Special Publication No. YY-XX

Protocol for Estimating Age of Weathervane Scallops, *Patinopecten caurinus*, in Alaska

DRAFT

by

Chris Siddon

Quinn Smith

Kevin McNeel

Dion Oxman

and

Kenneth Goldman

Month 2017

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

Symbols and Abbreviations

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

Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

SPECIAL PUBLICATION NO. YY-XX

PROTOCOL FOR ESTIMATING AGE OF WEATHERVANE SCALLOPS, *PATINOPECTEN CAURINUS*, IN ALASKA

by
Chris Siddon, Quinn Smith, Kevin McNeel, Dion Oxman, and Kenneth Goldman

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

Month 2017

The Special Publication series was established by the Division of Sport Fish in 1991 for the publication of techniques and procedures manuals, informational pamphlets, special subject reports to decision-making bodies, symposia and workshop proceedings, application software documentation, in-house lectures, and became a joint divisional series in 2004 with the Division of Commercial Fisheries. Special Publications are intended for fishery and other technical professionals. Special Publications are available through the Alaska State Library, Alaska Resources Library and Information Services (ARLIS) and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review

Chris Siddon
Alaska Department of Fish and Game, Division of Commercial Fisheries,
1255 W. 8th Street, Juneau, AK 99801

Quinn Smith
Alaska Department of Fish and Game, Division of Commercial Fisheries,
803 3rd Street, Douglas, AK 99824

Kevin McNeel
Alaska Department of Fish and Game, Division of Commercial Fisheries,
PO Box 115526, Juneau, AK 99811

Dion Oxman
Alaska Department of Fish and Game, Division of Commercial Fisheries,
PO Box 115526, Juneau, AK 99811

Kenneth Goldman
Alaska Department of Fish and Game, Division of Commercial Fisheries,
3298 Douglas Place, Homer, AK 99603

This document should be cited as follows:
Siddon C., Q. Smith, K. McNeel, D. Oxman, and K. Goldman 2017. Protocol for estimating age of weathervane scallops, Patinopecten caurinus, in Alaska. Alaska Department of Fish and Game, Special Publication No. YY-XX, Anchorage.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Age determination is an essential component to many fisheries stock assessments, which provide the foundation for sound fisheries management. While stock assessment models that include age data are generally an improvement over length-based models, errors in age data can have serious repercussions on fisheries management. Thus a standardized methodology and formal quality control measures are essential. Here we present a standardized protocol to assess the age of weathervane scallops, *Patinopecten caurinus*, collected by the Alaska Department of Fish and Game's (ADF&G) statewide scallop research and observer programs. These methods and analyses also provide measures and thresholds to test for precision (percent agreement and mean CV) and bias (Bowker's and Evans-Hoenig tests of symmetry) in age estimates along with quality control mechanisms for a long-term scallop age assessment program.

Key words: Weathervane scallops, *Patinopecten caurinus*, Alaska, age assessment, precision, bias.

INTRODUCTION

Determining the age of individual organisms provides the foundation of many quantitative fisheries stock assessments, which are considered more informative and precise than non-age-based models. However, ages can be difficult to estimate due to differences in biology (life spans, growth rates, and environments) and estimation procedure (structure processing and band identification) (Campana 2001). Potential error in estimated ages can cause bias in stock assessments and potentially lead to mismanagement of fisheries (Heifetz et al. 1998, Campana 2001). Such bias can deleteriously affect estimates of growth rates, stock-recruitment, year class strength (cohort abundance), fishing mortality, and ultimately yield (Kimura 1990, Lai and Gunderson 1987, Heifetz et al. 1998). The methods and error of ages estimated for Weathervane Scallops, *Patinopecten caurinus*, caught across Alaska has yet to be assessed. Assuming currently used sampling designs for Weathervane Scallops is appropriate this report will set a procedure for estimating and assessing ages. The common methods to minimize and assess age estimation error that will be used in this report include: 1) having a standard protocol 2) using separate individuals to estimate ages (age readers) to evaluate individual error, 3) using a standard set of specimens (reference collection) to train or evaluate individuals, 4) formally train new age readers, and 5) establishing repeatable tests for precision and bias.

AGE ESTIMATION METHODS

Common protocols used to estimate the age of bivalves such as geoduck clams, Arctic quahogs, and scallops include sectioning shells and acetate peels (Shaul and Goodwin 1982, Ropes 1984, Fiori and Morsán 2004, Lomovasky et al. 2008) as well as visually estimating age by counting rings visible on the surface of the shell (MacDonald and Bourne 1987). Sectioning shells involves the use of a precision diamond blade saw to remove sections of the shell, slide preparation, and sanding and polishing the resulting slide-mounted sections. Producing acetate peels involves cutting shells using tile or diamond blade saws, etching the resulting surface with acid (e.g. hydrochloric acid), and using acetone to pressing the acetate into the etched surface to transfer the annuli (Ropes 1984). These methods are typically time intensive and require potentially expensive laboratory equipment, but are necessary for species in which annual banding is not discernable on the external surface of the shell. For species where annual bands or circuli are visible from the surface, such as the weathervane scallops, developing estimates directly from the surface are more efficient and cost effective.

Annuli on the surface of weathervane scallops are described as bands or "rings" of a different color or texture observed under reflected light (Fig 1b; Ropes and Jearld 1987, Gustafson and

Goldman 2012, Chute et al. 2012, Spafard and Rosenkranz 2014). This sequential “light”-“dark” banding pattern visible on weathervane scallop shells using reflected light from the umbo (Fig. 1A) to the edge is in response to seasonal growth trends where the dark band (theoretically representing a slow growth cycle) is considered the annulus. Small textured ridges within these bands, called circuli, are also distinguishable and can be used to identify individual annuli (Fig 2, Spafard and Rosenkranz 2014). Annuli can also be counted on the auricle (Fig. 1A) and have been used to assist in determining age when the dark band and circuli methods proved ineffective on shells that were heavily worn (Fig. 6, R. Burt, ADF&G, pers. comm.). This annulus is ultimately what is counted to estimate age and the age assigned to individual annuli are estimated from the umbo (earliest growth) out to the outer edge (Fig. 1, CARE 2006, Gustafson and Goldman 2012).

Estimating the age of scallops using counts of annuli visible on the surface of shell is well established. While the earliest studies were completed on Atlantic scallops such as *Placopecten magellanicus* and *Pecten maximus* (Stevenson and Dickie 1954), age estimates of weathervane scallops in Alaska waters have been conducted since the late 1960’s (Hennick 1970). The enumeration of annuli (dark bands) is the most efficient and cost effective method, and can be aided using slightly more time consuming methods (e.g. identifying compressed circuli under magnification) or labor and equipment intensive processing (sectioning or preparing acetate peels). Further, several studies have supported the hypothesis that these annuli are formed once a year (Merrill et al. 1966, MacDonald and Thompson 1985, MacDonald and Bourne 1987, Smith et al. 2001, Hart and Chute 2009). However, there is evidence that these bands may not form annually in all species (Chute et al. 2012), and further validation of the annual nature is needed.

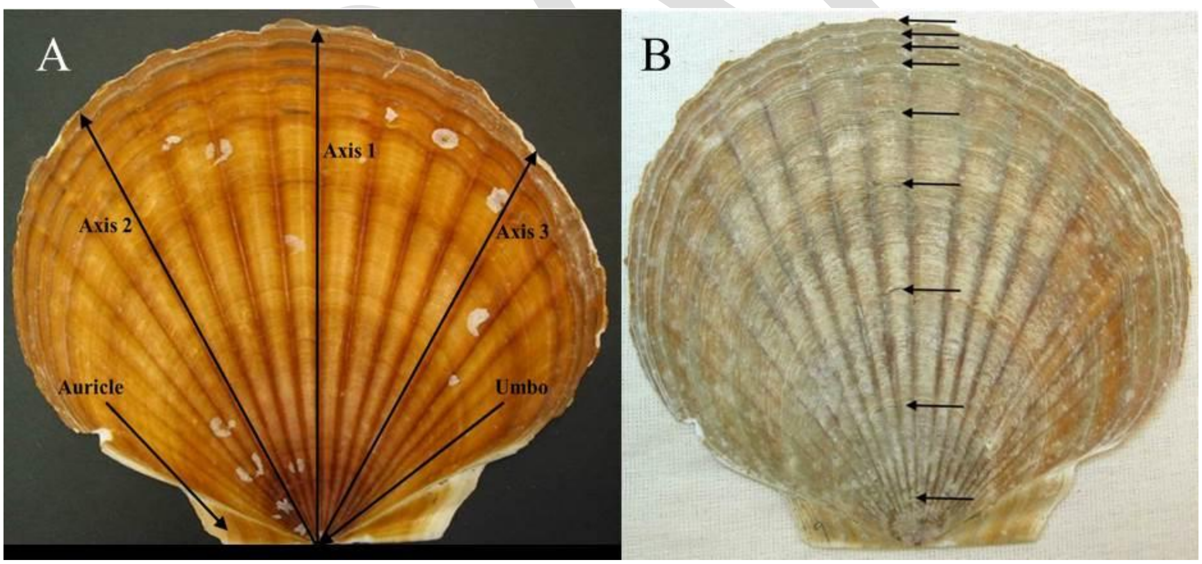


Figure 1.– A: Three axes from which age assessment counts are conducted. All axes start at the umbo and go to the shell edge. B: Weathervane scallop aged by the color band pair and circuli methods at 9-yrs. Arrows point to annuli.

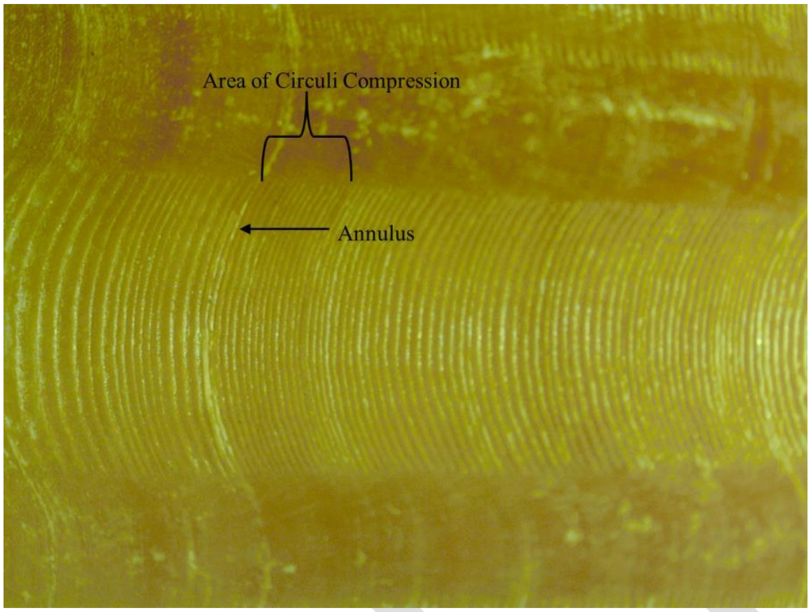


Figure 2.– Magnified image of scallop shell circuli showing area of compression and annulus.

ERROR AND QUALITY CONTROL

There are two main sources of error while estimating age: data and specimen mishandling, and incorrect identification of annuli. The former can be mitigated through formal procedures and careful data collection, and can be detected through similar quality control procedures as incorrect age estimates. The latter can be mitigated through formal criteria on annuli features, training, and continual reader assessment which will be discussed below. Errors in age estimates can be detected through evaluation of a reader's ability to detect annuli and analysis of repeat estimates both between readers and using a reference collection.

Formal annuli criteria may consist of objective measurement ranges for specific annuli and definitions of common features that can be mistaken as annuli. These features are commonly referred to as false checks, and can be present in all of the previously mentioned methods. For weathervane scallops, a false check is an irregularity, crack, or shock line on the scallop shell surface. Merrill et al. (1966) found that serious developmental disturbances caused by injury or stress can result in the formation of a "shock ring" on scallop shells, which can mask or cause problems in discerning true annuli. Scallops in unfished or lightly fished areas tend to show few shock rings whereas those from heavily fished areas tend to have such rings with considerably higher frequency (Merrill et al. 1966). Typically, shock rings/false checks can be distinguished from annuli because they do leave a continuous mark across the entire width of the shell, unlike annuli which can be tracked continuously along the entire span of the shell's surface (Spafard and Rosenkranz 2014). In depth descriptions of annuli characteristics and false checks is needed to develop precise age estimates and to train new readers.

An effective tool for training and evaluation of readers is a reference collection (Campana 2001). A reference collection is a standard set of prepared structures where the ages are known (through tagging or research corroboration), or the ages are at least developed through laboratory consensus. Ideally, reference specimens should represent all variation in annuli characteristic used to estimate age, and should generally account for geographic range, stock, sex, size, and brood years. This is especially true for weathervane scallops as growth potentially varies considerably both within (Fig. 1), and between geographic location (Appendix A). The development and continual use of reference collections is effective for insuring the accuracy and precision of age estimates. These evaluations can ensure that all readers are estimating structure ages similarly and that individual readers' criterion is not changing over time (reader drift).

A way to evaluate the error of ages and readers using either references or estimated ages is multiple reader comparisons. These repeated age estimates by different individuals allows for the statistical analysis of between-reader precision and bias (accuracy between readers), and assessment of the quality of the age estimates produced. Although it is important to assess precision, bias (also referred to as disagreement) is more deleterious, because it has systematic impacts on model estimates and the effect of the error produced cannot be limited through increasing sample sizes (Campana 2001). Further, Campana and Jones (1992) and Hoenig et al. (1995) state that estimates of precision are only of interest and worth conducting if there is no evidence of bias. Therefore, comparisons of individual readers with other trained individuals are important especially in the absence of references that are of known age.

Figure 3.– Two 9 year old scallops from Management Area D (Yakutat) in 2006 with different shell heights. Fishery observer codes on sticky notes in image are: D = management area; S = scallop; 06 = year; Code C2 = missing 2 annuli at shell margin where shell height measurement was taken.

To evaluate bias and precision for quality control, both statistical measures and tests and graphical analyses are used (Campana 2001). Common statistical tests for bias are the Evans-Hoenig and Bowker tests of symmetry (Bowker 1948, Hoenig et al. 1995), and graphical tests include bias plots (both describe in more depth below). Precision is commonly measured using calculated average percent error (APE), coefficient of variation (CV), and percent agreement (Campana 2001, CV is described below). Assessing these and tracking these provides for a standardized measure of data quality and ultimately results in more precise data. However, precision does not guarantee accuracy (i.e., reflect the true or absolute age), and should never be used as a substitute for accuracy (Campana 2001, Goldman et al. 2012).

The quality of age data relies on a solid protocol that ensures data are checked and potentially corrected in a consistent manner. While general methods pertain to all organisms being aged, species specific methods are required due to the difference structures and life history (eg., fish otoliths vs. bivalve shells). In this report we define the standard method for estimating ages of weathervane scallops, ensuring proper data management and dissemination, testing for and improving accuracy and precision, and provide suggestions for future research to improve age estimates.

METHODS

The methods for collecting representative and accurate age information to inform stock assessment can be broken down into four main categories: Shell Collection; Age Determination; Quality Control; and Data Management.

SHELL COLLECTION

Shells may be collected from multiple sources using a variety of sampling programs depending on the suitability to the project. Currently, shells are collected from the ADF&G preseason survey (see Smith et al. 2016), and the ADF&G Scallop Observer Program (ADF&G 2016). Although sampling regimes may vary, certain steps are necessary to collect and prepare shells for ageing.

The top, or left valve (hereafter referred to as a shell) will be collected for aging because the annuli (dark banding pattern) are more visible and the circuli are more distinct on this shell. The bottom shell is subject to excessive wear due to resting on the sea floor and lacks the characteristic color changes of seasonal growth which are needed to estimate age. The difficulty in distinguishing annuli from the bottom shell could result in a systematic bias in scallop age estimates (Spafard and Rosenkranz 2014).

Shells must be intact enough so annulus counts may be made along multiple axes (see Age Estimation section below). Age may be estimated from any shell that is not significantly damage. For example, shells with broken hinges are acceptable since that portion of the shell is not used for age estimation. Additionally, shells with a broken margin may be acceptable if the damage is minimal (i.e. minor chips at places along the margin), but are unacceptable if the damage is considerable (e.g. the entire margin is chipped away or crushed and potential annuli can no longer be counted). Crushed shells should not be collected as this kind of damage prohibits an acceptable estimation of age. See Appendix B for examples of these classifications of damage.

To prepare shells for age estimation, all epifauna must be removed by scraping and brushing the surface with a 10% bleach solution. Shells should be subsequently dried and labelled with the appropriate identifying information including unique specimen numbers, location, date of collection, and any other data pertinent to the project. Detailed methods describing the collection and preparation of scallop shells for age estimation purposes by the ADF&G Statewide Observer Program are documented in their Observer Program Manuals (ADF&G 2016).

AGE ESTIMATION

To create the most accurate and precise data for stock assessment, age estimation protocols must be standardized and consistently applied. Consequently, the methods used to identify annuli, count annuli, and ensure that false checks are not counted must be consistent within and between readers. Due to its simplicity and speed, the standard method used to estimate scallop age will be the enumeration of alternating light and dark bands from the surface of the shell. However, it may be necessary to use the variation in circuli densities observed under magnification to determine annuli location (described below). The standard method of assessing annuli on weathervane scallop shells will be as follows:

1. Examine the outside of the shell from the umbo to the outer margin for any false checks or cracks. Dark bands that do not traverse across the entire shell represent a false check (Figure 3A), and therefore should not be counted as annuli. Cracks typically appear as a light band and will often show irregularities not observed in the dark bands that represent annual growth; consequently these should also not be considered annuli (Figure 3B).

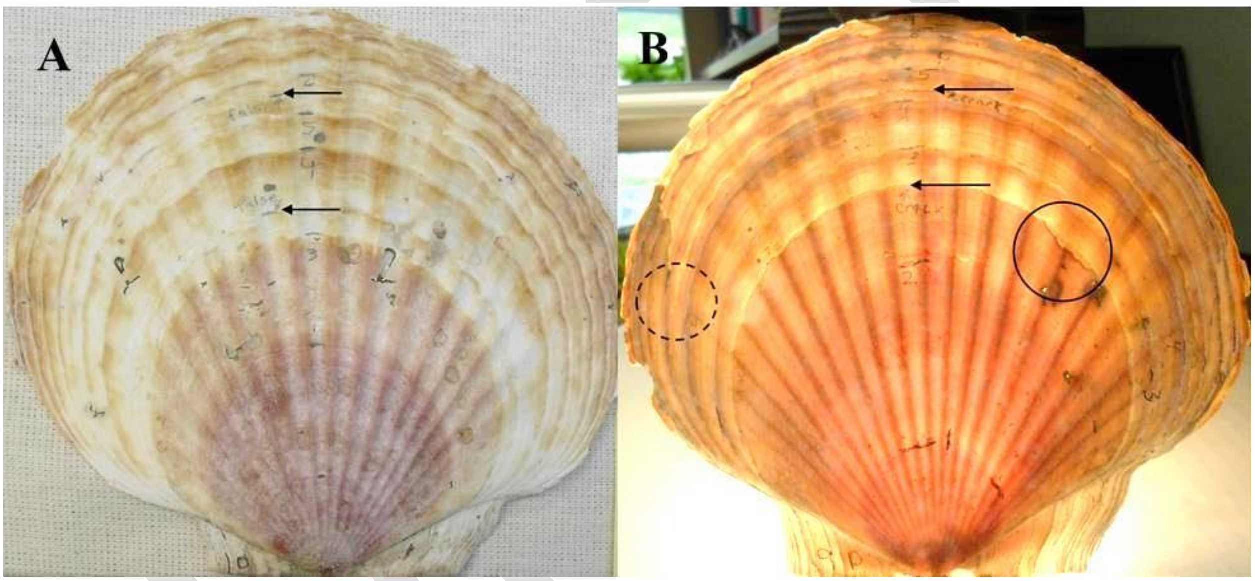


Figure 4.– A: Scallop aged at 10 years using the circuli method. The false checks observed between ages 3 and 4 and between ages 5 and 6 can also be seen using the color band aging method. False checks are marked in pencil on specimen and by arrows and ages are recorded with pencil. B: Scallop aged at 9 years using the circuli method, showing two false checks (denoted by arrows) in the shell which can also be seen using the color band method. Both cracks can be denoted by the abrupt color change to a white line (unlike an annulus which is composed of dark circuli). The crack between ages 2 and 3 also shows an irregularity from the crack in an area on the right side of the shell (encircled in a solid line). The second false check from a crack between ages 4 and 5 in the dashed circle shows where the crack crosses over (or blends) into the fifth annulus.

2. Because the outer margin of the shell can be damaged during collection, count the annuli along three different axes to ensure that annuli at the outer margin of shell are included, and cracks and false checks are not included in the assessed age (Figure 1A). Make the first or primary axis count perpendicular to the hinge starting at the umbo moving along

the straight-line height measurement to the outer margin of the shell. Make the second and third axes between 30 to 45 degrees from the umbo to an undamaged area at the outer margin on either side of the primary axis (Figure 1A).

3. Locate the first annulus, and use calipers to measure the distance from the umbo to the first annulus along the primary axis. For shells on which the dark band representing the first annulus is difficult to identify, take following steps:
   a) Back-light the shell using a small lamp or something similar to provide greater contrast.
   b) Use reflected light on the top of the shell under a magnifier or stereo-microscope to locate the first area of compressed circuli closest to the umbo (Figure 1B). If unsure about the presence or absence of an annulus, use first annulus measurements provided in Appendix C to assist in determining if the first annulus can be located. Changing the orientation of the shell or adjusting the angle of the light can provide contrast for identifying the ridges of the circuli.
   c) If the first annulus cannot be located using either of these methods, examine the auricle to see if the first annulus is visible.
   d) If the first annulus cannot be located by any of the methods described above, and if the first visible annulus lies beyond the maximum distance of any first annuli measured for a shell from that management area (Appendix C), count the remaining annuli and add one year to include the missing first annulus in the age of that shell.
4. Once the first annulus has been located, start with that annulus and count annuli along each of the three transects to the outermost edge of the shell. Special care must be taken when identifying annuli located near the outer margin of the shell because distances between annuli can decrease significantly as one moves away from the umbo, and shell damage in this area can obscure annuli. Use a magnifier to identify annuli near and at the outer margin of the shell. The maximum count from the three axes will be recorded as the final age for the shell. If shells are collected in the winter after January 1st or prior to the completion of the annulus (e.g. spring), count additional growth beyond the last visible annulus as another year due to application of the international January 1st birthdate (CARE 2006, NOAA 2012).
5. If the entire shell is heavily worn, or if conditions that otherwise obscure annuli from view are encountered (e.g. albinism, Figure 4), the reader will use the circuli method to estimate age.
   a. Using a lighted magnifier or a stereo-microscope (2.5 – 40X), identify areas where circuli are spread apart or compressed as you move along the shell from the umbo towards the shell edge. Mark the far edge of the compressed circuli area is the annulus (Figure 2).

Figure 5.– Twelve year old albino scallop shell from commercial fishery Management Area D (Yakutat) in 2006. Fishery observer codes on sticky notes in image are: D = management area; S = scallop; 06 = year.

6. If the entire shell is heavily worn and annuli cannot be determined from dark bands or circuli on the main plane of the shell, check the auricles to determine if age can be assessed from that location using the same methods outlined above (Figure 6).

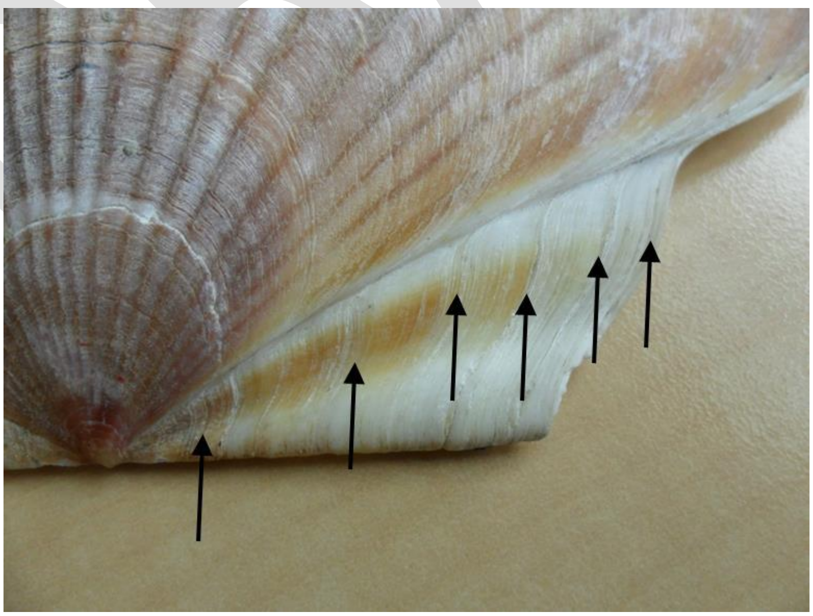


Figure 6.– Example of annuli on scallop shell auricle. Arrows point to annuli.

7. If the age of a specimen cannot be estimated using the above criteria, do not use the sample.

QUALITY CONTROL

Quality control for the ADF&G scallop age assessment program will be maintained by following similar standard practices to the Alaska Fisheries Science Center (AFSC) which uses a long-standing (since 1983), consistent and successful approach for quality control in age assessment practices (Kimura and Lyons 1991, Kimura and Anderl 2005, NOAA 2012).

Reference Collection

Due to the different appearances (Appendix A), growth rates and associated anomalies that can be encountered on shells while estimating the age of scallops from different beds across Alaska, a reference collection will be created for each ADF&G management area. The current weathervane scallop reference collection is incomplete, and only consists of specimens collected from 2 locations. Until such time as a reference collection of 200 shells exists for all fishing areas, the current reference collection will serve for training and quality control purposes.

The reference collection will be used for quality control maintenance for experienced age readers and to train new age readers. Prior to ageing individuals each year experienced age readers will use the reference collection to assess their precision and bias by estimating the ages of three sets of 20 individuals from each management area from which they will be ageing that year. Their results will be tested (see below) and must show a CV ≤ 10% and no bias before any field samples can be processed. If precision (CV) is >10%, the reader will re-examine the age estimation protocol and read the discrepant samples from the reference collection again to test precision. If tests of symmetry show bias, the reader will review the protocol and re-estimate the age of samples within the age range of the bias, and run tests of symmetry again.

Training new readers

Standardized training of new age readers and qualitative examination of their age estimation of reference specimens will help ensure standardization and repeatability among readers. The training of new age readers will be conducted as follows:

1. After thorough examination of this report, an experienced age reader will work with the new reader introducing the criteria used to identify and differentiate among annuli, cracks and false checks.
2. New age readers will examine specimens reference collection to practice identifying annuli; at this time trainees will have access to the age data associated with each specimen.
3. The new age reader will be given three sets of 20 individuals from each management area from the reference collection and conduct blind reads. Their age estimates will be tested for precision and bias (CV and tests of symmetry, respectively).
4. Once an acceptable level of precision is achieved (CV ≤ 10%) and tests of symmetry show no bias exists, the new reader will conduct a blind read of the entire reference

collection and their results will be tested for precision and bias. If the results show good precision and no bias, the trainee is ready to age. If the results show poor precision (CV > 10%), the new age reader will be required to re-age the entire reference collection again, until results no longer show poor precision. If the results show bias, the new age reader will work with an experienced reader to reduce bias until a test of symmetry shows differences between the reader and the reference collections are random.

Examining Precision and Bias

Tests of symmetry using contingency tables will be used to determine if bias exists between age readers (Hoenig et al. 1995, Evans and Hoenig 1998, Campana 2001). The symmetry test is designed to test the hypothesis that an *m* x *m* contingency table (where *m* is the maximum age in the table) containing two classifications of a sample into categories (e.g. one set of ages provided by two age readers) is symmetric about the main diagonal of the table (Bowker 1948). Evans and Hoeing (1998) provided a modification to the Bowker (1948) test of symmetry where age differences (observations) from each side of the main diagonal of the table are pooled to enhance the ability to detect bias in data sets with small sample sizes. Both tests of symmetry will be used to assess reader bias to provide the best ability to detect bias regardless of sample size. The test statistic is a chi-square distribution for both Bowker (1948) and Evans and Hoenig (1998), and is defined as:

$$\chi^2 = \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} \frac{(n_{ij} - n_{ji})^2}{(n_{ij} + n_{ji})} \qquad (1)$$

where n_{ij} = the observed frequency in the *i*th row and *j*th column and n_{ji} = the observed frequency in the *j*th row and the *i*th column. The degrees of freedom (*df*) for Bowker's (1948) test equals the number of comparisons across (on opposing sides of) the main diagonal of the table. The *df* for the Evans-Hoeing (1998) test is equal to the maximum difference between assigned ages that occurred between readers or methods and complete agreement (zero difference). The critical chi-square value will be determined based on the number of degrees of freedom at alpha = 0.05. If the chi-square result from a test of symmetry is less than the critical value, the reader interpretation differences (i.e. difference between reader age assessments) are considered to be random. If the chi-square result is greater than the critical value, then bias is present meaning that the reader interpretation differences are statistically significant and a detectable bias is present in the between-reader results.

Tests of precision for comparing between-reader ages will include percent agreement, percent agreement ±1yr (PA and PA ±1yr) and the coefficient of variation (CV) (see Chang 1982 and Campana 2001). While there is no absolute rule published for what is an acceptable mean CV for aging studies (Morrison et al. 1998, Campana 2001), Campana (2001) stated that 5–10% serves as a good reference value for many fishes aged by counting annuli in otoliths and vertebrae. Kilada et al. (2007) reported similar age precision for smoothcockle (*Serripes groenlandicus*), reporting a mean CV of 4.68%. The between-reader percent agreement and CV's from Kilada et al. (2007) are similar to between-reader percent agreement and CV's reported for numerous groundfish species (Kimura and Lyons 1991, Kimura and Anderl 2005). To allow for the effects of the variable shape, shell-wear, color, and look of scallop shells from different locations across

Alaska, a threshold of 10% will be used for mean CV’s generated by the ADF&G scallop aging program and will be calculate as such:

$$CV_j = 100 \times \frac{\sqrt{\sum_{i=1}^{R} \frac{\left(X_{ij} - X_j\right)^2}{R-1}}}{X_j} \qquad (2)$$

where CVj is the age precision estimate for the jth scallop, X_{ij} is the ith scallop age of the jth scallop, X_j is the mean age of the jth scallop, and R is the number of final ages . The number of readers will typically be two, however if a third reader independently provides an age on a sample, the R for that sample’s CV calculation will be three. Multiplying by 100 makes the CV value into a percent. The CV_j’s will then be averaged across all samples to produce a mean CV.

Addressing Bias and Poor Precision

Once age readers have completed their review of the reference collection and the results show acceptable precision and no bias, two readers (a primary reader and a second reader hereafter referred to as the test reader) will proceed to age collected shells. The primary reader will age all shells in a sample. The test reader will then independently read a 20% subsample without knowledge of the primary reader’s estimated ages. Statistics for bias and precision (consistent with the above assessments) will be conducted on the between-reader results to ensure there is no bias or precision problems with the primary reader’s assessed ages.

If no bias is detected with the test of symmetry and the CV for precision between the primary reader and the test reader is not greater than 10%, the original age estimated by the primary reader will be used for management.

If bias is detected, the following steps will be used until bias is eliminated:

1. The ages where between-reader bias is occurring will be assessed by examining the symmetry table and looking at the asymmetry of ages surrounding the main diagonal in the table to see which samples need to be re-aged. The symmetry table will show the ages where readers are either over- or under-aging samples (Appendix D, Table B). Those samples within the age range of the bias will be re-read by both readers and statistical analyses for bias will be run again.
2. If bias still exists, the primary and test reader will review all samples within the bias age range to determine ages by consensus. If no consensus can be reached on a specimen, a third reader will perform a blind read, if no two readers can agree on an assessed age the specimen will not be aged.
3. Once the final ages of the first subsample are determined, a second randomly selected 20% subsample will be read by both readers to ensure the bias has been rectified.

If bias is not present, but the CV is higher than 10%, the following steps will be used:

1. The primary and test reader will independently re-age all samples where their age estimates differed, and the CV will be calculated again. If the CV is still higher than 10%, the primary and test reader will work together to review all samples in question to

assess differences and ensure that the criterial for identifying annuli is being followed appropriately.

2. If protocols were not followed, the ages for the entire sample must be aged again by a trained age reader.
3. If protocols were followed, the final ages may be determined during this consultation though consensus. If no consensus can be reached, a third reader will perform a blind read on the specimen, if no two readers can agree on an assessed age the specimen will not be aged.

DATA MANAGEMENT

All age data will be uploaded, managed and housed into the ADF&G Mark, Tag and Age Laboratory's relational database available to ADF&G researchers and managers statewide. Date fields to be collected are in Appendix E.

REFERENCES CITED

Alaska Department of Fish and Game (ADF&G) Shellfish Observer Program. 2016. Scallop Observer Training and Deployment Manual. Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak. http://kodweb.fishgame.state.ak.us/index/Wiki:Observer_Program:Scallop_Observer_Program:Scallop_Observer_Manual:Archive.

Bowker, A.H. 1948. A test for symmetry in contingency tables. J. Am. Stat. Assoc. 43:572–574.

Campana S.E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. J. Fish Biology. 59:197–242.

Campana S.E. and C.M. Jones. 1992. Analysis of otolith microstructure data. *In*: D.K. Stevenson and S.E. Campana (Eds.) Otolith microstructure examination and analysis. Can. J. Fish. Aquat. Sci 39:1208–1210.

CARE (Committee of Age Reading Experts). 2006. Manual on generalized age determination. http://care.psmfc.org/docs/CareManual2006.pdf.

Chang, W.Y.B. 1982. A statistical method for evaluating the reproducibility of age determination. Can. J. Fish. Aquat. Sci. 39:1208–1210.

Chute, A.S., S.C. Wainright and D.R. Hart. 2012. Timing of shell ring formation and patterns of shell growth in the sea scallop *Placopecten magellanicus* based on stable isotopes. J. Shellfish Res. 31(3):649–662.

Evans, G.T. and Hoenig, J.M. 1998. Testing and viewing symmetry in contingency tables, with application to readers of fish ages. Biometrics 54:620–629.

Fiori, S.M. and E.M. Morsán. 2004. Age and individual growth of *Mesodesma mactroides* (Bivalvia) in the southernmost range of its distribution. ICES J. Mar. Sci. 61:1253–1259.

Goldman, K.J., G.M. Cailliet, L.J. Natanson and A. Andrews. 2012. Assessing the Age and Growth of Chondrichthyan Fishes. pp 423–451. *In*: The Biology of Sharks and Their Relatives. Second Edition. J. Carrier, J.A. Musick and M. Heithaus (eds.). CRC Press, Boca Raton, FL.

Gustafson, R. L., and K. J. Goldman. 2012. Assessment of weathervane scallops in Kamishak Bay and at Kayak Island, 2004 through 2012. Alaska Department of Fish and Game, Fishery Data Series No. 12-62, Anchorage.

Hart, D.R. and T.S. Chute. 2009. Verification of Atlantic sea scallop (*Placopecten magellanicus*) shell growth rings by tracking cohorts in fishery closed areas. Can. J. Fish. Aquat. Sci. 66:751–758.

Heifetz, J., D. Anderl, N.E. Maloney and T.L. Rutecki. 1998. Age validation and analysis of aging error from marked and recaptured sablefish, *Anoplopoma fimbria*. Fish. Bull. 97:256–263.

Hennick, D.P. 1970. Reproductive cycle, size at maturity, and sexual composition of commercially harvested weathervane scallops (*Patinopecten caurinus*) in Alaska. J. Fish. Res. Board of Canada. 27(11):2112–2119.

Hoenig, J.M., M.J. Morgan and C.A Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364–368.

Kilada, R.W., D. Roddick and K. Mombourquette. 2007. Age determination, validation, growth and minimum size of sexual maturity of the Greenland smoothcockle (*Serripes groenlandicus*, Bruguire, 1789) in eastern Canada. J. Shellfish Res. 26(2):443–450.

Kimura, D.K. and D.M. Anderl. 2005. Quality control of age data at the Alaska Fisheries Science Center. Mar. Fresh. Res. 56:783–789.

Kimura, D.K. and J.J. Lyons. 1991. Between-reader bias and variability in the age-determination process. Fish. Bull. 89:53–60.

Kimura, D.K. 1990. Approaches to age-structured separable sequential population analysis. Can. J. Fish. Aquat. Sci. 47:2364–2374.

Lai, H.L. and D.R. Gunderson. 1987. Effects of aging errors on estimates of growth, mortality and yield per recruit for walleye pollock (*Theragra chalcogramma*). Fish. Res. 5:287–302.

Lomovasky, B.J., M. Lasta, M. Valiñas, M. Bruschetti, P. Ribeiro, S. Campodónico and O. Iribarne. 2008. Differences in shell morphology and internal growth pattern of the Patagonian scallop *Zygochlamys patagonica* in the four main beds across their SW Atlantic distribution range. Fish. Res. 89:266–275.

MacDonald, B.A. and R.J. Thompson. 1985. Influence of temperature and food availability on the ecological energetics of the giant scallop *Placopecten magellanicus*. I. Growth rates of shell and somatic tissue. Mar. Ecol. Prog. Ser. 25: 279–294.

MacDonald, B.A., and N.F. Bourne. 1987. Growth, reproductive output, and energy partitioning in weathervane scallops, *Patinopecten caurinus*, from British Columbia. Can. J. Fish. and Aquat. Sci. 44:152-160.

Merrill, A.S., J.A. Posgay and F.E. Nichy. 1966. Annual marks on shell and ligament of sea scallop (*Placopecten magellanicus*). Fish Bull. 65:299–311.

Morrison, A.K., S.G. Robertson and D.C. Smith. 1998. An integrated system for producing fish aging: Image analysis and quality assurance. N. Amer. J. Fish. Manag. 18:587–598.

NOAA (National Oceanic and Atmospheric Administration). 2012. Age determination manual of the Alaska Fisheries Science Center age and growth program. M.E. Matta and D.K. Kimura (eds.). NOAA Professional Paper NMFS 13. US Department of Commerce, Seattle WA.

Ropes, J.W. 1984. Procedures for preparing acetate peels and evidence validating the annual periodicity of growth lines formed in the shells of ocean quahogs, Arctica islandica. Mar. Fish. Rev. 46:27-35.

Ropes, J.W. and A. Jearld Jr. 1987. Age determination in bivalves. *In*: Summerfelt, R.C. and Hall, G.E. (Eds.), The Age and Growth of Fish, Iowa State University Press, Ames, pp.517–526.

Shaul, W. & L. Goodwin. 1982. Geoduck (*Panopea generosa*: Bivalvia) age determined by internal growth lines in the shell. *Can. J. Fish. Aquat. Sci*. 39:632–636.

Smith, Q., B. Williams, and R. Burt. 2016. Statewide Weathervane Scallop survey operational plan, 2016 through 2018. Alaska Department of Fish and Game, Alaska Department of Fish and Game, Regional Operational Plan ROP.CF.1J.2016.07, Juneau.

Smith, S.J., E.L. Kenchington, M.J. Lundy, G. Robert and D. Roddick. 2001. Spatially specific growth rates for sea scallops (*Placopecten magellanicus*). *In*: Spatial processes and management of marine populations. Lowell Wakefield Fish. Symp. Ser. Vol. 17. 2001. Alaska Sea Grant College Program AK-SG-01-02.

Spafard, M. A., and G. E. Rosenkranz. 2014. Age and growth of weathervane scallops *Patinopecten Caurinus* from the Alaska statewide scallop fishery, 1996–2013. Alaska Department of Fish and Game, Fishery Manuscript Series No. 14-03, Anchorage.

Stevenson, J.A. and L.M. Dickie. 1954. Annual growth rings and rate of growth of the giant scallop, *Placopecten magellanicus* (Gmelin) in the Digby area of the Bay of Fundy. J. Fish. Res. Bd. Canada 11:660–671.

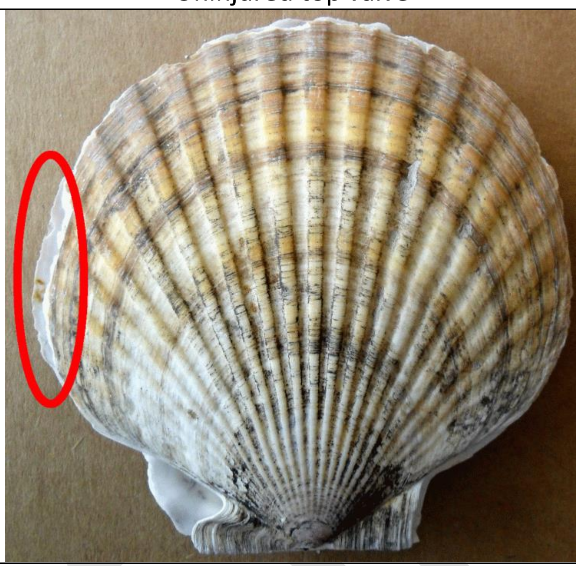
APPENDIX A: DIFFERENCES IN SHELL APPEARANCE ACROSS THE STATE OF ALASKA

Appendix A.– Example images of scallops from 5 management areas across the state of Alaska showing differences in shell appearance. Map of Areas is provided in Appendix B

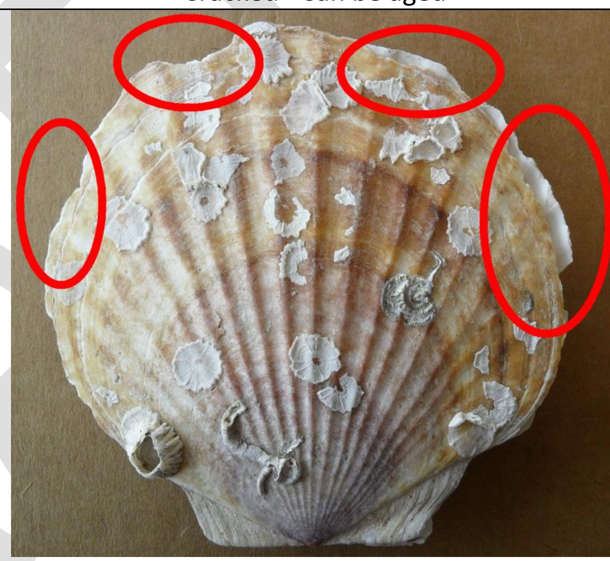
APPENDIX B: EXAMPLES OF DAMMAGED SHELLS

Uninjured top valve

Cracked– Can be aged



Broken Margin –Can be aged



Broken Margin – Cannot be aged

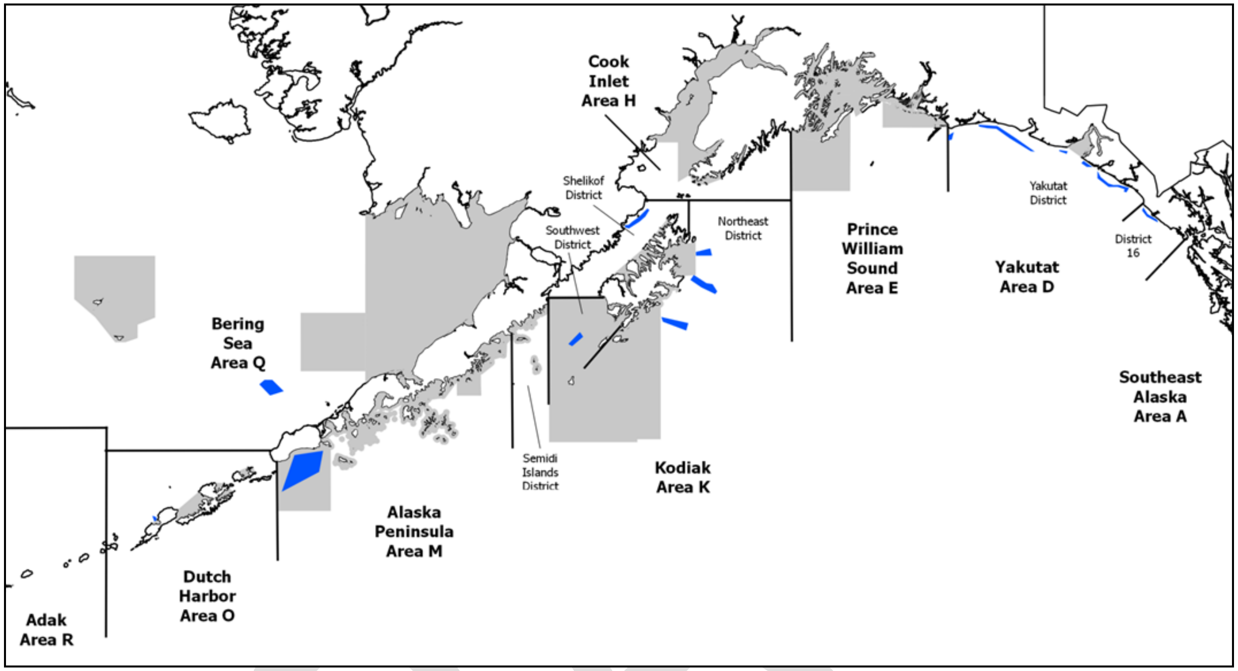
Broken Margin – Cannot be aged

Crushed – Cannot be aged

APPENDIX C: FIRST ANNULUS MEASUREMENTS

Appendix B.– First annulus measurements (mm) along the primary aging axis from scallops collected by ADF&G fishery observer program and research surveys. Map shows Management Areas of collection.

Area	District	Mean	SE	Minimum	Maximum	Sample Size	Collected From	Years
D	Yakutat	21.7	0.17	10	44	1069	Observer program	2003-2015
D	District 16	22.0	0.93	14	32	30	Observer program	2006-2015
E	Kayak Island	25.4	0.07	6.6	53.6	8637	Research survey	1996-2014
H	Kamishak	29.6	0.08	7.6	52.8	9299	Research survey	1996-2015
KNE	Northeast	25.8	0.18	12	54	1396	Observer program	1996-2015
KSH	Shelikof	30.2	0.16	12	55	2395	Observer program	1999-2015
KSEM	Semidistrict Islands	27.3	0.86	18	34	27	Observer program	1996
KSW	Southwest	23.4	0.50	14	49	178	Observer program	2011-2015
M	West Chignik	21.9	0.84	16	28	17	Observer program	2008
M	Central	29.4	0.59	21	39	60	Observer program	1998-2006
M	Unimak Bight	20.6	0.40	13	38	137	Observer program	2012-2015
O	Dutch Harbor	23.7	0.35	15	52	262	Observer program	2008-2015
Q	Bering Sea	25.1	0.39	15	45	285	Observer program	1999-2015



Map showing Alaska scallop fishery registration areas. General areas of effort are overlaid by blue polygons. Exploratory fisheries in waters normally closed to scallop fishing (gray shading) have been opened by ADF&G Commissioner's Permit in the Kodiak Southwest District and Alaska Peninsula Area during past seasons.

APPENDIX D: TABLE OF SYMMETRY EXAMPLES

Appendix C.– Two table of symmetry examples.

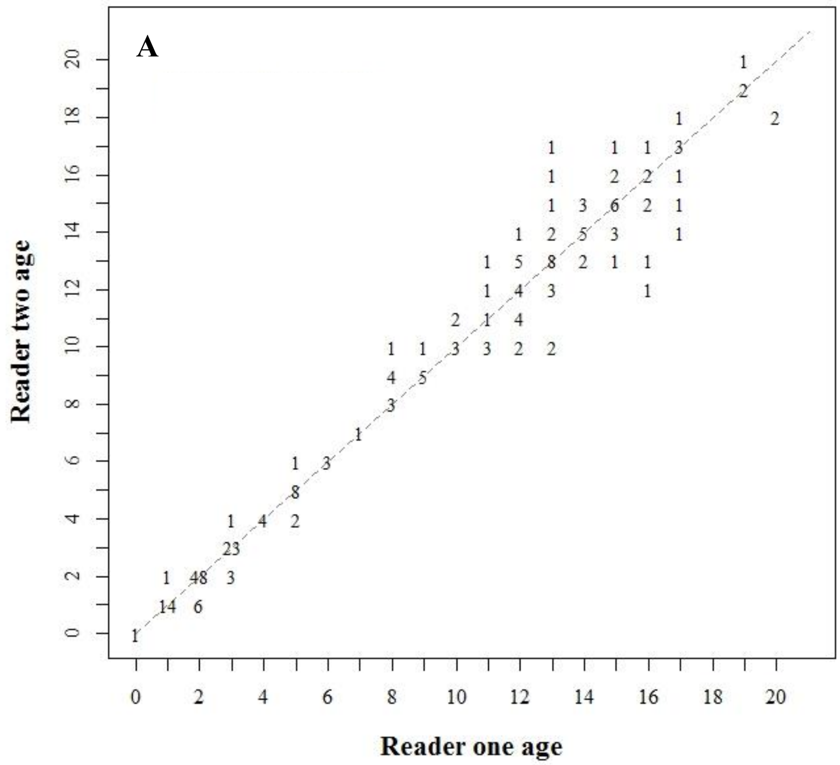


Table A shows no bias in results; ages are randomly distributed across the main diagonal of the table.

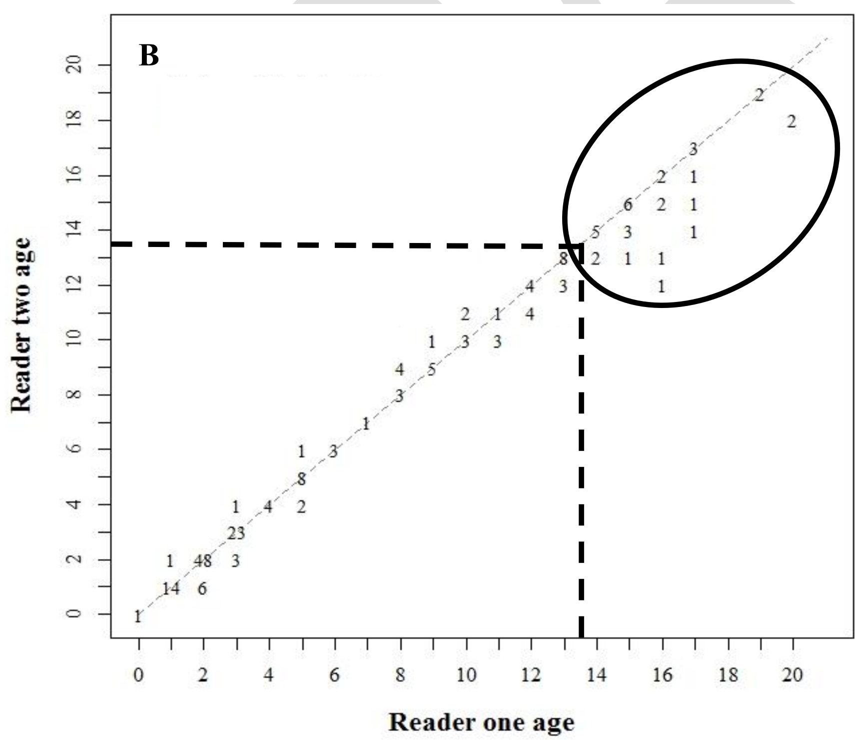


Table B shows asymmetry (bias towards overestimation) across the main diagonal after age 14, indicating specimens in the circled area need to be re-aged.

APPENDIX E: DATA COLLECTION FIELDS

Appendix D.– Data fields to be entered by age readers.

Primary Reader	**Test Reader**
Field Data (ties age samples back to databases)	Test reader's name
Event ID or Haul ID	Date of test read
Scallop or shell ID number	Method used to determine first annulus location
F&G Region	Assessed age
Species code	Test reader sample size
Shell height (mm)	Test reader comments
Lab data:	
Primary reader's name	
Date of primary read	
Shell condition code (0-5): 0 = undamaged 1 = broken hinge 2 = broken margin 3 = cracked 4 = punctured 5 = crushed	
Method used to determine first annulus location	
Distance from umbo to first annulus (mm)	
Assessed age	
Selected for second read (y/n)?	
Primary reader sample size	
Primary reader comments	
Precision and Bias Analysis:	
Between reader percent agreement	
Between-reader percent agreement ± 1 yr	
Between-reader CV (coeffienct of variation)	
Test of symmetry results:	
chi-square statistics	
Degrees of freedom (Bowker test)	
Degrees of freedom (Evans-Hoenig test)	

Note: Event ID and scallop ID # are identifiers used on surveys and Kamishak fishery; Haul ID and shell ID #are identifiers used in observer program.