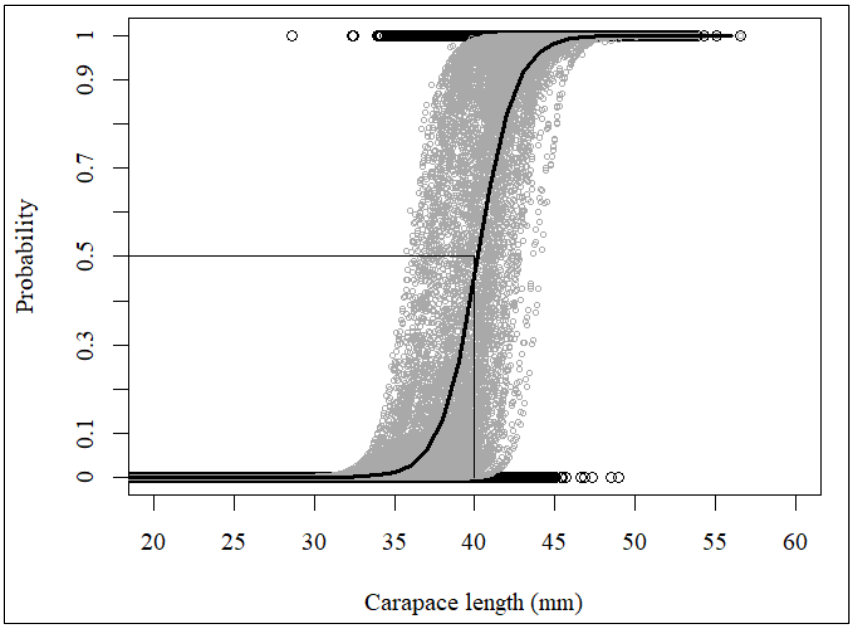

Figure 21.–Logistic regression to estimate size at transition to female (CL50) of spot shrimp from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

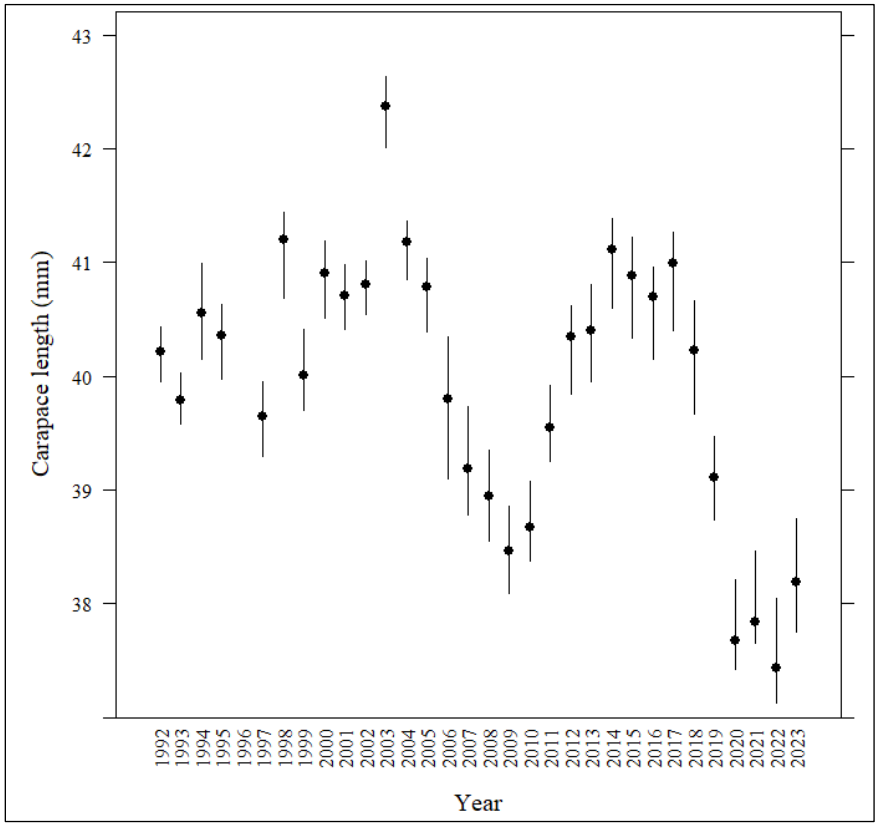

Figure 22.–Annual carapace length at transition to female (CL50) of spot shrimp from index stations at index sites in the Prince William Sound Area spot shrimp pot survey.

Note: Vertical lines are 95% CI.

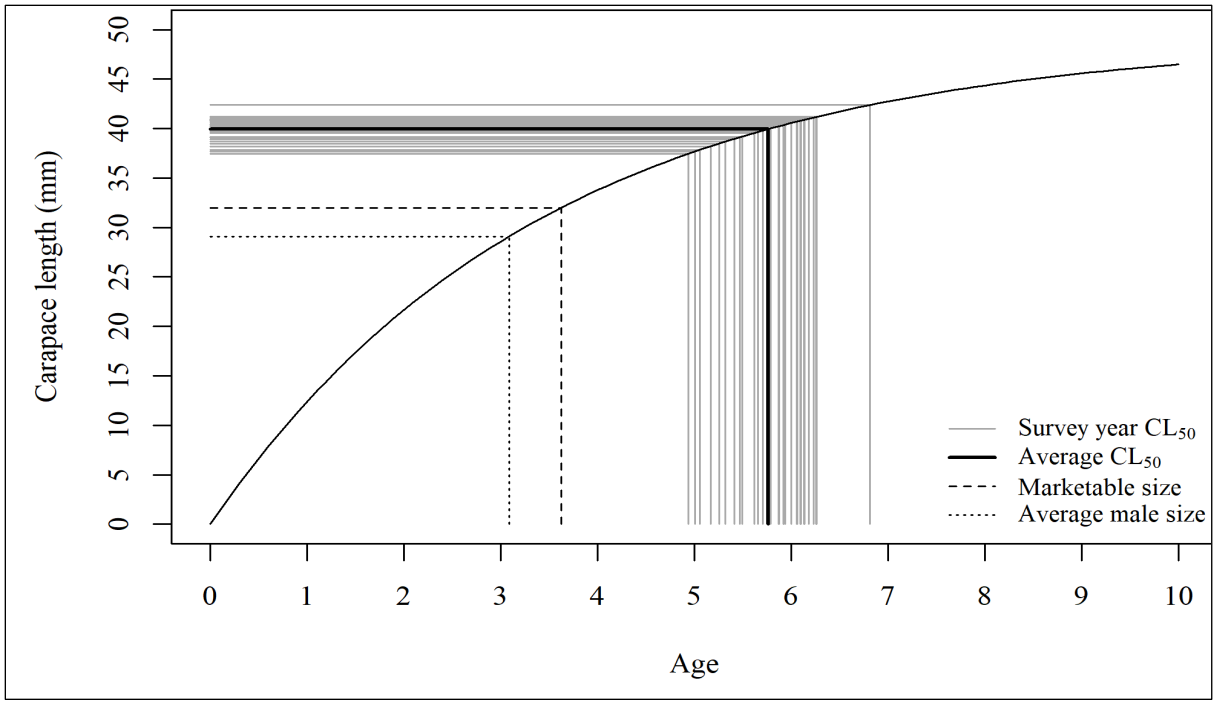

Figure 23.–Predicted age of spot shrimp from index stations at index sites in the Prince William Sound Area spot shrimp pot survey (1992–2023).

Note: Von Bertalanffy growth model from Kimker et al. (1996). CL_{50} = estimated size of spot shrimp at transition to female.

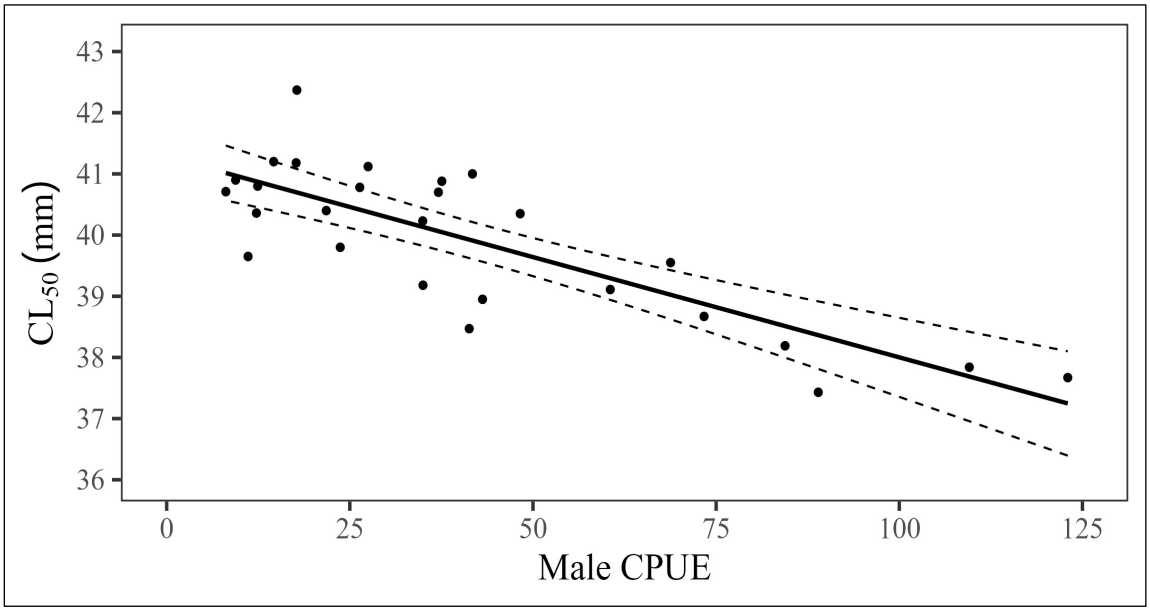

Figure 24.–Linear model to predict size of spot shrimp at transition to female (CL50) from 3-years prior male shrimp CPUE (counts per pot) from index stations at index sites in the Prince William Sound spot shrimp pot survey.

Note: Dashed lines represent the standard error.