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Age and Growth of Weathervane Scallops *Patinopecten Caurinus* from the Alaska Statewide Scallop Fishery, 1996-2013

by

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and

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September 2014

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

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

Onboard observers required on all commercial vessels fishing for weathervane scallops *Patinopecten caurinus* in Alaska waters outside Cook Inlet collect and deliver scallop shells to the Alaska Department of Fish and Game (ADF&G) for visual estimation of scallop age. ADF&G observer program technicians inspected over 26,000 scallop shells sampled between 1996 and 2013, estimating scallop age at time of capture, measuring shell height, and measuring distance from shell hinge to each annual mark (annulus) on a subsample used for growth modeling. This report details ADF&G scallop shell aging methods and presents comparisons of size-at-age, growth, and age composition of the commercial scallop harvest from different management units across Alaska. Results from this research showed that Kodiak scallops grew markedly faster than scallops from eastern Gulf of Alaska management units and moderately faster than scallops from western Alaska management units. Mean shell height for scallops with estimated age 7 years was 125 mm for Yakutat District (n = 462), 138 mm for Bering Sea Area (n = 65), and 147 mm for Kodiak Shelikof District (n = 759). Age distributions of retained scallops from eastern Gulf of Alaska and western Alaska management units contained higher proportions of old scallops than age distributions of retained scallops from Kodiak Area.

Key words: weathervane scallop, *Patinopecten caurinus*, onboard observer, shell height, shell aging, growth modeling.

INTRODUCTION

Gulf of Alaska and eastern Bering Sea weathervane scallops *Patinopecten caurinus* (scallops) are targeted by a dredge fishery with 2000–2013 average annual landings 220 metric tons (484,195 lb) scallop meat. Alaska Department of Fish and Game (ADF&G) manages most aspects of this fishery (NPFMC 1995), including a mandatory onboard observer program (Rosenkranz and Spafard 2011) that has been in place for all Alaska waters outside Cook Inlet[1] since 1994. Observers sample each vessel's catch to track fishery performance, collect biological information on scallops, and to monitor incidental catch (bycatch) of commercially important species such as *Chionoecetes* crabs and Pacific halibut *Hippoglossus stenolepis*. Observers also collect upper or left valves of scallop shells (shells) as part of their sampling duties and return them to the Kodiak ADF&G office for shell aging.

Researchers have used visual examination of shells as a method for estimating age and growth of various scallop species since at least the 1950s (Stevenson and Dickie 1954, Rees 1957, Merrill et al. 1966, Bourne et al. 1989, Defeo and Gutierrez 2003, Chute et al. 2012). According to theory, abundant food and warmer water temperatures in summer lead to wider spacing between circuli, the layers of new shell material laid down along the shell edge as the scallop grows. Conversely, circuli are packed closely together during winter due to colder water temperatures, lower food availability, and subsequently slower growth. These growth patterns result in zones of widely spaced circuli followed by zones of compressed circuli that frequently form visible annuli (rings) on shells that are indicative of scallop age.

ADF&G's scallop observer program employs and trains technicians to interpret visible annuli on scallop shells and estimate age at time of capture. Throughout this report, we refer to these technicians as "agers" and term the process of estimating scallop age from shells as "aging." In addition to aging, technicians measured scallop shell height (SH) on all shells inspected and recorded measurements of distance from the shell hinge to each annulus on a subsample of the shell collection. Together, these data allowed us to compare age distributions and growth of scallops sampled from different management units across Alaska.

[1] Scallop vessels operating in the Cook Inlet Area are limited to a single dredge with maximum width 6 feet and must accommodate an ADF&G observer on request. Most of the management area is closed to scallop fishing.

This report documents scallop aging methods used by the ADF&G scallop observer program and presents results from aging of shells collected over the period 1996–2013. We compare SH-at-age, age composition of the harvest, and growth model parameters from scallop management units in different parts of the state. This information is of interest to fishery managers and researchers given the broad spatial extent of the Alaska scallop fishery and previously observed between-area differences in scallop size and growth.

METHODS

SHELL COLLECTION

Scallops aged for this study were collected from all Alaska management areas and districts (management units) with the exception of Southeast Alaska Area and Adak Area, where no scallop fishing occurred, and Cook Inlet Area, where observers were not required (Table 1, Figure 1). These management units group naturally into 3 geographic zones that we define as follows: 1) eastern Gulf of Alaska, including Yakutat District, District 16, and Prince William Sound Area; 2) Kodiak Area, including Northeast, Shelikof, Southwest, and Semidi Islands districts; and 3) western Alaska, including Alaska Peninsula Area, Dutch Harbor Area, and Bering Sea Area (Table 1, Figure 1).

Guideline harvest levels (GHLs) for the commercial scallop fishery in each management unit are set annually by ADF&G. In general, fishing continues until the GHL is attained, the season is closed based on in-season data (e.g., poor fishery performance or high bycatch), or because the end of the July 1 through February 15 regulatory season is reached. This management structure produces shell samples that vary in size and collection dates between seasons, leading us to pool all shells collected in each management unit for all analyses presented here except plots of estimated scallop age distributions by season.

Observers collected two upper or left valves of scallop shells from the retained catch of each haul sampled during the 1996/97–2013/14 seasons. Observers were instructed to sample five hauls per day if possible following procedures detailed in Barnhart (2004) and ADF&G (2010) that were designed to provide an unbiased sample with respect to scallop size.

Each season during the 1996/97–2011/12 period, observers also collected upper valves from up to 10 scallops that measured less than 100 mm SH from the unsorted catch in each management unit. This “small-shell” collection was used as a reference set and training aid for agers (see below). Observers cleaned, dried, and labeled all shells collected for return to the Kodiak ADF&G office. Labels recorded directly on the shells enabled us to link shells with tow-specific information from the scallop observer database such as date sampled and fishing location.

SHELL AGING

ADF&G staff aged upper valves of scallop shells at the Kodiak office by visually examining them to locate annuli (Barnhart et al. 2006). As a guide, agers inspected shells collected by the observer program during 1996–2002 (Jeff Barnhart, unpublished data) that were sampled and analyzed using stable oxygen isotope ratios to estimate age and growth (Dare and Deith 1990). Upper valves were chosen for aging over lower valves because 1) circuli were more distinct on upper valves than lower valves which were worn due to seafloor contact, 2) annuli were difficult to distinguish near the margin of lower valves which could result in systematic underestimation

(bias) in scallop age estimates, and 3) characteristic differences in shell color indicative of summer versus winter growth were easier to detect on upper valves than on lower valves.

Counting annuli

The surface of each shell was examined under a microscope with 6.3–12.5 power magnification using sharply angled illumination (raking light) to produce shadows that highlighted circuli and allowed agers to identify patterns of circuli and count annuli. An annulus was defined as a zone of closely spaced circuli formed during a period of slow growth. Frequently, agers counted annuli along three axes (Figure 2) to confirm age and to distinguish annuli from cracks and false checks (Merrill et al. 1966), which do not leave continuous marks across the width of the shell. Location of annuli sometimes corresponded with changes in shell coloration, but the spatial pattern of circuli was the primary criterion used to identify annuli. Agers recorded total number of annuli counted on each shell as estimated age.

Edges of some shells collected by observers were broken or chipped so that one or more annuli were missing along part of the shell margin. When agers encountered such shells, annuli were again counted along three axes (Figure 2), and maximum number of annuli counted along any single axis was recorded as the age estimate. Agers also developed a coding system to denote cases where annuli were missing at the location of the SH measurement and to note shells with atypical first year growth. These codes (Table 2) were used when recording all shell aging results.

SH and growth increment measurements

SH of all shells aged was measured using digital calipers and the value recorded to the nearest millimeter. Additionally, calipers were used to measure growth increments on a subsample of shells from the 1996–2011 collection that consisted of approximately every fifth shell from the retained catch shell sample plus all shells from the small-shell collection.

To measure increments, agers first located and marked annuli on the exterior surface of the shell with pencil along axis 1 (Figure 2). The calipers were then used to measure distance from the umbo (Figure 2) to each of the marked annuli, with each distance measurement recorded along with corresponding age in years. If any annuli on a shell could not be positively located, no distance measurement was made and the record was marked as missing data, although other annuli from the same shell could potentially be used for increment measurements.

Results from all increment measurements were tabulated to define upper and lower size limits for scallops of each age from each management unit. This information was available for use by agers whenever annuli were difficult to locate on a given shell. The small shell collection provided valuable information because the first three annuli tended to be more distinct on shells from younger animals due to less wear and fouling.

DATA ANALYSIS

We compared SH-at-age between management units graphically by creating boxplots using all 1996–2013 aging results, except shells marked with letter codes C or D (Table 2). These plots were constructed so that the box ends marked the 25^{th} and 75^{th} percentiles of the data (Q_1 and Q_3) with the median value marked by a line spanning the box. Boxplot ”whiskers” extended to the most extreme data value that was within two times the interquartile range ($Q_3 - Q_1$) of the box.

Data beyond the whiskers were plotted individually and considered outliers. Minimum sample size for inclusion in these plots was 5 shells from a management unit for each age.

Barplots of estimated retained scallop age distributions were constructed for all management unit/season combinations with sample size of 50 or more shells aged. All shells aged from the retained catch were used for plotting including those with letter codes C and D (Table 2). Plots were combined in arrays to facilitate visual comparison of retained scallop age distributions between years.

To quantify differences in growth between areas, we fit Ludwig von Bertalanffy (LVB) growth models (Quinn and Deriso 1999) to the scallop umbo-to-annuli measurements from each management unit. We used the Cerrato parameterization of the LVB model (Quinn and Deriso 1999, p. 138),

$$D(t) = d_4 + (d_{10} - d_4)\frac{1-\rho^{t-\tau_1}}{1-\rho^{\tau_2-\tau_1}} \quad \textbf{(1)}$$

and chose τ_1 = 4 years and τ_2 = 10 years. Primary parameters estimated were d_4, and d_{10}, corresponding to distance in millimeters from the umbo (Figure 2) to the 4th and 10th annuli, and ρ, a curvature parameter that produces a steeper curve near the origin (i.e., faster growth at young ages) as it decreases. Because multiple, correlated measurements were recorded from the same shell, we used a nonlinear mixed effects model for each management unit with data grouped at the shell level via the R package nlme (Pinheiro et al. 2012). We used the software to estimate a mean response for each parameter (a fixed effect) and to estimate between-shell variability at the management unit level for each parameter as a random effect with a normal distribution (see Pinheiro et al. 2012 for technical details).

RESULTS

SHELL HEIGHT-AT-AGE

ADF&G staff aged over 26,000 shells from the retained scallop harvest and small-shell collection obtained from observer sampling during the 1996/97–2013/14 seasons. Large numbers of shells were aged from management units that produced large scallop harvests, with Yakutat District, Kodiak Northeast and Shelikof Districts, and Bering Sea Area well represented in the sample (see Rosenkranz and Spafard 2014 for GHLs and harvest totals). For comparison of scallop size-at-age between management units, records with letter codes C or D (Table 2) were excluded, leaving a sample size of 17,631 shells for this analysis.

Kodiak Area scallops grew faster and were larger at all ages than scallops captured in the eastern Gulf of Alaska (Tables 3–4, Figures 3–4). Mean SH of scallops with estimated age 7 years was 125 mm for Yakutat District and Prince William Sound Area, 118 mm for District 16, and 147 mm for Kodiak's Northeast and Shelikof Districts (Tables 3–4, Figure 3). At estimated age 14 years, Kodiak Area scallops averaged 164 mm SH compared to 134 mm for eastern Gulf of Alaska scallops (Figure 4).

Size of western Alaska scallops was comparable to eastern Gulf of Alaska scallops at young ages but became more similar to Kodiak scallops as age increased. For example, mean SH of scallops with estimated age 3 years was 90 mm for western Alaska, 91 mm for eastern Gulf of Alaska, and 114 mm for Kodiak (Tables 3–5, Figures 3–4). By age 14 years, mean SH of western Alaska

scallops increased to 163 mm, close to the Kodiak mean of 164 mm (Figure 4 lower plot). Although sample size for the Dutch Harbor Area was small, scallop shells collected from the fishery exhibited particularly rapid growth, with mean SH increasing from 92 mm at age 3 to 147 mm at age 7, the same value observed for age-7 scallops from Kodiak's Northeast and Shelikof Districts (Tables 4–5, Figures 3–4).

AGE DISTRIBUTION OF RETAINED SCALLOPS

Over 24,000 observer-collected shells from the 1996/97–2013/14 retained scallop catch were aged by ADF&G staff (Figures 5–17, Appendix A). The most notable result from this work was the small proportion of older scallops found in Kodiak Area catches prior to 2006. Combining the 2000/01–2005/06 seasons, 69% of Kodiak Northeast District shells and 78% of Kodiak Shelikof District shells were aged 6 years old or less (Figures 10–13). This compares with estimates of 24% and 41% of shells aged 6 years old or less for Northeast and Shelikof Districts during the 2007/08–2013/14 seasons.

Older scallops comprised a larger proportion of retained catches from other management units. Over half the Yakutat District shells (Figures 5–6) and 87% of Bering Sea Area shells (Figures 16–17) that were aged produced estimates of 9 years or older. Sample sizes from other management units were smaller (see Appendix A for complete listing), but in general, our results showed that retained catches from most management unit/season combinations excepting Kodiak's Northeast and Shelikof Districts prior to 2006 contained broad ranges of scallop ages.

Above-average year classes were evident through multiple seasons in some retained scallop age distribution plot arrays. A good example was the 2001 year class in the Kodiak Area, which first appeared as 5-year-old scallops in the 2006/07 harvest (Figures 10–12). This year class was prevalent in catches from both Northeast and Shelikof Districts during the 2006/07–2009/10 seasons and continued to contribute to the harvest in subsequent years.

MODELING UMBO-TO-ANNULI MEASUREMENTS

Results from fitting mixed-effects LVB models to umbo-to-annuli measurements (Table 6, Figures 18–19) provided statistical confirmation of differences in growth between scallop management units. Estimates of d_4 and d_{10} were significantly larger for Kodiak scallops than for eastern GOA scallops, with the lowest estimates for both parameters attributed to District 16 (Table 6, Figure 18). Fixed effect estimates of d_4 (Figure 18 upper left) showed a natural split, with 95% confidence intervals for each Kodiak district plus Dutch Harbor Area higher than estimates from all other management units. Estimates of d_{10} formed a gradient (Figure 18 upper right), with Alaska Peninsula and Bering Sea estimates falling between low estimates from the eastern Gulf of Alaska and high estimates from Kodiak Area.

Patterns were less distinct in estimates of ρ, a curvature parameter that steepens the left part of the LVB curve as it decreases (Figure 18 lower plot). Small parameter estimates indicative of rapid growth at young ages came from Dutch Harbor Area and Kodiak Shelikof and Northeast Districts, with Bering Sea Area and Alaska Peninsula Area shells producing the highest estimates (Table 6). Of note, 95% confidence intervals for fixed effects showed that ρ was significantly higher for Bering Sea scallops than for scallops from Kodiak Northeast District, Kodiak Shelikof District, and Yakutat District, implying significantly slower growth at young ages.

Large sample sizes from Alaska's major scallop-producing management units (Table 6) produced narrow confidence intervals for fixed effects LVB parameter estimates (Figure 18).

The precision of these estimates indicated significant statistical differences between management units where biological differences were small. For example, 95% confidence intervals for d_4 and d_{10} did not overlap between Kodiak Northeast and Shelikof Districts, but confidence interval borders were less than 1 mm apart for both parameters.

Combining LVB curves from three management units with large sample sizes and different geographic locations in one plot (Figure 19) provided a succinct summary of our scallop size and age data. Kodiak scallops grew faster than eastern Gulf of Alaska and western Alaska scallops and were subsequently larger at all ages. Western Alaska scallops were close in size to eastern Gulf of Alaska scallops when young but were nearly as large as Kodiak scallops at older ages (Figure 19). Between-district differences in growth of Kodiak Area scallops were small and likely attributable to small sample sizes from Southwest and Semidi Islands Districts (Table 6). Although Dutch Harbor Area scallops were somewhat faster-growing than other western Alaska scallops, the Dutch Harbor Area fishery is limited in spatial extent and sample size was small compared to Yakutat District, Kodiak Northeast and Shelikof Districts, and Bering Sea Area (Table 6).

DISCUSSION

Results from this research quantified geographic differences in scallop growth and size-at-age across Alaska using a large collection of shells obtained from onboard observer sampling over a period of 17 years. In general, eastern Gulf of Alaska scallops captured in Yakutat Area and Prince William Sound Area fisheries grew slower and attained smaller maximum sizes than scallops captured in Kodiak Area. These results were consistent with results from exploratory Gulf of Alaska scallop surveys conducted during the 1960s that provided evidence of more rapid growth for Kodiak scallops than for Yakutat scallops (Haynes 1970, Hennick 1970). For western Alaska, where no exploratory surveys were conducted prior to commercial harvesting that began in the 1980s (Kaiser 1986, Barnhart et al. 2008), our results showed that growth and size-at-age were intermediate between eastern Gulf of Alaska and Kodiak scallop management units.

Other researchers have documented geographic differences in weathervane scallop growth and size-at-age. Haynes and Hitz (1971) found that scallops captured from inside waters in Washington State's Strait of Georgia grew faster and were larger given their age than scallops sampled from the outer Washington coast. They compared growth of scallops from the inshore population with Kodiak scallops sampled in 1968 (Haynes 1970) and reported that Strait of Georgia scallops grew slightly faster at young ages but were surpassed in size by Kodiak scallops at about 5 years of age. MacDonald and Bourne (1987) found that growth of inshore scallops from Canadian waters in the Strait of Georgia was much faster and size-at-age significantly greater than for scallops sampled offshore west of Vancouver Island. These authors attributed the differences to warmer water temperatures and greater phytoplankton availability in inshore areas. Alaska scallop harvests come almost entirely from offshore beds, and observed differences in scallop growth and size-at-age are most likely due to differences in ocean productivity, temperature, and food availability.

Scallop size has a large effect on Alaska's commercial scallop fishery. "Shucking" scallops, or removing scallop meat from the shell, is a labor intensive process with yield directly related to scallop size[2]. To illustrate this point, we plotted estimated scallop SH–meat weight relationships

[2] Mechanical scallop shucking machinery is prohibited by Alaska regulation.

from three management units where experimental data were collected by ADF&G and added marks denoting average retained SH from 2013/14 observer data (Figure 20). Simple calculations show that to obtain one pound scallop meat, crewmembers shucked 31 average-size scallops in Yakutat District (15 g/scallop), 18 in Kodiak Shelikof District (25 g/scallop), and 15 in Bering Sea Area (29 g/scallop). In other words, labor required to produce one pound of product was doubled in Yakutat District compared to Bering Sea Area.

Another important consequence of observed differences in scallop growth rates is the effect of fishery removals (i.e., retained catch) on reproductive output. Research has shown that scallops devote an increasing proportion of energy expenditure to reproduction and a decreasing proportion to somatic growth as they age past maturity (e.g., MacDonald and Bourne 1987 for weathervane scallops, MacDonald and Thompson 1985 and Langton et al. 1987 for *Placopecten magellanicus*). Due to their comparatively rapid growth, Kodiak scallops reach marketable size by their third or fourth year, and our results show that in some seasons these ages provided a significant proportion of the Kodiak Area harvest (Figures 10–13). This is a potential source of recruitment overfishing, defined as a reduction in the ability of the stock to reproduce at its full potential (Sissenwine and Shepherd 1987), because harvest of 3- and 4-year-old scallops removes these individuals from the population before they contribute substantially to total reproductive output. Results from MacDonald and Bourne (1987) showed that gamete production of both male and female weathervane scallops sampled in British Columbia increased with age and was about twice as high by weight for 10-year old scallops than for 4-year old scallops.

Scallop life history is intrinsically related to formation of the patterns of circuli that are detected during shell aging. Spawning of Alaska weathervane scallops occurs primarily in spring to early summer (Hennick 1970, Kaiser 1986, MacDonald and Bourne 1987) followed by a pelagic larval phase which in a laboratory setting was shown to last approximately one month (Bourne 1991). Growth after settlement to the seafloor is rapid prior to onset of maturity at age 3–4 years (Hennick 1970), leading to relatively wide spacing between the first few annuli. Due to erosive wear on the shell surface and fouling by epibonts, annuli one through three may be difficult to locate on scallop shells from older individuals, leading us to collect, age, and tabulate data on shells from young scallops via our "small-shell" collection. Examples from studies on other scallop species include Dare and Deith (1990), who found that the first annulus was not visible on any of their sample of 22 *Pecten maximus* shells analyzed using stable oxygen isotopes, and Chute and Hart (2012), who reported that the first visible ring often occurred during the second year of life in *Placopecten magellanicus*.

Scallop growth rates decrease over time after maturity, producing annuli that are spaced progressively closer together. Shell chipping (Figure 2) is a common problem, and agers may also have difficulty accurately distinguishing each of the closely spaced annuli near the margin on shells from older individuals. This problem is more pronounced for very old scallops which are a common feature of retained catches in the Bering Sea Area (Figure 16, Appendix A16) and for slow-growing eastern Gulf of Alaska scallops simply due to less available shell area compared to Kodiak scallops. To obtain the most accurate age estimates possible, ADF&G methodology relies on lighting and magnification for detailed examination of shell surface structure, as well as reference tables of size-at-age that were developed through examination of thousands of shells, including many from scallops 4 years of age or less when captured (Appendix B).

A set of 14 observer-collected weathervane scallop shells from various management units that were analyzed using stable oxygen isotopes (e.g., Dare and Deith 1990, Chute and Hart 2012) were also useful in development of the scallop shell aging methods described here. Although not formally analyzed for this report, results from this study (Jeff Barnhart unpublished data) indicated that: 1) regions of compressed circuli identified by agers as annuli were typically created each year in fall around the time when water temperatures at primary scallop fishing depths of 70–120 m reached annual maxima and began to cool (Xiong and Royer 1984); 2) the first annuli was formed during the first winter after settlement and fell in the range 15–35 mm from the umbo with variability likely due to differences in settlement date as well as differences in individual growth rates; 3) errors in age estimation could occur on older individuals near the margin due to tight spacing of annuli.

Mixed effects modeling of umbo-to-annulus distance measurements quantified between-individual variability in scallop size-at-age for each management unit through random effects estimates of standard deviation for d_4 and d_{10} (Pinheiro and Bates 2000). Our results showed that between-individual variability was substantial, with estimated standard deviations for both parameters from management units with large sample sizes (Yakutat District, Kodiak Northeast and Shelikof Districts, and Bering Sea Area) in the range 5.6–8.9 mm (Table 6). Given the model assumption of normally distributed variation around the fixed effect, size-at-age of about one third of the individuals in a given scallop population would be expected to fall more than one standard deviation above or below the estimated mean. In this light, Ignell and Haynes' (2000) asymptotic shell height estimate of 175.7 mm for scallops from the east side of Kodiak was close to our Kodiak Northeast District estimate of 169 mm (Table 6), whereas Kaiser's (1986) estimate of 189.8 mm (n = 76) for Kodiak eastside scallops seems high. We note that the largest umbo-to-annuli distance measurement from our sample of over 1,000 Kodiak Northeast District shells (Appendix B4) was 181 mm from a scallop with estimated age 23 years.

As a final point, we fit LVB models to measurements of umbo-to-annuli distance rather than shell height at time of capture, greatly increasing sample sizes and precision of parameter estimates (Table 6). Growth between fall/winter formation of annuli and capture of the scallop the following summer accounts for differences between SH-at-age and umbo-to-annuli distances. These differences were substantial for young scallops due to their rapid growth but declined with increasing age and decreasing growth rates (c.f., Tables 3–5 and Appendix B).

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TABLES AND FIGURES

Table 1.–Alaska weathervane scallop management units and abbreviations used in tables and figures in this report; see map Figure 1 for locations.

Area	District	Management unit	Abbreviation
Yakutat (D)	Yakutat	Yakutat District	D
Yakutat (D)	District 16	Yakutat District 16	D16
Prince William Sound (E)		Prince William Sound Area	E
Kodiak (K)	Northeast	Kodiak Northeast District	KNE
Kodiak (K)	Shelikof	Kodiak Shelikof District	KSH
Kodiak (K)	Southwest	Kodiak Southwest District	KSW
Kodiak (K)	Semidi Islands	Kodiak Semidi Islands District	KSM
Alaska Peninsula (M)		Alaska Peninsula Area	M
Dutch Harbor (O)		Dutch Harbor Area	O
Bering Sea (Q)		Bering Sea Area	Q

Table 2.–Definitions of letter codes used by agers for recording shell damage and atypical first annuli.

Letter code	Definition	Action/Remarks
A	annulus developing at shell margin but not completely formed	annulus not counted
B	first annulus outside typical range	note with code and double check estimated age
C	annulus present in some locations at margin but shell chipped at location of SH measurement	age estimate OK, SH measurement not used
D	shell chipped at margin where SH measurement taken but all annuli intact	age estimate OK, SH measurement not used

Table 3.–Mean scallop SH-at-age and sample sizes for eastern Gulf of Alaska management units. Shells with letter codes C and D (Table 2) were excluded.

Estimated	D		D16		E	
Age (years)	Mean SH	n	Mean SH	n	Mean SH	n
0[a]	25	2	25	1		
1	47	27	38	4	50	4
2	67	81	63	5	71	14
3	91	54	78	5	91	11
4	105	153	95	4	101	12
5	114	355	105	18	114	18
6	120	418	109	41	120	20
7	125	462	118	67	125	49
8	128	360	118	32	129	72
9	130	264	122	13	132	73
10	132	247	118	7	133	84
11	133	219	126	8	138	73
12	135	195	135	6	135	65
13	135	133	126	8	138	53
14	135	104	126	16	137	33
15	138	88	127	26	140	29
16	136	65	130	28	143	24
17	137	61	136	9	146	26
18	140	43	149	2	148	10
19	139	32	138	2	148	19
20	141	21			147	5
21	136	19			146	3
22	136	10			149	2
23	137	3			148	1

[a] First annulus not formed.

Table 4.–Mean scallop SH-at-age and sample sizes for Kodiak management units. Shells with letter codes C and D (Table 2) were excluded.

Estimated	KNE		KSH		KSW[b]		KSM	
Age (years)	Mean SH	n	Mean SH	n	Mean SH	n	Mean SH	n
0[a]			23	25				
1	64	57	53	180	60	2		
2	82	184	82	224	82	15		
3	106	212	117	718	105	6	121	1
4	127	403	127	1473	127	12	127	4
5	135	723	135	1594	134	9	137	15
6	142	555	142	1163	139	16	141	4
7	147	427	147	759	144	44	155	2
8	150	269	152	531	148	29		
9	153	181	155	274	155	20	163	2
10	155	128	158	227	154	10	162	1
11	155	85	160	143	160	20	155	1
12	157	64	162	113	157	12		
13	159	26	166	74	165	7		
14	162	40	165	49	164	6		
15	168	19	171	39	157	7		
16	169	13	171	13	167	4		
17	173	11	169	8	159	10		
18	177	10	175	9	163	7		
19	179	3	178	9	168	22		
20	164	4	176	5	170	12		
21	174	4	187	3	175	19		
22					178	8		
23	182	1	177	3	177	8		
24					179	6		
25					176	7		
26	182	1			181	4		
27					182	2		

[a] First annulus not formed.

[b] From exploratory fisheries opened by Commissioner's Permit during the 2009/10–2013/14 seasons.

Table 5.–Mean scallop SH-at-age and sample sizes for western Alaska management units. Shells with letter codes C and D (Table 2) were excluded.

Estimated	M[b]		O		Q	
Age (years)	Mean SH	n	Mean SH	n	Mean SH	n
1					47	6
2	74	5	87	4	62	32
3	90	33	92	23	91	55
4	105	23	114	5	103	34
5	112	21	133	21	121	44
6	118	42	142	30	132	26
7	125	34	147	31	138	65
8	136	41	152	16	141	50
9	140	37	159	17	145	61
10	145	18	164	9	148	67
11	148	2	163	4	150	87
12	149	7			152	97
13	152	3			154	108
14	156	12	164	1	158	128
15	159	9			159	105
16	165	12	179	1	160	93
17	164	8	176	2	163	65
18	153	2			164	47
19	167	1			166	40
20	171	3			167	35
21	167	3			170	22
22	172	4			170	13
23	167	6			177	5
24	179	2			168	4
25	169	2			173	2
26	166	3			173	1
27	174	2				

[a] Includes exploratory Unimak Bight scallop fisheries opened by Commissioner's Permit during the 2012/13 and 2013/14 seasons.

Table 6.–Sample sizes and parameter estimates from LVB growth models fit to scallop umbo-to-annulus distance measurements.

Management unit	Number shells	Number measurements	d_4	d_{10}	sd(d_4)[a]	sd(d_{10})[a]	ρ	d_∞[b]
D	791	5746	93	132	8.2	8.6	0.73	139
D16	48	381	88	125	8.6	12.1	0.74	132
E	139	1116	94	134	10.1	6.9	0.75	143
KNE	1064	6906	115	161	7.9	7.7	0.72	169
KSH	1874	10943	116	159	6.6	5.6	0.72	166
KSW	22	382	113	158	8.9	8.2	0.73	166
KSM	34	212	109	161	3.6	5.0	0.75	173
M	88	643	95	144	8.2	7.7	0.77	156
O	83	631	112	156	10.5	10.8	0.72	163
Q	343	3203	97	147	8.9	6.7	0.77	160

[a] Standard deviations of random effects estimated by R nlme.

[b] Asymptotic umbo-to-annulus distance calculated from model.

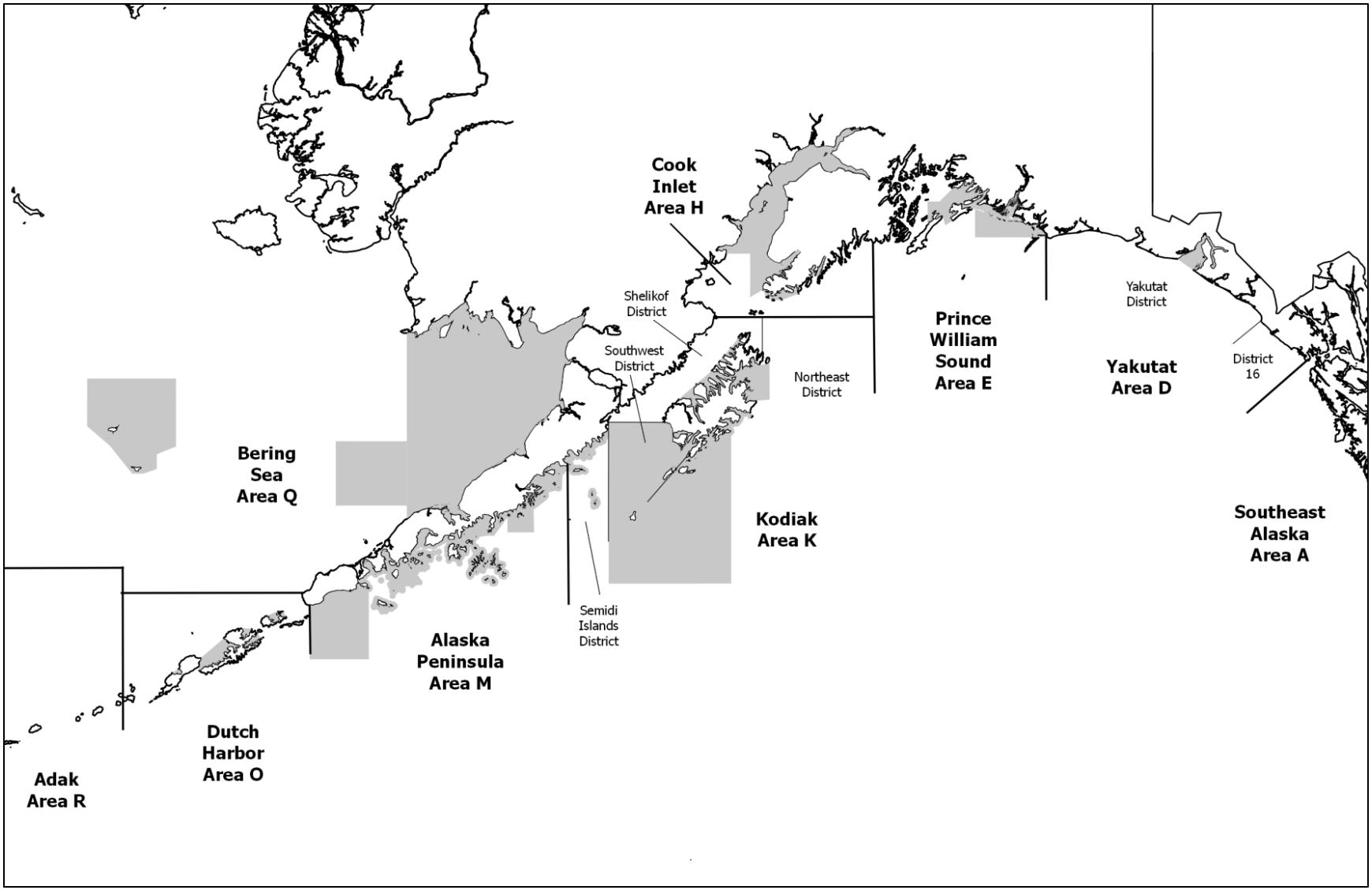

Figure 1.–Map showing Alaska weathervane scallop management units with waters closed to scallop fishing shaded grey.

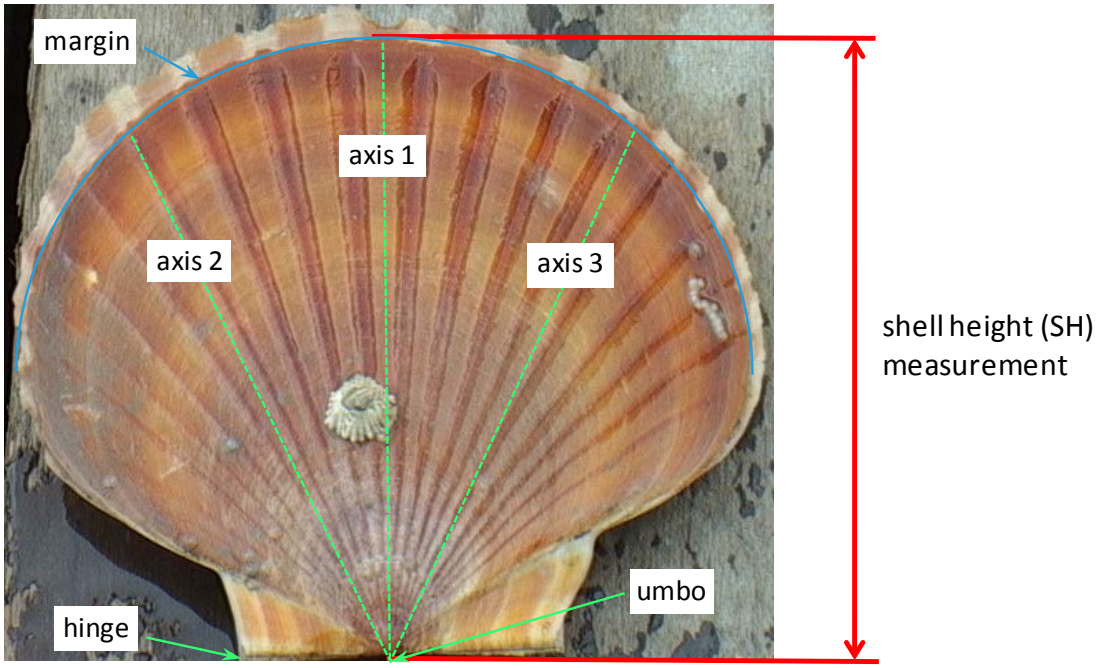

Figure 2.–Annotated photograph showing weathervane scallop shell parts, orientation of shell height measurement, and three axes used for aging chipped shells. The lower valve is slightly larger than the upper valve and can be seen extending beyond the upper valve margin.

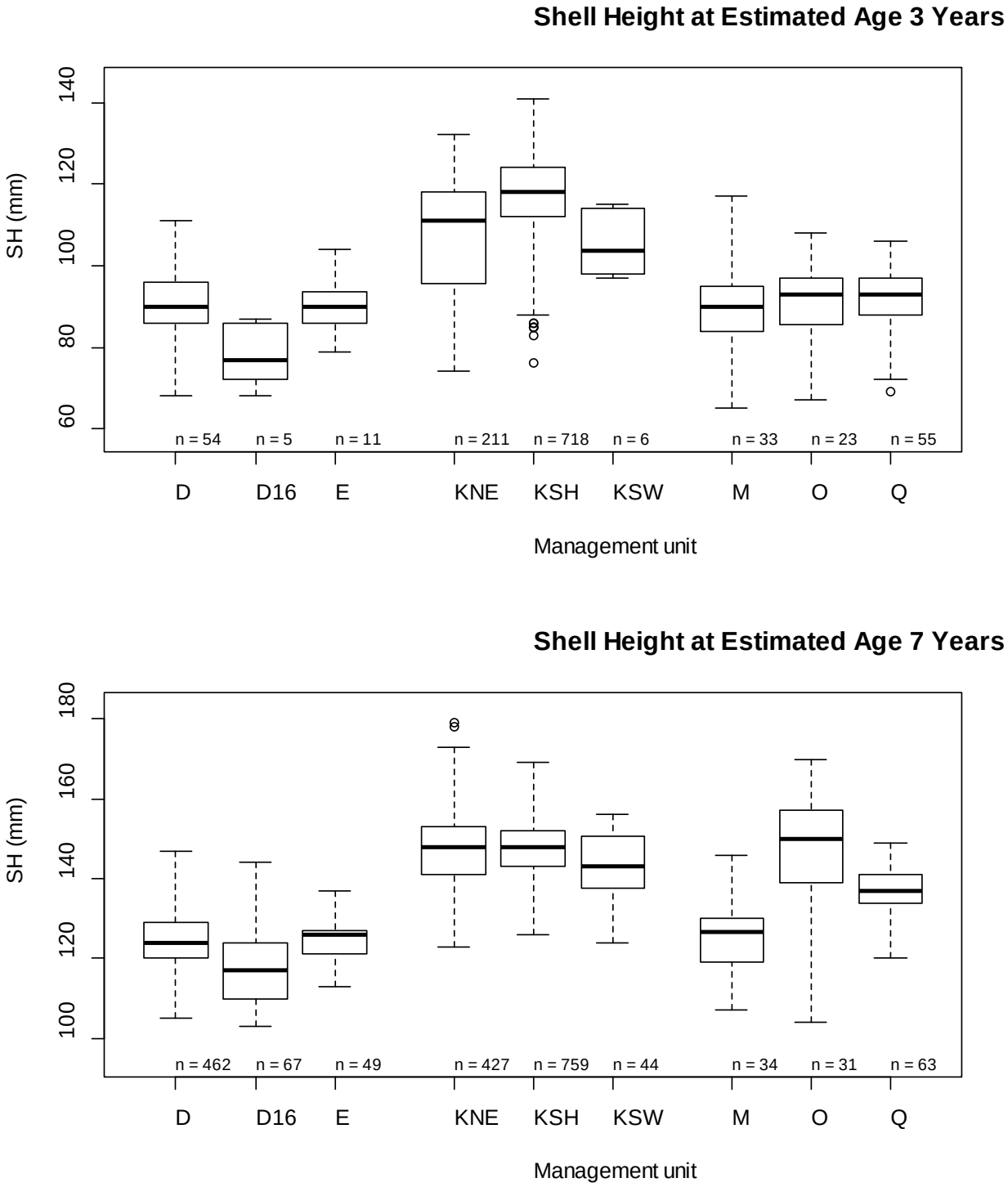

Figure 3.–Boxplots of shell height for weathervane scallops with estimated age 3 years (upper plot) and 7 years (lower plot).

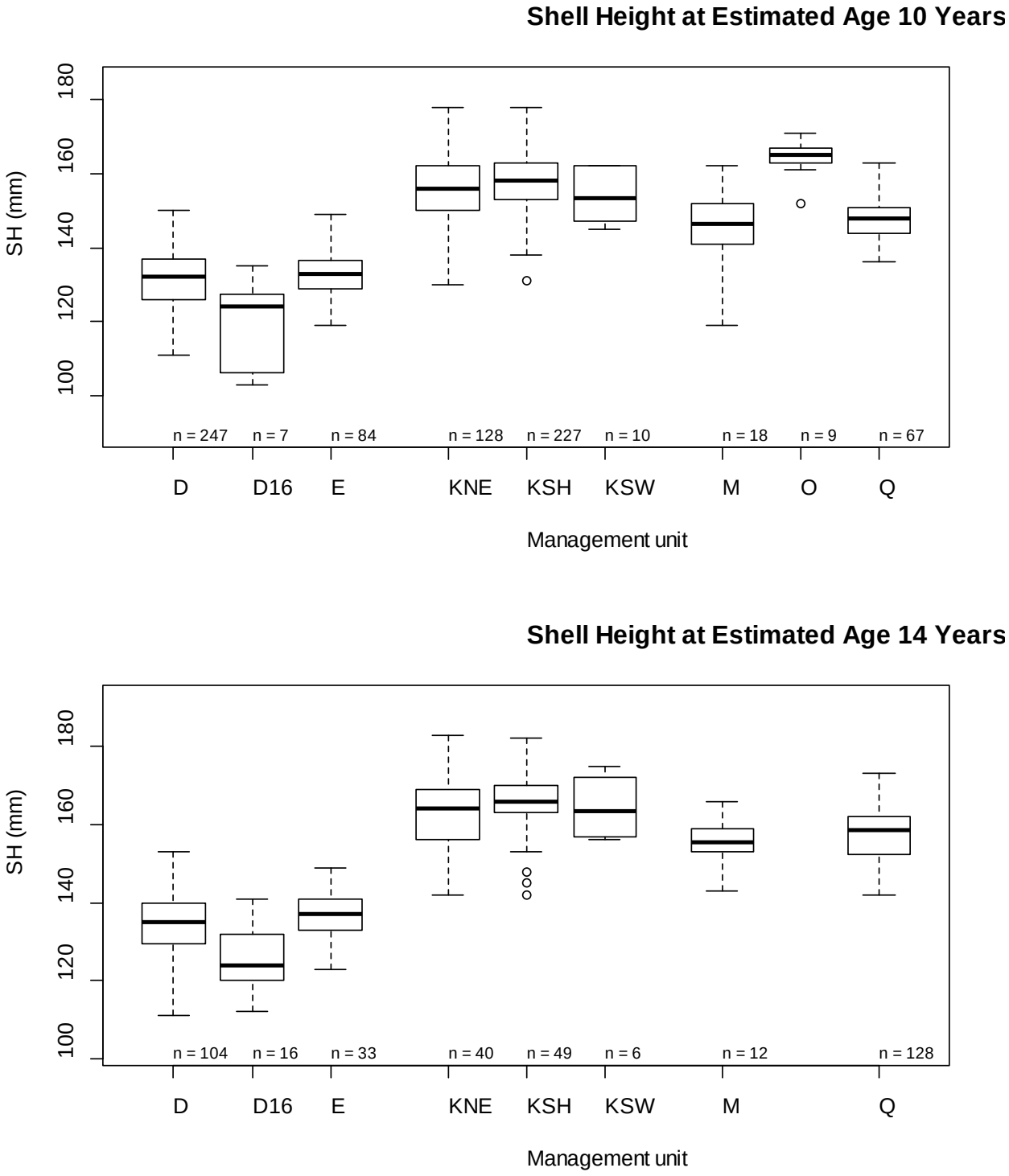

Figure 4.–Boxplots of shell height for weathervane scallops with estimated age 10 years (upper plot) and 14 years (lower plot). Sample size was not sufficient to include Area O in the lower plot.

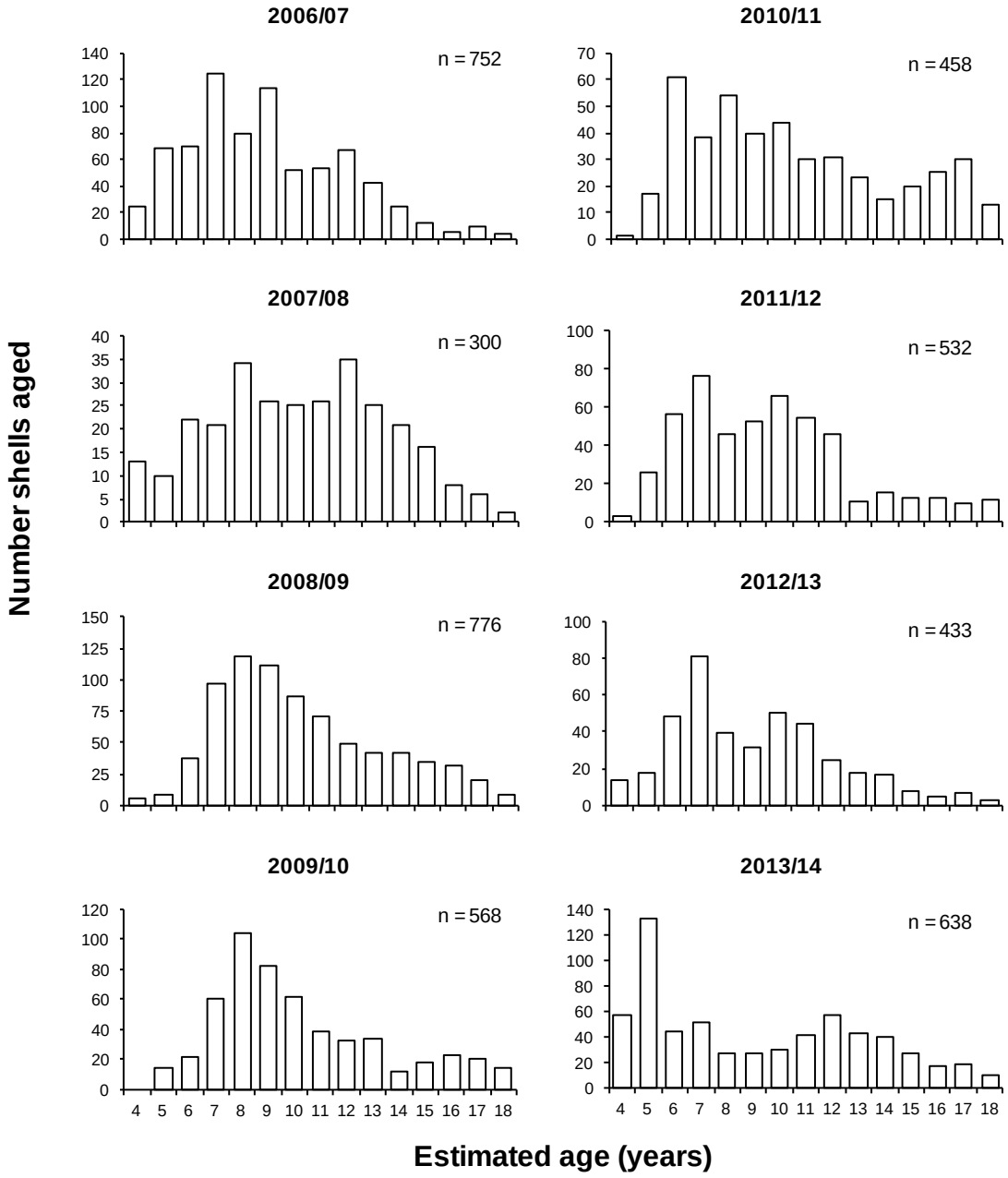

Figure 5.–Estimated age composition of weathervane scallops retained in the Yakutat District scallop fishery, 2006/07–2013/14.

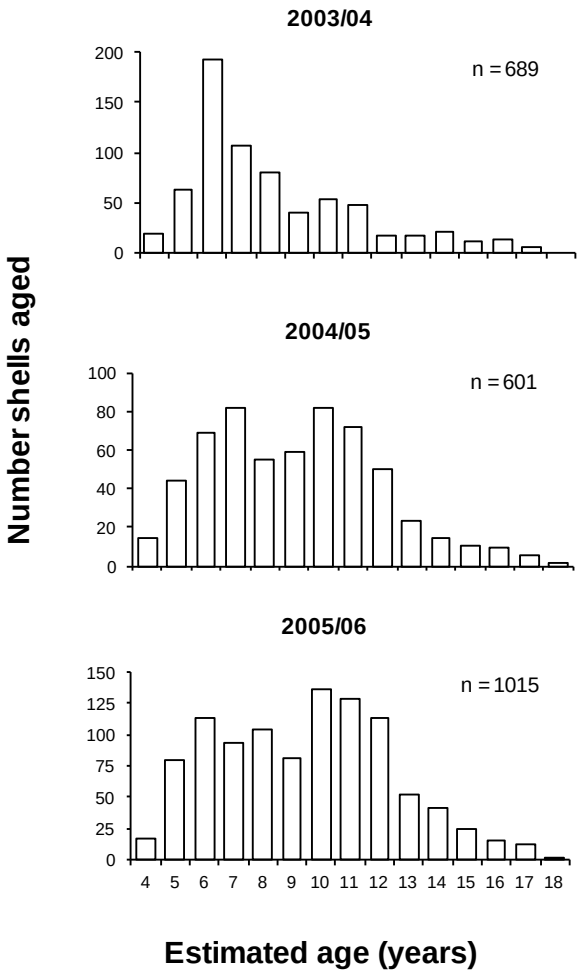

Figure 6.–Estimated age composition of weathervane scallops retained in the Yakutat District scallop fishery, 2003/04–2005/06.

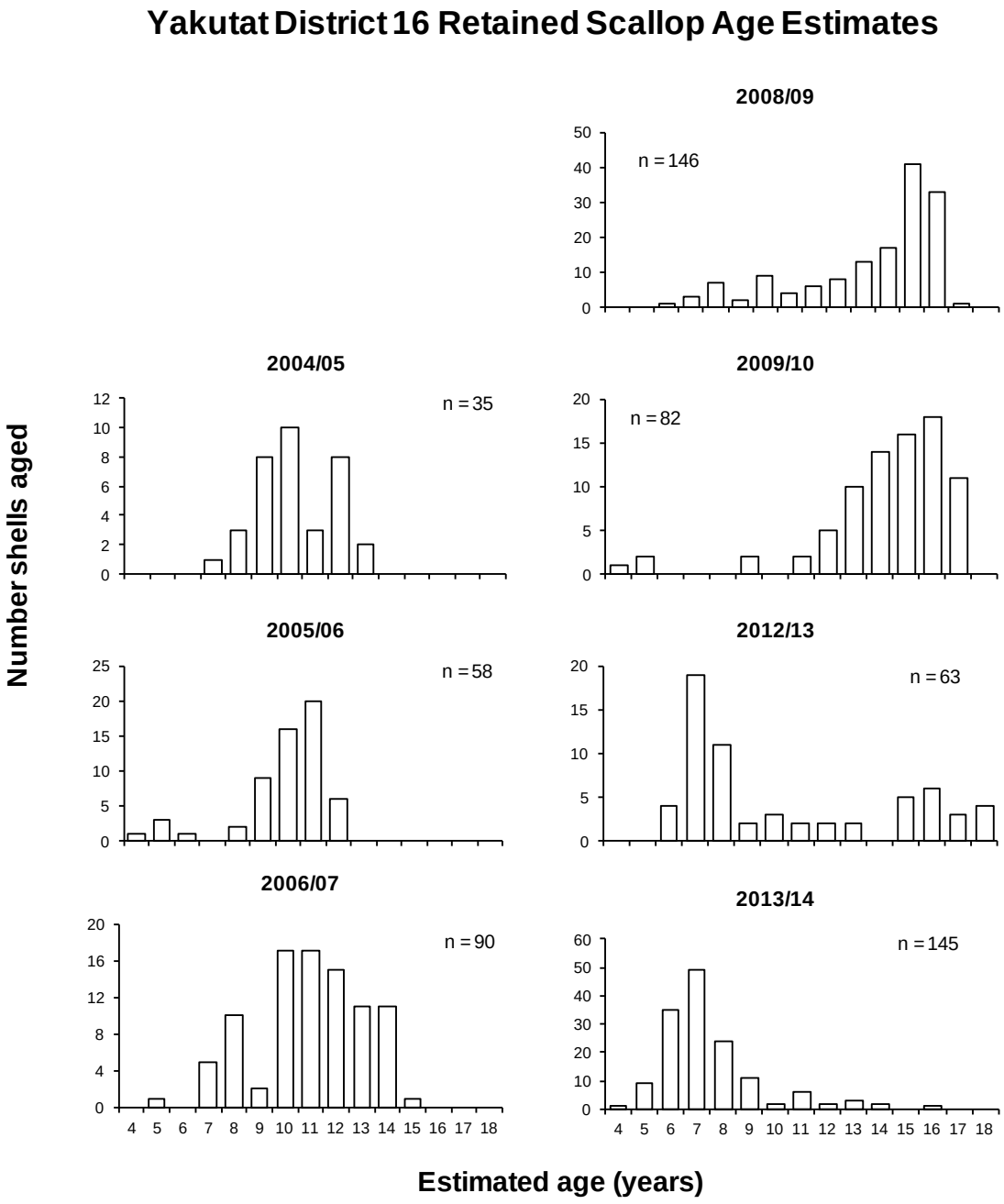

Figure 7.–Estimated age composition of weathervane scallops retained in the Yakutat District 16 scallop fishery, 2004/05–2013/14. Sample sizes were not sufficient to create plots for the 2007/08, 2010/11, and 2011/12 seasons.

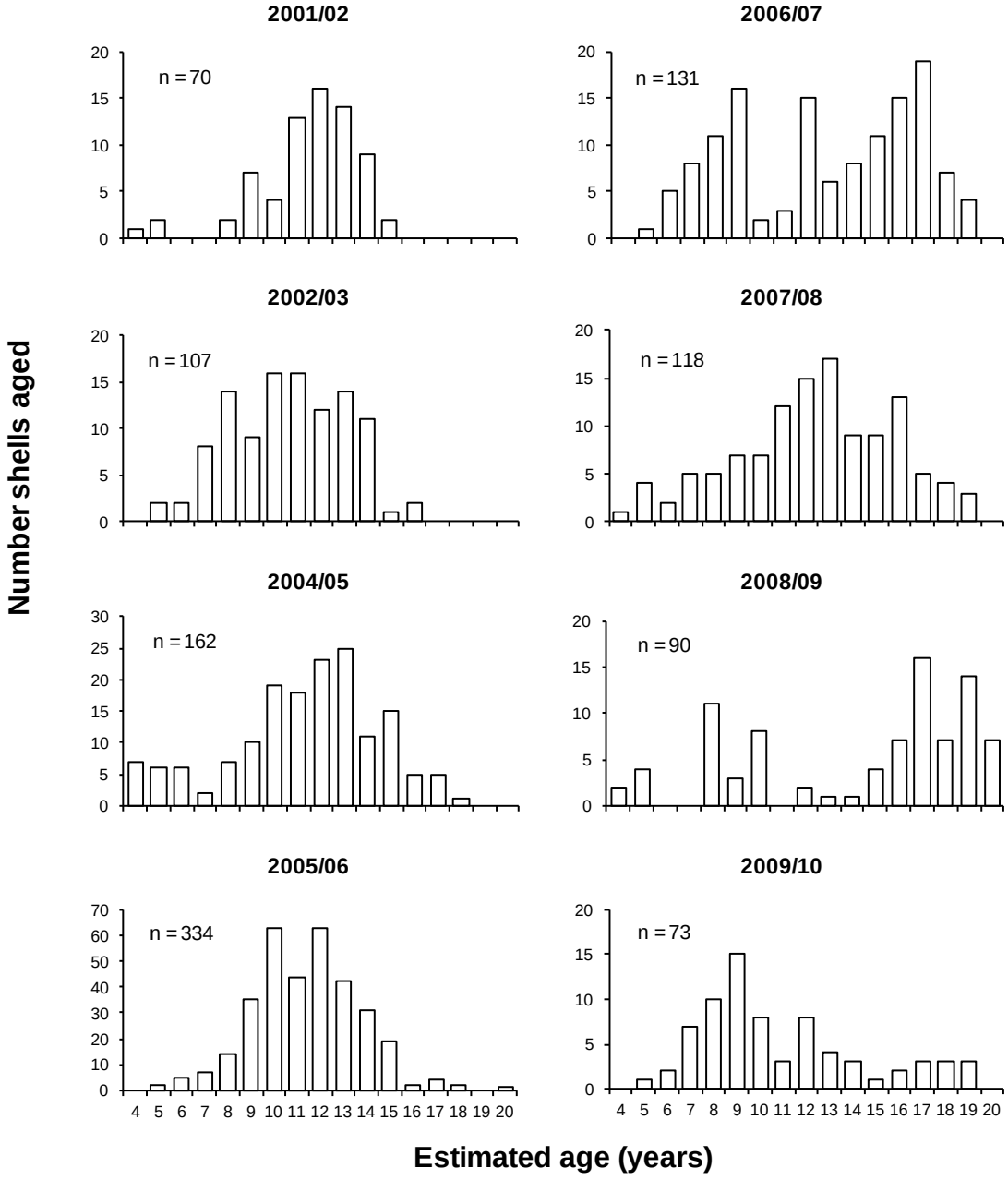

Figure 8.–Estimated age composition of weathervane scallops retained in the Area E scallop fishery, 2001/02–2009/10. Sample sizes were not sufficient to create plots for the 2003/04 and 2010/11–2011/12 seasons. Fishing was not opened in the area for the 2012/13–2013/14 seasons.

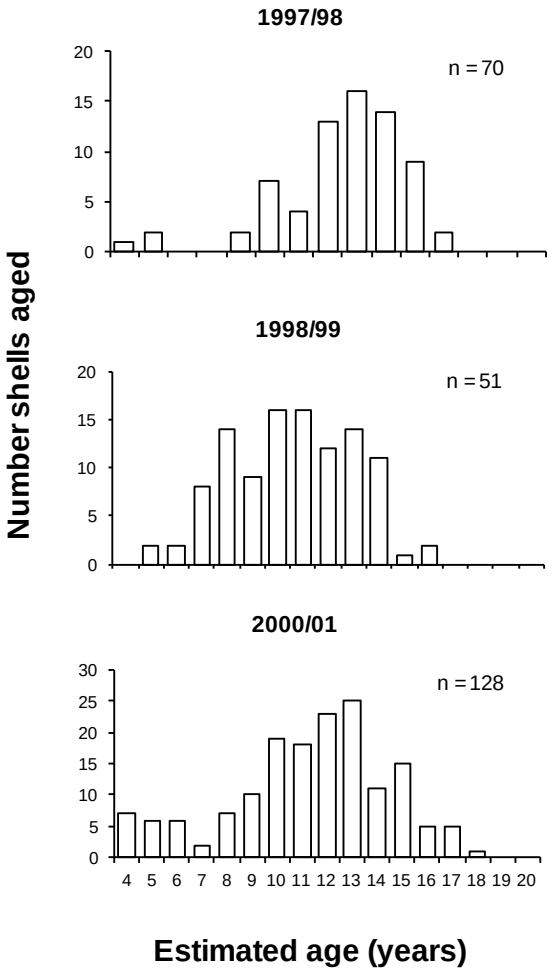

Figure 9.–Estimated age composition of weathervane scallops retained in the Area E scallop fishery, 1997/98–2000/01. Sample sizes were not sufficient to create plots for the 1999/2000 seasons.

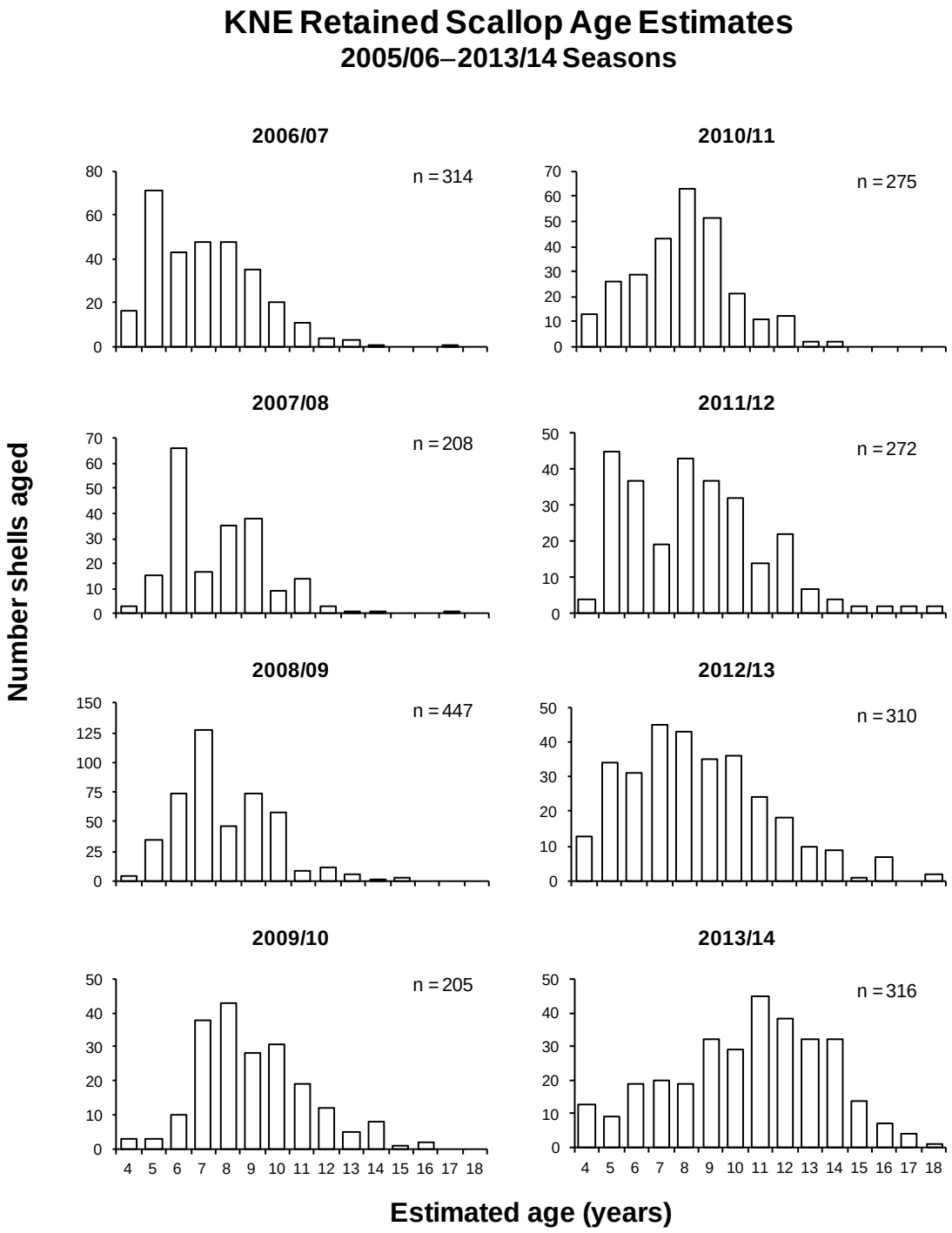

Figure 10.–Estimated age composition of weathervane scallops retained in the Kodiak Northeast District scallop fishery, 2006/07–2013/14.

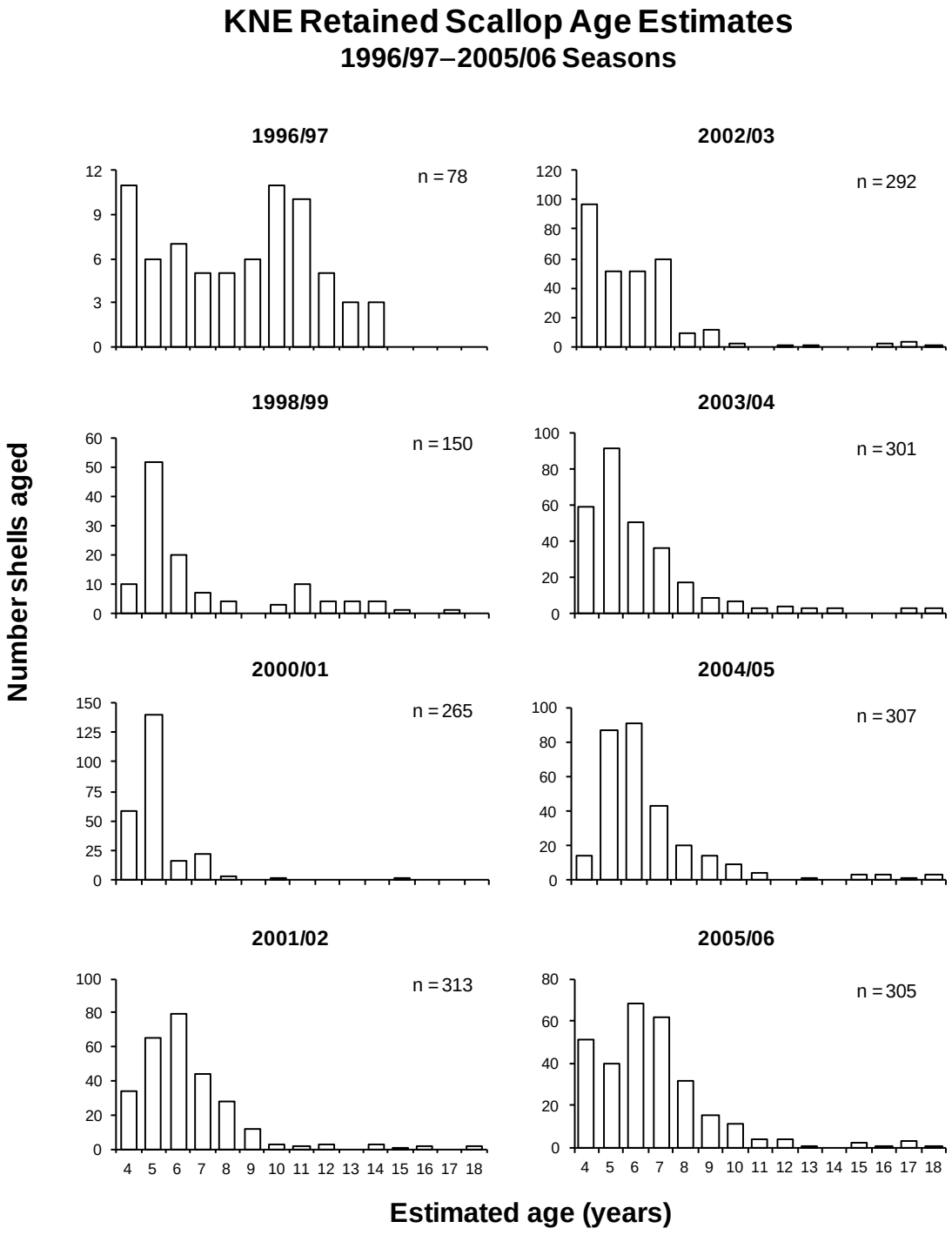

Figure 11.–Estimated age composition of weathervane scallops retained in the Kodiak Northeast District scallop fishery, 1998/99–2002/03. No shells were aged from the 1997/98 and 1999/2000 seasons.

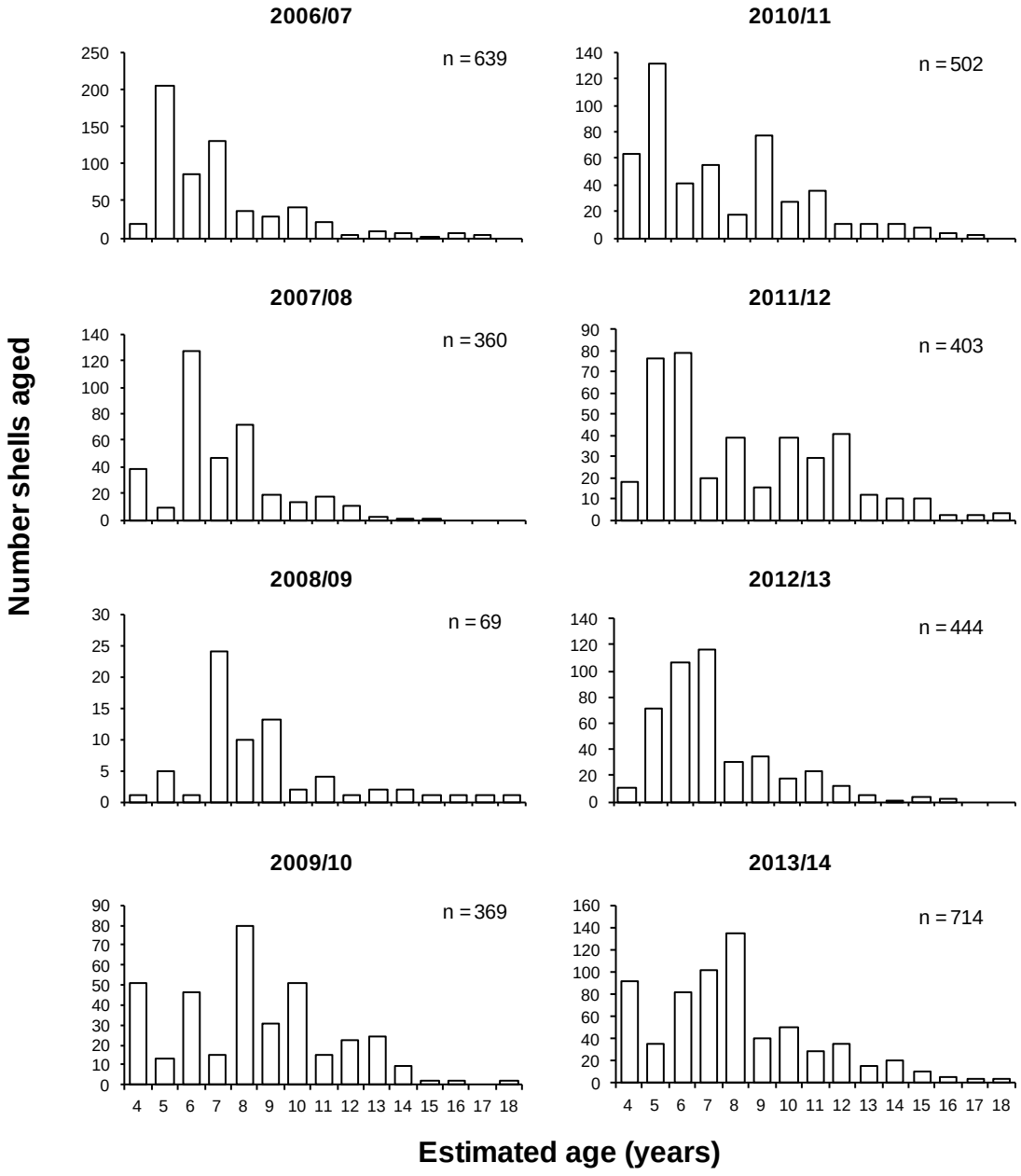

Figure 12.–Estimated age composition of weathervane scallops retained in the Kodiak Shelikof District scallop fishery, 2006/07–2013/14. The 2008/09 season was closed early due to excessive crab bycatch resulting in a small sample size.

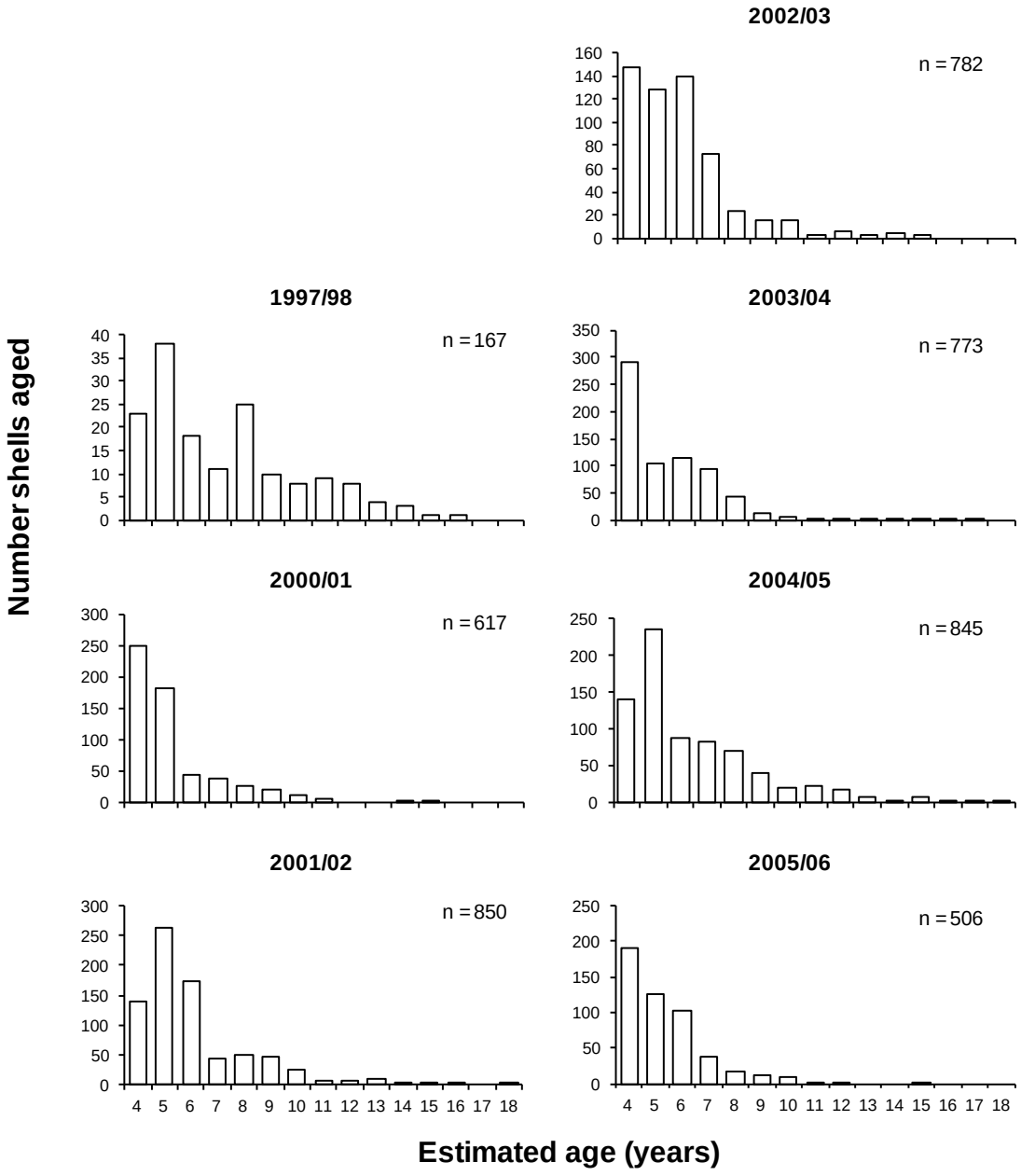

Figure 13.–Estimated age composition of weathervane scallops retained in the Kodiak Shelikof District scallop fishery, 2000/01–2003/04.

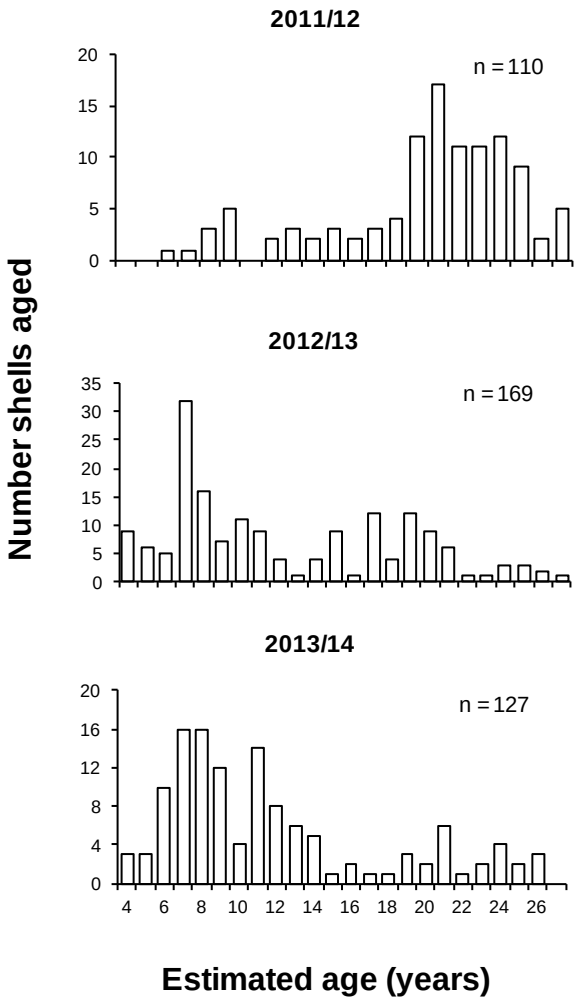

Figure 14.–Estimated age composition of weathervane scallops retained in the exploratory Kodiak Southwest District scallop fishery, 2011/12–2013/14.

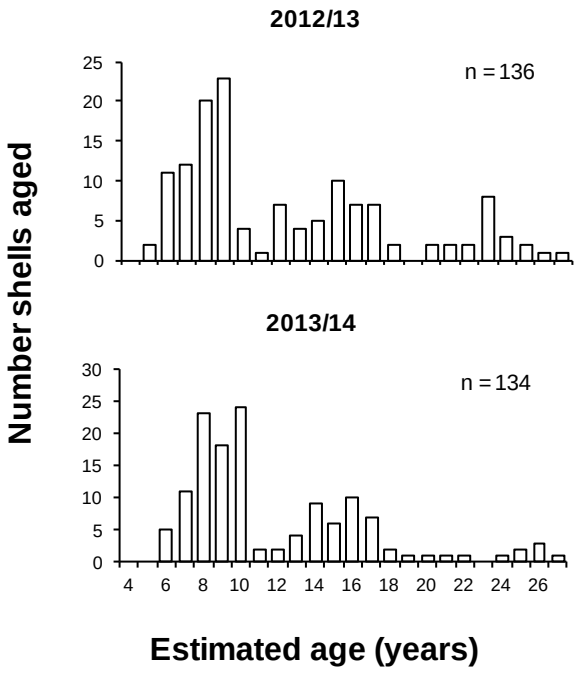

Figure 15.–Estimated age composition of weathervane scallops retained in the exploratory Area M scallop fishery in Unimak Bight, 2012/13–2013/14.

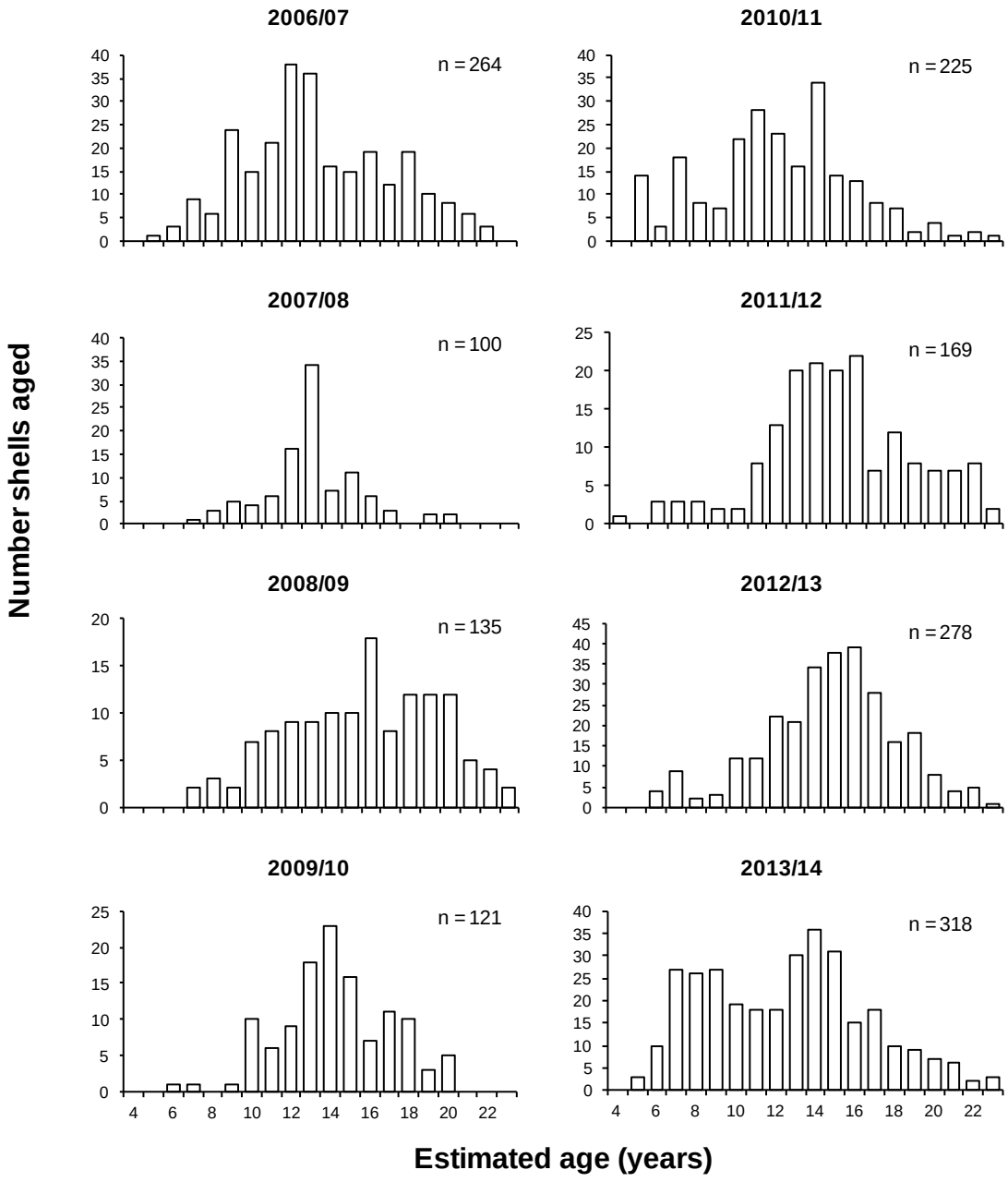

Figure 16.–Estimated age composition of weathervane scallops retained in the Bering Sea Area scallop fishery, 2006/07–2013/14.

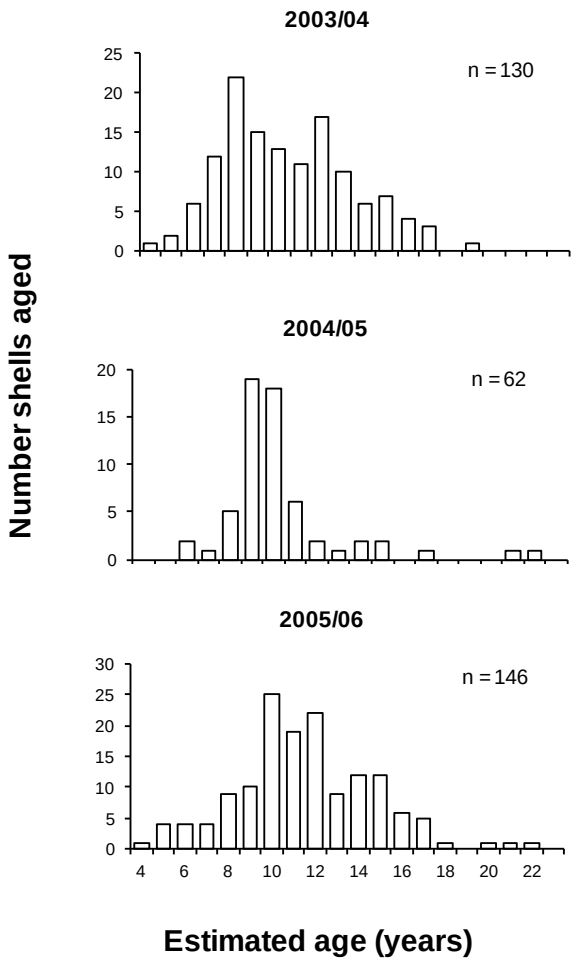

Figure 17.–Estimated age composition of weathervane scallops retained in the Bering Sea Area scallop fishery, 2003/04–2005/06.

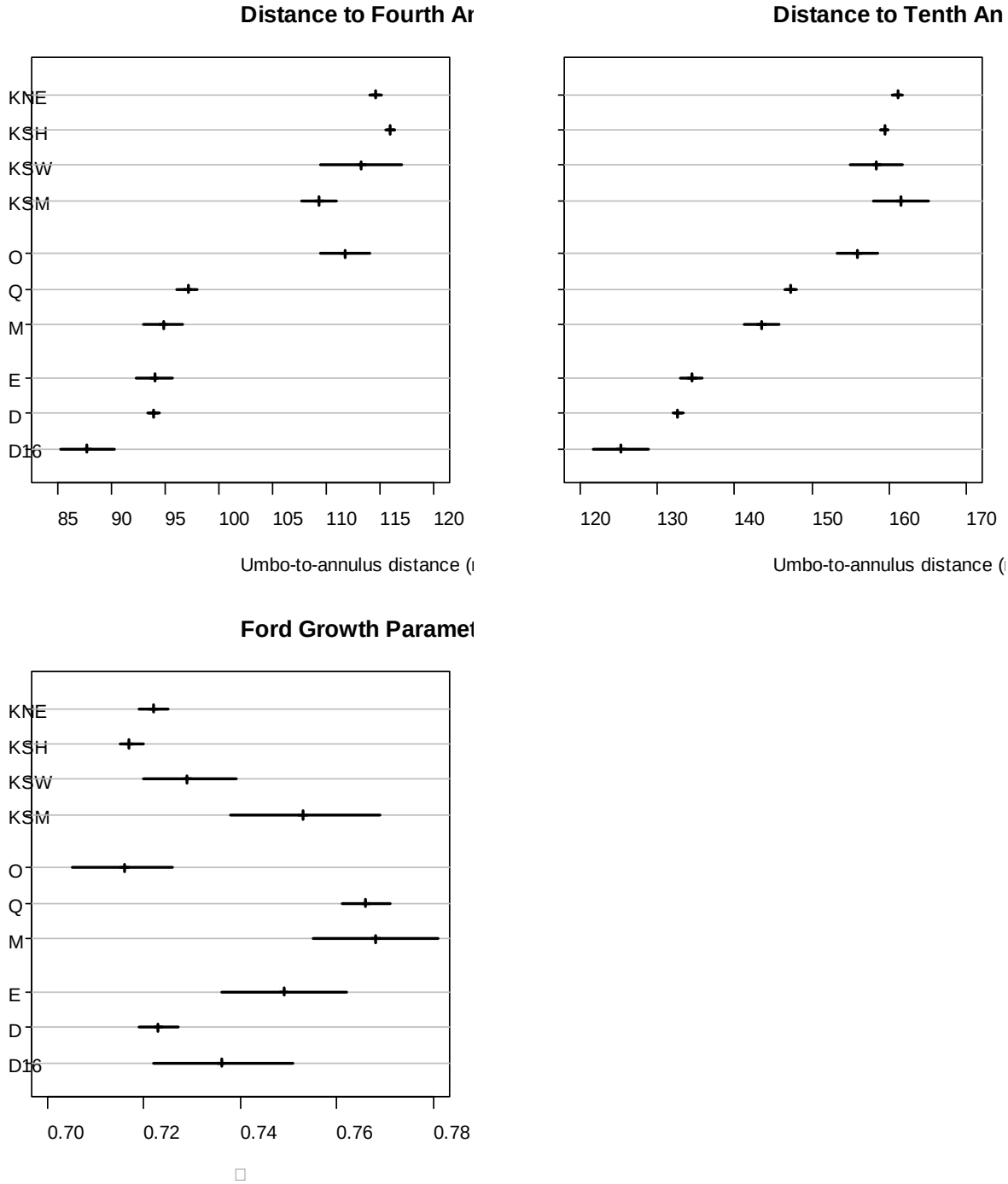

Figure 18.–Plots showing point estimates and approximate 95% confidence intervals for fixed effects parameters in LVB growth models fit to scallop umbo-to-annulus measurements from each management unit.

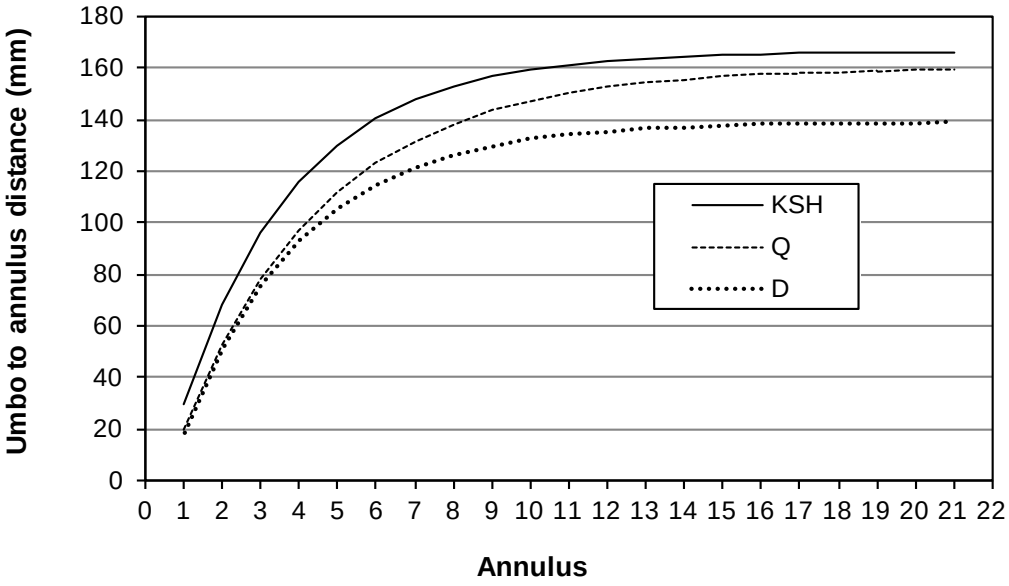

Figure 19.–Plot of growth curves from LVB models fit to scallop umbo-to-annulus distance for Yakutat District, Bering Sea Area, and Kodiak Shelikof District.

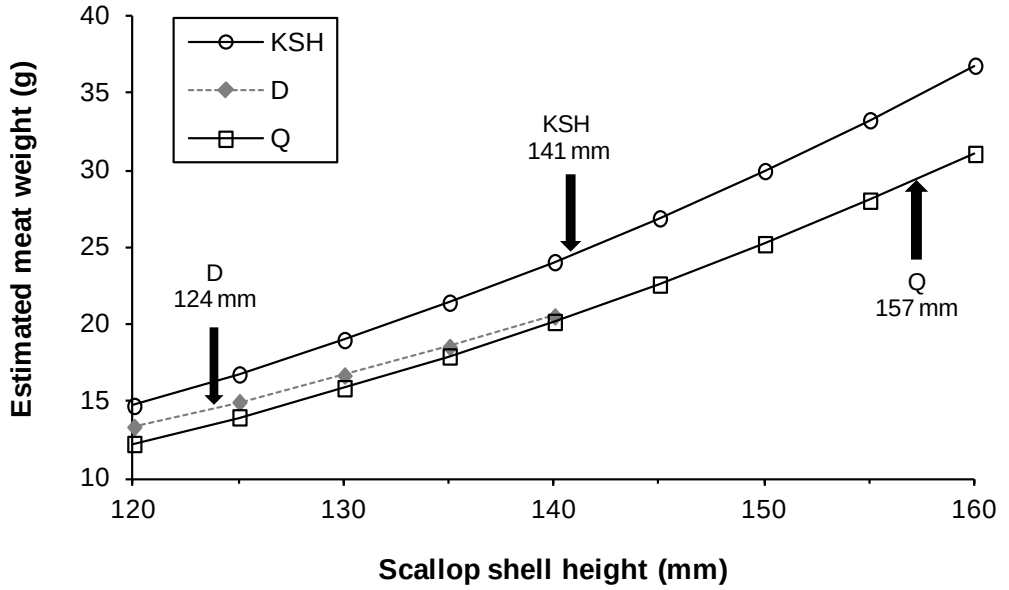

Figure 20.–Estimated scallop shell height–meat weight relationships from dredge samples made during experimental ADF&G surveys. Arrows denote average shell height of retained scallops for the three management units during the 2011/12 season.

APPENDIX A. COMPLETE SHELL AGING RESULTS BY MANAGEMENT UNIT

Appendix A1.–Counts of estimated ages of retained scallops by season for Yakutat District, 2003/04–2008/09.

Estimated	Season					
Age (years)	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
3		4			7	
4	19	15	17	24	13	6
5	63	44	80	68	10	9
6	192	69	114	70	22	37
7	106	82	94	125	21	97
8	81	55	104	80	34	119
9	40	59	81	114	26	111
10	54	82	136	52	25	86
11	48	72	129	54	26	70
12	17	50	113	67	35	49
13	18	23	53	42	25	42
14	21	15	41	24	21	41
15	11	11	24	12	16	35
16	13	10	16	5	8	32
17	5	6	12	9	6	20
18		2	1	4	2	8
19	1	1		2	1	4
20		1			2	5
21						5
Total	689	601	1015	752	300	776

Appendix A2.–Counts of estimated ages of retained scallops by season for Yakutat District, 2009/10–2013/14.

Estimated	Season					
Age (years)	2009/10	2010/11	2011/12	2012/13	2013/14	Total[a]
3				3		14
4		1	3	14	57	169
5	14	17	26	18	132	481
6	22	61	57	48	45	737
7	60	38	77	81	52	833
8	104	54	46	39	27	743
9	82	40	53	31	27	664
10	62	44	66	50	30	687
11	38	30	55	44	41	607
12	33	31	46	25	57	523
13	34	23	11	18	43	332
14	12	15	16	17	40	263
15	18	20	13	8	27	195
16	23	25	13	5	17	167
17	21	30	10	7	18	144
18	14	13	12	3	10	69
19	11	5	8	4	9	46
20	5	6	6	6	4	35
21	10	2	7	4	1	29
22	5	2	4	5	1	17
23			2	3		5
24		1	1			2
Total	568	458	532	433	638	6762

[a] Total 2003/04–2013/14 Yakutat District sample size.

Appendix A3.–Counts of estimated ages of retained scallops by season for Yakutat District 16, 2003/04–2008/09.

Estimated	Season					
Age (years)	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09
4			1			
5			3	1		1
6	1		1			3
7	2	1		5		7
8		3	2	10		2
9	1	8	9	2		9
10		10	16	17	2	4
11		3	20	17	1	6
12		8	6	15		8
13		2		11		13
14				11	1	17
15				1		41
16						33
17						1
18						
19						1
Total	4	35	58	90	4	146

Appendix A4.–Counts of estimated ages of retained scallops by season for Yakutat District 16, 2009/10–2013/14.

Estimated	Season					
Age (years)	2009/10	2010/11	2011/12	2012/13	2013/14	Total
4	1				1	3
5	2	2			9	18
6		3		4	35	47
7		4	2	19	49	89
8		1	2	11	24	55
9	2	1	1	2	11	46
10		1	1	3	2	56
11	2	4	1	2	6	62
12	5	1	1	2	2	48
13	10	1		2	3	42
14	14	2	2		2	49
15	16	1		5		64
16	18	2		6	1	60
17	11	1		3		16
18		1		4		5
19	1	1				3
Total	82	26	10	63	145	663

[a] Total 2003/04–2013/14 Yakutat District 16 sample size.

Appendix A5.–Counts of estimated ages of retained scallops by season for Prince William Sound Area, 1997/98–2004/05.

Estimated	Season							
Age (years)	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05
3				2				2
4		1		1	1			7
5	3			2	2	2	1	6
6	6	2	2	2		2	5	6
7	25	2	1	5		8	1	2
8	16	4	3	16	2	14	2	7
9	15	8	1	14	7	9	3	10
10	2	18	6	20	4	16	5	19
11	3	7	13	23	13	16	11	18
12		5	6	24	16	12	9	23
13		1	2	10	14	14	4	25
14		1		4	9	11	3	11
15		1		3	2	1	2	15
16		1				2		5
17				2				5
18								1
Total	70	51	34	128	70	107	46	162

Appendix A6.–Counts of estimated ages of retained scallops by season for Prince William Sound Area, 2005/06–2013/14.

Estimated	Season							
Age (years)	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	Total[a]
3								4
4			1	2				13
5	2	1	4	4	1			28
6	5	5	2		2	2		41
7	7	8	5		7	5	2	78
8	14	11	5	11	10	7	4	126
9	35	16	7	3	15	14	7	164
10	63	2	7	8	8	8	7	193
11	44	3	12		3	2	8	176
12	63	15	15	2	8	2	1	201
13	42	6	17	1	4		1	141
14	31	8	9	1	3			91
15	19	11	9	4	1	1	1	70
16	2	15	13	7	2	1	2	50
17	4	19	5	16	3			54
18	2	7	4	7	3	2	1	27
19		4	3	14	3	3	1	28
20	1			7		1	3	12
21				3			1	4
22							2	2
23							1	1
Total	334	131	118	90	73	48	42	1504

[a] Total 1997/98–2013/14 Prince William Sound sample size.

Appendix A7.–Counts of estimated ages of retained scallops by season for Kodiak Northeast District, 1996/97–2005/06.

Estimated	Season							
Age (years)	1996/97	1998/99	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06
3	6	30	21	34	3	7	11	8
4	11	10	58	34	97	59	14	51
5	6	52	140	65	51	92	87	40
6	7	20	17	79	51	51	91	68
7	5	7	23	44	60	36	43	62
8	5	4	3	28	9	17	20	32
9	6			12	11	9	14	15
10	11	3	1	3	2	7	9	11
11	10	10		2		3	4	4
12	5	4		3	1	4		4
13	3	4			1	3	1	1
14	3	4		3		3		
15		1	2	1			3	2
16				2	2		3	1
17		1			3	3	1	3
18				2	1	3	3	1
19						2	1	
20						1	1	
21						1		2
22								
23				1			1	
Total	78	150	265	313	292	301	307	305

Appendix A8.–Counts of estimated ages of retained scallops by season for Kodiak Northeast District, 2005/06–2013/14.

Estimated	Season								
Age (years)	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	Total
3	4	1			2				127
4	16	3	4	3	13	4	13	13	403
5	71	15	35	3	26	45	34	9	771
6	43	66	73	10	29	37	31	19	692
7	48	17	127	38	43	19	45	20	637
8	48	35	46	43	63	43	43	19	458
9	35	38	74	28	51	37	35	32	397
10	20	9	58	31	21	32	36	29	283
11	11	14	9	19	11	14	24	45	180
12	4	3	11	12	12	22	18	38	141
13	3	1	6	5	2	7	10	32	79
14	1	1	1	8	2	4	9	32	71
15			3	1		2	1	14	30
16				2		2	7	7	26
17	1	1				2		4	19
18						2	2	1	15
19	2	1							6
20	1	1						1	5
21	2	2		1					8
22	4								4
23								1	2
24				1					1
25							1		1
26							1		2
Total	314	208	447	205	275	272	310	316	4358

[a] Total 1996/97–2013/14 Kodiak Northeast District sample size.

Appendix A9.–Counts of estimated ages of retained scallops by season for Kodiak Shelikof District, 1997/98–2005/06.

Estimated	Season							
Age (years)	1997/98	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06
2				12	2	5		
3	7	22	43	60	218	90	111	5
4	23	14	249	140	148	292	139	191
5	38	7	182	264	128	104	236	125
6	18	4	43	175	140	115	88	103
7	11	1	38	43	73	94	82	38
8	25		25	49	23	43	70	18
9	10		19	47	15	12	40	13
10	8		10	27	16	7	20	9
11	9		5	7	3	1	21	1
12	8			7	6	1	16	2
13	4			9	3	2	6	
14	3		2	3	4	4	1	
15	1		1	2	3	1	7	1
16	1			3		1	2	
17						1	2	
18				1			2	
19							1	
20				1			1	
21	1							
Total	167	48	617	850	782	773	845	506

Appendix A10.–Counts of estimated ages of retained scallops by season for Kodiak Shelikof District, 2005/06–2013/14.

Estimated	Season								
Age (years)	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	Total
2									19
3	32			2	7	1	10	41	649
4	20	39	1	51	63	18	11	91	1490
5	205	9	5	13	132	76	71	35	1630
6	85	128	1	46	41	79	106	82	1254
7	130	47	24	15	55	20	116	102	889
8	36	72	10	80	18	39	30	135	673
9	29	19	13	31	77	15	34	41	415
10	42	14	2	51	27	39	18	51	341
11	22	18	4	15	35	29	24	29	223
12	4	10	1	22	11	41	12	36	177
13	10	2	2	24	10	12	5	16	105
14	7	1	2	9	10	10	1	21	78
15	2	1	1	2	8	10	4	11	55
16	6		1	2	4	2	2	5	29
17	3		1		2	2		4	15
18			1	2		3		4	13
19	4			1	2	4		2	14
20	2			2		2		2	10
21						1		2	4
22								2	2
23				1				2	3
Total	639	360	69	369	502	403	444	714	8088

[a] Total 1996/97–2013/14 Kodiak Shelikof District sample size.

Appendix A11.–Counts of estimated ages of retained scallops by season for the exploratory Kodiak Southwest District fishery, 2011/12–2013/14.

Estimated	Season			
Age (years)	2011/12	2012/13	2013/14	Total
3		1	2	3
4		9	3	12
5		6	3	9
6	1	5	10	16
7	1	32	16	49
8	3	16	16	35
9	5	7	12	24
10		11	4	15
11	2	9	14	25
12	3	4	8	15
13	2	1	6	9
14	3	4	5	12
15	2	9	1	12
16	3	1	2	6
17	4	12	1	17
18	12	4	1	17
19	17	12	3	32
20	11	9	2	22
21	11	6	6	23
22	12	1	1	14
23	9	1	2	12
24	2	3	4	9
25	5	3	2	10
26	1	2	3	6
27	1	1		2
Total	110	169	127	406

Appendix A12.–Counts of estimated ages of retained scallops by season for Kodiak Semidi Islands District, 1996/97.

Estimated	Season
Age (years)	1996/97
3	1
4	4
5	15
6	4
7	2
8	1
9	3
10	3
11	1
12	1
Total	35

Appendix A13.–Counts of estimated ages of retained scallops by season for Alaska Peninsula Area, 1998/99–2013/14.

Estimated	Season						
Age (years)	1998/99	2000/01	2006/07	2008/09	2012/13[a]	2013/14[a]	Total
3		3	3				6
4	2	5	4				11
5	1	13	1	1	2		18
6		16		5	11	5	37
7	1	9		3	12	11	36
8				3	20	23	46
9	2	1		4	23	18	48
10		1		1	4	24	30
11	1			1	1	2	5
12				9	7	2	18
13	1			3	4	4	12
14		1		3	5	9	18
15				1	10	6	17
16		1		2	7	10	20
17					7	7	14
18			1		2	2	5
19						1	1
20					2	1	3
21					2	1	3
22			1		2	1	4
23					8		8
24					3	1	4
25					2	2	4
26					1	3	4
27					1	1	2
Total	8	50	10	36	136	134	374

[a] Exploratory fisheries opened by Commissionioner's Permit in Unimak Bight.

Appendix A14.–Counts of estimated ages of retained scallops by season for Dutch Harbor Area, 2008/09–2013/14.

Estimated	Season					
Age (years)	2008/09	2010/11	2011/12	2012/13	2013/14	Total
4	1	1	1			3
5	8	7	3	2		20
6	13	10	5	2		30
7	9	4	8	9	5	35
8	1	3	4	9	4	21
9	14		2	10	6	32
10	3	1		4	6	14
11				3	2	5
12	1				1	2
13	2					2
14	1					1
15	1					1
16	3					3
17	1		1			2
18	1			1		2
19	2					2
Total	61	26	24	40	24	175

Appendix A15.–Counts of estimated ages of retained scallops by season for Bering Sea Area, 1999/00–2007/08.

Estimated	Season					
Age (years)	1999/00	2003/04	2004/05	2005/06	2006/07	2007/08
4	1	1		1		
5	18	2		4	1	
6	2	6	2	4	3	
7		12	1	4	9	1
8	5	22	5	9	6	3
9	3	15	19	10	24	5
10	6	13	18	25	15	4
11	1	11	6	19	21	6
12	2	17	2	22	38	16
13	2	10	1	9	36	34
14	4	6	2	12	16	7
15	2	7	2	12	15	11
16		4		6	19	6
17	1	3	1	5	12	3
18				1	19	
19		1			10	2
20				1	8	2
21			1	1	6	
22			1	1	3	
23						
24			1		1	
25						
26					1	
29					1	
Total	47	130	62	146	264	100

Appendix A16.–Counts of estimated ages of retained scallops by season for Bering Sea Area, 2008/09–2013/14.

Estimated	Season						
Age (years)	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	Total
4				1			4
5			14			3	42
6		1	3	3	4	10	38
7	2	1	18	3	9	27	87
8	3		8	3	2	26	92
9	2	1	7	2	3	27	118
10	7	10	22	2	12	19	153
11	8	6	28	8	12	18	144
12	9	9	23	13	22	18	191
13	9	18	16	20	21	30	206
14	10	23	34	21	34	36	205
15	10	16	14	20	38	31	178
16	18	7	13	22	39	15	149
17	8	11	8	7	28	18	105
18	12	10	7	12	16	10	87
19	12	3	2	8	18	9	65
20	12	5	4	7	8	7	54
21	5		1	7	4	6	31
22	4		2	8	5	2	26
23	2		1	2	1	3	9
24					1	1	4
25	2				1	1	4
26						1	2
29							1
Total	135	121	225	169	278	318	1995

APPENDIX B. GROWTH INCREMENT MEASUREMENTS BY MANAGMENT UNIT

Appendix B1.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Yakutat District weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
2	754	29	44	50	56	80
3	860	46	69	76	82	104
4	829	67	89	96	101	124
5	735	84	102	108	113	131
6	618	90	110	115	120	137
7	453	93	114	120	125	140
8	361	97	117	123	128	144
9	285	99	119	126	131	146
10	223	107	122	128	133	148
11	168	109	124	130	136	149
12	111	111	125	131	137	152
13	73	113	126	133	138	153
14	56	116	128	135	139	155
15	46	120	129	137	140	156
16	36	122	131	138	142	157
17	23	127	131	136	143	154
18	14	128	130	139	144	155
19	8	128	135	143	147	155
20	2	129		140		150
21	2	130		140		150
22	2	131		141		151
23	1			132		

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range ($Q_3 - Q_1$) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B2.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Yakutat District 16 weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	27	14	20	24	27	32
2	39	34	43	48	51	62
3	47	55	67	72	76	93
4	47	71	83	88	95	113
5	44	81	95	100	107	123
6	38	92	103	108	115	131
7	36	94	107	114	121	136
8	30	97	109	117	124	142
9	27	100	113	120	127	145
10	25	103	114	118	128	149
11	16	111	116	120	128	149
12	13	113	119	122	124	124
13	6	116	124	125	138	140
14	4	117		127		140
15	3	118		126		130
16	2	118		123		127

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range ($Q_3 - Q_1$) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B3.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Prince William Sound Area weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	107	14	21	24	27	34
2	130	31	45	53	58	72
3	148	44	70	80	86	98
4	150	66	89	98	103	116
5	120	83	102	108	114	125
6	99	94	110	116	121	133
7	82	102	116	121	125	137
8	74	107	120	125	128	139
9	55	113	123	128	130	135
10	43	120	126	130	133	137
11	33	123	127	131	135	139
12	29	126	130	133	137	142
13	26	128	131	135	140	144
14	23	129	134	137	142	146
15	21	130	135	140	144	148
16	16	131	137	142	146	150
17	8	134	139	144	148	152
18	6	134	141	146	150	155
19	6	135	141	147	151	157
20	3	146		149		152
21	2	147		148		149

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range ($Q_3 - Q_1$) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B4.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Kodiak Northeast District weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	1165	15	23	27	31	47
2	1185	36	54	61	67	92
3	1189	57	87	96	102	129
4	1064	90	112	118	123	143
5	896	106	125	130	136	157
6	615	119	133	139	144	164
7	414	125	139	144	150	171
8	277	130	143	149	155	172
9	181	138	148	154	158	175
10	113	141	152	157	161	178
11	68	143	153	158	162	174
12	43	146	158	162	166	176
13	30	149	160	164	168	178
14	19	153	164	166	173	180
15	13	155	165	168	178	181
16	8	156	165	169	176	182
17	5	167	167	168	170	172
18	5	169	169	169	173	174
19	4	162		173		175
20	3	164		172		177
21	1			178		
22	1			179		
23	1			181		

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range ($Q_3 - Q_1$) from the nearest quartile.
[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B5.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Kodiak Shelikof District weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	2009	13	28	32	36	52
2	2061	37	60	68	75	100
3	2099	65	91	98	104	126
4	1892	95	113	118	122	139
5	1382	110	126	131	134	148
6	810	117	135	140	144	160
7	477	125	142	146	151	167
8	337	128	146	150	155	167
9	211	131	150	154	159	169
10	142	135	152	156	161	172
11	95	144	156	160	164	175
12	70	142	158	161	166	176
13	44	148	160	164	168	178
14	30	150	162	165	169	180
15	15	159	164	167	173	182
16	6	165	165	173	183	185
17	3	167		170		177
18	3	168		171		178
19	1			170		
20	1			171		
21	1			172		
22	1			173		
23	1			174		

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range ($Q_3 - Q_1$) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B6.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Kodiak Southwest District weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	19	18	26	31	37	45
2	20	48	51	65	71	83
3	22	74	83	96	100	116
4	22	102	110	117	123	141
5	22	116	126	131	136	155
6	22	123	134	140	143	155
7	22	128	138	145	149	167
8	22	134	143	148	152	160
9	21	138	147	151	156	174
10	19	142	150	155	160	176
11	19	144	152	158	162	179
12	18	145	153	160	163	181
13	18	147	154	162	165	183
14	17	148	158	165	168	184
15	15	150	160	166	170	186
16	15	152	161	168	171	187
17	14	152	162	169	173	188
18	14	153	164	170	174	189
19	12	161	165	171	178	190
20	8	162	166	172	177	190
21	6	166	166	172	182	191
22	6	167	167	173	182	192
23	4	168		171		175
24	2	169		173		176
25	2	170		174		177
26	1			177		

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range ($Q_3 - Q_1$) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B7.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Kodiak Semidi Islands District weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	33	18	24	29	30	34
2	35	40	51	56	62	71
3	35	70	82	87	90	101
4	34	100	108	113	116	125
5	30	118	124	127	132	40
6	15	124	135	137	144	150
7	11	132	141	145	151	155
8	8	134	146	150	155	160
9	8	136	149	154	160	165
10	4	138		156		164
11	2	154		160		166

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range ($Q_3 - Q_1$) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B8.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Alaska Peninsula Area weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	96	15	24	27	33	40
2	109	31	43	52	59	74
3	104	51	68	77	83	102
4	88	66	88	97	101	126
5	76	91	106	112	115	124
6	62	100	116	122	124	134
7	41	109	123	129	133	152
8	29	126	133	136	140	145
9	26	120	136	138	144	148
10	21	133	139	143	146	151
11	19	137	141	145	150	166
12	15	138	145	149	152	157
13	10	141	146	152	155	170
14	4	143		151		172
15	3	145		145		174
16	2	146		161		176
17	1			179		

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range (Q3 – Q1) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B9.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Dutch Harbor Area weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	92	15	21	25	30	46
2	98	34	50	60	66	91
3	99	56	81	90	99	116
4	83	82	105	116	121	133
5	78	104	121	129	135	142
6	64	113	133	138	143	152
7	45	121	138	143	149	156
8	28	125	142	147	152	162
9	23	128	145	154	156	168
10	13	133	146	149	158	162
11	11	137	151	156	162	165
12	10	142	153	158	166	166
13	9	145	154	165	168	169
14	8	148	156	168	171	172
15	6	157	157	171	174	175
16	6	159	159	172	176	177
17	4	160		166		178
18	1			161		

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range (Q3 – Q1) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).

Appendix B10.–Sample sizes (number measurements) and five-number summaries of umbo-to-annulus distance measurements (mm) from Bering Sea Area weathervane scallop shells.

Annulus	n	Min[a]	Q1[b]	Median	Q3[b]	Max[a]
1	176	15	28	33	37	45
2	320	28	48	55	60	79
3	378	51	68	77	83	107
4	354	75	89	98	103	130
5	318	92	108	114	119	139
6	287	101	119	125	129	149
7	271	113	128	132	137	154
8	242	120	134	138	142	157
9	216	128	138	143	146	162
10	191	131	142	146	150	166
11	161	136	145	149	153	168
12	135	138	148	152	155	169
13	102	140	150	154	158	172
14	77	141	153	156	161	174
15	52	143	156	159	166	175
16	45	144	158	160	167	176
17	29	146	159	164	170	177
18	19	156	166	169	172	180
19	15	157	167	170	172	176
20	10	150	165	171	175	178
21	7	151	163	169	178	179
22	5	167	170	178	180	181
23	3	168		181		183
24	1			184		
25	1			184		

[a] Minimum and maximum values were trimmed by excluding outliers greater than twice the interquartile range ($Q_3 - Q_1$) from the nearest quartile.

[b] Quartiles of data, (i.e., 25th and 75th percentiles).