Regional Operational Plan CF.1J.2019.05

Operational Plan: Dive Fisheries Stock Assessment Surveys in Southeast Alaska

by

Kyle Hebert

Mike Donnellan

and

Katie Palof

May 2019

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

REGIONAL OPERATIONAL PLAN CF.1J.2019.05

OPERATIONAL PLAN: DIVE FISHERIES STOCK ASSESSMENT SURVEYS IN SOUTHEAST ALASKA

by

Kyle Hebert and Mike Donnellan

Alaska Department of Fish and Game, Division of Commercial Fisheries, Douglas

Katie Palof

Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau

Alaska Department of Fish and Game
Division of Commercial Fisheries

May 2019

Kyle Hebert, Mike Donnellan and Katie Palof,
Alaska Department of Fish and Game, Division of Commercial Fisheries,
P.O. Box 110024, Juneau, Alaska, 99824-0024

This document should be cited as:
Hebert, K., M. Donnellan, and K. Palof. 2019. Operational plan: Dive fisheries stock assessment surveys in Southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Operational Plan. ROP.CF.1J.2019.05, Juneau.

SIGNATURE PAGE

Project Title:	Dive Fisheries Stock Assessment Surveys in Southeast Alaska
Project leader:	Quinn Smith
Division, Region, and Area:	Commercial Fisheries, Southeast Region, Southeast Alaska
Project Nomenclature:	
Period Covered:	1 May 2019 to 30 April 2023
Field Dates:	Annually April through June
Plan Type:	Category II

Approval

Title	Name	Signature	Date
Project leader	Quinn Smith		
Biometrician	Chris Siddon		
Research Coordinator	Kyle Hebert		

TABLE OF CONTENTS

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

PURPOSE

The primary purpose of this project is to assess stocks and if warranted, develop fishery area-specific guideline harvest levels (GHLs) for commercial dive fisheries in Southeast Alaska, including sea cucumbers, sea urchins, and geoduck clams. GHLs are calculated as a percentage of biomass estimates, which requires periodic stock assessment surveys to collect data on densities and weights for target species. The secondary purpose of this project is to monitor species-specific stock status over time for evaluation of long-term stock viability and the performance of fishery management. The purpose of this document is to describe the methods and rationale for dive fisheries stock assessments in enough detail to facilitate repeatable methods and scientifically defensible results and conclusions.

Keywords: sea cucumber, *Apostichopus californicus*, geoduck, *Panopea generosa,* sea urchin, *Mesocentrotus franciscanus,* shellfish, stock assessment, dive survey, dive fishery, commercial fishery, Southeast Alaska

OBJECTIVES

1. For each species, estimate mean density of the total population within species-specific depth ranges for each commercial fishery area scheduled to be opened during the next season. The statistical objective is to estimate density such that the lower bound of the one-sided 90% confidence interval is within 30% of the mean value (i.e. 70% precision).
2. For each species, estimate mean weight of the total population within species-specific depth ranges for each commercial fishery area scheduled to be opened during the next season. The statistical objective is to estimate weights such that the lower bound of the one-sided 90% confidence interval is within 20% of the mean value (i.e. 80% precision).
3. For each species, estimate total biomass of the total population within species-specific depth ranges for each commercial fishery area scheduled to be opened during the next season. The statistical objective is to estimate biomass such that the lower bound of the one-sided 90% confidence interval is within 30% of the mean value (i.e. 70% precision).
4. For sea cucumbers and sea urchins, conduct annual estimates of density, weight, and biomass within the same species-specific depth ranges as open commercial areas for seven control areas where commercial harvest is prohibited. The statistical objective for each metric is the same as for commercial fishery areas.
5. For each species, calculate GHLs for each commercial fishery area scheduled to be opened during the next season.
6. For geoduck clams, conduct show factor studies in concert with geoduck surveys for as many fishery areas as logistically feasible. The statistical objective is to estimate the show factor such that the lower bound of the one-sided 90% confidence interval is within 30% of the mean value (i.e. 70% precision).
7. For geoduck clams, compare biomass estimate from new survey of each fishery area with biomass estimate from original stock assessment survey to determine whether the biomass is less than 30% of the original biomass estimate and the area must be closed per regulation.

BACKGROUND

Previously published operational plans (Larson et al. 2001a, Pritchett and Hoyt 2007) and reports by the Alaska Department of Fish and Game (ADF&G) describing stock assessment, research, and management have provided the foundation and much of the text for this operational plan. For sea cucumbers, the reference reports were: ADF&G 1990a, ADF&G 1990b, Kruse and Imamura 1990, Imamura and Kruse 1990, Woodby et al. 1993, Larson et al. 1995, Woodby and Larson 1997, Larson et al. 2001b, Larson et al. 2001c, Hebert et al. 2001, Clark et al. 2009, Hebert

2010a, Hebert 2010b, and Hebert 2012a. For geoducks, this operational plan was based on Pritchett 1999, Pritchett et al. 1999a, Pritchett et al. 1999b, Pritchett et al. 2000, Walker 2000, Pritchett and Hebert 2001, Pritchett and Hebert 2002, Pritchett 2003, Siddon 2007, and Rumble and Siddon 2011. For red sea urchins, the references were Woodby 1990, Marshall et al. 1991, Davidson et al. 1992, Davidson et al. 1993, ADF&G 1996a, ADF&G 1996b, Larson and Woodby 1996, Woodby et al. 1996, Woodby and Larson 1996, Larson et al. 1998, Hebert and Larson 1999, Hebert and Larson 2000, Hebert and Larson 2001, Hebert and Clark 2001, and Walker et al. 2003.

The most recent operational plans and reports, which this operational plan is primarily based upon, were critically reviewed prior to re-incorporation in this document. Historical documents were critically reviewed when necessary (e.g., if a method was omitted from the most recent reference). While much of the text remains the same as in previous operational plans and reports, this operational plan has been updated substantially. This plan contains clarified statistical objectives, additional method details, data processing steps, and corrections to statistical methods. Rationale for methods (or changes to methods) deemed important is provided for context, but neither a complete history of method changes, nor a rationale for every subjective decision, is provided in the interest of trying to preserve a relatively concise, readable document. While more comprehensive than the two previously published operational plans for the dive fisheries (Larson et al. 2001a, Pritchett and Hoyt 2007), this document nevertheless does omit some important methods (e.g., survey area maps, geographic coordinates of transect starting points, protocols for sea cucumber and sea urchin survey development). These omissions were intentional due to time constraints, but these should be included in future operational plans.

A brief background section for all species of interest is provided below; see Hebert 2017 for a more detailed treatment.

SEA CUCUMBERS

The commercial species of sea cucumber harvested in Southeast Alaska is the California sea cucumber *Apostichopus californicus*. The commercial sea cucumber fishery expanded rapidly in the late 1980s and in 1989 the fishery exceeded the ability of the department to manage by a permit system. The Alaska Department of Fish and Game (ADF&G) closed the fishery in May 1990 and reopened it in October 1990 following development of the Southeast Alaska Sea Cucumber Commercial Fisheries Management Plan (5 AAC 38.140). This management plan was initially developed in 1990 (ADF&G 1990a, ADF&G 1990b, Kruse and Imamura 1990, Imamura and Kruse 1990) and adopted into regulations (5 AAC 38.140.) by the Alaska Board of Fisheries (ADF&G 1991, 1992). The management plan incorporates multiple conservative elements to hedge against uncertainties and potential errors in stock assessment design, data collection, and management (Woodby et al. 1993) and was designed to protect subsistence opportunities and provide for sustained commercial fishing harvests. To protect subsistence opportunities and to provide refuge areas from commercial fishing, the cucumber management plan established 18 areas closed to commercial fishing (5 AAC 38.140 (k)). A subset of these closed areas was established as research control areas to evaluate stock status and the effectiveness of fishery management relative to natural population dynamics. There are also provisions to prevent the use of diving gear in the subsistence (5 AAC 02.020 (1)) and personal use (5 AAC 77.010 (l)(3)) fisheries in closed areas.

Fishing areas are opened on a three-year rotational basis. The rationale for rotational fisheries in this instance is to reduce costs from an annual to triennial basis for any given fished area. Annual harvest rates are calculated from stock assessment surveys, then this harvest rate is multiplied by three to arrive at a three-year harvest rate for the triennial fishery. This rotational system was not implemented to allow an area to recover between harvests but the two-year fallow period between fisheries may fortuitously have a positive effect on stock recovery. This possibility has not been studied. Through the 2017/18 fishing season, annual commercial fishery guideline harvest levels were calculated as the product of the lower 90% confidence limit on the biomass estimate and the annual target exploitation rate of 6.4%, multiplied by three to adjust for triennial harvest. This equated to a target exploitation rate of 19.2% every three years. In January 2018 the Board of Fisheries opted to reduce a conservative factor in the harvest rate equation, which increased the target exploitation rate to 7.68% (annual) and 23.0% (every three years). However, because the lower bound confidence limit is used in calculating GHLs, the effective harvest rate on the population is less. Other aspects of the survey provide added conservative measures. These include surveys restricted to a depth of 50 ft Mean Lower Lower Water (MLLW) even though sea cucumbers occur deeper, and, probable minimum sea cucumber counts along transects, due to limitations from kelp coverage and underwater visibility. (Note that depth figures in this document are provided in feet, per custom with scuba diving in the U.S., and depths will be specified as relative to either relative to the MLLW tidal datum or absolute feet of seawater [fsw].)

Despite intentions to be conservative, there are also elements in the survey methods that may lead to GHL overestimation and bias to an unknown degree, such as how shoreline length is calculated and how transects are positioned and oriented along the shoreline. Further, although the harvest rate and the biomass estimate contain conservative elements, there is currently not a control rule in the management plan designed to trigger a reduction in harvest rate or fishery closure. Trends in density, average weight, and biomass are not a primary consideration when making decisions about whether to close a fishery area for an entire season or indefinitely. Instead, the primary criterion for these decisions is whether an area has a GHL large enough to be worthwhile to manage. Within a season, the main consideration in the decision whether to open or close a fishery is whether a guideline harvest level can be accurately targeted based on expected fishing effort.

GEODUCKS

Prior to the 1991/1992 season, there existed little interest in the geoduck clam (*Panopea generosa*) fishery and geoduck clam harvest was minimal. Beginning with the 1992/93 season, the number of divers increased, and the fishery value increased as local interest and participation by divers from Washington state increased. Fishery participation fluctuated in the late 1990s due to decreasing ex-vessel value of processed product. During this period the primary fishery product was processed geoducks, which were valued substantially less than live-marketed product. However, beginning with the 2003/04 season, the Alaska Department of Environmental Conservation (ADEC) approved changes in paralytic shellfish poisoning (PSP) testing protocol which resulted in over 90% percent of the harvested product sold live. This was a major change to the fishery, and since the change, most harvest has been sold live, which has increased the value of the fishery and generated increased participation.

The largest expansion in the geoduck clam fishery occurred between the 2005/06 and 2009/10 seasons as a result of: 1) federal funding through the Nearshore Marine Research grants, which funded survey costs; 2) reconnaissance surveys, conducted by members of the Southeast Alaska Regional Dive Fisheries Association (SARDFA); and 3) implementation of a fishery logbook program. These have allowed identification and mapping of new geoduck clam beds both within existing fishing areas and in new areas.

A management plan was developed for geoducks in 1999 (Pritchett 1999). Annual commercial fishery guideline harvest levels for geoducks have been calculated as the product of the lower 90% confidence limit on the biomass estimate and the annual target exploitation rate of 2%, multiplied by the number of years in the rotation for a given fishery area (e.g., for a two-year rotation, the harvest rate would be 4%). However, because the lower bound confidence limit is used instead of the point estimate, the effective harvest rate for the population is less. The 2% harvest rate was based on the harvest rate in Washington State in the early years of the fishery (Washington subsequently increased their harvest rate to 2.7% of standing stock; Bradbury et al. 2000b). Other aspects of the survey provide added conservative measures. These include surveys restricted to 60 ft depth MLLW even though geoducks occur deeper.

Stock assessment surveys were first conducted in Southeast Alaska in 1982 at Noyes Island and in 1988 and 1989 at Biorka Island, Kah Shakes, and Gravina Island. Although commercial fisheries have been ongoing in these areas since 1985, no additional surveys were conducted until 1997. Beginning in 1997, surveys were conducted regularly in existing commercial harvest areas, and in several new fishery areas. The last fishery added to the pool was in 2018 (Cleveland Peninsula), but it is unclear if this area is viable. In most instances, surveys were conducted using a shoreline-based design until 2006, then transitioned to an area-based design thereafter. This transition was made in order to increase precision of the density and biomass estimates per unit of sampling effort (shoreline- vs area-based design details are described in a subsequent section), which also has the practical effect of increasing GHLs.

RED SEA URCHINS

The red sea urchin occurs primarily on rocky shorelines of the outside coast of Southeast Alaska, with the largest concentrations in southern Southeast Alaska, currently. Urchins are harvested for their roe, or “uni”, with no distinction made between males and females. The product is most valuable fresh and is marketed primarily in Japan.

Harvests of red sea urchins in Southeast Alaska began in 1981 near Ketchikan, primarily around Gravina Island. Participation and harvest built through the mid-1980s, expanding to include Districts 1, 2, 3, and 4. Harvest grew to 890,092 lb in 1986/87 and then tapered off due to difficulties in marketing. Interest in establishing a commercial urchin fishery in Southeast Alaska resurged in 1990 due to the success of urchin fisheries in California, Washington, and British Columbia. This interest was directed towards the Sitka area; however, lacking basic stock information, further commercial harvest was postponed until completion of a test fishery in late 1990 and early 1991 to estimate population size and to gather size frequency data. Fully developed red sea urchin fisheries have occurred since the 1996/97 fishing season. The overall quota has ranged between 4.4 and 6.8 million pounds; however, selected areas have seen reductions in biomass, probably due to sea otter predation. Most areas in Southeast Alaska supporting red sea urchin populations are threatened by the rapidly sea otter population. The numbers of participating divers and landings have been low in recent years, relative to the early year of the fishery. Although market interest in red sea urchins has increased in the last few years (ADF&G unpublished data), substantive geographic expansion of the red sea urchin fishery is not anticipated.

The increasing geographic range and abundance of sea otters following their reintroduction to Southeast Alaska (see Sea Otters section below) has already dramatically reduced the extent of commercially viable populations of red sea urchins on the outer coast. The red sea urchin population is kept at very low levels by sea otters in many areas of the outside coasts, including the Barrier Islands, Baker Island, Chichagof Island, Dall Island, Kuiu Island, Lulu Island, Maurelle Islands, Noyes Island, Sumez Island, southern Prince of Wales Island, and nearby areas (Hebert 2017). In non-sea otter areas, densities of red sea urchins are low in most fishery areas not currently in the rotation of assessment surveys (ADF&G unpublished data).

Prior to 1996 permits to fish for sea urchins were given under authority of 5 AAC 38.062. In 1984, the first year with significant landings of red sea urchins, there was a size limit of 3–5 inches test diameter to protect small urchins for recruitment, to provide large urchins as a protective spine canopy for small urchins, and to give processors the desired size urchin. An interim management plan was in place in 1987 for the Ketchikan area with a three-year area rotation and size limits modified slightly to 3–4.5 inches. A second interim plan was developed for 1991 through 1993 for the Sitka area (Marshall et al. 1991). The Sitka area plan included a 3.2% annual harvest rate on the estimated biomass, three-year area rotations, weekly fishing periods of noon, Saturday through noon, Thursday, and no size limits.

In 1996, the department and the sea urchin industry developed interim regulations and a management plan for the commercial urchin fishery in Southeast Alaska (ADF&G 1996a, ADF&G 1996b). The regulations were adopted by the commissioner under authority of 5 AAC 39.210 for High Impact Emerging Fisheries and became effective in December 1996. The Alaska Board of Fisheries formally adopted the red sea urchin management plan during their regular meeting in January 1997. One of the elements of the plan included annual guideline harvest levels of 6% of the biomass estimate, which was based on a modified surplus production model similar to that used for the sea cucumber fishery in Southeast Alaska (Woodby et al. 1993). Another element of the plan was a requirement for biomass surveys within the previous 3 years of a fishery. However, in practice the 3-year interval was a minimum and subdistricts from non-scheduled districts were often included in a year, particularly control or experimental areas, which required more intensive surveying. During the 2006 Board of Fish meeting, the board extended the interval between assessment surveys from three to six years, with the stipulation that no more than the equivalent of the combined 3-year annual guideline harvest levels could be harvested within those six years. This reduced the number of surveys required to maintain red sea urchin areas open to commercial harvest when those area's GHL were not entirely taken; the GHL not taken in any one year can be forwarded into subsequent year's GHL. This regulation allowed the more efficient and cost-effective surveying of areas whose GHL is not taken each year, without increasing the overall harvest between surveys. Fishery areas are opened annually, not on a rotation like the sea cucumber and geoduck fisheries. As of the 2018/19 season, there are 12 red sea urchin fishery areas, with a total GHL of 3,453,700 lb.

No new sea urchin areas were surveyed for several years until 2018. The market for red sea urchins has increased in the last few years and the dive industry requested four new survey areas near Ketchikan in 2018. Of these, ADF&G surveyed three in 2018.

SEA OTTERS

Sea otters are managed solely by the United States Fish and Wildlife Service (USFWS), not the State of Alaska, but they are treated here briefly because they have significantly impacted, and continue to affect, commercial dive fisheries in Southeast Alaska (e.g., Larson 2013, Hoyt 2015, Hebert 2017).

Sea otters were intensively hunted in Alaska during the fur trade of the 18th and 19th centuries and were ultimately exterminated from the Alexander Archipelago. They remained absent until 1965, when the ADF&G successfully reintroduced 412 animals on the outer coast (Pitcher 1989). The sea otter population remained low until approximately 1987, when it began a period of rapid growth (Pitcher and Imamura 1990). Population growth has continued unabated to date, and the most recent population estimate for Southeast Alaska was 25,712 animals (USFWS 2014). Given that the primary data used in that estimate were collected in 2010–2012, and the population reportedly doubled between 2008 and 2013, the actual current population is likely far higher. The extant geographic range of sea otters in Southeast is primarily on the outer coasts of Chichagof Island, Baranof Island, Kuiu Island, Prince of Wales Island (including the Barrier Islands to the west), and, somewhat anomalously, in the inside waters of Glacier Bay. However, the range of sea otters has been expanding rapidly into food-rich inside waters, including Icy Strait, lower Chatham Strait, lower Frederick Sound, Sumner Strait, upper Clarence Strait, and the west side of the Dixon Entrance.

Sea otters exert strong predation pressure on shellfish (Estes and Palmisano 1974), and a release from predation during the long period when sea otters were absent allowed substantial shellfish populations to develop in the nearshore ecosystem of Southeast Alaska. Lucrative dive fisheries developed in the early stage of rapid sea otter recolonization; these fisheries may not have developed in an ecosystem with a sea otter population at or near equilibrium. Sea otter recolonization could now be considered as in an intermediate stage (i.e. has not yet reached carrying capacity) and is posing a serious threat to commercial dive fisheries. Numerous commercial fishery areas for sea cucumbers, sea urchins, and geoducks within the sea otter range have already been closed due to low abundance, and no fishery areas that were closed due to sea otters have rebounded or re-opened to date (Hebert 2017). Overwhelming circumstantial and direct evidence has indicated that sea otter predation has been primarily responsible for these closures. Numerous geoduck fishery areas within the sea otter range are scheduled for assessment surveys in the next 2-3 years, and it is likely that at least some of these areas within the sea otter range will fall below the 30% biomass threshold in regulation that stipulates a commercial fishery must close. The current range expansion of sea otters into eastern Prince of Wales Island waters is a serious near-term threat to the large commercial fisheries for sea cucumbers in those fishery areas. Barring any major natural (e.g., disease, killer whale predation) or human (e.g., hunting) perturbances to the sea otter population, many more fishery area closures are expected on the current trajectory.

STUDY SITES

Stock assessment surveys for sea cucumbers will be conducted in numerous commercial areas (typically about 20 per season), and up to seven research control areas. Additional surveys may be conducted either in new potential fishery areas (locations TBD) if requested by SARDFA, or in areas of high sea otter presence that have been closed to the fishery to evaluate evidence of population rebound. Sea urchin stock assessment surveys may be conducted simultaneously with sea cucumbers in areas both species require surveys (e.g. 101-27 Control). Geoduck stock assessment surveys will be conducted in fishery areas at a minimum within the required 12-year maximum period identified in regulations, and when feasible, more frequently.

METHODS

ALL SPECIES

Logistics

Stock assessment surveys for all species will rely primarily upon data collection via SCUBA diving. The State of Alaska–owned research vessel *R/V Kestrel* will be the primary vessel used to support dive surveys. The *R/V Kestrel* is a 32 m (105 ft), steel-hulled live-aboard vessel equipped with an air and Nitrox dive compressor for filling SCUBA cylinders, and two 5.8 m (19 ft) aluminum skiffs (Workskiffs ™) on deck. The skiffs are customized to support SCUBA dive teams and are outfitted with modern electronics, including a high-accuracy Global Positioning System (GPS) with the Wide Area Augmentation System enabled. Dive skiffs are loaded and deployed from the *R/V Kestrel* using hydraulically-powered davits rigged with winches. Additional details about the *R/V Kestrel* and dive skiffs can be found in Appendix A. Three Boat Officers will operate the vessel (see Responsibilities section for personnel details).

Typically, about eight dedicated dive fisheries survey trips aboard the *R/V Kestrel* are scheduled for each season. Trips are usually about one week in length. There is a high likelihood the order in which fishery areas are surveyed will be rearranged due to weather/sea conditions, last-minute staffing availability, and other dynamic logistical issues. Staff availability permitting, six ADF&G divers will be assigned to each dive survey trip, which will allow 2 three-person dive teams to operate simultaneously and independently.

All diving will be conducted in accordance with the ADF&G *Dive Safety Manual* (Hebert 2012b). The project's not-to-exceed maximum operating depth for all surveys is 80 fsw. The tidal range in Southeast Alaska can exceed 20 ft, but in all but extremely rare cases, the maximum depth required to complete a survey to target depth is less than 80 fsw. Most diving will involve multiple dives per day (usually between 5–10 dives per person), multiple consecutive days of diving (usually 5–6 days per trip), "reverse" dive profiles (diving shallow to deep), and regularly diving to depths of 60–80 fsw. Because of the elevated risk factors for decompression illness (which includes both arterial gas embolism and decompression sickness, i.e. the "bends") associated with this type of diving, a 36% Nitrox mixture will be used as the breathing gas. Use of Nitrox instead of air will reduce nitrogen accumulation in body tissues, all else being equal, and thereby increase safety margins. Modern dive computers (e.g., ScubaPro's Galileo Luna and Galileo Sol models) will be used by each diver to log and monitor dives. All divers will use dry suits to minimize exposure. A manual diver recall device will be used by the dive tender in the skiff to signal divers to ascend immediately in the event of an emergency.

In-Common Stock Assessment Design Elements

The basic design of stock assessment surveys is very similar among target species (Table 1) so are treated together in this section; species-specific differences are treated in subsequent sections. The survey design and field methods for sea cucumbers and sea urchins are so similar that they are surveyed simultaneously when possible to improve overall cost effectiveness. All stock assessments require estimation of the survey area size, average density and average weight for a statistical population (a subset of the true biological population) within a given fishery area; these values are then multiplied together to produce a biomass estimate.

Density is estimated using either a shoreline-based design (for sea cucumbers and all but one sea urchin area) or an area-based design (for geoducks and one sea urchin area). An area-based design is used when the extent of seafloor within the target depth zone of a given fishery area, or the area of a geoduck bed, is known. Areal density can then be estimated within this known area (metric: individuals/ m^2). If the areal extent cannot be estimated with a reasonable degree of accuracy, a shoreline-based design is used, and the cumulative length of the shoreline is used as the denominator for estimating density (metric: individuals/ linear m of shoreline). Additional details about each design are provided in subsequent method sections.

For all species, SCUBA divers will conduct visual surveys (i.e. counts), which will be used to estimate the density of the target species. The primary spatial sampling unit for density estimation is a paired strip transect. Transects are paired because two divers independently count individuals in parallel transects. The primary assumption of a strip transect is that all individuals of the target species are detected and enumerated within its boundaries. Counts from each diver's transect will be combined for analysis because the two transects are subsamples and not statistically independent (Hurlbert 1984). The width of each diver's transect will be fixed and varies by species surveyed (1 m for sea urchins and geoducks, 2 m for sea cucumbers), although on occasion transect width may be decreased for reasons such as heavy algae cover or high current. The length of a transect will be fixed or variable, depending upon which of the three transect "types" (I, II, or III) is used for a given survey.

Type I Transects

Type I transects use the shoreline as a reference starting point (at 0 ft MLLW), are oriented perpendicularly offshore to the shoreline, are variable in length, and are used for all target species. Type I transects can be used for either shoreline- or area-based designs. This transect type is used for typical surveys in which the area to be surveyed is relatively large. This is the case for most surveys, therefore this is the most common transect type. The transect end point is either a species-specific target depth (i.e., 50 ft MLLW for sea cucumbers and sea urchins, and 60 ft MLLW for geoducks or a point where the transect intersects an imaginary transect line emanating from an adjacent or opposite shoreline (i.e. a "halfway" transect), whichever is reached first. The species-specific target depths were chosen to largely coincide with the depth range in which most commercial harvesting occurs. For most transects, the perpendicular orientation of Type I transects forces surveying across this depth range, which also corresponds to the primary axis of maximum variability in organism density.

Halfway transects may be subjective in practice because it is difficult to precisely determine where imaginary lines intersect, and therefore where a transect should end, except for within small bays. Problems may be compounded for sea cucumber and sea urchin surveys along complex shoreline because most of the original shoreline hardcopy and electronic files are missing, therefore the location and degree of smoothing (or generalization) of the survey shoreline is usually unknown. There is one special case for Type I transects for geoducks only in which a bed extends beyond a halfway point prior to target depth being reached, but there is no survey shoreline on the opposite shoreline; in this case, the transect extends to the far side of the geoduck bed.

The horizontal component of transect length for Type I transects varies depending on the slope of the seafloor, therefore the sample unit size for Type I transects varies greatly. At one extreme, a vertical wall results in a transect length exactly equal to the target depth, and generally only takes 1–2 minutes to survey; at the other practical extreme, a transect may be two kilometers long and take 4 50-minute dives to survey. The area swept by each of these theoretical transects is vastly different, and the density value for the transect with the greater amount of area swept is less influenced by random chance (all else being equal). It should also be noted that an important bias of the survey shoreline-based system is that offshore reefs within the target depth range are systematically excluded from the survey if there is no associated shoreline and the seafloor exceeds the species-specific target depth between the offshore reef and the nearest survey shoreline.

Type II Transects

Type II transects are only used for geoduck surveys where geoduck clam beds have been accurately mapped and do not exceed target depth. This is most often the case in large, shallow bays or shallow island complexes. Transects are oriented across the bed and transect starting points are placed on one side. The transect endpoint is determined by divers when they run out of geoducks or suitable habitat. Type II transects can only be used in an area-based design. Type I and II transects can be used in the same survey, based on whichever is more appropriate for a given bed.

Type III Transects

Type III transects are fixed in length and used where a reasonable estimate of seabed area can be made, and the overall area is relatively small. This situation is typically within coves and bays, but is also applied to offshore reefs that do not have any shoreline that can be used as a reference point for Type I transects. Type III transects are used for geoduck surveys primarily, but also for a sea urchin survey in an area comprised of only an offshore reef (i.e. Bee Rocks, 101-22). Type III transects were primarily designed to increase precision of the density estimate in areas that would otherwise have few Type I transects placed. Precision is improved by increasing the sample size (i.e. number of transects) while decreasing sample unit size (i.e. transect dimensions). Transect dimensions are fixed and predetermined prior to surveys, and usually are 20–30 m long by 2 m wide (including both divers' 1 m wide transect subsamples combined). This transect type is used in area-based designs only. The implementation of this method has evolved over time. In the past, a buoyed anchor was dropped on a transect location where divers descended and surveyed a predetermined measured distance. Beginning at the anchor, a 1-m^2 PVC frame was flipped along a compass heading (generally toward the mouth of a bay), and all individuals of the target species within each frame were counted and recorded. This implementation of a Type III transect method has not been used in many years. In recent years, divers have been dropped off as close to the transect starting point as possible using a GPS (no anchor buoy deployed) and transect length has been measured using a 10 m string with a weight on one end. The string would simply be strung out multiple times (i.e. a transect "interval") until the pre-determined transect length was reached. Type III transects are not employed in the same survey with any other transect type.

For Type I and Type II transects, transect placement within a fishery area is systematic (i.e. fixed between transect distances) with a random starting point. The random starting point preserves the probabilistic framework for population estimators because every meter of shoreline (or geoduck bed) has a known and equal probability of being selected. For Type III transects, transect placement is based on a grid system and is entirely systematic; no adjustment to estimators are used, however, so they are treated as random samples. We assume that there is no systematic spatial structure (i.e., length scale in kriging parlance), and therefore no bias, in populations of target species at the scale of transect spacing. Transect spacing varies from tens to hundreds of meters for geoduck surveys and from hundreds to thousands of meters for sea cucumber and sea urchin surveys, except for one Type III transect survey for the latter.

Transects for sea cucumber, sea urchin, and some geoduck surveys are "pseudo-permanent", in that the same transect starting points from previous surveys are targeted for subsequent surveys. For pseudo-permanent transects, no hardware is installed on the seafloor to ensure that the exact same transect is resurveyed. Therefore, transects cannot be considered truly permanent. Geoduck transects employing Type I or II transects are usually, but not always, reassigned with each resurvey, assuming that the geoduck bed boundaries identified in the previous survey have changed (e.g., due to new fishery logbook data, elimination of transects in which no geoducks were counted). Random variation in transect heading by divers is probably a leading reason for sometimes high variability in sea cucumber counts among years for transects with complex bathymetry, because slightly different headings can result in very different transect lengths. Halfway dives are also less repeatable, therefore probably more variable. Historically, the horizontal positional accuracy of relocating transect starting points was approximately 20 m (Larson et al. 1995), but the intervening development of high-accuracy GPS technology has improved accuracy to within a few meters. Therefore, variability in transect counts due to transect starting point relocation is probably minimal. This design, which isolates the effect of time by minimizing variability due to space, is optimized for time-series analysis. Clark et al. (2009) proposed a compromise approach between optimizing for time series analysis vs. stock assessment by retaining some pseudo-permanent transects and randomly placing other transects within an area, but this approach has not been implemented to date.

Weights

Weight data acquisition design for biomass estimation is different for each target species so is covered in subsequent species-specific methods.

The precision goals for the density, weight, and biomass estimates have varied over the years, but were standardized starting in 2019 with the other species for consistency (see Objectives section).

In-Common Field Survey Methods

Density

In the field, a team of three divers will navigate their skiff as closely as possible to a predetermined density transect starting point using the skiff's GPS/chartplotter. For most Type I transects (there are exceptions, especially in boat traffic lanes when it may be dangerous to ascend offshore), the starting point will be at 0 ft MLLW. The depth of the starting point will be variable for Type II and III transects because they are independent of the shoreline. The transect target depth range to be surveyed on any given transect will be calculated by adjusting the reference target depth to the tidal height immediately prior to the survey dive. For example, geoduck surveys have have a reference target depth of 60 ft MLLW, so a +5 ft tide results in an actual target depth of 65 fsw. The dive tender will then fill out as much header information on the divers' field datasheets as possible, including the tide-adjusted target depths. The predetermined compass bearing will also be recorded from a survey-specific field reference sheet. Compass bearings will be either the same as for the previous survey or will be new if the survey is new or redesigned. The tender and divers also will determine whether the transect is a halfway dive so the divers will know whether to expect to be alerted by the dive tender ringing a diver recall device, which signals the end of the transect (the dive tender will need to keep close track of the divers' location during halfway dives, by watching their bubbles). Two divers equipped with survey gear and datasheets (Appendix B) will then enter the water.

To survey a transect, two divers will swim parallel to each other along the seafloor on their predetermined compass bearing while each holding a transect "rod". A transect rod consists of a white PVC tube that is 2.1 cm in diameter and either 1- or 2-m long, depending upon which species is being surveyed and underwater conditions (Figure 1). The transect rod is attached to a board that is outfitted with a compass, simple dive computer, and pencil, and a datasheet is clipped to the board. While surveying, the transect rod will be held level with the seafloor in a horizontal position, and perpendicular to the transect bearing. The transect bearing will be followed as well as possible by frequently referencing the compass. The distance between transect pairs varies, but usually ranges from 1–5 m. This distance varies depending on underwater visibility, topography, how closely divers monitor their partner's position, compass "stickiness", and random horizontal wobble in swimming course. Search images for target species will be guided by a defined or undefined size threshold. Searches for target species will be noninvasive, which we define as not moving the substrate (e.g., turning over rocks); moving algae is allowed and indeed required in some circumstances to see the seafloor. Survey speed is not standardized, so each two-diver team will use their discretion to survey as slowly as necessary to obtain reasonably accurate counts. Perfect accuracy is often not feasible because surveying transects in difficult conditions would be too slow to complete all transects in a survey area in the allotted time (generally, one day). Difficult conditions include, in isolation or combination, poor underwater visibility, complex substrate (e.g., bedrock or boulders with many interstitial spaces), heavy algae cover, strong wave surge, strong water currents, and low light levels.

At the end of each transect (or distance/depth interval), divers will record counts for target species, end depth, presence of other species of interest, and any other interesting or potentially relevant observations. Although for many years the total percent cover of vegetation (planar view) in each transect/interval has been estimated and recorded, along with the primary (most prevalent) and secondary vegetation types, collection of these data has been discontinued for sea cucumber and sea urchin transects beginning in 2019. This is because 1) resulting data was highly subjective since interpretation of percent coverage and predominant algal type was highly variable, and 2) the data was not used to assess stocks, nor did it have a foreseeable use. However, for geoducks, substrate and vegetation will continue to be recorded for the two most common types on each interval, with the most prevalent type listed first. See datasheets in Appendix B for full list of data fields that the diver and tender must complete. Definitions of the vegetation and substrate type codes recorded during the assessment surveys are included in Appendix C.

Transect start and end points will be recorded using each skiff's GPS, and waypoint identification numbers will be recorded with the transect number on the dive profile field datasheet (Appendix B). Waypoint data will be downloaded from each field GPS at the end of each dive trip, archived, compiled into a database at the end of the dive season, then subsequently linked to transect survey data. The archived digital data will serve as a permanent record of actual transect locations. The data have several other potentially important uses, such as allowing for calculation of a standardized density metric (individuals/ m^2) for sea cucumber and sea urchin density data, which will in turn allow for transition (and retroactive reanalysis) to an area-based stock assessment for sea cucumbers and sea urchins.

The location of each skiff is recorded in the GPS every 5 seconds (i.e., the track log). Track logs from the GPS will be archived and used for reference when transect start or end waypoints were accidentally not recorded, or if the need arises to determine where exactly a skiff was at a given time (e.g., if an incorrect transect identification number is recorded on the transect datasheet).

Weight

Weight data for sea cucumbers and sea urchins involves collection of individuals in the field in concert with density surveys. Weights are measured directly for sea cucumbers and indirectly for sea urchins via estimation using test diameters. Geoduck weight data are obtained from port sampling of commercial fisheries.

Contingency Plans

Situations inevitably arise in the field (e.g., inclement weather or seas, poor underwater visibility, staffing issues) that dictate deviation from the ideal survey design and/or plan. To reduce the need for ad hoc decisions in the field about how to deal with these deviations, some of the more common issues are identified below in species-specific sections and contingency plans are outlined. Given the wide range of possible difficulties encountered in the field, this will not be an all-inclusive treatment. When scenarios not treated in this document arise in the field, the chief scientist/project leader will confer with available dive team staff, boat officers, biometric staff, and senior divers to discuss the situation and how to best resolve it. The chief scientist will weigh all options and input, and safety issues notwithstanding, ultimately has the responsibility for making the decision about how to proceed.

SEA CUCUMBERS

Survey Design

To summarize sea cucumber-specific survey design elements from the previous section (In-Common Stock Assessment Design Elements; Table 1), surveys are triennial for each of three rotation area groupings, shoreline-based, use pseudo-permanent Type I transects with a maximum depth of 15.2 m (50 ft) MLLW, and transects are systematically spaced with a random starting point. The spatial replicate is a variable length, paired transect 4m wide (2 m per transect per diver x 2 divers). Beginning in 2018 transects were extended to 18.3 m (60 ft) on a temporary experimental basis to better understand the depth distribution of sea cucumber biomass, and possibly to incorporate this biomass into future GHLs. Data will be recorded separately from and in addition to the 0–50 ft transect interval, and GHLs will only be developed for the 0–50 ft transect interval, unless after evaluating data a determination is made that GHLs should include data from extended depth maximum.

Sea cucumber fishery areas are required by regulation to be surveyed within three years of a fishery opening, so surveys are usually performed for areas in a given rotation during the spring or summer immediately preceding the first fishery opening of the season in October. On a few occasions in the past, fishery areas have been surveyed in the second year after it was last fished. However, this practice was discontinued because it generally resulted in lower biomass estimates, which was interpreted to suggest that the biomass was still recovering from the fishery. The sample size of fishery areas that were surveyed a year early was small, however, so the cause of lower biomass estimates is not clear.

Among commercial survey areas, the amount of shoreline ranges widely (38,480–254,311 m), as do the number of transects per fishery area (15-40) and associated average transect spacing. The number of transects per area was based on several factors originally (e.g., logistics), but the most important factor was meeting the statistical objective of the lower bound of the one-sided 90% confidence interval being within 30% of the mean density estimate (Larson et al. 2001b). Generally, the precision of the density estimate is assumed to vary inversely with the length of shoreline (i.e. via spatial autocorrelation in habitat and/or population areal density) and habitat heterogeneity.

The precision of the density estimate naturally fluctuates somewhat among survey years within an area (personal observation). However, when the precision has been consistently below the target objective, and the area is not occupied by sea otters (which indirectly drive precision values down via spatial patterns in predation), transects have been added to the original set of transects to improve the precision. Additional transects were always placed systematically (e.g., halfway between existing transects, or halfway between an existing transect and the fishery area boundary). Although several areas were below the target precision during the previous survey, no new transects will be added in any fishery areas. This decision was made for several reasons, including adding transects did not significantly improve precision in a preliminary analysis in 2016 (ADF&G, unpublished data), adding transects is problematic for many areas because the location of the original survey shoreline is unknown, and staffing time was limited. In the past, transects have also been added when additional shoreline was added to a fishery area, or when multiple fishery areas were combined into one area. If fishery area boundaries require modification, commensurate adjustment of transect number may also be necessary.

Some fishery areas have had new transects added to the original set in the past, but the new transects have not been surveyed since, or they have been surveyed only periodically since inception. Examples include fishery areas 101-10,11 in the 2018 area rotation and 106-10,20,22,25 in the 2019 rotation. The reason for the transect additions is unknown due to lack of documentation, but presumably transects were added to improve the precision of the density and biomass estimates. The reason the added transects were not surveyed again, or were surveyed infrequently is also unknown, but a plausible speculation is that either there was no precision gain, or the cost to benefit ratio for increased precision was too high to justify additional survey time. In the case of transects having been added but not surveyed again after the initial addition (e.g., fishery area 106-10,20,22,25), these added transects will not be surveyed again. In the case of fishery areas in which transects were added and periodically resurveyed (e.g., fishery area 101-10,11), the additional transects will be surveyed at a frequency no higher than has been the case in the past, and if time permits. An example of the latter would be when sea urchins are surveyed concurrently in the same fishery area, and an additional survey day is inevitable anyway.

Field Survey Methods

Density

Not all transects in a survey area will necessarily be surveyed. If the sea cucumber density on any given transect has been zero for the previous three surveys, that transect should not be sampled but will be included in the overall average density calculation for that area and assumed to be zero. In this case, the length of shoreline used in the analysis will be treated as if the transect had been completed and remain unchanged. Alternatively, if several adjacent transects have resulted in densities of zero for the three previous surveys, those transects may be considered unsuitable sea cucumber habitat and removed entirely from analysis, along with the corresponding shoreline length that they represent.

Density estimates are typically made by counting all sea cucumbers ≥ 10 cm total length within 2 meter-wide strip transects. On rare occasions, transect width may be reduced to 1 m for each diver if it is determined that the critical assumption of strip transects (~100% detectability of target organism) is grossly violated, or if a transect is expected to be extraordinarily long (e.g., > 45 min) and conditions are challenging. Conditions that may cause a gross assumption violation include very poor underwater visibility/light, heavy kelp cover, and strong currents (or most likely, a combination thereof). Undoubtedly, at least some sea cucumbers are not detected and enumerated during normal transects that are 2 m wide because of either heavy kelp cover, poor underwater visibility, or abundant crevices in rocky habitats. It would be cost-prohibitive to require 100% detection because many transects would take too much time to be logistically feasible without dramatically reducing sample size (i.e. the total number of transects in an area). Therefore, divers are given leeway to determine for themselves how much time is reasonable to conduct a transect survey, and among-diver variability in this determination is probably high. As such, diver counts are most likely underestimated and resultant density estimates should technically be considered an index (or, relative density estimate) rather than an absolute density estimate.

The sea cucumber size threshold of 10 cm total length for including in density counts was established as method in 2016. Prior to 2016, a general rule was followed to not count sea cucumbers smaller than “finger size”. A massive sea cucumber recruitment event in 2015 or early 2016 precipitated the institution of this threshold; such high densities of very small sea cucumbers had not been observed previously during ADF&G dive surveys, to the best of anyone’s knowledge or recollection (Hebert, personal communication). A size threshold was instituted in order to improve consistency and repeatability of density counts, and because it was impractical to include very small sea cucumbers in the density survey; it would have taken far too long to survey a transect in which small sea cucumbers were abundant because searches would have needed to be much more intensive. The size threshold of 10 cm was chosen in order to include the majority of the sea cucumber population in the biomass estimate, while recognizing that this estimate includes more of the biological population than is harvested commercially. The total length of a sea cucumber can vary considerably on the order of seconds due to longitudinal muscle contraction/relaxation, so it is not a precise measure of animal size. However, there is no other way to easily exclude small size classes during visual surveys, so we accept it as an imperfect compromise.

Historically, fine-scale density and habitat data were recorded for each transect during the first year of a stock assessment survey in a new area. Due to time constraints, such fine-scale data were not recorded for the 102-60 Control and 112-18,71,72,73 Control areas during 2018, the first year that these areas were surveyed. Therefore, fine-scale data should be collected for these areas when feasible.

Weight

Sea cucumbers will be collected from multiple sites within each survey area and weighed to estimate average individual weight. This is done for two reasons: 1) to estimate the overall biomass [by multiplying the average weight by the number of sea cucumbers], and 2) for comparisons among years and areas (e.g., to assess potential fishery impacts, population trends, recruitment events, area-specific issues). The number of sample sites targeted for collection in a survey area varies by area type: commercial fishery areas vs. closed research control areas. For each commercial fishery area, half of the transects will be randomly selected for collections using the "RANDBETWEEN" function in Microsoft Excel. [1]Transects will be re-selected for each future survey. This target sample size falls within the sample size of 10–15 collection sites recommended by Clark et al. (2009). In control areas, samples will be collected in 4–6 designated collection sites that are associated with transect locations. These designated collection sites are sampled during every survey (currently, annually). Control areas are sampled differently to avoid potentially impacting transect counts from annual collections.

In open commercial areas, the target sample size per transect is 15 sea cucumbers. If less than 15 sea cucumbers are obtainable along a transect in an open area, divers will search for sea cucumbers in the adjacent vicinity (and ≤ 50' MLLW) after completion of the density transect. If less than 10 sea cucumbers are collected even after a search of the adjacent area, the data will not be used for analysis (per recommendation by Clark et al. 2009) unless less than 10 transects in the fishery area have ≥ 10 samples each. Therefore, all sea cucumbers should be retained and subsequently weighed. However, 15 sea cucumbers will be targeted for collection on the next transect surveyed to compensate for the inadequate sample. In control areas, the target sample size is 30 individuals. The sample size was greater in control areas because samples were intended to better track changes in weight over time, as opposed to simply being pooled to provide an adequate sample size to estimate overall mean weight as is done for commercial areas. All sea cucumbers will be collected regardless of size, even if they are < 10 cm total length (the threshold for not including in transect density surveys). Collections will be as unbiased as possible. For example, sea cucumbers will not be consistently collected from the same depth zone (if less than the depth zone encompassed by the entire transect), and divers will attempt to collect sea cucumbers using the same technique and search image that they use for transect surveys (e.g., moving kelp to see underneath, not targeting large, obvious individuals in the open).

Individual sea cucumbers will be eviscerated and drained in the dive skiff as soon as possible after collection, and then brought back to the R/V Kestrel. As soon as possible, samples will be weighed on a non-motion stabilized scale to the nearest gram. If the sea state causes the weight value on the scale to fluctuate more than by approximately +/- 5 g, then weighing will be

[1] Product names appearing in this operations plan are included for completeness and do not reflect an endorsement by the Alaska Department of Fish and Game.

postponed until the sea state is more conducive. Sea cucumbers < 10 cm total length will be flagged on the weight measurement datasheet (see Appendix B) and those records will be excluded in calculations of average weight for a transect/collection site. Sea cucumber length can vary greatly due to the state of contraction of longitudinal muscles, but the measurement will be made in whatever state the animal is in at the time of measurement.

Contingency Plans

The most common need for a contingency plan is when a transect(s) is not able to be surveyed, in whole or in part, for some reason. Those reasons can be divided into two general categories: foreseeable and unforeseeable. Foreseeable reasons may include lack of time (at least in the afternoon of a survey day) or obvious environmental conditions (e.g., current-, wind-, or wave-exposed transects). Foreseeable reasons allow for choosing which transects to survey and which to omit. Criteria to consider in deciding which transects to omit include logistical ease of surveying on a subsequent day or trip, and the historical mean density of the transect. Priority should be given to completing transects that cannot be surveyed during a later survey. If a future survey is impossible or unlikely, then prior to omitting transects consideration should be given to the likely impacts on biomass estimate and confidence interval, including the distribution/representativeness of transects, density history, likely sea otter impacts, weather, cost-benefit ratio, etc.

Unforeseeable conditions may include environmental conditions (e.g., very poor visibility, unexpected or sudden large waves, strong currents or winds), mechanical breakdowns, diver illness, etc. Environmental conditions may not be obvious until a dive is attempted, in which case a transect must be aborted. (A halfway dive is not considered aborted.) For the purpose of data analysis, an aborted transect is considered the same as an un-attempted transect, in general. This is the case because the density metric used for sea cucumber population estimation is not standardized per unit area (e.g., like it is for geoducks), so it is crucial that the entire transect is surveyed. The project leader will decide on a case by case basis whether to include the data as-is and not repeat the transect at a later time or date. The primary criteria that will be used to make this decision include the reason the dive was aborted, the maximum depth surveyed (relative to target depth), the approximate distance between the aborted transect endpoint and the actual endpoint (if known), the counts for target species immediately prior to the aborted endpoint, the suitability of the habitat type where the transect was aborted (e.g., quivering mud substrate is not suitable for sea cucumbers), diver confidence in their existing count, and the diver's opinion about whether they think their count is a good representation of the count they think they would have obtained if they were able to finish the transect. Divers will record adequate notes to this effect on their datasheets, as well as any other relevant information, to facilitate this decision. If not enough information is recorded by the divers for the project leader to make an informed decision, a conservative approach will be taken and the data will not be used. If the primary stated or implied reason a transect was aborted is because it was deemed too long (in distance or duration), the data will not be used in analysis.

Statistical Analysis and GHL Calculation

Density

Mean sea cucumber density will be weighted for each fishery area by the amount of survey shoreline each transect represents. Weighting is necessary because transects have been added to some fishery areas for various reasons (e.g., fishery areas being combined, to increase precision of the density estimate). For fishery areas in which all the original transects are intact, and no transects have been added or removed, each transect has a weight = 1. This is the most common scenario, but it is treated as a special case here of a more generalized analysis that can also treat areas where transects have been added.

For cases in which multiple smaller fishery areas were combined to create a larger fishery area (e.g. 2018 101-10,11) and transect spacing was different among areas, the amount of shoreline represented per transect is calculated for each of the component areas. For each component area, the amount of original shoreline is divided by the original number of transects to obtain the amount of shoreline represented per transect. This figure is then divided by the sum of the component shorelines to obtain a weighting factor. The weightings are then applied to each respective area.

For cases in which transects were added systematically to an existing fishery area in an attempt to improve precision (e.g. 2018 101-90,95), the total amount of shoreline in the fishery area is divided by the number of original transects to obtain the amount of shoreline represented per original transect. Transect weightings are then assigned using the following criteria:

1. A weighting of 1.0 for the original transect if no added transects were added next to it (i.e. no adjustment is made)
2. A weighting of 0.75 for the original transect if it had one (and only one) added transect placed next to it
3. A weighting of 0.50:
   a. for the original transect if it had an added transect placed on both sides
   b. for an added transect if it was placed between two original transects
4. A weighting of 0.25 for an added transect if it was placed between an original transect and the fishery area boundary

The average number of sea cucumbers per linear meter of shoreline, *d*, and henceforth called "density" is calculated as:

$$\boldsymbol{d} = \sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{n}} \frac{\boldsymbol{C_i}}{\boldsymbol{kmn}} \quad (1)$$

where:

i = transect index,

C_i = the total number of sea cucumbers counted in transect i,

n = the number of transects,

k = the number of divers on a transect, and

m = width of the transect per diver.

The variance of the mean, σ_d^2, is estimated as:

$$\sigma_d^2 = \frac{\sum_{i=1}^{n}(d - C_i)^2}{(n-1)n} \quad (2)$$

Confidence limits about d were calculated using a t-value with n-1 degrees of freedom.

Weight

Average weight for transect i, (W_i) and associated variance of the mean weight (σ_W^2,) for m_i sea cucumbers sampled on transect i was estimated as,

$$W_i = \sum_{j=1}^{m_i} \frac{w_{ij}}{m_i}, \tag{3}$$

$$\sigma_W^2 = \frac{\sum_{i=1}^{m} \left(W - w_{ij}\right)^2}{(m-1)m}. \tag{4}$$

The estimated mean weight for the entire fishery area (W_A) and associated variance of this mean weight are calculated as follows:

$$W_A = \sum_{i=1}^{k} \frac{W_i}{k}, \tag{5}$$

$$\sigma_{W_A}^2 = \frac{\sum_{i=1}^{k} \left(W_i - W_A\right)^2}{(k-1)k}, \tag{6}$$

where k equals the number of transects from which a cucumber sample was taken for weight measurements. The average weight and precision of this estimate were used to expand the estimated number of sea cucumbers in an area to the biomass of the population.

Biomass

Biomass estimates and associated precision were estimated as a product of two random variables (Goodman 1960). The total number of sea cucumbers in a fishery area (N_c) is the product of the average number of sea cucumbers per meter of shoreline and the total estimated length of shoreline (L):

$$N_C = Ld, \tag{7}$$

and,

$$\sigma_{N_C}^2 = \sigma_d^2 L^2. \tag{8}$$

For purposes of analysis, the shoreline length estimate is assumed to be measured without error, but this is not technically accurate. Most surveys were designed in the early 1990s, prior to widespread use of Geographic Information Systems. Shoreline length was measured manually by rolling a hand-held map wheel along a shoreline on the largest scale nautical charts available (usually 1:40,000). Presumably, the path of the map wheel was drawn in behind as the wheel was rolling. Most hardcopy records are currently missing, so it is unknown which map scale was used for any given survey. Further, the degree to which the actual shoreline was smoothed, generalized, or linearized to derive the survey shoreline is unknown. ArcView (ESRI 1988) was used in subsequent years to develop surveys and create survey shorelines, but all shoreline files prior to 2017 are missing. In any case, it is certain that the shoreline length was not perfectly repeatable for any fishery area.

The biomass (B_c) is estimated as,

$$B_C = N_C W_A \quad (9)$$

Biomass variance is estimated as,

$$\sigma_{B_C}^2 = (\sigma_d^2 W_A^2 + \sigma_{W_A}^2 d^2 - \sigma_d^2 \sigma_{W_A}^2) L^2 \quad (10)$$

As an additional safeguard for conservatism, the lower bound of the one-sided 90% confidence interval will be used as the basis for calculating the GHL.

$$\left(t_\alpha \frac{\sigma}{\bar{b}_j \sqrt{n_j}} \right)$$

The literal interpretation of this safeguard is that we want to be 90% sure that the mean value of population size is greater than the value we use to calculate a quota. The certainty in the estimate of biomass is expressed as the percent precision. The index is equal to the lower bound of the one-sided 90% confidence interval expressed as a percent of the average biomass. The percent precision is calculated from the biomass density (lb/m) and applied as a proportion to the mean estimate of average biomass (Eq. 9), since the average biomass can also be calculated from a product of the average density, average weight and total shoreline. The precision is calculated using the biomass density before it is expanded by the shoreline value:

$$\text{Percent precision} = 100 \left(1 - t_\alpha \frac{\sigma}{\bar{d}_{lb} \sqrt{n_j}} \right), \quad (5)$$

where:

t = the t-value from Student's distribution for a one-sided interval with significance level α = 10% and n-1 degrees of freedom, and

σ = the standard deviation of the biomass density (lb/m) among n transects.

Guideline Harvest Level

As described in the Southeast Alaska Sea Cucumber Commercial Fisheries Management Plan (5 AAC 38.140 (h)), quotas were calculated as,

GHL = 3 x CF x GF x M x P

where:

CF = 0.4 scaling factor relating maximum sustainable fishing mortality to unexploited population size;

GF = 0.6 correction factor to allow for errors in assumptions upon which the surplus production model is based;

M = 0.32 estimated instantaneous mortality rate for sea cucumbers;

P = most recent biomass estimate, taken as the lower bound of the one-sided 90 percent confidence interval. This can also be defined a product of B_c and the Precision.

These variables are multiplied by three to account for the three-year rotational openings, and then rounded to the nearest 100 lb. In March 2018, the GF variable was changed in regulation by the Board of Fisheries from 0.5 to 0.6, which increased the 3-year harvest rate from 19.2% to 23.0%.

GEODUCKS

Survey Design

To summarize geoduck-specific survey design elements (Table 1), each area is surveyed at least once every 12 years and density is assessed using an area-based design and Type I, II, or III transects, depending on the configuration of geoduck beds in the area being surveyed. Surveys are typically conducted during May or June because it is assumed that geoducks are more likely during these months to be feeding, and therefore more easily identified and enumerated (Goodwin 1973). Transects are systematically spaced along a shoreline or geoduck bed (Type I or II, respectively) with a random starting point, or in a systematically spaced grid pattern (Type III). The spatial replicate is either a variable length, paired transect 2m wide (1 m per transect per diver x 2 divers) for Type I or II transects, or a fixed-length paired transect 20–30 m long for Type III transects. Each transect has one or more subsamples (termed "intervals"), depending on transect length and geoduck density, but the typical interval length is 10 m. Transects are surveyed to a maximum depth of 60 ft MLLW. This depth zone includes the majority of the depth zone in which commercial divers normally operate, although commercial geoduck beds and harvesting do occur deeper. Geoduck densities calculated from density surveys are adjusted via a show factor adjustment to account for unseen geoducks below the surface of the substrate at the time of the survey. Show factor is often, but not always, based on a show factor study associated with a survey. If there is no associated show factor study, then a default show factor of 80% is used instead.

Field Survey Methods

Density

For all transect types, two divers will be dropped off by the skiff operator as close to the pre-determined transect starting point as possible, and the skiff operator will mark a waypoint in the GPS at that location. Divers will swim roughly parallel to each other, with both divers holding a 1-meter transect rod (Figure 1) in a horizontal position perpendicular to the transect bearing. One diver (the "measurer") will have a 10 m line, a weight, and a compass mounted on the transect rod to follow the predetermined compass bearing. The second diver (i.e. the "recorder") has a writing slate with a datasheet (Appendix B4) attached to the rod. For Type III transects, the measurer will drop the weight onto the seafloor, unspool the measuring line, then both divers will proceed on transect for 10 m counting geoducks "shows" occurring directly below their 1 m transect rods. A geoduck "show" is either a siphon visible above the substrate or a depression in the substrate that can be identified as having been made by a geoduck siphon (Goodwin 1973). At the end of the 10 m interval, which is determined by the line becoming taut, the recorder will record both his/her and the measurer's count on the datasheet along with ancillary information (see datasheet in Appendix B). The measurer will communicate with the recorder using hand signals and then retrieve the weight by pulling the line to the end of the interval, which is also the start of the next interval. The divers will repeat the interval procedure for 1–2 more intervals, depending on the fixed transect length for the particular survey.

When divers are dropped off for Type I or II transects, they will first swim along the pre-determined transect bearing while counting geoducks and measuring distance "virtually" using arm spans roughly calibrated to distance. When ≥ 3 geoducks in close proximity (~1 m) are observed by either diver, it is treated as the beginning of the geoduck bed and the divers will stop, record data including count and distance traveled (to the nearest meter), then deploy a portable surface float (i.e. "Pelican" float) to mark the inshore boundary of the geoduck bed. The skiff operator will obtain a GPS waypoint at the Pelican float once the divers are clear and retrieve the float. The divers will then collect data in consecutive, adjacent 10 m intervals until either the target depth is reached, they are called up by the skiff operator for a halfway transect, they reach the limit of their air supply, or habitat becomes unsuitable (e.g., cobble, boulder, bedrock), whichever comes first. If the habitat becomes unsuitable. The measurer will estimate the distance covered (if not the full 10 m interval) and communicate that number and his/her count to the recorder. If the interval is stopped because of unsuitable habitat, the measurer will reel up the weight and line and then continue along transect while virtually estimating distance. If suitable geoduck substrate is encountered before target depth has not been reached, the divers will stop, record the distance traveled and geoduck count, then begin 10 m intervals again using the line and weight. In shallow, flat or gently sloping areas of seafloor, the divers may terminate the transect at their discretion after at least 100 m of unsuitable habitat. When the divers ascend after either the transect is complete or their air supply is too low to continue, the skiff operator will mark a waypoint in the GPS. The transect will continue for as many dives as are necessary.

Identification and enumeration of geoducks in the field can be challenging because 100% positive identification is often not possible when shows are poor. Unambiguous, positive identification (i.e. a good show) is defined here as a clear view of an open inhalant and exhalant siphon, regardless of whether it is below, at, or above the surface of the substrate (Figure 2). For ambiguous or uncertain identifications (i.e. poor shows; Figure 3), divers will use secondary clues to aid identification such as siphon/hole size and shape, siphon tip hardness, and presence of other clams in the immediate vicinity that can be positively identified. When geoducks are not showing well, divers may employ additional methods to aid detection, such as pounding the seafloor with a fist or a rock to induce geoducks to retract into their siphon holes. Divers will count an ambiguous identification as a geoduck only if they are reasonably certain (100% positive identification is not required); it will be up to each diver to make the determination of what is "reasonable" for themselves. It is assumed that misidentifications do occur, and other species are counted as geoducks, but it is assumed this incidence is low. Show plot studies (see section below for details) associated with some surveys correct for misidentification to some extent. Identification and enumeration of geoducks is undoubtedly biased toward large, obvious individuals, but this bias has not been successfully quantified in Alaska to date. An attempt was made to quantify the bias indirectly in 2012 using a suction dredge to excavate a plot in which geoducks were counted first. However, the experiment failed because the dredge was either ineffective or ineffectively operated, and the sides of the plot continually caved in.

Extensive prior experience surveying geoducks is highly useful for aiding geoduck identification. For this reason, generally only experienced geoduck survey divers participate in geoduck surveys. Less experienced divers occasionally do participate, but their counts are not used for data analysis until one or more core project personnel have determined that their identification skills are good enough to warrant inclusion of their data. The initial learning process usually takes at least 2 days of surveying, but the duration of the learning curve depends on how many geoducks are seen, the diversity of habitats and substrate types encountered, and the range of geoduck show quality observed. Prior to surveys, all divers are encouraged to review pertinent literature (e.g., Bradbury et al. 2000), identification field guides (e.g., Harbo 1977), identification cheat sheets, and slideshows featuring photographs of geoducks and commonly mistaken species in various stages of showing.

Show Factor

It is difficult to detect or verify the presence of geoduck clams when they are hidden below the substrate, so their true density may be underestimated by the one-time visual counts used during surveys. The method to account for this underestimation was initially developed by Goodwin (1977), who coined the term "show factor." Show factor is defined as the ratio of geoduck shows visible during a single observation of any defined area to the true abundance of harvestable geoducks in that area (Bradbury et al. 2000).

Show factor studies were originally developed (Goodwin 1977) and refined (Bradbury et al. 2000) in Washington. Using methods based on those of the Washington Department of Fish and Wildlife (WDFW; Bradbury et al. 2000), show factor studies were initiated in Southeast Alaska in 1998 (Pritchett et al. 1999). The same methods were used during the 2000 field season and results from 1998 to 2000 were reported by Pritchett and Hebert (2001). Show factor studies were not resumed until 2012, and the overall average show factor of 80% developed from the original surveys (Pritchett and Hebert 2001) was applied to all geoduck surveys between 2000 and 2011. (This value is similar to the default value of 75% used by WDFW; Bradbury et al. 2000). In 2012, a dedicated show factor study was conducted using modified methods (ADF&G unpublished data). Modifications included reallocation of spatial sampling effort within a fishery area (i.e. increasing spatial replicates, reducing subsamples, reducing sample unit size), collection of show plot data simultaneous with stock assessment survey transects, and random sampling within and among sites. Beginning in 2013, ADF&G placed a renewed emphasis on show factor studies in concert with density surveys, and most surveys between 2013 and 2018 have had an associated show factor study. Show factor studies in 2013–2014 retained the methodology used in 2012, but methods were modified in 2015 when it was determined that the 2012 methods were logistically infeasible and had to be reduced in scope to become more time-efficient. Methods continued to evolve in 2017 and 2018 (no geoduck surveys were performed in 2016), and the methods described below are the most recent iteration.

The goal to conduct show factor studies in conjunction with all geoduck surveys is not always feasible due to either lack of time, staffing, or funding resources. To increase efficiency, show factor studies will be conducted so that they can be applied to multiple fishery areas. The proximity of surveys in space and time will be a primary consideration. If for some reason a show factor survey cannot be done in conjunction with a survey of a fishery area(s), then the default value of 80% (Pritchett and Hebert 2001) will be used instead.

Show factor studies will employ 1 x 10 m show plots (Figure 4), which are the fundamental spatial replicate. Each show factor study will have a target sample size of six show plots. For comparison, WDFW uses one 6 x 150 ft (1.83 x 45.72 m) show plot per survey. While the cumulative sample unit size of the show plots used by ADF&G (60.0 m^2) is 18% less than WDFW's (83.6 m^2), the ADF&G method has the distinct benefit of having a larger sample size (i.e. n = 6 vs. 1), thereby enabling an estimate of the show factor mean and variability.

Show plots may be conducted in different fishery areas in the same vicinity if those same areas are being surveyed during the same dive trip or within a two-week period prior to or after the dive trip.

Each of the six divers on the survey will do an initial count in a show plot to fully represent all personnel counting geoducks on survey transects. One show plot will be installed per transect. Show plots will be either directly on, or in the immediate vicinity of, transects surveyed in the stock assessment, and in less than 60 ft MLLW water depth (for consistency with density surveys). Show plot transect priorities will be assigned based on simple random selection from all possible transects in the survey(s). Transects will be surveyed for density in show plot priority order, with the goal being to get the show plots installed as soon as possible in the dive trip so they can be studied for as long as possible.

The planned duration of show plot studies is limited by the amount of time available in the nearby vicinity. Assuming potential show plots with sufficient numbers of geoducks can be found, ideally show plots would be installed for approximately five full days over six calendar days, which is the recommended range used by the Washington Department of Fish and Wildlife (Bradbury et al. 2000). For show plots in place less than five days, it is likely that not all geoducks in a show plot will be detected. This will probably result in an overestimation of the show factor. The practical effect of overestimating the show factor is that the biomass estimate will be lower than it otherwise would be if all geoducks in a plot were detected. This adds an additional conservative element into the biomass estimate adjustment, and corresponding GHL. In 2018, ADF&G will be investigating modifications to the show factor calculation (e.g., estimating the true abundance via non-linear modelling) for application to future surveys.

To reduce the chance of spurious show factor results due to small numbers of geoducks in a show plot, a geoduck density of $1/\ m^2$ (= count of 10 per show plot) will be considered the minimum acceptable for establishment. We recognize that including an element of non-random siting within a transect may result in a bias toward geoducks occurring in higher densities, but we accept that risk to reduce the chance of spurious results and submit that the random selection of transects for show plot is far more important. If geoduck density is $< 1/\ m^2$ in all 10 m intervals on the density transect surveyed by each diver, then that transect will be eliminated from contention for a show plot and divers will move on to the next show plot priority transect. If geoduck density is $\geq 1/\ m^2$ on at least one transect interval for either diver, then a show plot will be attempted on that transect after the divers complete their density transect. Divers will consult their transect datasheets and target the depth range where the highest density of geoducks was observed and the show plot will be attempted in that location.

Divers will be dropped off in the target location and will search for the nearest area of seafloor that appears to have a geoduck density $\geq 1/\ m^2$. When they find such an area, they will then either ascend directly to the surface or deploy a portable surface float, and the skiff operator will obtain a GPS waypoint for the exact location. Show plot equipment, supplies, and a datasheet (Appendix B5) will then be sent to the seafloor along with an anchor, line, and surface buoy. A full list of equipment and supplies, and a detailed field protocol, can be found in Appendix D: Show plots should be oriented along the axis of the predominant current direction (usually parallel to shore) in areas with strong currents in order to minimize the chance that drift kelp will catch on the show plot boundary lines and pull out the hardware. The diver conducting the initial count (i.e. the “counter”) will then simulate an actual transect interval and count geoduck shows using the same technique and speed that s/he would survey a typical transect interval. The counter will also be carrying one end of the show plot with them, and at the end of the 10 m interval (determined when the show plot they are carrying becomes taut) will stop and record their count. If the count is less than 10 geoducks, the counter will discard the data and swim back to the show plot origin, then try again in a different direction and/or distance from the anchor. If the count is ≥ 10 geoducks, the counter will record the count and hold the end of the show plot in place until the other diver catches up with them and secures the end to the seafloor with rebar. The divers will then secure the entire show plot with rebar stakes, as shown in Figure 4 and place flags attached to thin metal stakes in a consistent relative location (e.g., offshore 90 degrees) to each geoduck show. Flags should be planted deeply to minimize the chance of drift algae getting caught and pulling out the stake. Other species that can be confused for geoducks (e.g., *Tresus* spp., *Panomya* spp.) will be flagged with a bare stake. Multiple flagging passes should be made to try and make sure all shows are flagged. On the final pass, divers will pound a rebar stake with a mallet as they move along the show plot in an effort to encourage cryptic geoducks to show. Each diver will then count both geoduck and non-geoduck flags and compare counts. If the counts match, the counter will record the number; if not, the divers will repeat the process until their counts match. When this process has been completed, the counter will draw a site layout schematic that shall include depth of anchor (corrected to MLLW after dive), distance and bearing to origin of show plot, bearing of show plot from origin to distal end, depth of show plot origin and distal end (corrected to MLLW after dive) substrate type, algal cover and type, geoduck show quality, and any other relevant notes.

Depending on logistical feasibility, divers will revisit the show plot up to two times per day throughout the survey and flag any unflagged geoducks and other species. During revisits, the first flagging pass should be made while generating as little disturbance as possible in order to maximize positive identification by viewing open siphons. A second flagging pass should employ the rebar and mallet pounding method. Divers will record the number of flags added (to back-calculate whether any flags were pulled out by drift algae) and a final flag count. Again, individual diver counts should match exactly before terminating the dive. Show plots should be reflagged at least three times (not including the initial flagging) over a minimum of three calendar days.

Weight

Geoduck weight data (undrained wet weight, including shell) for biomass estimation will be obtained from two sources: fishery-independent research data and fishery-dependent port sampling data. The fishery-independent data are sourced from a research project in 2012 and 2014 in which geoducks were obtained in several fishery areas for age and growth research (Palof et al. in prep). Approximately 200 clams were extracted by research divers from each of nine fishery areas. Sample sites within fishery areas were randomly allocated in beds with known high densities of geoducks, and geoducks were extracted in as unbiased a manner as possible using water jets (which have a known size bias). Weights from the research data should be used when appropriate in conjunction with port sampling data for biomass estimation. When weights from recent research data do not exist for specific survey areas, weight data from port sampling should be used exclusively.

The sampling goal for port sampling is 25 geoducks from each of four fish tickets (i.e. divers) per fishery area per season, for a total sample of 100 individuals (Buettner et al. 2016). Individuals are sampled randomly from each fish ticket. To minimize the potential for outdated data (e.g., a decreasing trend in average individual weights) being included in a stock assessment, only port sampling data collected from the three previous commercial fisheries will be included in the analysis. Typically, this translates to 6–7 years because most fishery areas are in a two-year management rotation, but for areas in the four-year management rotation, the previous three fisheries are equivalent to the last 12–15 years. Port sampling data are recorded by subdistrict (not fishery management area), so mean weights are calculated from the subdistricts included in the fishery management areas. We assume that the statistical population of geoducks harvested by the commercial fishery is similar to the statistical population of geoducks captured in density surveys, but this has not been evaluated.

Contingency Plans

In general, there is more uncertainty regarding how much time geoduck surveys and associated show factor studies take, relative to sea cucumber and sea urchin surveys. Some of the uncertainty is because geoduck resurveys are usually modified each time, often with new transects in portions of the fishery area that have not been surveyed previously. Precise transect locations from the previous survey are generally not re-surveyed because either the amount of survey shoreline or the number of transects was changed, which results in different transect spacing and location. (One exception to this is in fishery areas with a grid pattern of Type III transects, which typically are re-used.) Therefore, there is not as much prior information to estimate the amount of time transects will take as there is for sea cucumber and sea urchin surveys. Another important source of uncertainty is how long it takes to find and install geoduck show plots (if applicable). This process can be very time-consuming, especially in fishery areas where geoduck densities are low, which usually equates to areas where sea otters are present (i.e., Districts 3, 4, and 13, presently). Regardless of the source of uncertainty, the amount of time allotted for the survey is usually fixed, so decisions often must be made in the field about how best to allocate available time and resources. There are too many possible scenarios/trade-offs and options to outline, so general priorities that will be considered are listed in descending order of importance:

1) Installation of at least three show plots, if there is an associated show factor study. Given the relatively short duration of most surveys/trips, it is imperative to get show plots installed quickly in order to maximize the number of days available to re-survey them. Show plots installed for less than two full days have marginal value because it is unlikely that it encompasses enough time to provide a valid estimate of the total number of clams actually within a plot. Other researchers have suggested that 5–7 days as a minimum, but we have prioritized obtaining area- and time- specific show factor studies in order to have an estimate, even if it is an imperfect one. A sample size of three is the minimum number we deem reasonable, given the risk of spurious results with small sample sizes. A sample size of six plots is the ideal, realistic target, but three should be considered sufficient if completing the bulk of the density survey (i.e., not including spatial outliers or singletons) is at risk.
2) Transects in “core” areas of the fishery area (core areas are the largest, highest-density beds that are most important to the fishery).
3) Spatial coverage of transects. Skip every other or every third transect on the first pass, then fill in the gaps on subsequent passes. Unexpected events (e.g., weather, staffing) can and do arise, so if the survey is cut short at least there is a chance that it could be analyzed with existing data if the entire area was covered.
4) Prioritize transects in beds that were previously surveyed over transects in new beds added from logbook or reconnaissance data.
5) Prioritize transects in the interior of geoduck beds over the edges of the beds. The transects on the edges of the beds will likely have lower density or no geoducks.

6) Skip every other interval on long transects, ensuring to clearly document on the datasheet (include a record for each skipped interval) and in notes so analysis can be adjusted accordingly.
7) Survey skipped transects on a subsequent dive trip, if possible.

While every effort should be made to complete transects that are attempted, the consequences for data analysis are not necessarily as severe as they are for sea cucumber (or most sea urchin) surveys if a transect is aborted. Whereas sea cucumber surveys rely on counts that are standardized per linear meter of shoreline, geoduck counts are standardized by the area swept, so counts from an aborted transect can be used if the degree of depth bias is minimal. Again, divers should record detailed notes (see points to include in the sea cucumber contingency plan section), and the decision about whether to redo the transect or use the data as-is is up to the project leader on a case-by-case basis.

Statistical Analysis and GHL Calculation

Total biomass and numbers by sampling area

In general, geoduck clam biomass in a fishery management area, B_a, is calculated using average geoduck clam density, average weight, and total area of beds within the management area.

The total biomass of geoduck clams for an area, B_a, is estimated from the biomass density per meter squared, $D(lb)_a$, and the total area:

$$B_a = D(lb)_a A_a \tag{1}$$

where:

$D(lb)_a$ = average density in lbs/m^2 for the total sampling area, and

A_a = the area of the total sampling area, m^2.

The variance of the biomass estimate is the product of the variance of the geoduck clam average density, in lb/m^2, and the area squared:

$$\sigma^2_{B_a} = A^2_a \sigma^2_{D(lb)_a} \tag{2}$$

Total geoduck clam abundance, N_a, in a fishery management area is calculated as a product of the average density (number per m^2) and the total area:

$$N_a = D_a A_a \tag{3}$$

where:

A_a = the area (in square meters) of the total sampling area,

D_a = the average density (number per m^2) of the total sampling area.

The variance of geoduck clam abundance, N_a, is equal to the product of the variance of the density times the area squared:

$$\sigma^2_{N_a} = (A_a)^2 \sigma^2_{D_a} \tag{4}$$

Geoduck clam density

Geoduck clam density for a given area is calculated using a stratified design with two strata based on density: 1) transect segments with densities equal to or less than 0.25 geoduck clams per meter, and 2) transect segments with densities greater than 0.25 geoducks per meter. This is meant to separate non-geoduck habitat and geoduck habitat.

The density (in numbers per square meter) estimate of the entire sampling area is calculated as:

$$D_a = \frac{\sum_{h=1}^{2} A_{ah}\overline{d_{ah}}}{A_a} \quad (5)$$

and having variance:

$$\sigma_{D_a}^2 = \frac{\sum_{h=1}^{2}(A_{ah})^2 \sigma_{\overline{d_{ah}}}^2}{(A_a)^2} \quad (6)$$

where:

A_{ah} = area (m^2) of strata h in area a, and

$\overline{d_{ah}}$ = the average geoduck clam density (m^{-2}) in area a and strata h.

The guideline harvest level for the fishery is set in biomass (lb), therefore the density can be converted to pounds/m^2 using the average weight of geoducks and its variance.

The density in biomass (lb/m^2) is:

$$D(lb)_a = D_a W_a \quad (7)$$

where:

W_a = the average weight of geoduck clams in the area,

and having variance:

$$\sigma_{D(lbs)_a}^2 = D_a^2 \sigma_{w_a}^2 + W_a^2 \sigma_{D_a}^2 - \sigma_{w_a}^2 \sigma_{D_a}^2 \quad (8)$$

where:

σ_{w_a} = variance of weights in the area.

The estimate of unbiased variance is taken from Goodman (1960) equation 5, the unbiased estimate of variance of two independent variables.

The average density for each strata h within bed a is calculated from the counts and each for each of the transects sampled in area a. First, the density of geoduck clams for each interval within a transect must be calculated to be able to assign the interval to the correct density strata. The counts for each interval are adjusted by the show factor, Q, to account for geoduck present that are not visible during a single observation. A density for each interval is estimated using the following equation:

$$d_{aij} = \frac{\sum_{v=1}^{2} c_{jv}}{kL_j Q} \quad (9)$$

where:

i = transect index, j = interval index, a = area index, v = diver index, and

L_j = the distance of the interval,

c_{jv} = the count of geoduck clams for each diver in the specific interval,

k = the number of divers on an interval/transect, and

Q = the show factor, which is the ratio of geoduck clam shows visible during a single observation and the true abundance of harvestable geoduck clams within the area.

Based on this calculation intervals are assigned to be in either strata 1 (high density or geoduck habitat) or strata 2 (low density or non-geoduck habitat).

Once the intervals within each transect are assigned to a stratum, two densities for each transect are calculated – one for each stratum. These are calculated using the raw diver counts and adjusted using the area specific show factor, Q. The average density for each stratum is then calculated as an average of all transects within the area that contain intervals assigned to that strata. These are calculated as:

$$d_{ahi} = \frac{\sum_{j=1}^{m} c_{ihj}}{\sum_{j=1}^{m} K * L_{ihj} Q} \tag{10}$$

$$\overline{d_{ah}} = \frac{\sum_{i=1}^{n} d_{ahi}}{n_h} \tag{11}$$

where:

m = the total number of intervals in the specific transect in the desired strata,

n_h = the total number of transects in the specific strata in the area,

c_{ihj} = the total count of geoduck clams for an interval within a transect that are assigned to the desired strata,

Q = the show factor, which is the ratio of geoduck clam shows visible during a single observation and the true abundance of harvestable geoduck clams within the area, and

L_{ihj} = the total distance of an interval within a transect that are assigned to the desired strata.

and having variance:

$$\sigma^2_{(\overline{d_{ah}})} = \frac{\sum_{i=1}^{n} (d_{ahi} - \overline{d_{ah}})^2}{n_h - 1} \tag{12}$$

Geoduck Counts Adjusted for Show Factor

The show factor, Q, is the ratio of geoduck clam shows visible during a single observation of any defined area and the true abundance of harvestable geoduck clams within that area:

$$Q = n / N, \tag{13}$$

where:

n = the number of visible shows within a defined area (show plot),

N = the absolute number of harvestable geoduck clams within the area.

The counts in each interval/transect are adjusted by the show factor for a specific area to accurately reflect geoduck abundance, eq.9 and 10 above.

Geoduck Weight Estimates

Mean weight per geoduck clam within a given area is estimated as:

$$W_a = \frac{\sum w_i}{n_w}, \tag{14}$$

where:

W_a = estimated mean weight per geoduck clam,

w_i = weight of the *i*th geoduck clam from the available data,

n_w = sample n for weight.

and having variance:

$$\sigma^2_{W_a} = \frac{\sum_{i=1}^{n_W}(w_i - W_a)^2}{n_w - 1} \tag{15}$$

Geoduck Area Estimates

Geoduck fishery areas consist of multiple beds that have been defined by density information collected by industry reconnaissance, fishery logbook data, and previous surveys. After boundaries of the beds have been defined, the area of these beds is determined using ArcGIS.

Complete fishery management area is calculated as:

$$A_a = \sum_{i=1}^{n} Ai \quad , \tag{16}$$

where:

A = total area (m^2),

A_i = area of bed i (m^2) determined by ArcGIS.

The area of each strata within a sampling area is calculated using the fraction of the sampled area that was assigned to that strata and the complete fishery management area:

$$A_{ah} = \frac{\sum_{i=1}^{n} 2\, L_{ih}}{\sum_{i=1}^{n} 2\, L_{i1} + \sum_{i=1}^{n} 2\, L_{i2}} * A_a$$

where:

A_{a1} = the proportion of the total area (m^2) that is approtioned to strata 1, this proportion for strata 2 would be calculated by replacing the area sampled from strata 1 in the numerator with that of strata 2, and

A_a = total area for this sampling area.

Guideline Harvest Level

The guideline harvest level (GHL) in a fishery management area is the product of estimated geoduck clam biomass and a fixed 2% annual harvest rate. Before the harvest rate is applied, the biomass estimate is adjusted to account for the precision of the biomass estimate, the show factor was previously accounted for here but is not included in the density calculations. The biomass of geoduck clams in a given area is calculated as a product of the geoduck clam density in pounds per meter squared and the total area of the beds in the specific fishery management area.

$$\mathrm{GHL}_{\mathrm{fishery}} = B_{\mathrm{adj}}\ \mathrm{H}, \tag{17}$$

where:

$\mathrm{GHL}_{\mathrm{fishery}}$ = geoduck GHL estimate,

B_{adj} = precision adjusted biomass estimate,

H = harvest rate, 2% annually or 4% if fishery is fished every other year,

and:

$$B_{adj} = B_a\, P_{lb/m^2}, \tag{18}$$

where:

B_a = biomass estimate of fishery adjusted for show factor from Eq. 1,

P_{lb/m^2} = percent precision of pounds per meter squared density estimate.

Uncertainty in the estimate of biomass density (lbs/m^2) is expressed as the percent precision. This index is equal to the lower bound of the one-sided 90% confidence interval expressed as a proportion of the biomass density and calculated as:

$$P_{lb/m^2} = 1 - t_\alpha \frac{s}{D(lbs)_a\sqrt{n}}, \tag{19}$$

where:

P_{lb/m^2} = percent precision of the biomass density estimate,

s = standard deviation of the mean biomass density estimate ($\sigma^2_{D(lbs)_a}$, from Eq. 8).

t_α = t-value from Student's distribution for a one-sided interval with significance, level α = 10%,

$D(lbs)_a$ = estimated total biomass density of geoduck clams in area from Eq. 7, and

n = the total number of transects with an area.

RED SEA URCHINS

Survey Design

To summarize sea urchin-specific survey design elements from the "In-Common Stock Assessment Design Elements" section above and Table 1, surveys are at least once every seven years (the minimum frequency allowed by regulation), and density is assessed using a shoreline-based or area-based (one area: Bee Rocks 101-22) design with pseudo-permanent Type I or III transects, respectively. Type I and III transects are systematically spaced, with Type I transects having a random starting point. The spatial replicate for Type I transects is a variable length, paired transect 2 m wide (1 m per transect per diver x 2 divers). The spatial replicate for Type III transects is a fixed length (30 m), paired transect 2 m wide (1 m per transect per diver x 2 divers). Type I transects are subsampled in three depth zones: 0–33, 33–40, and 40–50 ft MLLW. Type III transects are subsampled in three 10 m distance intervals and are restricted to a maximum depth of 50 ft MLLW. The 0–50 ft MLLW depth zone captures the majority of the depth zone in which commercial divers normally operate, although urchins are generally most abundant in the 0–33 ft MLLW depth zone.

The number of transects per area was based originally upon several factors (e.g., logistics), but the most important factor was meeting the statistical objective of the lower bound of the one-sided 90% confidence interval being within 30% of the mean density estimate (Woodby 1991). Generally, the precision of the density estimate is assumed to vary inversely with the length of shoreline (i.e. via spatial autocorrelation in habitat and/or population areal density) and degree of habitat heterogeneity.

Field Survey Methods

Density

All red sea urchins ≥ 60 mm outside test diameter (i.e. not including spines) will be counted by each diver within a 1 m-wide strip transect. A ruler or mark 60 mm wide will be inscribed on the diver’s transect rod or dive slate as a visual cue for the urchin size threshold. The size threshold of 60 mm was chosen in order to include the majority of the red sea urchin population that is harvested in the biomass estimate, as well as to place a limiter on survey time and effort. Counts and ancillary data will be recorded for three depth intervals: 0–33, 33–40, and 40–50 ft MLLW.

Red sea urchin counts may be biased to some degree due to several factors. Sea urchins in the 50–70 mm size range often make up a large proportion of the animals observed, and sea urchins are often very abundant, so it is usually not feasible to measure all marginally-sized urchins against the 60 mm mark on a dive slate. Furthermore, it is likely that among-diver variability exists and counts are biased high or low based on a diver’s ability to estimate sea urchin size quickly and accurately, as is required for surveys in practice. Undoubtedly, at least some sea urchins are not detected and enumerated because of heavy kelp cover, poor underwater visibility, or abundant crevices in rocky habitats. It would be cost-prohibitive to require 100% detection because many transects would take too much time to be logistically feasible without dramatically reducing the total number of transects in an area. Therefore, divers are given leeway to determine for themselves how much time is reasonable to conduct a transect survey.

Weight

In both commercial fishery areas and control areas, a target sample size of 30 red sea urchins will be collected from each transect surveyed for density. The lower size threshold for individual sea urchins in collections is 10 mm outside test diameter, and divers will endeavor to not be size selective (e.g., collect larger and/or less cryptic animals) so collections are as unbiased as possible. Urchins will be collected from at least one sample depth chosen on each transect pair. Divers will choose a target depth zone (i.e., shallow, mid-depth, or deep) prior to their dive and when the target depth zone is reached, they will pause their transect counts and collect all visible urchins surrounding the sample location until 30 urchins are obtained. When urchins are scarce, divers will search for urchins outside of the pre-chosen depth. Collected sea urchins will be placed in mesh bags and will be carried by hand up to the dive skiff or placed in mesh bags with a buoyed line extending to the surface. In the latter scenario, bags will be retrieved by the tender in the dive skiff.

Outside test diameters of red sea urchins will be measured to the nearest millimeter with calipers, excluding the spines. If conditions permit, urchins will be measured immediately after the dive aboard the skiff and returned to the general area from which they were removed. Average weight will be estimated from the average test diameter via regression analysis (see Statistical Analysis section below).

Contingency Plans

Because of the high degree of similarity between sea urchin surveys and sea cucumber surveys, the contingency plans for red sea urchins are the same as for those addressed in the sea cucumber section.

Statistical Analysis and GHL Calculation

Density

As for sea cucumbers, mean sea urchin density will be weighted for each fishery area by the amount of survey shoreline each transect represents (except for 101-22 Bee Rocks, which uses Type III transects and are calculated similarly as for geoducks). The weighting criteria are the same as for sea cucumbers.

Weight

Average mass (g) is estimated from average test diameter (mm) for each area using the relationship:

$$\text{mass} = 0.00124 \text{ x diameter}^{2.696}. \tag{2}$$

Equation 2 was estimated from 113 urchins sampled from the test fishery in District 1 on December 20, 1995 using a log transformed regression (Woodby et al. 1996). The equation was applied to each urchin measured.

The average mass (W_t) for each fishery area is estimated as:

$$\overline{W_t} = \left(\frac{\sum_{j=i} \Sigma w_i / \Sigma o_i}{n_j} \right), \tag{3}$$

where:

w_i = the estimated weight (based on Equation 2) of all urchins in sample *i*,

o_i = the count of all urchins greater than 60 mm in the sample, and

n_j = the total number of weight samples taken in fishery area *j*.

Population Size and Biomass

The population size of urchins ≥ 60 mm diameter in each fishery area is calculated as the product of average density (urchins per meter of shoreline) and the total available habitat (meters of urchin-compatible shoreline).

Total biomass (b) for each fishery area (j) is calculated as:

$$b_j = \bar{d}_j W_j l_t \text{,} \tag{4}$$

Where:

l = the total length of shoreline in a subdistrict,

d_j = the average density of urchins per meter of shoreline (calculated similarly to sea cucumbers), and

W_j = the average weight of urchins.

The lower bound of the biomass estimate is calculated as the percent precision (Equation 5) times the biomass.

A sample goal of 15 to 25 transect pairs has been established for each fishery area. This sample size is expected to achieve at least 70% precision (defined in Equation 5 below) based on information from prior urchin surveys. In non-control areas where precision from past surveys has fallen below the target, the number of transect pairs has been increased to between 18 and 35. The certainty in the estimate of biomass is expressed as the percent precision, which is equal to the lower bound of the one-sided 90% confidence interval expressed as a percent of the average biomass:

$$\text{Percent precision} = 100\left(1 - t_\alpha \frac{\sigma}{\bar{b}_j\sqrt{n_j}}\right), \tag{5}$$

where:

t = the t-value from Student's distribution for a one-sided interval with significance level

α = 10%,

σ = the standard deviation of the biomass among n transects.

The t-value is approximately 1.32 to 1.38 for the various fishery areas.

Guideline Harvest Level

The GHL for red sea urchins was based on a modified surplus production model similar to that used for the sea cucumber fishery in Southeast Alaska (Woodby et al. 1993; ADF&G 1996a, ADF&G 1996b). The annual GHL for a fishery area is developed after each new survey and is currently calculated as:

$$\text{GHL} = \text{CF x M x P} \tag{6}$$

where:

CF = 0.4 scaling factor relating maximum sustainable fishing mortality to unexploited population size (Caddy 1986);

M = 0.15 estimated instantaneous mortality rate for sea cucumbers;

P = most recent biomass estimate, taken as the lower bound of the one-sided 90 percent confidence interval. This can also be defined a product of b_j and the Precision.

This annual GHL is used for each of the first three seasons following a new survey. For the fourth through sixth season after a survey (if applicable), the GHL is reduced if harvest since the survey exceeded a given threshold. The original annual GHL is multiplied by three and the total amount of harvest since the first season after the survey is subtracted. If the calculated value is less than the original annual GHL, then the calculated value is set as the GHL. If the remaining value is greater than the original annual GHL, then the original annual GHL is used.

SCHEDULE AND DELIVERABLES

SCHEDULE

Planning (e.g., geoduck survey design) and preparation for the dive survey season will be conducted primarily from February through April. Dive surveys will be conducted from April through August. Goals for timeline to complete key steps are:

Early-August - Meet with biometric staff to review analytical methods and any novel issues that may affect data analysis of sea cucumber and sea urchin data.

Mid-August - Complete sea cucumber and sea urchin data entry and verification.

Late August - Complete data analysis and send biomass estimation and GHL calculations to biometric and research staff for review

Early-September - Make corrections to biomass/GHL calculations; send calculation spreadsheets to fishery managers for review.

Early to Mid-September - Address manager questions, make corrections if necessary; finalize biomass/GHL analysis spreadsheet and send GHLs to managers by close of business.

DATA ENTRY / DATABASE AND SOFTWARE REQUIREMENTS

Geoduck survey data will be entered into ADF&G's Integrated Fisheries Database (IFDB), which is an Oracle database, via the ZANDER data entry form. Ideally, data will be entered in the field by a designated dive team member within the same day of data collection to maximize recall of dives. Remotely-entered data will be uploaded to the master Oracle database upon return to the regional office network. Data that were not entered in the field will be entered in the office using ZANDER and automatically uploaded into the master Oracle database. Record-by-record review will be conducted on-screen at the time of data entry using the ZANDER entry form. Additional quality control will be conducted in Microsoft Excel or other software during data analysis. Final biomass and GHL calculations will be performed in Microsoft Excel for ease of internal peer reviewers.

Due to problems with the sea cucumber and sea urchin ZANDER/IFDB entry/databases, data will be entered into a Microsoft Excel spreadsheet as an interim solution until IFDB data issues are resolved. Survey data entry will be conducted during dive survey trips, as well as between trips, and after the season ends if necessary. Ideally, data will be entered by a designated dive team member within the same day of data collection to maximize recall of dives. On-screen record-by-record review will be conducted in Microsoft Excel. Additional quality control will be conducted in Microsoft Excel or other software, as will biomass and GHL calculations.

BIOMETRIC REQUIREMENTS

Biometric review of all field and statistical methods and results of analysis will be provided by ADF&G biometric staff. A preliminary review will be conducted prior to data analysis, and a final review will be conducted prior to review by fishery managers.

OTHER NECESSARY RESOURCES

The *R/V Kestrel*, based in Petersburg, will be used as the support research vessel and base dive platform for most, if not all, stock assessment surveys. There is a possibility that staff divers in regional offices will need to assist with completion of surveys using regional vessel resources. The *R/V Kestrel* is a live-aboard 105-foot vessel capable of accommodating up to nine divers in addition to three vessel officers. It is equipped with compressors for on-board filling of scuba tanks with air and Nitrox. A 36% Nitrox breathing mixture will be used for all dives to enhance safety. Two 19-foot aluminum skiffs that have been enhanced for diving purposes will accompany the *R/V Kestrel* and all diving will be conducted directly from these skiffs. A more detailed description of the *R/V Kestrel* and dive skiffs is provided in Appendix A.

All diving will adhere to guidelines and procedures outlined in the department's Dive Safety Manual (Hebert 2012b) and emergency response to dive accidents will follow the most recent dive safety plan, which will be made readily available in the wheelhouse of the *R/V Kestrel*.

DELIVERABLES

Stock assessment survey results will be compiled and summarized in Excel spreadsheets. A report of the stock assessment survey results for sea cucumbers and geoducks will be published annually in the ADF&G Fishery Data Series.

RESPONSIBILITIES

Kyle Hebert, Herring/Miscellaneous Shellfish Research Program Leader, Fishery Biologist IV. Oversight of all aspects of the project and vessel operation, including planning, budgeting, sample design, field work, personnel; assists with review of data analysis and reporting; participates in dive surveys.

Quinn Smith, Miscellaneous Shellfish Research Project Leader, Fishery Biologist III. Leads project, including planning, budgeting, sample design, field work, personnel, data entry, data analysis, and reporting; participates in dive surveys.

Jeff Meucci, Dive Research Project, Fish and Wildlife Technician V. Assists with operational planning, oversees dive operation safety as dive master, acts as lead on medical issues in the field, maintenance of skiffs and dive gear/equipment, data entry, participates in dive surveys.

Katie Palof, Regional Shellfish Biometrician, Biometrician II. Assists with/recommends survey design; overall analytical and scientific review.

Joselito Skeek, Captain of *R/V Kestrel*, Boat Officer IV. Command of dive research vessel and overall responsibility of vessel operations, safety and conduct aboard the vessel.

Erik Larson, Chief Engineer of *R/V Kestrel*, Boat Officer III. Operation and maintenance of engine room, safety systems, davits/cranes and hydraulic deck gear, assists with operation of vessel, operates dive cylinder air/Nitrox compressor.

Alisa Jestel, Deck Mate and Cook of *R/V Kestrel*, Boat Officer I. Galley operations/cook, operation of davits/cranes, assists engineer, assists with dive compressor.

REFERENCES CITED

ADF&G (Alaska Department of Fish and Game). 1990a. Synopsis of the draft fishery management plan for sea cucumbers in Southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J90-06, Juneau.

ADF&G (Alaska Department of Fish and Game). 1990b. Interim management measures for the red sea cucumber fisheries in Southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J90-30, Juneau.

ADF&G (Alaska Department of Fish and Game). 1991. Commercial shellfish regulations. Regulations of the Alaska Board of Fisheries for commercial fishing in Alaska. Alaska Department of Fish and Game, Juneau.

ADF&G (Alaska Department of Fish and Game). 1992. Commercial shellfish regulations. Regulations of the Alaska Board of Fisheries for commercial fishing in Alaska. Alaska Department of Fish and Game, Juneau.

ADF&G (Alaska Department of Fish and Game). 1996a. Management plan for the harvest of red sea urchins in Districts 101-104 of Southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J96-19, Juneau.

ADF&G (Alaska Department of Fish and Game). 1996b. Management plan for the harvest of red sea urchins in Southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J96-27, Juneau.

Buettner, A. R., A. R. Reynolds, and J. Rice. 2016. Operational Plan: Southeast Alaska Shellfish Port Sampling, 2014–2018. Alaska Department of Fish and Game, Regional Operational Plan CF.1J.2016.03, Ketchikan.

Bradbury, A., and J. V. Tagart. 2000. Modeling geoduck, *Panopea abrupta* (Conrad, 1849) population dynamics. II. Natural mortality and equilibrium yield. Journal of Shellfish Research 19 (1): 63–70.

Bradbury, A., B. Sizemore, D. Rothaus, and L. Timme. 2000. Stock assessment of subtidal geoduck clams *Panopea abrupta* in Washington Fisheries. State of Washington, Washington Department of Fish and Wildlife, Olympia, Washington.

Caddy, J.F. 1986. Stock assessment in data-limited situations the experience in tropical fisheries and its possible relevance to evaluation of invertebrate resources. Pages 379-392 in G.J. Jamieson and N. Bourne, editors. North Pacific Workshop on Stock Assessment and Management of Invertebrates. Canadian Special Publication in Fisheries and Aquatic Sciences 92.

Clark, J. E., M. Pritchett, and K. Hebert. 2009. Status of sea cucumber stocks in Southeast Alaska and evaluation of the stock assessment program. Alaska Department of Fish and Game, Fishery Data Series No. 09-12, Anchorage.

Davidson, B., D. Woodby, and B. DeJong. 1992. Interim management measures for the red sea urchin in Southeast Alaska for the 1992 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J92-05, Juneau.

Davidson, B., D. Woodby, and B. DeJong. 1993. Interim management measures for the red sea urchin in Southeast Alaska for the 1993 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J93-01, Juneau.

Estes, J. A., and J. F. Palmisano. 1974. Sea otters: their role in structuring nearshore communities. Science 185: 1085–1060.

FAA. 2001. Specification for the Wide Area Augmentation System (WAAS). Archived 2008-10-04 at the Wayback Machine. FAA-E- 2892b.

REFERENCES CITED (Continued)

Goodman, L. A. 1960. On the exact variance of products. American Statistical Association Journal 55:708–713.

Goodwin, C.L. 1973. Subtidal geoducks of Puget Sound, Washington. Wash. Dept. Fish. Tech. Rep. 13. 64 p.

Goodwin, C. L. 1977. The effect of season on visual and photographic assessment of subtidal geoduck clam (*Panopea generosa*, Gould) populations. The Veliger 20(2): 155–158.

Harbo. R AI. 1997. Shells and shellfish of the Pacific northwest. Harbor Publishing, Canada. 270 p.

Hebert, K. 2010a. Southeast Alaska sea cucumber stock assessment surveys in 2009. Alaska Department of Fish and Game, Fishery Data Series No. 10-77, Anchorage.

Hebert, K. 2010b. Southeast Alaska sea cucumber stock assessment surveys in 2010. Alaska Department of Fish and Game, Fishery Data Series No. 10-88, Anchorage.

Hebert, K.P. 2012a. Southeast Alaska sea cucumber stock assessment surveys in 2011. Alaska Department of Fish and Game, Fishery Data Series No. 12-26, Anchorage.

Hebert~~,~~ K. 2012b. Dive Safety Manual. Alaska Department of Fish and Game. Special Publication No. 12-16, Anchorage.

Hebert, K. 2017. 2018 Report to the Board of Fisheries, miscellaneous shellfish fisheries. Alaska Department of Fish and Game, Fishery Management Report No. 17-59, Anchorage.

Hebert, K, and R. Larson. 1999. Red sea urchin assessment surveys, Districts 101, 102, and 104, 1998. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J99-27, Juneau.

Hebert, K, and R. Larson. 2000. Red sea urchin assessment surveys, Districts 101, 103, and 104, 1999. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J00-22, Juneau.

Hebert, K, and R. Larson. 2001. Red sea urchin assessment surveys, Districts 101, 102, and 104, 2000. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-07, Juneau.

Hebert, K, and J. E. Clark. 2001. Red sea urchin assessment surveys, Districts 101, 102, and 104, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-08, Juneau.

Hebert, K, M. Pritchett, T. Thynes, R. Larson, and J. Clark. 2001. Southeast Alaska sea cucumber control area stock assessment Part IV: 1993–2001 seasons. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-34, Juneau.

Hebert, K, M. Pritchett, R. Larson, T. Thynes, and J. Clark. 2002. Southeast Alaska sea cucumber stock assessment and management Part III: 1992, 1995, 1998, and 2001 seasons. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-30, Juneau.

Hurlbert, S.H. 1984. Pseudoreplication and the Design of Ecological Field Experiments. Ecological Monographs, 54, 187–211.

Hoyt, Z. 2015. Resource competition, space use and forage ecology of sea otters, *Enhydra lutris*, in southern Southeast Alaska. PhD Dissertation. Fairbanks, AK.

Imamura, K. K. and G. H. Kruse. 1990. Management of the red sea cucumber in Southeast Alaska: biology, historical significance in Pacific Coast fisheries, and regional harvest rate determinations. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J90-31, Juneau.

Kruse, G. H. and K. K. Imamura. 1990. Issue paper: management options and recommendations for the sea cucumber fishery in Southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information report 5J90-06, Juneau.

Larson, R., Minicuccui, T., and D. Woodby. 1995. Southeast Alaska Sea Cucumber Research Report 1993. Regional Information Report No. 1J95-04, Juneau.

Larson, R., and D. Woodby. 1996. Red sea urchin assessment surveys, Districts 103 and 104, July 1996. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J96-21, Juneau.

REFERENCES CITED (Continued)

Larson, R., D. Woodby, and J. Rumble. 1998. Red sea urchin assessment surveys, Districts 101, 102, 104, and 113, 1997. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J98-13, Juneau.

Larson, R., K. Hebert, M. Pritchett, and J. Clark. 2001a. Project operational plan marine invertebrate (sea cucumber, sea urchin, and geoduck) stock assessment, 2000. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-18, Juneau.

Larson, R., K. P. Hebert, T. Thynes, and J. Clark. 2001b. Southeast Alaska sea cucumber stock assessment and management Part I: 1990, 1993, 1996, and 1999 seasons. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-09, Juneau.

Larson, R., K. P. Hebert, T. Thynes, and J. Clark. 2001c. Southeast Alaska sea cucumber stock assessment and management Part II: 1991, 1994, 1997, and 2000 seasons. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-28, Juneau.

Larson, S.D., Z.N. Hoyt, G.L. Eckert, and V. A. Gill. 2013. Impacts of sea otter (*Enhydra lutris*) predation on commercially important sea cucumbers (*Parastichopus californicus*) in Southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 70: 1498–1507.

Marshall, S., R. Larson, and D. Woodby. 1991. Interim management measures for the red sea urchin in Southeast Alaska for the 1990–1991 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J91-08, Juneau.

NSTB (National Satellite Test Bed). 2006. WAAS PAN Report. Retrieved December 27, 2018.

Pitcher, K.W. 1989. Studies of Southeastern Alaska sea otter populations: distribution, abundance, structure, range expansion and potential conflicts with shellfisheries. Anchorage, Alaska. Alaska Department of Fish and Game, Cooperative Agreement 14-16-0009-954 with U.S. Fish and Wildlife Service. 24 pp.

Pitcher, K. W., and K. K. Imamura. 1990. Impacts of sea otter predation on Dungeness crab abundance in Cross Sound – Icy Strait Area, southeastern Alaska. U. S. Fish and Wildlife Services Cooperative Agreement No. 14-16-009-954 Final Report – Part III, Alaska Department of Fish and Game, Juneau.

Pritchett, M. 1999. Management plan for the harvest of geoduck clams *Panopea abrupta* in Southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J99-39, Juneau.

Pritchett, M. 2003. Geoduck clam stock assessment surveys and fishery management for the 2002/2003 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J02-47, Juneau.

Pritchett, M., R. Larson, and J. E. Clark. 1999a. Geoduck clam stock assessment surveys and fishery management for the 1998/1999 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J99-36, Juneau.

Pritchett, M., R. Larson, and J. E. Clark. 1999b. Geoduck clam stock assessment surveys and fishery management for the 1998/1999 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J99-37, Juneau.

Pritchett, M., R. Larson, and J. E. Clark. 2000. Geoduck clam stock assessment surveys and fishery management for the 1999/2000 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J00-34, Juneau.

Pritchett, M., and K. Hebert. 2001. Geoduck clam stock assessment surveys and fishery management for the 2000/2001 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-25, Juneau.

Pritchett, M., and K. Hebert. 2002. Geoduck clam stock assessment surveys and fishery management for the 2001/2002 season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J02-17, Juneau.

REFERENCES CITED (Continued)

Pritchett, M., and Z. Hoyt. 2007. Project operational plan: marine invertebrate (sea cucumber, red sea urchin, and geoduck) stock assessment, 2007. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J07-14, Douglas.

Rumble, J. and C. Siddon. 2011. Southeast Alaska 2009 geoduck stock assessment. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Data Series No. 11-37, Anchorage.

Siddon, C. 2007.Evaluation of the Southeastern Alaska geoduck (*Panopea abrupta*) stock assessment methodologies. Alaska Department of Fish and Game, Division of Commercial Fisheries, Special Publication No. 07-02, Anchorage.

United States Fish and Wildlife Service (USFWS). 2014. Northern sea otter (*Enhydra lutris kenyoni*): Southeast Alaska stock. 18 p. https://www.fws.gov/alaska/fisheries/mmm/stock/stock.htm

Walker, S. 2000. An historical overview of the geoduck commercial fishery in Southeast Alaska, 1973–1997. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J00-35, Juneau.

Walker, S., K. Hebert, M. Pritchett, and J. E. Clark. 2003. Red sea urchin assessment surveys, Districts 101, 103, 107 and 109, 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J01-07, Juneau. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J03-28, Juneau.

Woodby, D. 1991. The red sea urchin test fishery of southern Sitka Sound, 1990. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J91-03, Juneau.

Woodby, D. A., G. H. Kruse, and R. H. Larson. 1993. A conservative application of a surplus production model to the sea cucumber fishery in Southeast Alaska. Pages 191–202 [In] G. Kruse, D. M. Eggers, R. J. Marasco, C. Pautzke, and T. J. Quinn II, editors. Proceedings of the International Symposium on management strategies for exploited fish populations. Alaska Sea Grant College Program Report No. 93-02, University of Alaska Fairbanks.

Woodby, D., and R. Larson, R. 1996. Red sea urchin assessment surveys in District 102, August 1995. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J96-23, Juneau.

Woodby, D., R. Larson, and T. Minicucci. 1996. Red sea urchin assessment surveys in District 101, August 1994 to May 1995. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J96-20, Juneau.

Woodby, D. A., and R. Larson. 1997. Conservative fishery management: simplistic methods for avoiding undesirable ecosystem effects in a developing sea cucumber fishery. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J97-17.

TABLES

Table 1.–Summary of stock assessment study design elements by target species.

Design Element	Sea Cucumber	Sea Urchin	Geoduck
Density			
Abundance Estimation Design	shoreline-based	shoreline-based, area-based (1 area)	area-based
Abundance Estimate Correction	No	No	Yes
Min. Survey Frequency (yr)	3	7	12
Spatial Replicate	paired transect	paired transect	paired transect
Sample Size (no. of transects per fishery area)	variable	variable	variable
Transect Type	I	I or III	I or II or III or I & II
Paired Transect Width (m)	4 (2, if poor conditions)	2	2
Transect Length	variable	Type I: variable; Type III: 30 m	Type I, II: variable; Type III: 20–30 m
Transect Target Depth (ft MLLW)	50	50	60
Subsample	depth interval (= single transect)	Type I: depth; Type III: 10 m interval	Type I, II, & III: distance interval (usu. 10 m)
Subsample Width (m)	2 (1, if poor conditions)	1	1
Subsample Length	variable	variable (Type I) or 10 m (Type III)	10 m (Type I, II, & III)
Subsample Target Depth (ft MLLW)	50	Type I: 33, 40, 50; Type III: N.A. (max. = 50)	N.A. (max. = 60)
Density Metric	no. animals/ linear m shoreline	Type I: no. animals/ linear m shoreline; Type III: no. animals/ m^2	no. animals/ m2
Individual Size Threshold	≥ 10 cm length	≥ 60 mm test diameter	all sizes (but biased against small animals)
Weight			
Spatial Replicate	open area: paired transect; control area: sample site	paired transect	fish ticket
Target Sample Size (no. of transects sampled per fishery area)	open area: variable (= density transect sample size/ 2); control area: 4–6	variable (= density transect sample size)	0
Target Sample Size (no. of fish tickets sampled per fishery area for 3 previous fisheries)	0	0	12
Subsample Target Sample Size (no. of individuals per transect/ sample site)	open area: 15; control area: 30	30	0
Subsample Target Sample Size (no. of individuals per fish ticket)	0	0	25
Individual Size Threshold	1 cm	1 cm	N.A.

FIGURES

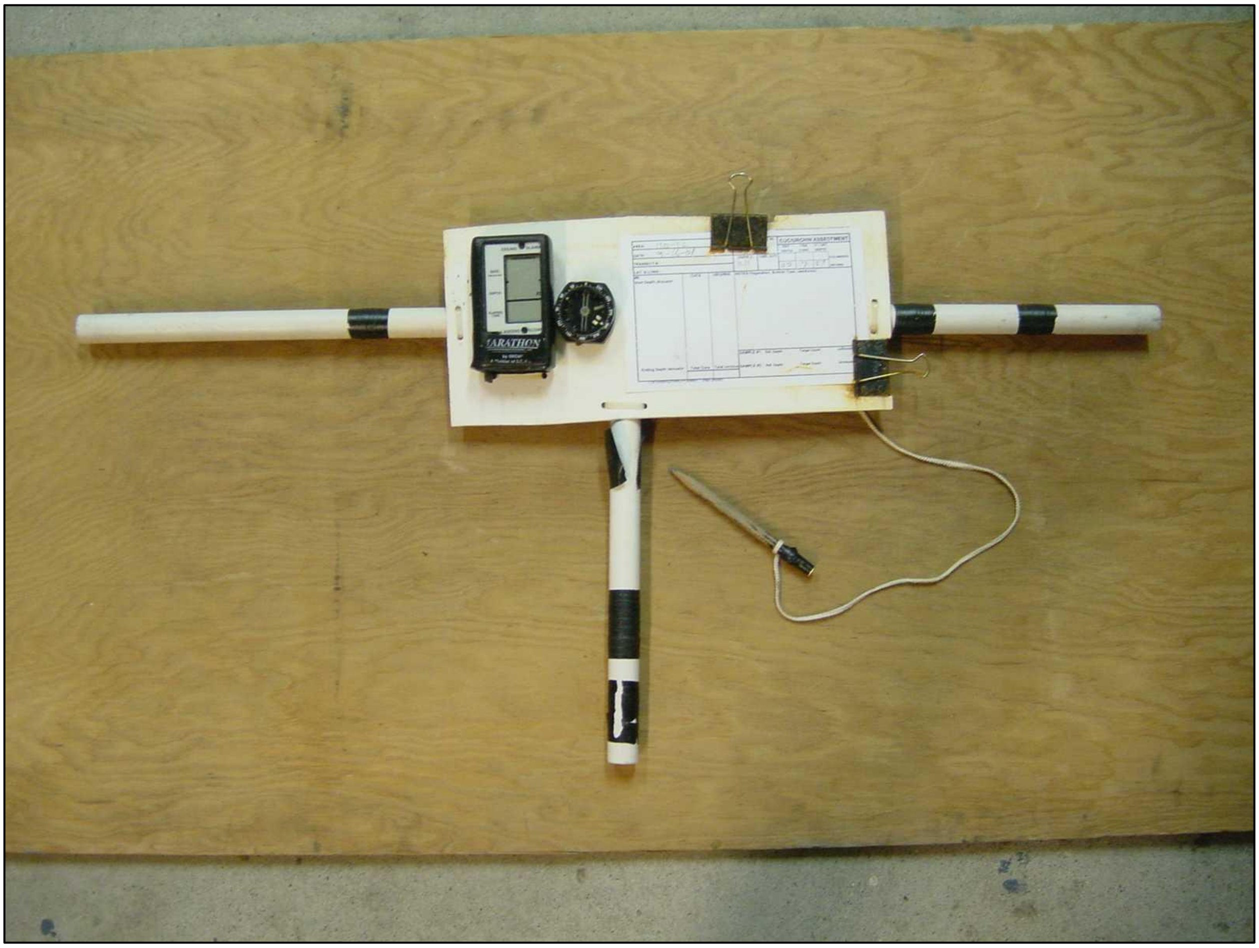

Figure 1.–One-meter transect rod used for density transect surveys of geoducks and red sea urchins. A rod two meters in width is used for sea cucumber survey transects. ©2017 ADF&G. Photo by Kyle Hebert.

Figure 2.–Exposed geoduck siphon tips at 50 feet of depth near Craig, Alaska. Siphon tips such as these, called “shows”, provide clear geoduck identification. ©2016 ADF&G. Photo by Scott Walker.

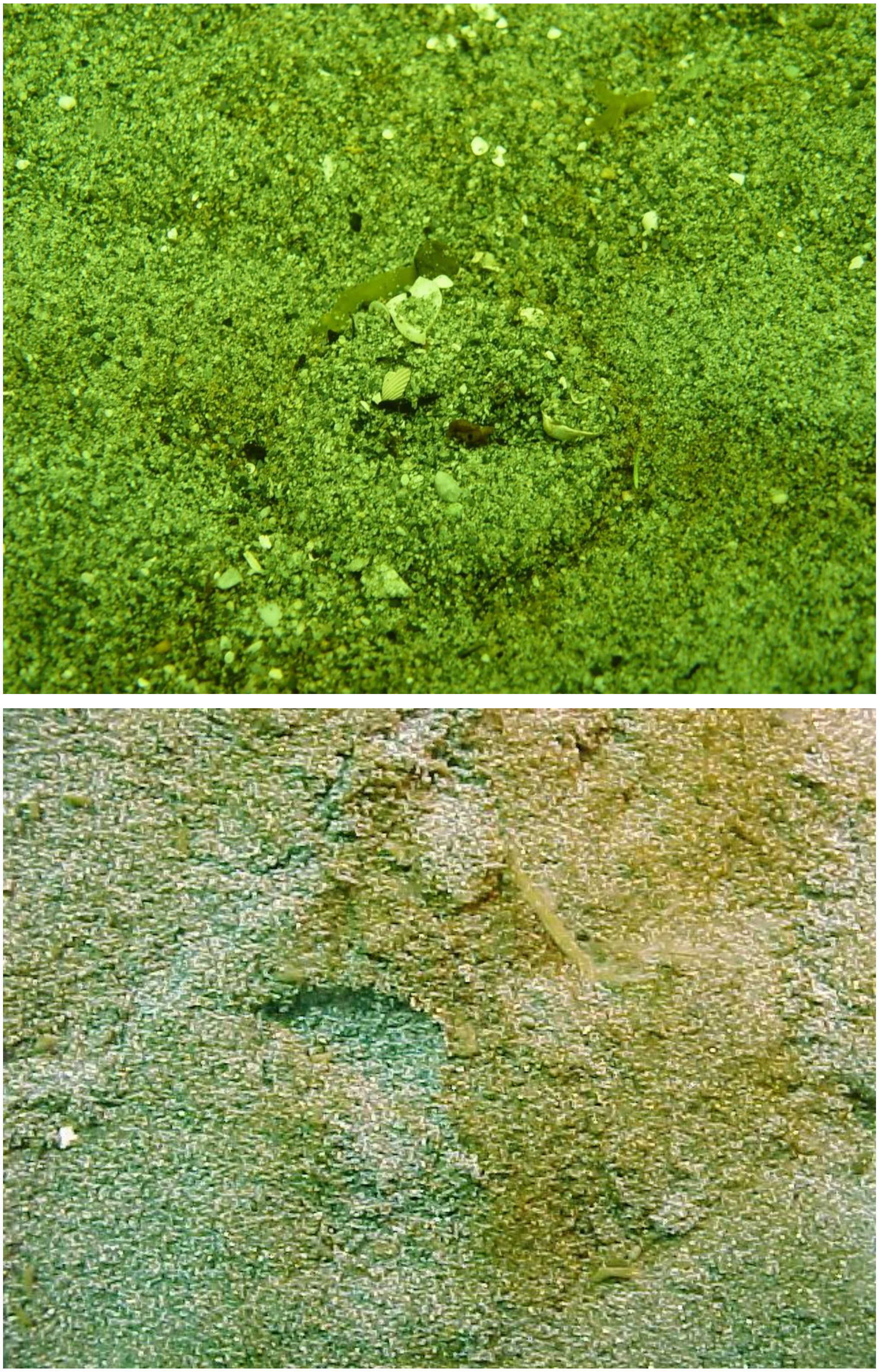

Figure 3.–Obscured geoduck siphon tips at 50 feet of depth near Craig, Alaska. Depressions formed by slightly retracted siphon tips, called "shows", make geoduck identification difficult and ambiguous. ©2016 ADF&G. Photo by Scott Walker.

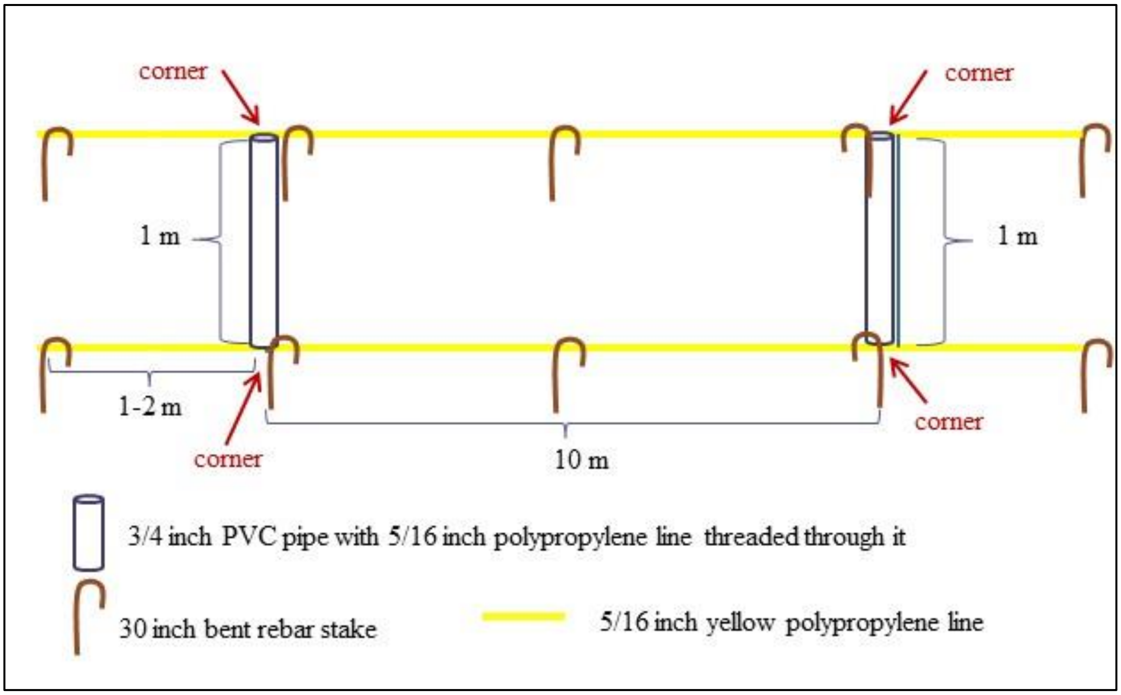

Figure 4.–Schematic of geoduck show plot. Geoducks are counted and flagged within show plots over several days to determine the ratio of initial to total counts, which is used as a correction factor to more accurately estimate geoduck population size.

APPENDICES

APPENDIX A: SUPPORT VESSELS

Appendix A1.–Description of dive support vessels.

The *R/V Kestrel*, owned and operated by the State of Alaska, ADF&G and home-ported in Petersburg, Alaska will serve as base vessel supporting all dive operations. The vessel is a 32-meter (105-foot), steel- hulled live-aboard vessel capable of accommodating up to 13 people comfortably for voyages up to two weeks in duration. Three Boat Officers operate the vessel. The R/V Kestrel and crew routinely work throughout the waters of Southeast Alaska with a primary mission of supporting scientific dive surveys of benthic invertebrates (sea urchins, sea cucumbers, geoducks, abalone) and herring from April through mid-September.

The dive compressor system aboard the R/V Kestrel is capable of providing either air or enriched air nitrox up to 36%. The system consists of a Nuvair nitrox system with three Hankison moisture filters, a Nuvair Champion low pressure compressor (160–175 psig), and two Bauer high pressure compressors (2300 and 3000 psig). A bank of 48 80-cubic foot aluminum tanks are available for daily use. A dive locker and wet lab houses dive gear and provides area for suiting up and processing biological samples.

The *R/V Kestrel* carries two 19' aluminum Workskiffs ™ on deck, which are loaded and deployed with hydraulically-powered davits rigged with winches. Each skiff is powered by a 4-stroke 150-horsepower Yamaha outboard engine, and is customized to support SCUBA dive teams. Customizations include a pivoting ladder for retrieving divers, rack for SCUBA cylinders, elevated tank holders for securing cylinders with attached buoyancy control devices and regulators, hand rails on the hull along the water line, Furuno depth sounder, VHF radio, emergency oxygen kit, first aid kit, integrated chartplotter with Global Positioning System (GPS; Garmin echomap 54dv) and accessory GPS whip antenna. The chartplotter/GPS has Wide Area Augmentation System (WAAS), which when enabled results in a minimum positional accuracy of +/- 7.6 m (FAA 2001), but is typically +/-1.0 m in the nearshore waters of Southeast Alaska (NTSB 2006). However, positional accuracy may suffer to an unknown extent in locations/times with poor satellite coverage (e.g., in steep fjords, under tree cover very near shore).


R/V Kestrel (left) and dive skiff (right).

APPENDIX B: SURVEY FORMS

Appendix B1.–Field datasheet for dive profiles. This form is used to record all diving activities for all surveys.

Dive Site and Diver Profile Datasheet

Page ___of ___

Skiff #: _____ Fishery/Stat Area: ____________________ Date (m/d/yy): ____/_____/_____

Dive #	Transect or Sample Site #	Species	Dive Purpose (e.g., transect, sample, recon, proficiency)	Dive Tender	Diver 1	Diver 2	Max Depth (ft)	Dive Time In (hh:mm)	Transect Start Waypoint #	Dive Time Out (hh:mm)	Transect End Waypoint #
1								:		:	
2								:		:	
3								:		:	
4								:		:	
5								:		:	
6								:		:	
7								:		:	
8								:		:	
9								:		:	
10								:		:	
11											
12											
13											
14											
15											
16											

Notes:

Appendix B2.–Field datasheet for sea cucumber and sea urchin transects. Form is used to record data while diving.

Cucumber and Urchin Transect Data Sheet

Target Species: **Cuc** / **Urchin**	Fishery Area:			
Transect #:	Ref. Depth: **50** / **60**	Tide (ft):	Target Depth:	Date: ___ /___ / 20 __ __
Bearing (°):	Recorder:	Buddy:	Time In / Out (hhmm): __ __ __ __ / __ __ __ __	

Int #	Start Depth	End Depth	Distance (m)	# Sea Cucumbers	# Red Urchins	Interval Comments
1			10 or ____			
2			10 or ____			
3			10 or ____			

Sea Otter Evidence: **Y** / **N**	Abalone Evidence: **Y** / **N**	Transect Comments:
If applicable: **Assumed 0** / **Halfway** / **Dive Aborted**		
Count Confidence: **Acceptable** / **Unacceptable**		

Appendix B3.–Field datasheet for sea cucumber weights and sea urchin diameters. Used to record size data during surveys.

Sea Cucumber Weight/Sea Urchin Diameter Survey Sampling Form

Date___________ **Subdistrict # (s)**____________________________ **Species**___________

Transect #										
Depth (ft)*										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										

*enter depth for sea urchin sampling only, relative to Mean Lower Low Water

Appendix B4.–Field datasheet for geoduck transect surveys. Form is used to record data while diving.

Geoduck Transect Datasheet Last modified: 5/7/2019

Fishery Area:			Trans. #:	Bearing (° M):	Page__of__
Dive #:	Date: / /20	Tide (ft):	Target depth (ft):	Recorder (D1):	Buddy (D2):

Int #	Start depth	End depth	Dist. (m)	# Geoducks D1	D2	Substrate 1°	2°	% Veg Cover	Veg. Type 1°	2°	Interval Comments
1			10 or___								
2			10 or___								
3			10 or___								
4			10 or___								
5			10 or___								
6			10 or___								
7			10 or___								
8			10 or___								
9			10 or___								
10			10 or___								
11			10 or___								
12			10 or___								

Sea Otter Evidence?	Y / N	Horse clams or False GD?	Y / N	Comments:

Appendix B5.–Field datasheet for geoduck show plots. Used to record flagged geoducks and other data collected over several separate dives.

Geoduck Show Plot Datasheet

Fishery Area:______________________________ Transect #:________

Lat: 5__ . __ __ __ __ __ Lon: -13 __ . __ __ __ __ __ Plot: A or B (circle 1)

Pass # 1	Date: ___/___/18	Counter: _____	Buddy: _____	# Initial Count: ______	Total # Flags: ______	Time In / Out: _____/_____
Pass # 2	Date: ___/___/18	Diver 1: _____	Diver 2: _____	# Flags Added: _____	Total # Flags: ______	Time In / Out: _____/_____
Pass # 3	Date: ___/___/18	Diver 1: _____	Diver 2: _____	# Flags Added: _____	Total # Flags: ______	Time In / Out: _____/_____
Pass # 4	Date: ___/___/18	Diver 1: _____	Diver 2: _____	# Flags Added: _____	Total # Flags: ______	Time In / Out: _____/_____
Pass # 5	Date: ___/___/18	Diver 1: _____	Diver 2: _____	# Flags Added: _____	Total # Flags: ______	Time In / Out: _____/_____
Pass # 6	Date: ___/___/18	Diver 1: _____	Diver 2: _____	# Flags Added: _____	Total # Flags: ______	Time In / Out: _____/_____

Notes:	Site Layout:

APPENDIX C: SUBSTRATE/VEGETATION CODES

Appendix C1.–Vegetation definitions for field datasheet codes. Used to record vegetation type observed on dive transects.

Code	Expanded code	Species included	Latin names
AGM	Agarum	Sieve kelp	*Agarum clathratum*
ALA	Alaria	Ribbon kelps	*Alaria marginata, A. nana, A. fistulosa*
ELG	Eel grass	Eel grass, surfgrasses	*Zostera marina, Phyllospadix serrulatus, P. scouleri*
FIL	Filamentous algae	Sea hair	*Enteromorpha intestinalis*
FIR	Fir kelp	Black pine, Oregon pine (red algae)	*Neorhodomela larix, N.oregona*
FUC	Fucus	Rockweed	*Fucus gardneri*
HIR	Hair kelp	Witch's hair, stringy acid kelp	*Desmarestia aculeata, D. viridis*
LAM	Laminaria	split kelp, sugar kelp, suction-cup kelp	*Laminaria bongardiana, L. saccharina, L. yezoensis (when isolated and identifiable)*
LBK	Large Brown Kelps	Five-ribbed kelp, three-ribbed kelp, split kelp, sugar kelp, sea spatula, sieve kelp, ribbon kelp	*Costaria costata, Cymathere triplicata, Laminaria spp., Pleurophycus gardneri, Agarum, Alaria spp.*
MAC	Macrocystis	Small perennial kelp	*Macrocystis sp.*
NER	Nereocystis	Bull kelp	*Nereocystis leutkeana*
RED	Red algae	All red leafy algae (red ribbons, red blades, red sea cabbage, Turkish washcloth)	*Palmaria mollis, P. hecatensis, P. callophylloides, Dilsea californica, Neodilsea borealis, Mastocarpus papillatus, Turnerella mertensiana*
ULV	Ulva	Sea lettuce	*Ulva fenestrata, Ulvaria obscura*
COR	Coralline algae	Coral seaweeds (red algae)	*Bossiella, Corallina, Serraticardia*

Appendix C2.–Substrate definitions for field datasheet codes. Used to record substrate type observed on dive transects.

Code	Expanded code	Definition
RCK	Bedrock	Various rocky substrates >1 m in diameter
BLD	Boulder	Substrate between 25 cm and 1 m
CBL	Cobble	Substrate between 6 cm and 25 cm
GVL	Gravel	Substrate between 0.4 cm and 6 cm
SND	Sand	Clearly separate grains of <0.4 cm
MUD	Mud	Soft, paste-like material
SIL	Silt	Fine organic dusting (very rarely used)
BAR	Barnacle	Area primarily covered with barnacles
SHL	Shell	Area primarily covered with whole or crushed shells
MUS	Mussels	Area primarily covered with mussels
WDY	Woody debris	Any submerged bark, logs, branches or root systems

APPENDIX D: FIELD PROTOCOL FOR GEODUCK SHOW PLOT INSTALLATION AND SURVEY

Appendix D1.–Field protocol for geoduck show plot installation and survey, including list of equipment and supplies required.

Geoduck Show Plot Methods for Stock Assessments

Summary

- Show plot dimensions: 1x10 m
- Target # of show plots: 6
- Show plot target locations randomly selected from entire transect pool, and additional transects will be selected and prioritized in case any of the first 6 are inadequate
- One show plot per transect
- Each diver will do an initial count of a show plot
- Non-randomly choose show plot location based on transect counts (target high-density patches of seafloor)
- No element of diver “surprise” (i.e. diver chooses plot and knows their counts will be used)
- Minimum # of geoduck initial counts for each show plot: 10
- Maximum depth of show plot: 60 ft MLLW
- Combine tasks of show plot installation and initial count into same dive

Materials (per transect/site)

- 1x10 m show plot (PVC and polypro line) - 1
- Mini sledge hammer -1
- Rebar “candy canes” - 8
- Bundle of ~200 flags
- Transect rod with dive slate & compass - 1
- Datasheet -1
- 25 m transect tape spool with clip on end - 1
- Game bag -1

Methods

1. Please carefully follow the methods described below. The biomass estimate and associated GHL can change markedly based on the final show factor value, and having to eliminate even one show plot from analysis would be an important loss.
2. The first order of business on the first day of the survey is to conduct transect density surveys in the priority order determined for show plot installation; one skiff will go to the priority 1 transect, and the other skiff will go to the priority 2 transect.
3. Complete density transect, as usual.
4. If counts in any 1 x 10 m interval did not have at least 10 geoducks, go to the next priority transect for a show plot.

5. If counts in any 1 x 10 m interval did have at least 10 geoducks, target a show plot in the immediate vicinity of the transect and within the depth range of transect intervals with the highest densities.
6. Drop off divers within the target depth range, and divers will search in the immediate vicinity for the nearest concentration of geoducks with the highest density (at least $1/m^2$).
7. Divers deploy a Pelican float or return to surface and retrieve show plot equipment and supplies, or dive tender deploys anchor/buoy with the show plot supplies.
8. Divers extract PVC/polypro show plot rectangle and untangle it. Clip end of transect tape to anchor, then swim with show plot, transect rod and game bag with the rest of the gear (rebar, flags, hammer), and swim to the nearest suitable location down-current within 5-10 m of the anchor, and slightly offset perpendicularly to the current direction. The goal of offsetting the show plot is to get away from the immediate area where geoducks may have already been disturbed enough by the divers or anchor to affect the initial count, and to offset the show plot so it won't get pulled out if the surface buoy's anchor drags. While it is ideal to set up show plots along the depth contour (to minimize the chance of kelp getting caught on the lines and pulling the plot out), it is also acceptable to set it up across depths if the area does not experience strong currents. This will be the show plot starting point.
9. Decide upon compass bearing in the most promising direction, then record the distance and bearing from the anchor and depth of show plot origin in the site layout sketch box. Begin show plot installation and initial count. One diver will serve as the anchor point for one end of the show plot (i.e. will remain in place) and the other diver will swim with the transect rod/dive slate and one of the PVC rod ends of the show plot along the chosen compass bearing while performing the initial geoduck count. Although this is not a transect count, it should be treated as one to the extent possible (e.g., swim at your usual speed, don't be any more careful than you otherwise would be, pound the seafloor if that's your style).
10. When the counting diver reaches the end of the show plot:
    a. If < 10 geoducks were counted, ditch the show plot and swim back to the anchor with all of the gear. Repeat this process on the opposite side of the anchor.
    b. If ≥ 10 geoducks counted, pull the PVC taut enough for the polypro line to be hugging the bottom, then signal the "anchor diver" to secure their end of the show plot with rebar.
11. While ensuring the show plot PVC rod remains in place, the counting diver will then record their count on the datasheet, sketch in the site layout details and depth of the far end of show plot, and any other important notes (e.g., presence/absence of horse clams and false geoduck clams) and wait for the anchor diver to swim down to his end and secure it.
12. The anchor diver will swim to the far end, bringing the rebar, hammer, and flags. Secure the far end of the show plot.
13. Both divers will slowly swim back to the show plot starting point along opposite sides of the show plot and flag all geoducks seen. Use all of your normal techniques for flagging (e.g., substrate pounding). Plant flags deeply so they are less likely to be pulled out by drift kelp.

Flag false geoducks and horse clams with bare flag stakes (pull the flag off first). Secure polypro to seafloor with rebar in the middle of each side of the show plot along the way.

14. Once the first round of flags have been planted, swim back the other direction and repeat the flagging process for any remaining geoducks.
15. Swim back to the show plot origin and each diver will independently count the # of flags. Record and compare counts when done. If they are not the same, repeat the flag-counting pass until diver counts match exactly (exception: if there are huge counts (> ~ 80) and the difference in counts between divers is < 2, cap the number of counting passes to 3 and average the counts).
16. Draw a 2D site layout on the datasheet that includes a map of the relative locations of the anchor and show plot, distances and bearings from the anchor to the nearest end of the show plot, bearing of the show plot from origin to far end, depths of anchor and each end of each show plot, approximate direction to shore and deeper water (arrows ok, bearings unnecessary).
17. Obtain GPS fix on surface buoy and record in Site Layout section of datasheet. Calculate and record MLLW-corrected depths on Site Layout datasheet. Review and clarify site map and datasheets.
18. Move to the next priority site and repeat process. Coordinate with other skiff since one diver from each skiff will do an initial count for the two remaining show plots.
19. At end of the first day, return to show plot and do another flagging and counting pass. Use a copy of the original completed datasheet. On the first pass (origin to far end), flag any new geoduck shows seen, counting the # of new flags planted as you go. Record summed count at far end. On the return pass, each diver will independently count the # of flags, then compare counts afterwards. If counts match, record data and you’re done. If they don’t, repeat counting pass(es) until they do.
20. Repeat flagging/counting protocol as frequently as is reasonable (i.e. first thing in the morning and last thing in the afternoon) for the remaining survey days, using a copy of the datasheet from the previous visit.
21. After the final flagging/counting, break down and pack up show plot.