Fishery Data Series No. 17-09

2016 Statewide Weathervane Scallop Dredge Survey Report

by

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and

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March 2017

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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2016 STATEWIDE WEATHERVANE SCALLOP DREDGE SURVEY REPORT

by
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ABSTRACT

The Alaska Department of Fish and Game manages the majority of the statewide scallop fishery based on fishery-dependent data collected by onboard observers during the fishery. However, in surveyed areas a harvest rate is applied to an estimate of biomass to determine the guideline harvest level (GHL). Five beds were surveyed in 2016: 2 near Kayak Island in the Prince William Sound area, and 3 in the Shelikof District northwest of Kodiak Island. Abundance estimates of large (≥100 mm) scallops were 7.7 million in Prince William Sound and 4.2 million in the Shelikof District. A scallop meat weight to round weight ratio was established for each bed and used to calculate meat weight GHLs. Using a 5% annual exploitation rate, the estimated GHLs ranged from 13,773 (6,191–22,901) for Prince William Sound to 14,219 (10,496–18,764) for the Shelikof District. A 10% annual exploitation rate increase the estimated GHLs from 27,543 (12,384–4,801) for Prince William Sound to 28,440 (16,314–37,526) for the Shelikof District. The CV estimates from the survey met the target of 20 for the Kodiak Shelikof District bed 1 and was close for the East Kayak bed 1. The CVs for the other 3 beds sampled were higher than desired and sample sizes may need to be increased for those beds in future surveys.

Key words: Weathervane scallops, *Patinopecten caurinus*, dredge, area swept, Alaska

INTRODUCTION

Weathervane scallops, *Patinopecten caurinus*, are distributed in the northeast Pacific Ocean from Pt. Reyes, California, north to the Pribilof Islands in the Bering Sea, and west to the Aleutian Islands, and occur from the intertidal to 300 m (Foster 1991). Scallops are a relatively long-lived species, attaining ages between 20 and 28 years in Alaska waters (Hennick 1973; Bechtol et al. 2009). Densities that support commercial harvest typically occur at depths of 45–130 m on discrete aggregations, or beds (Kruse et al. 2005), and in a wide variety of habitats—ranging from rock and gravel to silt and mud (Hennick 1973). Scallop beds are typically elongated or elliptical in shape and oriented in the direction of mean current flow (Kruse et al. 2000).

Stock assessments for scallops have improved over time from solely fishery-dependent (catch and effort) data to fishery-independent surveys in some areas. Initial surveys were conducted for Kamishak Bay beds in 1984 and Kayak Island beds in 1996 (Hammarstrom and Merritt 1985; Bechtol et al. 2003), and have been conducted biennially since 1996 (Gustafson and Goldman 2012). These surveys have enabled the department to (1) delineate the primary scallop beds, (2) estimate scallop abundance and biomass within these beds, (3) define bed composition through age and shell height data, and (4) estimate bycatch rates of nontarget species, particularly Tanner crab (*Chionoecetes bairdi)*. Fishery managers have used the results of these surveys to set guideline harvest limits (GHLs) and manage the commercial scallop fishery in the Cook Inlet and Prince William Sound (PWS) registration areas. All other management areas in the state rely on fishery-dependent data gathered from the statewide scallop observer program to inform management decisions (NPFMC 2015). Amendment 6 of the Alaska Scallop Fishery Management Plan established an overfishing control rule of F = 0.13, where F is the instantaneous rate of fishing mortality. An F of this level corresponds to a maximum of a 12% annual exploitation rate.

In the spring of 2016, scallop surveys were reviewed, expanded, and reallocated to assess the resource statewide (Smith et al. 2016). The spring 2016 survey was scheduled to include the PWS, northern Yakutat, and Shelikof Strait areas. Due to weather, the northern Yakutat portion was not surveyed. In addition, the Shelikof survey was truncated due to a survey vessel breakdown in May. A contracted commercial scallop vessel was used to complete the survey in July. Future survey plans include surveying the Shelikof District and Yakutat areas in 2017, then transitioning to alternating biennial surveys between the Yakutat and Kodiak areas. These areas are given priority because together they produced an average of 84% of the statewide harvest over the past 10 seasons.

In this report we examine the methods and results of the 2016 scallop dredge surveys including (1) changes in methods from Smith et al. 2016, (2) analysis of CV results at the bed level, (3) the survey abundance estimate from survey sites, and (4) appropriate harvest rates based on exploitation rates.

STUDY SITE

The statewide scallop survey is currently planned to cover the main scallop beds from Cape Fairweather south of Yakutat to the Southwest District of the Kodiak Area. The 2016 survey included 3 beds in Shelikof District, and 2 beds off Kayak Island in the PWS Area.

Shelikof District

The Kodiak Shelikof District study area (KSH) is located in the northwest portion of Shelikof Strait between Kodiak Island and the Alaska Peninsula, Alaska (Figure 1). Depth contours run from southwest to northeast, approximately parallel to the Alaska Peninsula shoreline. Bottom depths in the scallop beds slope from approximately 30 fathoms (55 m) in the northwest to over 80 fathoms (146 m) in the southeast portions of KSH bed 1.

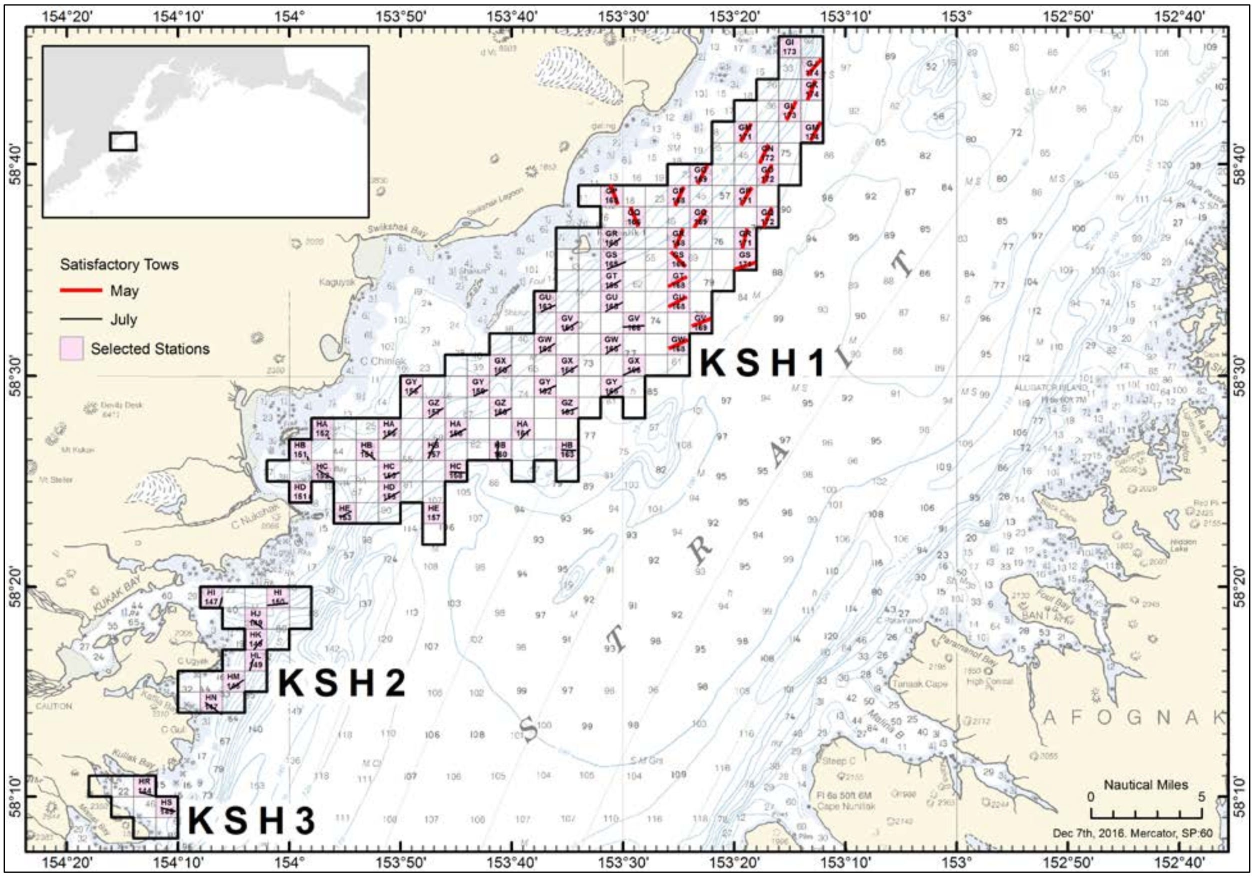

Figure 1.–Kodiak Shelikof District survey area showing location of the 3 beds (outlined in black): Shelikof 1 (KSH1), Shelikof 2 (KSH2), and Shelikof 3 (KSH3). Beds were subdivided into 1 nm^2 grids. Every third gird was selected as a station in the 2016 survey. Red lines show tows sampled in May, black lines show tows sampled in July. The tows are depicted as straight lines connecting the start and end points and do not accurately portray curvilinear tows (e.g., many of the nearshore stations sampled in July).

Prince William Sound Area

The PWS study area is located near the southern end of Kayak Island in the Gulf of Alaska (Figure 2). Depth contours run from southwest to northeast, approximately parallel to the Kayak Island shoreline. Bottom depths in the scallop beds gradually slope from approximately 30 fathoms (55 m) in the northwest to over 60 fathoms (110 m) in the southeast.

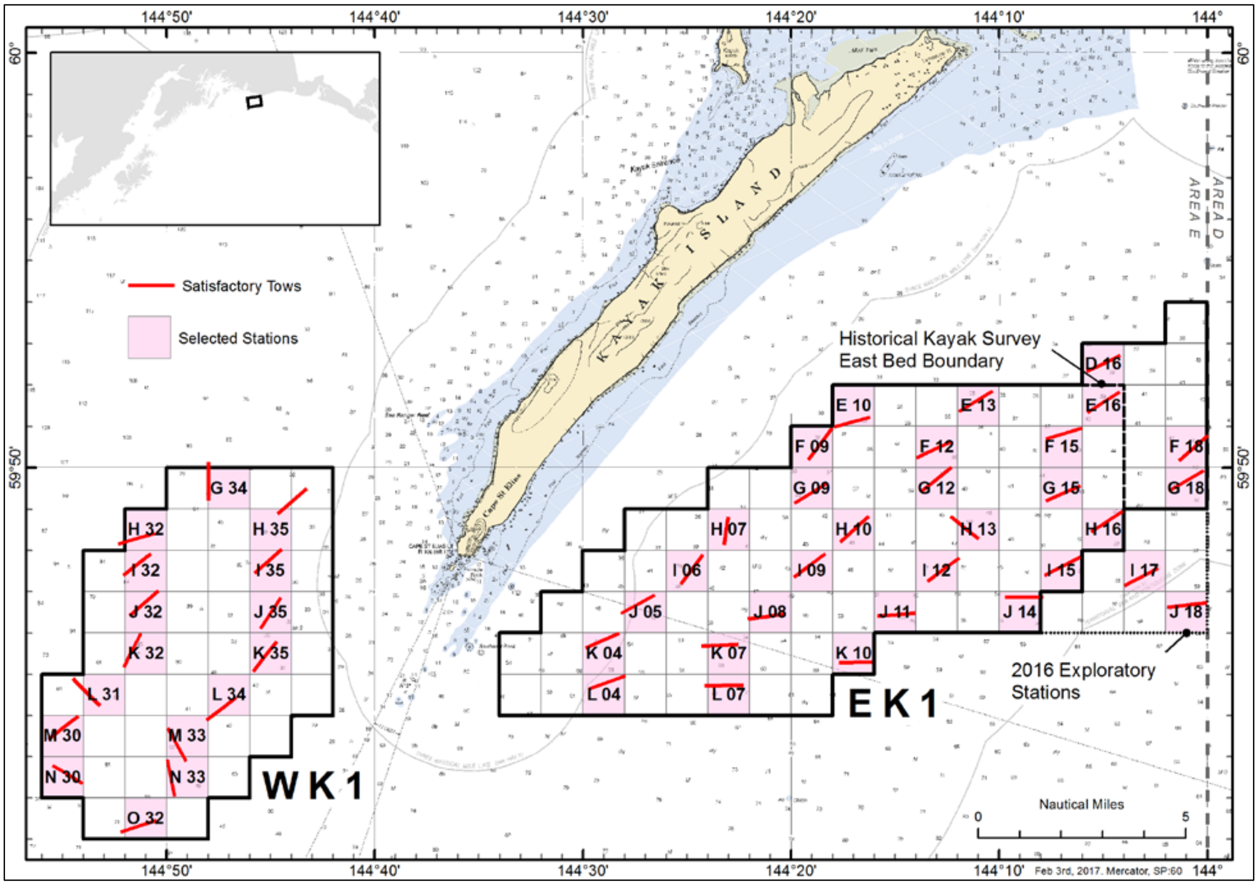

Figure 2.–Prince William Sound survey area showing location of the 2 beds: East Kayak 1 (EK1), and West Kayak 1 (WK1). Beds were subdivided into 1 nm^2 grids. Every third gird was selected as a station in the 2016 survey. Red lines show the tows of stations sampled in April.

METHODS

DREDGE SURVEY

One tow was made in each of the selected sampling units (Figures 1 and 2). Contents of dredge hauls were sorted; scallops were enumerated, weighed, and measured (shell height); and bycatch was quantified following procedures detailed in the statewide scallop survey operational plan (Smith et al. 2016), except that due to the high sea state during the survey, the Yakutat bed 1 (YAK1) and Yakutat boundary bed (YAKB) were not surveyed (Figure 3).

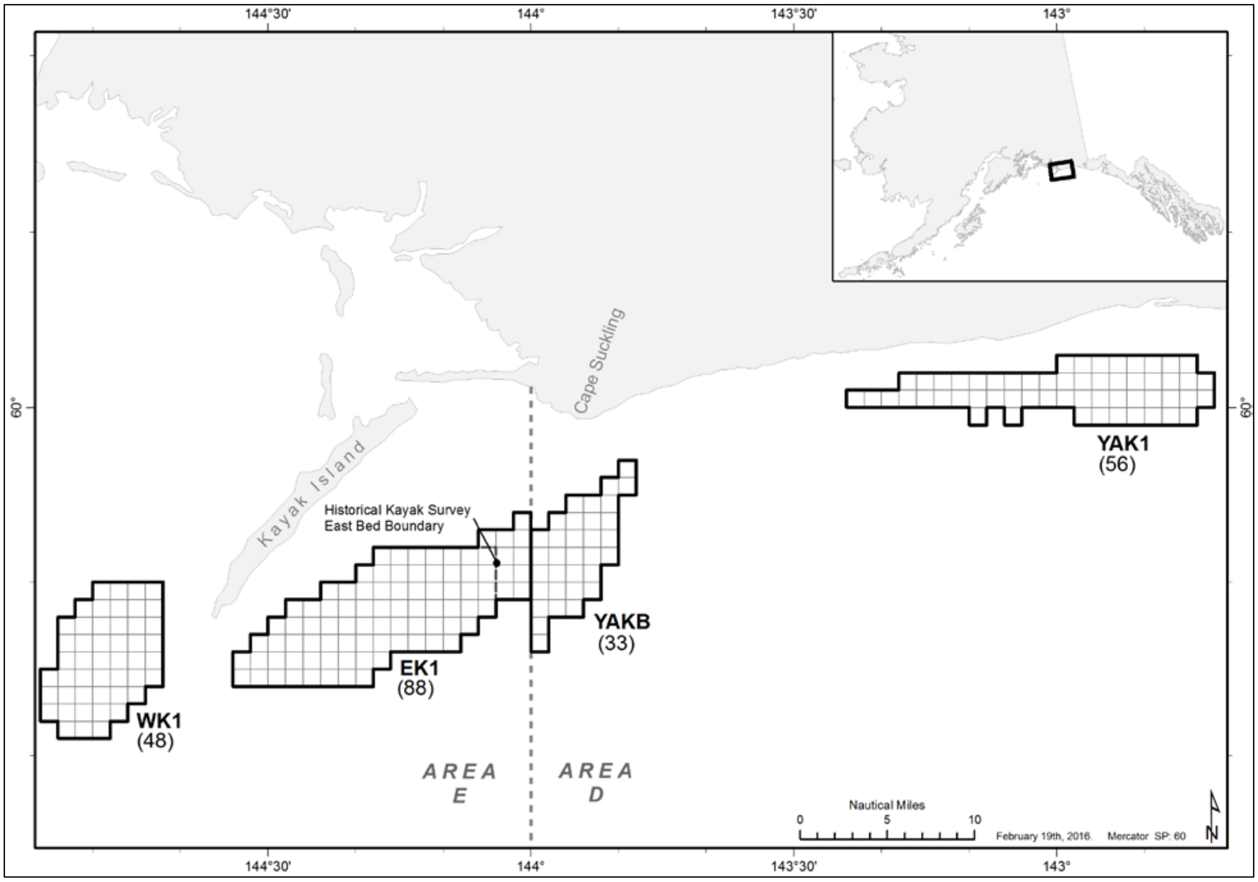

Figure 3.–Weathervane scallop survey sites in the north Yakutat and Kayak Island area. The 2016 survey priorities were the EK1 and YAKB complex, as well as the YAK1 and WK1 beds. Parentheses contain the number of stations in each bed.

Tow lengths were calculated as the linear distance between the start and end points of the tow, unless this calculated distance was greater than 10% more than the length recorded by the vessel's navigation system. If the difference was greater than 10%, the vessel's distance was used. The reason for using the vessel's recorded distance from the navigation system was an assumption that either the start and end points of the tow had been recorded incorrectly or the tow path was nonlinear and therefore greater than the straight line distance between the 2 points.

The average scallop density and abundance per bed were estimated along with their respective confidence intervals, and CVs relative to a target CV of 20 as established in Tables 1–3 in Smith et al. 2016. Scallop abundance calculations were performed for both size classes (small and large) and for all scallop combined (Figures 4 and 5).

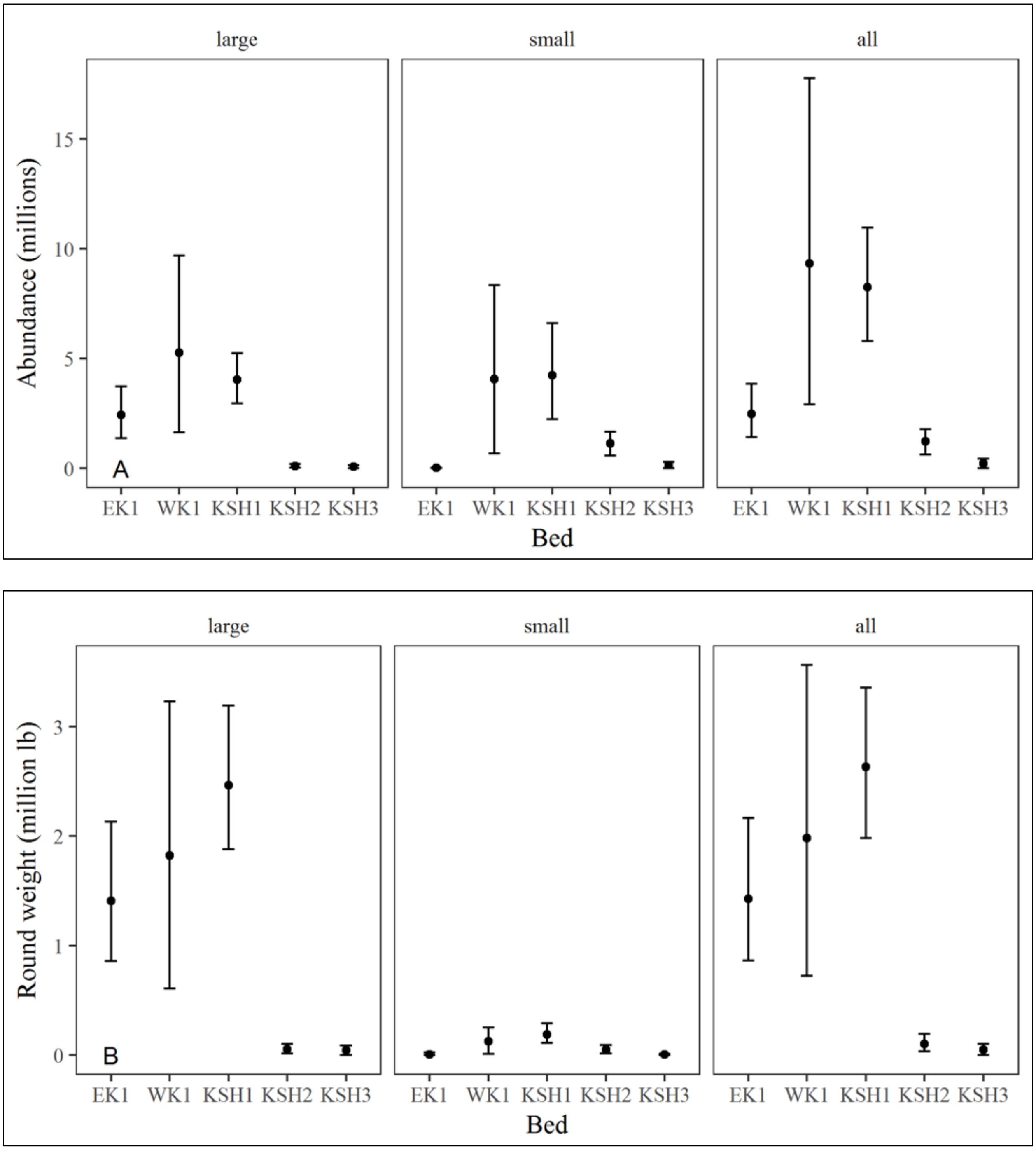

Figure 4.–A: Abundance (numbers of individual scallops) with 95% bootstrap confidence intervals by size class. B: Abundance in round weight (lb) of scallops by size class with 95% bootstrap confidence intervals.

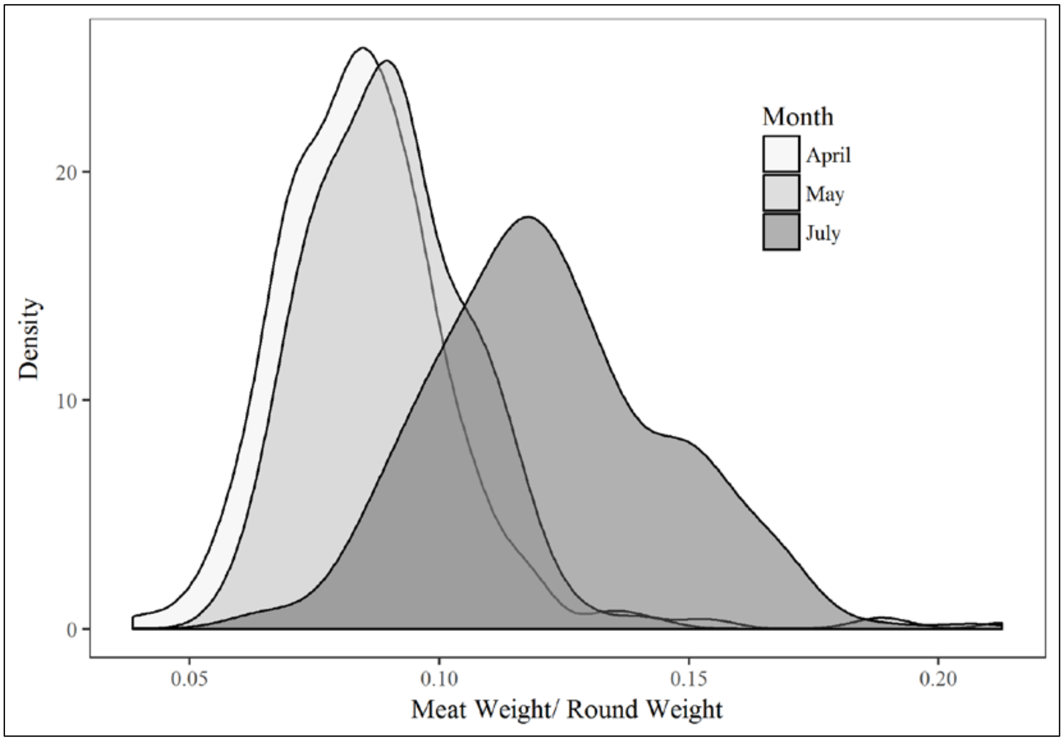

Figure 5.–Scallop meat weight to round weight ratio by month during 2016 surveys in the Shelikof District.

STOCK ASSESSMENT AND QUOTA CALCULATIONS

The scallop stock assessment methods consist of a dredge sample, biomass estimation using an area swept estimate, and visual examination of other key biological parameters (e.g., shell height, meat weight). Scallop size, number, and weight compositions from each tow were pooled within beds to determine population metrics. Scallop samples were categorized by size class: large (≥ 100 mm), and small (< 100 mm). Shell heights were recorded, along with round weights (weight of the whole unshucked scallop), and meat weights from shucked scallops. Scallop abundance estimations were based upon area-swept calculations. The scallop density of a given tow d_i was calculated as

$$d_i = \frac{c_i}{a_i},$$

where

$$a_i = l_i \cdot w \cdot Q,$$

and

$$\overline{d} = \frac{1}{s}\sum_{i=1}^{s} d_i.$$

c_i = the catch of a species, either as abundance or weight, in sample tow i,
a_i = the nmi^2 sampled in haul i,
l_i = the nautical miles towed for sample haul i,

w = the dredge width in nmi,
Q = dredge efficiency, and
s = the number of stations sampled.

A preliminary Q of 0.83 calculated from the Kayak Island beds in 2004 (Gustafson and Goldman 2012) was used in lieu of bed specific efficiencies. The variance of scallop density was calculated using a nonparametric bootstrap resampling procedure with replacement. Bootstrap percentile intervals were used to estimate 95% confidence intervals.

An estimate of the surveyed population abundance $\hat{N}$ was calculated by expanding $\overline{d}$ over the defined bed area A encompassing all grid cells as

$$\hat{N} = A\overline{d}.$$

Variance and confidence intervals for the surveyed population $\hat{N}$ were estimated using a nonparametric bootstrap procedure.

An estimate of the surveyed population round weight (lb) $\hat{RW}$ was calculated in the same manner as the abundance estimates, by changing c_i to weight instead of numbers.

Available meat weight (weight of the shucked abductor muscle) biomass (lb) of large scallops was calculated for each bed using 2 methods. Both methods use the meat/round weight ratio calculated from a subsample of 10 large individuals for each tow (where available).

For every individual the meat weight ratio was calculated as

$$r = \frac{MW(g)}{RW(g)}.$$

A nonparametric bootstrap procedure was used to estimate the mean ratio $\overline{r}$, variance, and percentile confidence intervals for each bed.

The first meat weight estimation method was calculated using the estimated abundance $\hat{N}$ of large scallops in each bed and the mean individual round weight of large scallops $\overline{RW}$ per bed:

$$MW_1 = \hat{N}\,\overline{r}\,\overline{RW}.$$

The second meat weight estimation method applied the $\overline{r}$ to the estimated round weight $\hat{RW}$(lb) of large scallops by bed. The round weight of large scallops by bed was calculated using the average density of scallop round weight by bed multiplied by the area of each bed (Table 3):

$$MW_2 = \hat{RW}\,\overline{r}.$$

Projection intervals for the meat weight (lb) estimates were calculated from the nonparametric bootstraps performed for the abundance estimates (both $\hat{N}$ and $\hat{RW}$) and the mean ratio $\overline{r}$.

A GHL was calculated based upon 5% and 10% population exploitation levels from the meat weight estimates.

Graphical representations of biological data are presented for evaluation and tables are presented for monitoring biological characteristics of interest. Histograms of scallop shell heights have been expanded to reflect the measured size distribution to the total number caught by tow.

Additionally, the prevalence of clappers in each bed was calculated as a proxy for an estimate of natural mortality and is reported here as the percent of the estimated weight or numbers by bed.

RESULTS

DREDGE SURVEY

Shelikof Area

A total of 65 successful 1 nmi dredge tows were conducted during the 2016 Shelikof area scallop survey: 56 in bed 1, 7 in bed 2, and 2 in bed 3 (Figure 1). A total of 3,424 scallops were sampled, weighing 441.7 kg (973.8 lb). Scallop density ranged from 0 to 113 for large scallops/nmi and 0 to 331 for small scallops/nmi.

Kayak Island

A total of 47 successful 1 nmi dredge tows were conducted during the 2016 Kayak Island scallop survey with 31 in the east bed and 16 in the west bed (Figure 2). A total of 768 scallops were sampled, weighing 196.7 kg (433.7 lb). Catch abundance ranged from 1 to 609 for large scallops/nmi and 0 to 604 for small scallops/nmi.

STOCK ASSESSMENT AND QUOTA CALCULATIONS

2016 Abundance Estimate

The KSH1 bed was within the target CV when examined by number of scallops. No other area met the target CV (Table 1), although the EK1 bed is reasonably close. Scallop density and abundance were highest for the Western Kayak Island bed (Table 2; Figure 3), although round weights were greatest in the Kodiak District Shelikof 1 bed (Table 3; Figure 4). The CV for round weight estimates was similar to the abundance-based CV for all beds (Tables 1 and 3).

2016 Harvest Rate

Harvest rates of scallops have, at times, been based upon the meat weight (lb) available in a bed. Using the individual scallops that were measured for biological metrics (i.e., weight and shell height), the meat weight to round weight ratio was between 0.082 and 0.12, with little variability found within beds. The greatest ratio was from those scallops sampled later in the year (Table 4; Figure 5). Additionally, for those scallops from KSH1, the only bed sampled in both May and July, the scallops from July were lighter for a given shell height (Figure 6). Proposed GHLs were generally similar between the 2 meat weight estimates (Tables 5 and 6), alhough the estimates based upon weights, as opposed to numbers, have lower overall variability.

The meat to round weight ratio was determined from a subsample of 10 large scallops, which were part of a larger random sample of 40 individual large shells collected for shell height measurements. A goodness-of-fit test (K-S test) was performed for each tow to confirm that the shell heights of the subsample of 10 shells were representative of all the large scallops in the greater subsample of 40. The examination was constrained to tows with at least 11 large scallops. Results suggest that the subsample rate is appropriate with 90% of the tows (n = 55) having a p-value greater than 0.05, and 10% of tows (n = 6) having a p-value less than 0.05. A p-value of greater than 0.05 suggests that the 10 large scallop shell heights are from the same distribution as the 40 in the original sample.

Table 1.–Estimates of large (≥100 mm shell height) scallop abundance and CV by bed.

Bed	Area (nmi^2)	No. Tows	No.	CV
EK1	89.11	31	2,424,942	26
WK1	48.66	16	5,275,834	39
KSH1	181.63	56	4,051,025	14
KSH2	21.15	7	110,587	38
KSH3	8.49	2	79,587	65

Table 2.–Estimates of abundance and density with 95% bootstrap confidence intervals

Bed	Size class	No.	No. Lower Limit	No. Upper Limit	Density (scallop/nmi)	Density Lower Limit	Density Upper Limit
EK1	all	2,481,295	1,421,963	3,859,454	27,845	15,957	43,311
	large	2,424,942	1,364,733	3,730,349	27,213	15,315	41,862
	small	21,612	8,356	36,342	243	94	408
WK1	all	9,321,238	2,914,121	17,753,685	191,559	59,887	364,852
	large	5,275,834	1,631,237	9,689,194	108,422	33,523	199,120
	small	4,072,688	679,929	8,339,352	83,697	13,973	171,380
KSH1	all	8,234,391	5,793,121	10,960,363	45,336	31,895	60,344
	large	4,051,025	2,969,534	5,241,531	22,304	16,349	28,858
	small	4,231,931	2,253,265	6,616,964	23,300	12,406	36,431
KSH2	all	1,241,363	638,734	1,773,931	58,693	30,200	83,874
	large	110,587	30,272	196,657	5,229	1,431	9,298
	small	1,139,188	594,232	1,665,086	53,862	28,096	78,727
KSH3	all	226,476	7,261	443,944	26,676	855	52,290
	large	79,587	7,261	150,624	9,374	855	17,741
	small	140,647	0	293,320	16,566	0	34,549

Table 3.–Estimates of round weight (lb) with 95% bootstrap confidence intervals for large (≥100 mm shell height) scallops by bed.

Bed	Weight (lb)	Weight (Lower Limit)	Weight (Upper Limit)	CV
EK1	1,407,335	856,760	2,129,457	23
WK1	1,822,844	608,376	3,229,152	37
KSH1	2,465,030	1,880,572	3,192,463	13
KSH2	56,542	15,226	104,246	40
KSH3	47,253	3,474	89,484	62

Table 4.–Meat weight to round weight ratio (lb) by bed from individual scallops with 95% bootstrap confidence intervals.

Bed	Ratio	Lower Limit	Upper Limit
EK1	0.082	0.0807	0.0841
WK1	0.088	0.0840	0.0916
KSH1	0.111	0.1080	0.1131
KSH2	0.121	0.1135	0.1293
KSH3	0.112	0.1008	0.1250

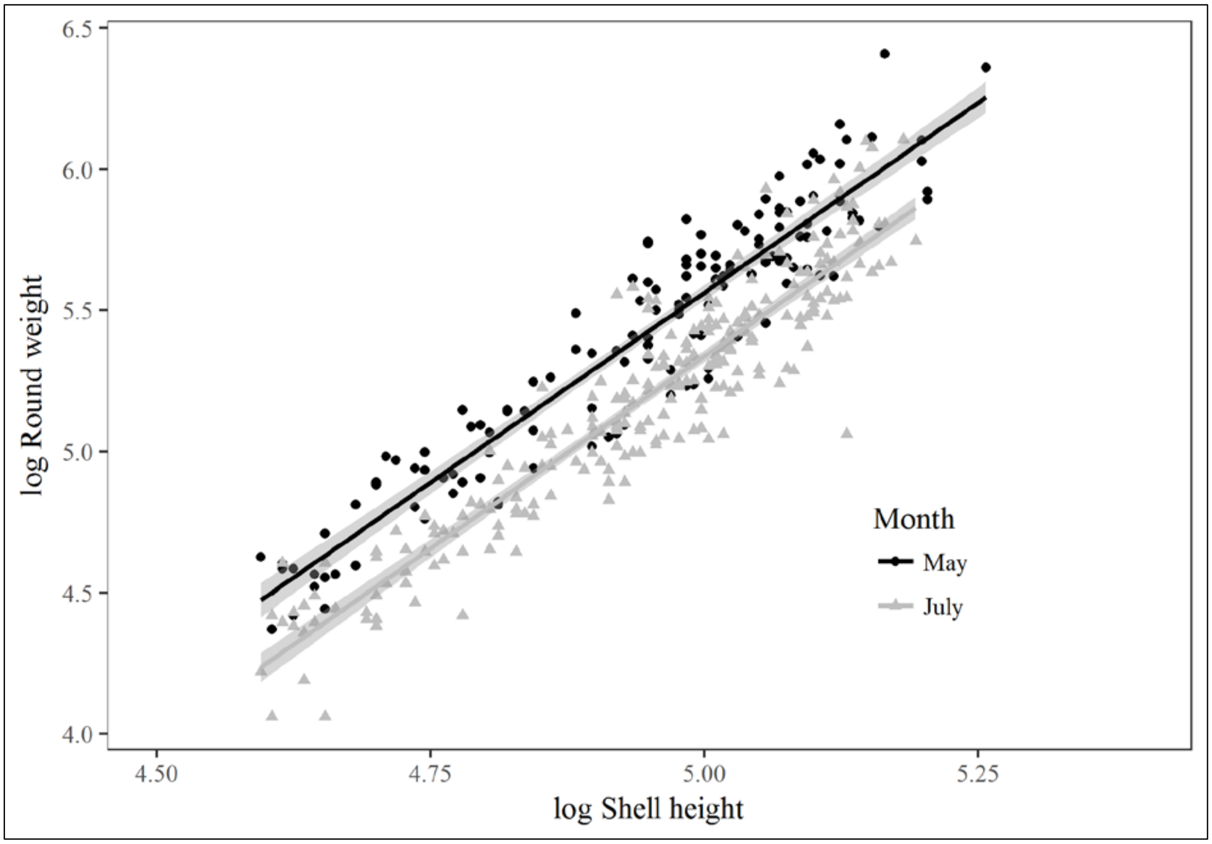

Figure 6.–Round weight vs shell height for the KSH1 bed by month with linear models fit using least squares.

Table 5.–Meat weight GHL (lb) estimates by bed, using meat weight estimate 1, at a 5% or 10 % annual exploitation rate, with 95% confidence intervals.

	5% exploitation			10% exploitation		
Bed	GHL	Lower Limit	Upper Limit	GHL	Lower Limit	Upper Limit
EK1	5,332	3,001	8,202	10,663	6,001	16,404
WK1	8,797	2,720	16,157	17,595	5,440	32,314
KSH1	11,017	8,076	14,255	22,034	16,152	28,510
KSH2	233	64	414	465	127	828
KSH3	193	18	365	386	35	730

Table 6.–Meat weight GHL (lb) estimates by bed, using meat weight estimate 2, at a 5% or 10 % annual exploitation rate, with 95% confidence intervals.

	5% exploitation			10% exploitation		
Bed	GHL	Lower Limit	Upper Limit	GHL	Lower Limit	Upper Limit
EK1	5,799	3,530	8,775	11,598	7,061	17,549
WK1	7,974	2,661	14,126	15,948	5,323	28,252
KSH1	13,611	10,384	17,628	27,223	20,768	35,256
KSH2	343	92	633	686	185	1,265
KSH3	265	20	503	531	39	1,005

Scallop Shell Height

Histograms of scallop height by bed (Figure 7) show dominant size classes that vary by bed. The smallest scallop measured had a shell height of 13 mm and the largest had a shell height 192 mm. The EK1 bed had very few small scallops sampled, and the size structure was narrowly grouped for large scallops. The WK1 bed scallops were generally smaller than those sampled from EK1, although an evident size structure is observed that includes a substantial number of small scallops. The KSH1 bed has a widely dispersed size structure with many scallops observed in the smallest size mode, as well as a second mode of large scallops. The KSH2 and KSH3 beds have more small scallops present, although few scallops were measured from the KSH3 bed.

Scallop Reproductive Condition

Gonad development state was determined for all scallops sacrificed to obtain meat weights. A distinct temporal difference was seen with most (>90%) of the scallops sampled in April and May classified as either *filling* or *full* gonads, whereas most of the July scallops were classified as either *empty* or *initial recovery* (Table 7).

Clappers

Clappers, empty shells still connected at the umbo, were counted, weighed, and the shell height measured for each tow (Figure 8). The number of clappers was calculated for each bed and compared to the live scallop estimates to report a percentage of clappers per bed. The percent of clappers was calculated using both numbers and round weights (Table 8). The percentage of clappers can be used as a rough proxy for natural mortality, and all the estimates here fall below or close to the assumed 12% annual mortality.

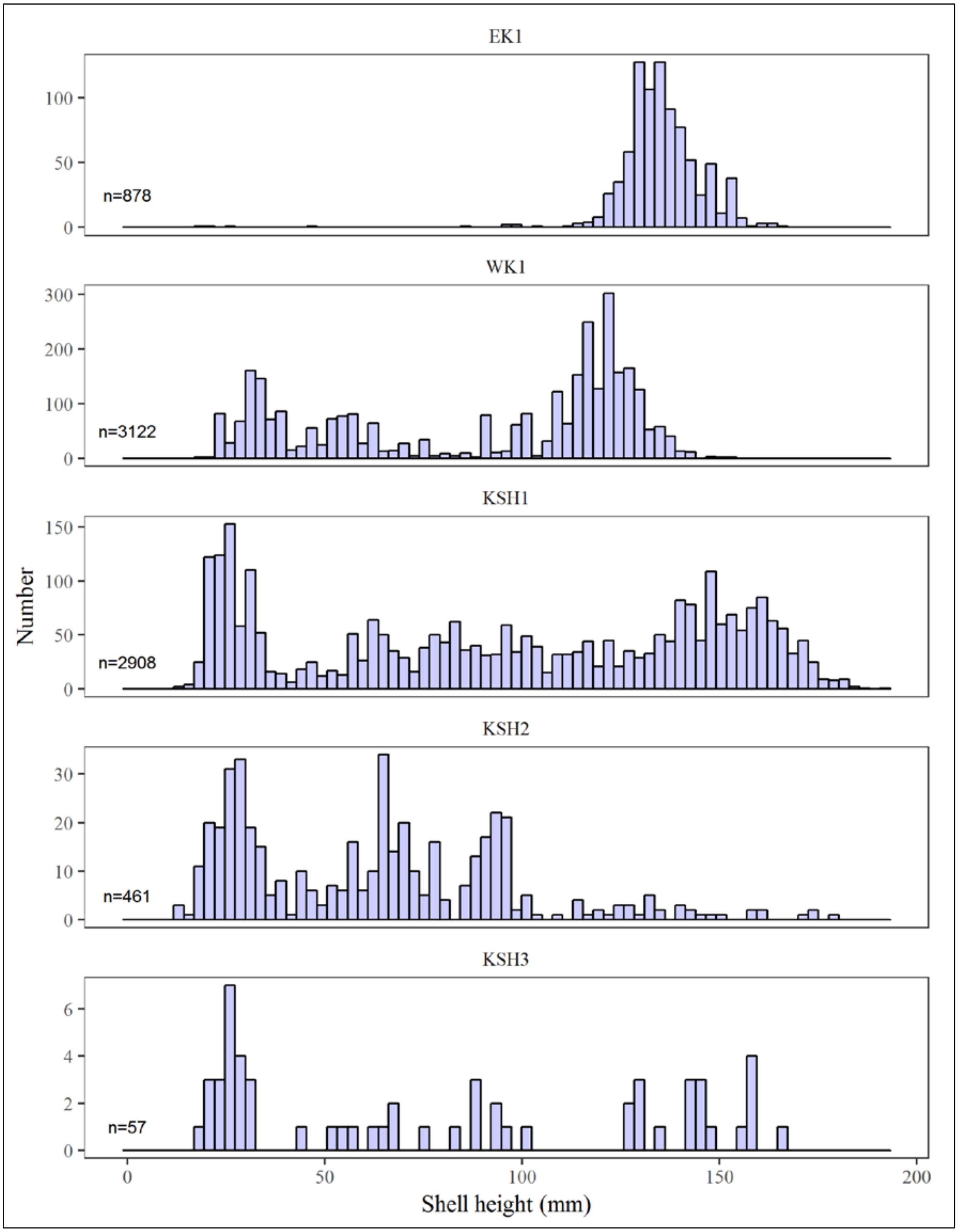

Figure 7.–Scallop shell height histograms by bed. Sampled shell heights have been expanded to the total number sampled. Sample sizes are shown for each bed. Note the differing *y*-axes.

Table 7.–Gonad development stage of scallops by bed and month.

	April		May	July		
Stage	EK1	WK1	KSH1	KSH1	KSH2	KSH3
Empty	1.0	3.5	0.5	1.7	0.0	0.0
Initial Recovery	8.9	6.3	6.4	97.5	90.5	100.0
Filling	75.1	89.5	76.6	0.8	9.5	0.0
Full	15.0	0.7	16.5	0.0	0.0	0.0
No. Sampled	213	143	188	236	21	5

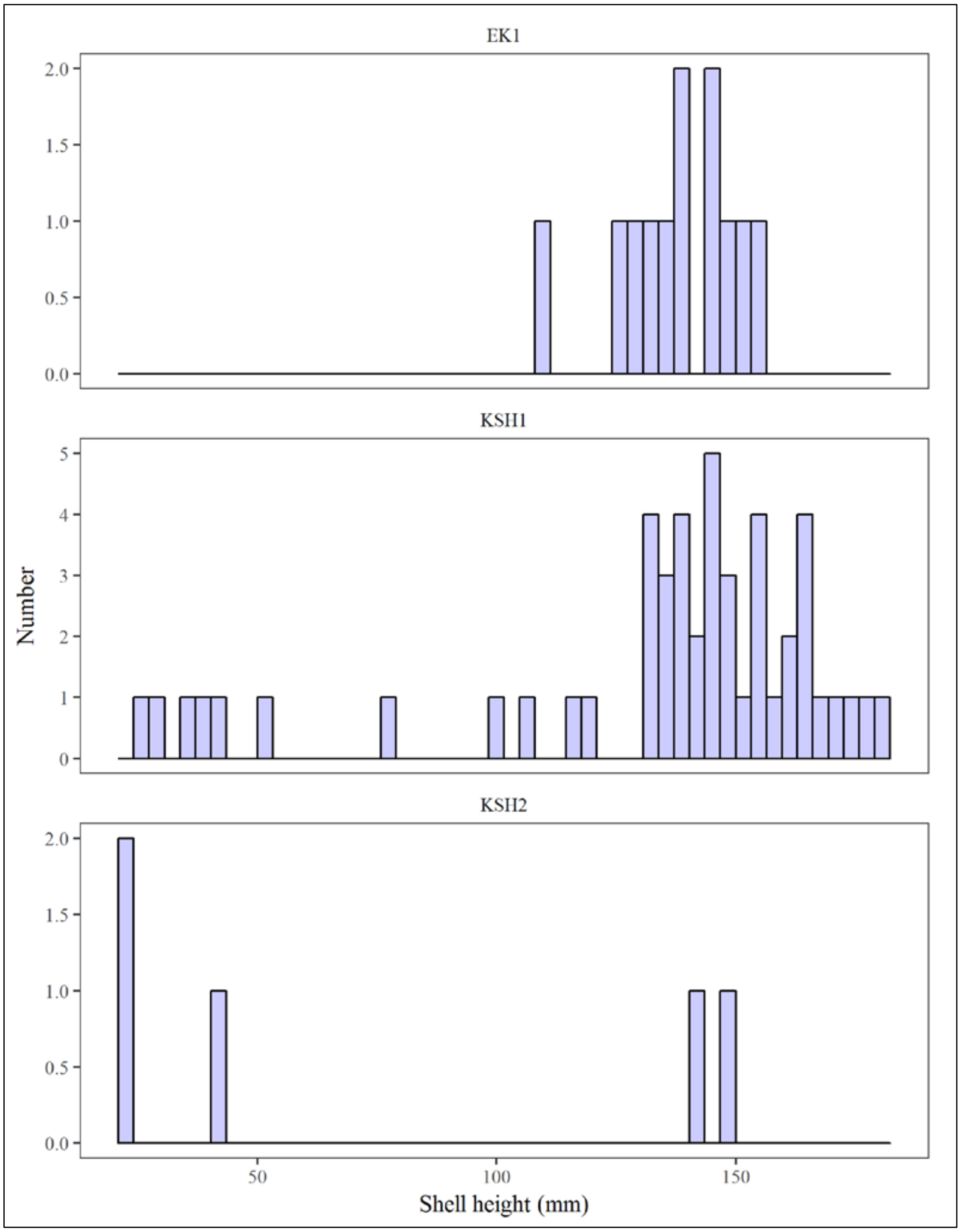

Figure 8.–Scallop shell height histograms by bed for clappers (empty shells connected at the umbo).

Table 8.–Percent of clappers in numbers and round weight by bed.

Bed	Year	% Numbers	% Round Weight
EK1	2016	2.36	1.93
WK1	2016	0.00	0.00
KSH1	2016	3.51	1.83
KSH2	2016	16.17	5.42
KSH3	2016	0.00	0.00

DISCUSSION

The primary objective of this survey was to estimate scallop abundance by survey area with a CV less than or equal to 20 (Smith et al. 2016). From the results reported in Table 1, only EK1 and KSH1 were near that level. Additional sampling would be recommended to achieve a smaller CV in the remaining 3 survey areas (KSH2, KSH3, and WK1). Increased sampling will be performed when these beds are surveyed again, sampling 40% of the quadrats (up from 30% in 2016). This should reduce the CV closer to the desired 20.

The estimated GHLs for Kayak Island area range from 6,191 to 45,801 lb meat weight. The estimated EK1 bed abundance was on the lower end of survey estimates from 1996 to 2010, although it has a similar CV (Gustafson and Goldman 2012, Table 2). Coupled with the lack of small scallops observed during sampling, the EK1 bed remains a concern. If past recruitment was successful it is expected that small scallops would be observed during the survey. Given the lack of observed recruitment there is concern that the population in this bed will continue to decline. The WK1 bed abundance was within the range of historic estimates, although the CV was higher (Gustafson and Goldman 2012, Table 2). This high CV probably relates to a reduced sampling schedule (30% vs 50% of the bed sampled) and patchily distributed scallops.

There are no previous surveys with which to compare the Shelikof Strait abundance estimates; however, the historic GHLs from this area have been high (NPFMC 2015). The abundance and weights estimates (Tables 2 and 3) of large scallops do not appear well suited to supporting harvest at the historic GHLs. The estimated GHLs for KSH district range from 10,496 to 37,526 lb meat weight. This range is substantially smaller than the GHLs for the past 5 years (75,000 to 135,000 lb meat weight). However, the catch for the 2015/16 season is of similar scale, although higher than our estimated GHL range (39,876 lb of meat retained). Without abundance estimates from previous years, it is difficult to ascertain if this district has experienced a recent decline or if the survey is underestimating abundance. Future surveys in this area will help clarify this question.

Individual scallops were collected for biological metrics (specifically age, length, and weight). According to the operational plan, a random sample of 40 large class scallops was taken from each tow. Ten of these scallops were further sampled to determine a meat weight to round weight ratio. Statistical tests were performed to confirm that the shell heights of the 10 random large samples were representative of all the large scallops in the subsample of 40. This analysis indicates that the sample design proposed in the operational plan (Smith et al. 2016) is reasonable for the analyses examined in this study.

Amendment 6 of the scallop Alaska Scallop Fishery Management Plan established an overfishing control rule of $F = 0.13$, where F is the instantaneous rate of fishing mortality. An F

of this level corresponds to a maximum of a 12% annual exploitation rate. Therefore, a target annual exploitation should be less than 12%. Barnhart (2003) proposed that harvesting at a 10% annual exploitation rate is appropriate for maintaining a precautionary approach and is "consistent with the NMFS technical guidance on implementing National Standard 1." In the past, GHLs in the PWS and Cook Inlet areas were set based upon a 5% annual exploitation rate (Gustafson and Goldman 2012). Herein, GHLs based upon both round weight and abundance estimates are presented at 5% and 10% annual exploitation rates, as well as the lower and upper projection intervals. The authors recommend that managers utilize the range of estimates, given by the lower and upper confidence estimates in Tables 4 and 5, instead of simply choosing the point estimate. An appropriate GHL should be determined by adjusting within the ranges provided, depending on the population size structure information (Figure 7), future age structure information, and fishery performance. Ideally, a healthy scallop bed would have consistent recruitment, and therefore have a wide range of scallop shell heights (similar to KSH1; Figure 7) and ages. Gaps in shell height histograms may indicate sporadic recruitment or spatial segregation within the bed and should be evaluated before choosing a GHL range.

The greater meat weight to round weight ratio observed in July relative to that observed in April and May may be an effect of the scallops spawning between the May and July cruises. The gonad development data support this explanation, with most (>90%) of the scallops sampled in April and May classified as either *filling* or *full* gonads, whereas most of the July scallops were classified as either *empty* or *initial recovery* (Table 8). Additionally, for those scallops from KSH1, scallops from July were lighter for a given shell height (Figure 8). Based on these gonad development and shell height to meat weight observations, presumably the July scallops yielded the greatest meat weight to round weight ratio because of weight lost as spawned gametes. Study of such weight difference will need to be expanded upon in the future if the fishery is to move to round weight based GHLs.

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